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Jeffrey R. Rutland
West Virginia University

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Depositional Environments Comprising the Birch River Section (Middle Pennsylvanian), Powell Mountain, Nicholas County, West Virginia

Jeffrey R. Rutland

**Thesis submitted to the
Eberly College of Arts and Sciences
at West Virginia University
in partial fulfillment of the requirements
for the degree of**

**Master of Science
in
Geology**

**Richard Smosna, Ph.D., Chair
Alan Donaldson, Ph.D.
Bascombe M. Blake, Jr., M.S.,
West Virginia Geological & Economic Survey**

Department of Geology and Geography

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ABSTRACT

Depositional Environments Comprising the Birch River Section (Middle Pennsylvanian), Powell Mountain, Nicholas County, West Virginia

Jeffrey R. Rutland

A field analysis of Middle Pennsylvanian strata (Kanawha Formation and Allegheny Formation) in central West Virginia was performed to test two depositional models, coastal plain and fluvial-deltaic. Sedimentary descriptions form the basis for two levels of interpretations, where the first goal is to interpret the depositional settings of individual architectural elements within the section. The second task was to place the compiled interpretations into the previously established regional stratigraphic framework. At Birch River, the Kanawha Formation is composed of both estuarine and alluvial facies. The estuarine facies include, estuary margin, estuarine channels, and estuarine lagoon. Alluvial facies make up the remainder of the Kanawha Formation and include, meandering stream, crevasse, floodplain, swamp, freshwater lakes, and levees. Alluvial deposits including those of meandering stream, channel-fill, floodplain, and swamp facies dominate the Allegheny Formation. This study supports the coastal-plain regional stratigraphic framework over the fluvial-deltaic stratigraphic framework.

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Chapter 1

Introduction

Detailed sedimentary descriptions were made for a series of well-exposed outcrops (see Figs. 1a-1f) of the Kanawha and Allegheny formations (Middle Pennsylvanian) in central West Virginia (see Fig. 2). Sedimentary features described include, rock type, texture, thickness, cross-bedding and other sedimentary structures, and fossil content. The main goal of this study was to interpret the depositional environments of the individual architectural elements within the described sections. The study area is located along a 5-mile section of U.S. Route 19 between the town of Birch River and the crest of Powell Mountain in Nicholas County, West Virginia (Fig. 3). Recent highway construction to widen Route 19 created a series of fresh outcrops exposing the upper two-thirds of the Kanawha Formation (lower to middle Middle Pennsylvanian) and the entire Allegheny Formation (upper Middle Pennsylvanian) (Fig. 2). The total thickness for the complete section is approximately 1147 feet.

A second goal was to fit the sedimentary interpretations into a previously established regional stratigraphic framework. Some workers (Beerbower, 1969; Ferm 1970, 1974; Donaldson 1974, 1979; Horne et al., 1978; Presley, 1979; Howell and Ferm, 1980) have modeled upper-delta-plain or alluvial-plain depositional systems for these sediments (Donaldson et al, 1985; Cecil et al, 1992) (see Figs. 4, 5, and 6). Later, Martino (1996, 1998) suggested that a coastal-plain model of depositional systems would provide a more appropriate analog for strata of the Kanawha Formation in southern West Virginia (Fig. 7). Martino's (1996, 1998) two-part model emphasized

the facies changes that occur during a transgressive-regressive cycle, a shifting mosaic of near-shore, coastal, and estuarine facies.

From this study, several relative transgressive-to-regressive events can be identified. Distinguishing between autocycles and allocycles at small- and large-scale can aid in interpreting the causal affects of the sequence (i.e. tectonic, glacial-eustatic, or river avulsion). It is not feasible to identify allocycles from autocycles within the aerally-restricted study area. However, if these described sections can be placed into a larger, regional context some inferences as to the source of the cycles can be inferred.

Figure 1a. Photo of Powell Mountain Outcrops.

Exposed strata of the Allegheny Formation near the crest of Powell Mountain, Birch River, West Virginia. An overlook on the side of U.S. Route 19 can be seen at lower right.

Figure 1b. Photo of Outcrop Delta.

Exposed strata of the Kanawha Formation and the Allegheny Formation midpoint of Powell Mountain, near Birch River, West Virginia. The formation contact is at the top of the first bench at left. Note the large-scale channel in the middle of the cut. A series of normal faults run beneath the channel.

Figure 1c. Photo of Outcrop Epsilon.

Exposed strata of the Allegheny Formation, from the overlook off Route 19, Powell Mountain, near Birch River, West Virginia. Figure 1d is located at the red circle at the left end of outcrop. Note the large-scale channels present across the outcrop face.

Figure 1d. Photo of Soft Sediment Deformation, Outcrop Epsilon.

Soft sediment deformation in beds of the Allegheny Formation, Powell Mountain, near Birch River, West Virginia. Picture is a close up of the area indicated on the left sided of Figure 1c.

Figure 1e. Photo of Outcrop Zeta.

Exposure of the Allegheny Formation across from Route 19 overlook, Powell Mountain, Birch River, West Virginia.

Figure 1f. Photo of coal bed, Outcrop Zeta.

Lower Kittanning coal bed, Allegheny Formation, across from Route 19 overlook, near the top of Powell Mountain, Birch River section, West Virginia. Notice truncation of the top of the coal bed and the partial formation of a peat raft.

Figure 2. Generalized stratigraphic column of the Pennsylvanian Period in the central Appalachian basin.

Marine units of the Middle Pennsylvanian, Kanawha Formation are shown on the right. (Modified from Martino et al., 1998)

Figure 3. Structural elements of West Virginia and location map of study area.

Location of Birch River study area (Nicholas County, West Virginia) on map of major Alleghenian structural features and lineaments. Enon anticline trends roughly NW-SE, (not shown). Note: The term Valley and Ridge province is more often used for the Folded Appalachians. The greatest extent of West Virginia lies within the physiographic province termed the Appalachian Plateau. The Appalachian Plateau is that region immediately west of the Valley and Ridge province. (Modified from, Arkle et al., 1979)

Figure 4. Paleogeographic map of major Kanawha Formation deposystems. Idealized paleogeographic distribution of Kanawha Formation (Middle Pennsylvanian) alluvial, deltaic and marine units (Modified from Donaldson and Shumaker, 1981).

Figure 5. Paleogeographic map of Allegheny Fm. deposystems. Idealized paleogeographic distribution of Allegheny Formation (Middle Pennsylvanian) deltaic, alluvial, and marine units (Modified from Fenn, 1970).

Figure 6. The Delta Plain Model of Ferm (1974).

Idealized delta model showing locales of major delta elements, upper delta plain, lower delta plain and the alluvial plain and including distributions of major deltaic and alluvial elements (channels and levees, bays and lakes, and barrier) for the Middle Pennsylvanian in northern West Virginia.

(Modified from Ferm, 1974) Compare to Figure 7, the two-part transgressive-regressive coastal-plain model of Martino (1996).

Figure 7. The Coastal Plain Model of Martino (1996).

This model emphasizes the shifting mosaic of nearshore, coastal, and estuarine facies that occur during a transgressive (A) – regressive (B) cycle. (Taken from Martino, 1996) Key: A, Transgression: ts – transgressive sands, stf – subtidal flat, itf – intertidal flat, rb – restricted bay, ec – estuarine channel, lk – lake, ac – alluvial channel, swp – swamp. B, Regression: mb – distributary mouthbar, dc – distributary channel. Compare to Figure 6, the deltaic model of Donaldson et al., 1979.

Methods

Interpretations of depositional environments, sequential analysis of transgressive to regressive sequences, and the role of climatic and tectonic factors are based on field-site measurements of stratigraphic thickness and a detailed description of the strata, with emphasis given to sedimentary features. The strata were broken into lithologic units for measurement. Thickness measurements include the total thickness for each unit described. The units in the study were identified based on change in the lithologic character. In some cases, several lithotypes were lumped together as one unit for simplification. This lumping of lithotypes was primarily done where there were gradational changes in lithotype over several decimeters. Sedimentary features, such as lithology, texture, bed geometry, contacts, sedimentary structure and fossil content are important indicators of depositional environment and were recorded for each lithologic unit identified.

Once the sections were described and sedimentary features were identified, the focus of the study shifted to interpreting the individual depositional environments of each successive section. The goal was to build a sequential history of events that resulted in the deposition of these rocks. The basic assumption of this study is that these strata would match one or more models formulated by previous workers (i.e., Beerbower, 1969; Ferm 1970, 1974; Donaldson 1974, 1979; Donaldson et al., 1985; Donaldson and Eble, 1991; Horne et al., 1978; Presley 1979; Howell and Ferm, 1980; Cecil et al., 1992; Martino 1994, 1996; Martino et al., 1998) (see Figs. 4-7).

Study Area

The study area lies in the eastern portion of the Appalachian Plateau physiographic province (Fig. 3). Topography of the Appalachian Plateau is characterized by rugged, low-lying mountainous to hilly terrain (Arkle et al., 1979). The highest elevations (>3000 feet) in Nicholas County are found towards the southern and eastern parts. The crest of Powell Mountain is at 2484 feet. Valley bottom elevations in Nicholas County range between 700 to 800 feet (Reger, 1921). Major streams, such as the Gauley River and New River, have cut steep-walled valleys (gorges) deep into the mostly Carboniferous-aged strata of this part of the Appalachian Plateau.

Geologic Setting

Early to Middle Pennsylvanian paleogeographic maps (Fig. 8) of Laurentia (Euramerica) place the Appalachian foreland in a location proximal to or straddling the paleoequator (Donaldson and Eble, 1991; Cecil et al., 1992; Martino et al., 1998). This low latitudinal position brought ever-wet tropical conditions to the region bordering the rising southern Appalachian uplands (Cecil, 1990). The Allegheny clastic wedge is, in part, a result of the combination between the Early to Middle Pennsylvanian tropical climate and the rising source areas (Donaldson and Shumaker, 1981)(Fig. 9).

Figure 8. Paleogeographic map of eastern U.S. coal basins during the Pennsylvanian.

Note the position of the paleoequator along the axis of the Appalachian Foreland (from Donaldson and Eble, 1991).

Thrusting associated with the growing Appalachian orogeny to the east depressed the crust lowering the Appalachian foreland. This orogeny occurred during the amalgamation of Gondwanaland and Euramerica and the subsequent formation of the supercontinent Pangea (Ross and Ross, 1985; Veevers and Powell, 1987; Donaldson and Eble, 1991). Donaldson and Shumaker (1981) attributed deposition of the Pennsylvanian coal measures to "...molasse sedimentation (in the Appalachian foreland) derived from adjacent orogenic belts (the rising Southern Appalachian uplands)" (i.e., the Allegheny clastic wedge) (Donaldson and Eble, 1991) (Fig. 9).

Figure 9. The Allegheny Clastic Wedge (Pennsylvanian and Permian) of Donaldson and Shumaker (1981).

This Allegheny Clastic Wedge of Donaldson and Shumaker (1981) was sourced from the rising Appalachian uplands to the southeast. (Modified from Donaldson and Shumaker, 1981).

Structurally, the study area is located on the northwest edge of what is now called the Southern coalfield (formerly known as the Pocahontas “Basin”), an elongate sub-basin within the larger Appalachian foreland (Fig. 10). More accurately, the study area lies in a transitional position between the Northern coalfield (Dunkard “Basin”) and the Southern coalfield (Fig. 10). According to Blake, (personal communication, 1999) the structural term “hingeline” is also no longer valid, as it connotes the presence of two separate structurally controlled sub-basins, within the foreland trough. However, for discussion purposes, the term “hingeline” is retained herein as the boundary between the Northern and Southern coalfields.

Figure 10. Map Showing the Locations of and the Boundary between the Northern and the Southern Coalfields.

Location of Birch River study area, proximal to the boundary between the older mining district and the younger mining district (Southern and Northern coalfields, respectively). (Modified from Arkle et al., 1979)

Within the Southern and Northern coalfields, thickness trends are partially a function of accommodation space. In the Middle Pennsylvanian, the Southern Coalfield was subsiding at a faster rate than the Northern Coalfield, creating more accommodation space and thus allowing for greater thickness of Middle Pennsylvanian strata (Blake, 1997, 1998) (Fig. 11).

Figure 11. SE to NW Cross-Section of Mississippian and Pennsylvanian Strata in West Virginia. Sediments within the Southern Coalfield (Pocahontas Basin) are much thicker than those within the Northern Coalfield (Dunkard Basin). This is due, in part, to the greater accommodation space and the faster rate of subsidence within the Southern Coalfield. Pocahontas Basin = Southern Coalfield; Dunkard Basin = Northern Coalfield (Modified from Ferm, 1974).

As a whole, rocks in West Virginia are part of a regional monoclinical structure that dips to the north-northwest. This monoclinical structure is the eastern limb of a large synform that extends from Alabama to New York along the western fringe of the Appalachian Mountains (Arkle et al., 1979) and is referred to as the Appalachian foreland basin (Fig. 8). According to Reger, (1921), strata rise over 3,000 feet from the northwest to the southeast across Nicholas County. Additional, smaller-amplitude structures are superimposed on the broad regional structural framework (Fig. 3). In Nicholas County, these smaller structures include the NE-SW trending Mann Mountain and Webster Springs anticlines, which are flanked by the Lockwood and Clifftop synclines respectively. Perpendicular to the regional trend, the Enon anticline dissects Powell Mountain, originating at the Clay-Nicholas County line (Reger, 1921). The

overall NW-SE trend of the Enon anticline is evident by the southward rise of beds as one travels Route 19 southward from Birch River to the top of Powell Mountain. Several normal faults likely related to the Enon Anticline are present in outcrop Delta.

Interestingly, the trend of the Enon anticline is sub-parallel to that of the longer Burning Springs anticline, which runs NW-SE through Wirt, Ritchie, and Pleasants counties in the west-central part of the state, adjacent to the Little Kanawha and Ohio Rivers.

Deposition of these Middle Pennsylvanian rocks occurred approximately 300 Ma (Faill, 1997) during the many transgressions and regressions associated with the Allegheny clastic wedge (Donaldson and Eble, 1991). The strata were sourced from the Southern Appalachian highlands (Donaldson and Shumaker, 1981). According to Faill (1997), the extreme low relief of the Appalachian basin during the Middle Pennsylvanian made it vulnerable to a series of marine incursions from a mid-continent sea lying to the south and west (Fig. 12). In the described sections, four marine zones were identified in the Middle Pennsylvanian Kanawha Formation (Blake et al, 1992). However, no rocks of open-marine origin have been found in or around the vicinity of Powell Mountain other than the Winifrede Shale (Blake, personnel communication, 1999).

Figure 12. Maximum extent of paleoshorelines during the Middle Pennsylvanian to Late Pennsylvanian.

The paleoshoreline position, number 4 - the Winifrede, Magoffin, L. Mercer, is proximal to the Birch River study area. (From Donaldson and Eble, 1991)

As stated previously, most of the early interpretations of Middle Pennsylvanian rocks in southern, central and northern West Virginia focus on upper- and lower-delta-plain and alluvial-plain environments (Cecil et al., 1992; see also, Beerbower, 1969; Ferm, 1970, 1974; Donaldson, 1974, 1979; Donaldson et al., 1970; Donaldson and Shumaker, 1981; Donaldson et al., 1985; Horne et al., 1978; Presley, 1979, and Howell, 1980)(Figs. 4, 5, and 6). The Mississippi River delta is the “type” example of a river-dominated delta and previous models are heavily influenced by this river-delta system.

Recent work, including that of Donaldson and Eble (1991), Cecil et al., (1992), Martino (1994, 1996), Martino et al. (1998), and Blake (1997), emphasize the

transgressive deposits of a coastal-plain environment, as well as the regional extent of the marine zones (Martino, 1994, 1996) and the tidal influence in marginal-marine facies (Cecil et al., 1985)(Martino, 1994, 1996)(Martino et al., 1998) (Fig. 7). Moreover, Blake (1997) has shown that the Kanawha marine zones can be correlated with related paralic deposits of western European basins.

Blake (personal communication, 1999) suggests the Ganges and Indus River systems (Pakistan) for a modern coastal-plain analog. Likewise, Cecil et al. (1992) and Cecil et al. (1985) see the ever-wet, tropical to sub-tropical Indonesian archipelago (particularly Malaysia), with its high mountain ranges and vast freshwater and mangrove swamps, as an excellent modern analog. Interestingly, Coleman et al., (1970) were impressed at how similar the root impressions within mangrove-dominated, clayey tidal flats of the Klang-Langat delta (Malaysia) are in comparison to Middle Pennsylvanian root-bioturbated underclays of Ohio and Pennsylvanian.

Martino (1996) sees the tidal structures of Kanawha rocks as important clues in his coastal-plain model. Such structures include lenticular, wavy, and flaser bedding, herringbone cross bedding, and reactivation surfaces. Additionally, Martino (1996) interprets some Kanawha sandstones as deposits of river-dominated deltaic distributary and mouth-bar environments. Finally, Cecil et al., (1985) suggested river-dominated deltas played a subordinate role to meso- to macrotidally-dominated estuaries during the Middle Pennsylvanian (Kanawha).

The coastal-plain model (Fig. 7) stresses the development of facies deposited during transgressive phases, whereas the siliciclastic deltaic deposits typically developed during falling sea-level (lowstands or stillstands). Furthermore, the coastal-

plain model focuses on allogenic processes initiated by glacio-eustatic events, whereas the older deltaic models interpreted the deposits to be the result of autogenic processes, i.e., stream avulsion (see for instance Beerbower, 1969).

Chapter 2

Stratigraphy

The regional stratigraphic framework of Middle Pennsylvanian rocks in West Virginia changes across the hingeline. Stratigraphically lower beds of the Kanawha pinch-out first and those higher in section disappear along this northwest trend; however, the thickness of the middle Kanawha remains relatively unchanged across the same trend (Blake, 1992). In the vicinity of the hingeline, the stratigraphic nomenclature becomes overlapping and confused. Traditionally, Pennsylvanian rocks of the Southern Coalfield are composed of the Lower Pennsylvanian Pocahontas and New River Formations, the Lower and Middle Pennsylvanian Kanawha Formation, and the upper Middle Pennsylvanian Charleston Sandstone. In the Northern Coalfield, the lower Middle Pennsylvanian is called the Pottsville Formation and the upper Middle Pennsylvanian is named the Allegheny Formation. The Conemaugh Group is the name given to Lower Upper Pennsylvanian strata. Beds of the Conemaugh Group are regionally extensive in the Northern Coalfield, but they are present only throughout northern and western sections of the Southern Coalfield. (Arkle et al., 1979).

Because the rocks are transitional across the hingeline, the current stratigraphic nomenclature in and around the Birch River Section utilizes bed, member, and rank names from both the Northern and Southern Coalfields. The only published stratigraphic column for the Birch River section is found in a West Virginia Geologic Survey Fieldtrip Guidbook by Cecil et al. (1992). In this stratigraphic column, the Middle Pennsylvanian is assigned to the older Kanawha Formation and the overlying Allegheny Formation. Recent work has shown some of the previous correlations made for the

uppermost part of the Birch River stratigraphic column are wrong (Blake, personal communication, 1999). Specifically, there is no Conemaugh (Lower Upper Pennsylvanian) exposed in the Powell Mountain section.

Interestingly, the Nicholas County Report (Reger, 1921) shows that early workers who studied the strata in the vicinity of Powell Mountain identified and described beds of the Conemaugh Group. However, they did not locate or describe Conemaugh rocks on Powell Mountain itself. From the report, it appears the Conemaugh Group is not present any farther south than a few kilometers to the north and west of Powell Mountain.

In the fieldtrip guidebook, Blake (1992) generally discussed the lithologies of the formation exposed on Powell Mountain. He identified four widespread marine zones in the Kanawha Formation, three of which are seen in the Birch River section and include the Dingess Shale Member, Winifrede Shale Member, and a marine shale equivalent of the Kanawha Black Flint of White (1891) (See Figure 2). The Betsie Shale Member was the fourth marine zone identified by Blake (1992). The Betsie is below drainage at Powell Mountain. Additionally, Blake (1992) described the Allegheny strata of the Birch River – Powell Mountain outcrops as comprising "thick, multistoried fluvial-deltaic channel sandstones with minor amounts of siltstone, mudrock, coal beds and flint clays." Blake (1992) also described strata on the crest of Powell Mountain as "dominated by massive, conglomeratic (mainly quartz pebbles) sandstones with mudrocks and thin, low quality coal beds... (with) shale and mudstone beds (having) a slight red- and green-gray tint..." As an unwritten rule, workers in the Appalachian

basin generally assign the red and green rocks above the Allegheny Formation to the Upper Pennsylvanian, hence the miscorrelation of Conemaugh Group strata.

Litho-sequences of the Middle Pennsylvanian in West Virginia are composed of repetitive successions of rock types with regressive (progradational) to transgressive phases. According to Donaldson (1974), the widespread and massive Middle Pennsylvanian units of sandstone and shale are the result of the progradation of the West Virginia deltaic complex, which is a part of the Allegheny clastic wedge (Donaldson and Eble, 1991). Causes of transgressive-regressive cycles can be autogenic or allogenic. Autogenic sequences may be the result of river avulsion. In such cases, a change of sediment supply and resultant shoreline shift can create situations where shorelines undergo simultaneous transgression and regression within the same drainage basin (Donaldson and Eble, 1991). In contrast, allogenic sequences are brought on by more global controls, such as eustasy. In an allogenic sequence, the regional shoreline as a whole (basinwide) will show the effects of a (eustatic) transgressive or regressive event (Donaldson and Eble, 1991). However, such eustatic signals cannot be identified in a study of lithologic successions of only one basin.

Repetitive sequences (allocycles) of Late Paleozoic Laurentian or Laurussian lithologies have been related to glacial-eustatic fluctuations in the volume of ice on Gondwanaland (Veevers and Powell, 1987). Veevers and Powell (1987) compared North American Mid-Continent cyclothems (Middle and Late Pennsylvanian) with the thickest Gondwanan glaciogenic sediments. The Pennsylvanian Mid-Continent series have been correlated with the Appalachian Pennsylvanian and European Middle to Upper Carboniferous Series (Blake, 1997). Veevers and Powell (1987) showed that the

dominant period of cyclothemic deposition was on the same order as the long earth orbit, approximately 400,000 years. Additionally, they showed the time interval of cyclothemic deposition in Laurentia (Euramerica) to be comparable to a concurrent glacial episode on Gondwanaland. Finally, Veevers and Powell (1987) correlated major Laurentian regressions of the Carboniferous (European stages: Visean, Namurian, Westphalian, and Stephanian) with glacial events in Gondwanaland. They concluded that their correlations support Wanless and Shepherd's (1936) interpretation of climatic controls for the deposition of the repetitive Middle Pennsylvanian strata.

Busch and Rollins (1984), interpret the Pennsylvanian Period as a 2nd order T-R (transgressive-regressive) cycle of Vail et al., (1977) or that which Ramsbottom (1979) called a synthem. That is, the Pennsylvanian is a single T-R unit bounded by major unconformities (Busch and Rollins, 1984). Major Pennsylvanian allocycles, (Donaldson and Eble, 1991; 10-14 Ma duration; 300-550 m avg. thickness) are representative of large-scale transgressive events and have been suggested to coincide with the separation of the Pennsylvanian into the Lower, Middle, and Upper Series (Donaldson and Eble, 1991). These major allocycles are on the scale of the Vail et al., (1977) 3rd order T-R unit of 8 to 10 m.y.

According to Donaldson and Eble (1991), curves of the major Pennsylvanian allocycles do not match well with global sea-level curves. As a result, they have been interpreted to be the result of tectonic movements and are termed tectophases by Ettensohn (1985). More specifically, they may be the result of crustal loading due to the episodic advancement of thrust sheets from the emerging southern Appalachian uplands during the Allegheny orogeny. Crustal loading caused broad downwarping of

the crust, which allowed for rapid transgression by epeiric seas into the foreland basin (Donaldson and Eble, 1991).

The long time scale of the major Pennsylvanian allocycles (Vail et al., 1977; 3rd order T-R units) can be divided further into intermediate allogenic cycles. According to Donaldson and Eble (1991) and Chesnut (1994), intermediate allocycles within the Appalachian basin have a range of 2.5 to 3 Ma duration and an average thickness of 90 to 115 m. These intermediate allocycles represent transgressive sequences that are bounded by widespread marine zones. The Lower and Middle Pennsylvanian of Kentucky has been divided into eight intermediate allocycles by Chesnut (1994). The Pocahontas, Bottom Creek, and the Alvy Creek Formations make up the Lower Pennsylvanian and the Grundy, Pikeville, Hyden, Four Corners, and Princess Formations of the Breathitt Group are the names given to the Middle Pennsylvanian divisions in Kentucky (Chesnut, 1994). Equivalent Middle Pennsylvanian strata of West Virginia are bound by the widespread marine zones of the Betsie Shale Member, Dingess Shale Member, Winifrede Shale Member and the Kanawha Black Flint of White (1891). According to Chesnut (1994) and Donaldson and Eble (1991), causes of the 2.5 Ma transgressive sequences are unknown. The sequences do not correspond to current sea-level curves or any understood tectonic sequences within the Appalachian basin (Chesnut, 1994). Additionally, they do not match any of the Milankovitch cycles (Chesnut, 1994).

Aitken and Flint (1994) studied the frequency of incised valley fill (IVF) sequences of the Breathitt Group in eastern Kentucky. In this model, one IVF is equal to a fourth-order sequence or the Coal Clastic Cycle of Chesnut (1994) (see below and

Fig. 13), and approximately four to five stacked IVFs make up one (2.5 Ma) third-order sequence (Aitken and Flint, 1994). Aitken and Flint (1994) suggest the third-order sequences are related to the stacking pattern of fourth-order sequences into lowstand or highstand sequence sets, LSS and HSS, respectively. Furthermore, Aitken and Flint (1994) interpret maximum incision at the base of a sequence concurrent with the superimposition of the third-order sea-level curve on the fall of the fourth-order curve forming a LSS. In this hypothesis, minimum incision is the result of the third-order sea-level curve being synchronous with the rise of the fourth-order sea-level curve and a resultant HSS.

Minor allocycles of the Middle Pennsylvanian in the Appalachian basin range from 500,000 to 600,000 years and average 15 to 42 m in thickness (Donaldson and Eble, 1991). This is close to a 5th order T-R unit of Vail et al., (1977) with a range of 400,000 to 450,000 years. In the mid-continent of North America, Carboniferous rocks show cyclicity on this same time scale and are termed cyclothems (Busch and Rollins, 1984).

A similar cycle described in Middle Pennsylvanian strata of Kentucky by Chesnut (1994) is called a Coal Clastic Cycle or the Generalized Appalachian Cyclothem (Fig. 13). It is composed of a coarsening-upward succession above a major coal; that is, coal overlain in turn by shale, siltstone, and sandstone. This first succession is thought to represent marine to brackish-water environments. Above this succession and sometimes truncating it, lies a fining-upward succession. The fining-upward succession consists of channel sandstone, topped by minor siltstone and shale, with seat-rock and the next major coal bed on top. This second succession is interpreted as fluvial

channels. The minor allocycle of Donaldson and Eble (1991), the Coal Clastic Cycle of Chesnut (1994), and the mid-continent cyclothem are thought to be the result of glacial-eustatic fluctuations. Chesnut (1994) stated that the Coal Clastic Cycle has a duration of roughly 400,000 years, which matches the second-order, Milankovitch, Long Earth-eccentricity cycle.

Figure 13. The generalized Appalachian cyclothem of Chesnut (1994). Also termed a coal-clastic cycle, this model of an Appalachian cyclothem is composed of a coarsening-upwards sequence that is truncated by a fining-upwards sequence and two bounding coals that are widespread.

Coal Geology

Geochemical analysis of coal bed quality indirectly allows for climatic interpretations to be made. Within the Pennsylvanian of the central Appalachian foreland basin, variations in coal-forming environments (swamps) resulted from seasonal fluctuations in rainfall or the lack thereof (Cecil, 1990) (see Fig. 14). Although coal bed quality can be important in determining climatic phases, a detailed description, including the proximate analysis of such variables as percent sulfur, ash, and volatiles, was well beyond the scope of this project. Therefore, for the purposes of this study, coals are representative of a wet climate and a swampy (peat bog) depositional environment.

Figure 14. Model of Swamp Types and Paleoflora for the Middle Pennsylvanian.

Note the importance of the water table in the formation of the specific swamp type and the distribution of paleoflora. (Modified from, Grady, 1998)

Chapter 3

Coastal Plain Model

Martino (1994, 1996) proposed a two-part coastal-plain model for the Middle Pennsylvanian Kanawha Formation in southern West Virginia. Martino (1994, 1996) interprets a mosaic of facies that develop during different stages of a transgressive-regressive cycle, where facies fit into five broad depositional zones (see Fig. 5 and 16). The five zones are as follows: 1) offshore and nearshore shallow marine, 2) tidal flats, tidal creeks and estuarine channels along interdeltic and transgressive coastal settings, 3) river-dominated deltaic distributaries and mouth bars, 4) meandering river channels and 5) interfluvial channel margins, lakes and swamps (clastic and peat).

Additionally, Martino, (1996) summarizes the differences between his proposed, two-part coastal-plain model and the contrasting deltaic models (e.g. Donaldson, 1974). First, Martino (1996) proposed that a greater proportion of the Kanawha Formation resulted from tidal processes in estuarine environments. Second, Martino used on trace-fossil assemblages to define facies boundaries. Third, Martino suggested that transgressive-regressive cycles are the result of basin-wide allocycles, not autocycles (i.e., delta switching). Finally, Martino points to the importance of ravinement surfaces (disconformities) at the base of marine units in interpreting high-frequency sequences.

Sedimentology and Facies Architecture of the Coastal Plain Model

Zone 1 (offshore and nearshore zones of a shallow sea and transgressive sands)

Offshore

The offshore zone extends seaward from storm-wave base (Lewis and McConchie, 1994; Link, 1996). Link (1996) suggests, "marine deposition within intracratonic basins relates to shallow-water environments associated with shelf conditions." That is, slope, rise, and deep (abyssal) ocean environments are not typical of intracratonic basins. Bioturbated muds dominate shelf deposits, although fine sands and silts are not uncommon (Coleman and Prior, 1982). As the finest sediments are deposited from suspension, below storm wave base, the mudrocks are very often laminated where burrowing activity was low.

Faunal distributions of offshore-marine deposits include a variety of benthic organisms, and the faunal assemblage is dependent on the substrate (Martino, 1994). However, Kanawha marine deposits in West Virginia lack the diverse faunal assemblages found in the corresponding marine facies of Kentucky (Martino, 1994). Suggested causes for the lack of normal-marine faunal assemblages include fluctuating salinity, oxygen-poor or anoxic bottom waters, and turbid bottom waters, as well as destruction of soft-bodied organisms induced by compression of overlying strata, and from decay and scavenging (Martino, 1994).

Martino (1994, 1996) describes the lithologies of (Kanawha) offshore deposits as "dark gray to black shales with micritic limestone nodules (0.5 to 1.0 m) and thick to thin beds and nodules of siderite." Offshore marine shales interfinger with nearshore (inner

shelf) facies and may extend into interdistributary bays and/or restricted bays.

Previously, such deposits have been interpreted as “bay-fills” (e.g., Arndt, 1979).

However, Chesnut (1989) suggests the term “sea-fills” may be more appropriate, as the marine shales have been correlated with European sequences.

Nearshore

According to Martino (1996), the “nearshore zone extends from low tide to storm wave base. It includes shallow subtidal areas of delta front, as well as interdeltic or nondeltic nearshore (i.e., shoreface and transition zone) deposits.” Nearshore sediments are coarser than those deposited in the offshore zone, and grain size distribution typically increases landward towards the higher-energy regions (Davis, Jr., 1978). Sands and silts are common in the nearshore.

Previous interpretations of Middle Pennsylvanian stratigraphic sections included such nearshore environments as barrier island/beach and backbarrier facies. Today, these same deposits are viewed as fluvial deposits of the upper delta-plain and alluvial-plains (Wizevitch, 1992). Donaldson (1979), Donaldson et al., (1985) and Martino (1994, 1996) postulated the presence of ephemeral longshore bars, although typical beach (sub)environments are not included in their models. Beaches are replaced in Donaldson’s (1979) model by tidal plains (Martino, 1994). Finally, Martino (1994) suggests that Kanawha nearshore zones were primarily composed of muds.

According to Davis, Jr. (1978), the surface of nearshore zones is often covered in ripples. More specifically, Davis, Jr. (1978) describes three variations of ripples, typical of nearshore environments. They are current, wave, and combined flow ripples, where

the predominant ripple type is dependent on the dominant or lack of dominant process acting in the nearshore. Longshore bars, also known as sand bars, run parallel to the shoreline and are found at the edge of the nearshore zone (Davis, Jr., 1978). Davis, Jr. (1978) interprets a lack of longshore bars as an indication of a steep shelf gradient or a cutoff of sediment supplied to the shelf. Another typical structure of nearshore environments is hummocky cross-bedding. The presence of hummocky bedding is generally interpreted to be the result of extremely high-energy conditions brought on by large storms.

An unusual silica-rich deposit, the Kanawha Black Flint (KBF) of White (1891) is found in the extreme western portion of Nicholas County, reaching westward into Fayette and Kanawha counties, (Reppert, 1979). The KBF is a very dark chert likely deposited in isolated shallow-water lows adjacent to deltaic facies in the nearshore zone (Martino, 1994; Reppert, 1979). The presence of such a deposit indicates a tropical climate during the end of Kanawha deposition as suggested by the coal geology (Reppert, 1979). The KBF chert facies grades into the study area into a light- to medium-gray marine shale that is present in the locality of the Birch River section (unpublished data, West Virginia Geologic and Economic Survey). Blake, (personnel communication, 2000) prefers the term “KBF equivalent” for the shale facies (south end of Outcrop Delta). At some localities, a hummocky, cross-bedded, fine-grained sandstone occurs in a non-silicified “sea-fill” at the same stratigraphic interval as the KBF chert facies (Martino, 1996).

Transgressive Sands

In two studies of Middle Pennsylvanian (Kanawha) deposits in southern West Virginia, Martino (1994, 1996) and Martino et al (1998) identified ravinement (scour) surfaces above coalbeds and overlain by thin (<1m) very-fine grained sandstones, with lags of siderite nodules overlain by the marine shales discussed above. Martino (1994, 1996) believes that the ravinement (scour) surfaces are the result of regional shoreface retreats initiated by the start of a marine transgression. The thin, discontinuous sandy lags are interpreted as reworked nearshore sand deposited in deltaic or alluvial environments of the previous sea-level lowstand. Sedimentary structures within these deposits include bioturbation and cross-stratification (Martino, 1994, 1996).

Zone 2 (tidal flats, tidal creeks and estuarine channels along interdeltic and transgressive coastal settings)

Estuaries, Estuarine Channels, and Restricted (Interdistributary) Bays

The estuarine environments interpreted in Martino (1996) are based on the tide-dominated estuarine model proposed by Dalrymple et al. (1992). Most definitions of estuaries rely on the salinity range between the head of the river and the bay (e.g. Pritchard, 1967). However, Dalrymple et al. (1992) define an estuary as “the seaward portion of a drowned valley system which receives sediment from both fluvial and marine sources and which contains facies influenced by tide, wave and fluvial processes. The estuary is considered to extend from the landward limit of tidal facies at

its head to the seaward limit of coastal facies at its mouth.” Dalrymple et al. (1992) further propose that an estuary is, in essence, the product of a relative sea-level rise.

Figure 15. The Three Zones of an Estuary Based on Dominant Process.

The outer, marine-dominated, inner, river-dominated, and central, mixed-energy zones of estuaries. Dalrymple et al (1992) propose this model for both wave-dominated and tide-dominated estuaries. (From, Dalrymple et al., 1992)

Dalrymple et al. (1992) divide estuaries into two types, wave-dominated and tide-dominated, based on the dominant process acting in the estuary. Martino (1996) cites Scotese (1986) in disregarding the effects of waves during Kanawha (Middle Pennsylvanian) deposition within the central Appalachian basin.

Both tide-dominated and wave-dominated estuaries have three distinct regions, 1) an outer, relatively high-energy region dominated by marine processes (i.e. waves and tides); 2) a central, relatively low-energy region of mixed fluvial and marine influence; and 3) an inner, relatively high-energy region dominated by fluvial processes (Dalrymple et al., 1992) (see Fig. 15). The typical grain-size distribution within estuaries, i.e., coarse-fine-coarse, corresponds to the outer-high energy, central-low energy, and inner-high energy regions (Dalrymple et al., 1992)(see Fig 16). However, since tidal currents reach farther into the headwaters of estuaries than do waves, sand

occurs throughout tide-dominated estuaries, and fine sand is typical of the lower energy regions (i.e., tidal channels) (Dalrymple et al., 1992) (Fig 16). Suspended-load sediments (i.e., silts and clays) are deposited along the margins of estuaries in very low-energy zones, such as marshes and tidal flats (Dalrymple et al., 1992) (Fig. 16).

Dalrymple et al., (1992) (see Fig. 17 and Fig. 18) outline the typical facies distribution of a tide-dominated estuary. The facies succession includes cross-bedded alluvial channel and rooted overbank deposits from the previous sea-level lowstand, overlain by transgressive, inner straight, tidal-fluvial deposits with tidal bedding and tidal lamination. Next, transgressive, tidal-bedded and tidal-laminated, tidal-meander and salt marsh deposits overlie the inner straight, tidal-fluvial deposits. A scour surface and a transgressive lag deposit might overlie tidal-meander deposits during the rising sea. Farther up slope into the estuary, tidal, cross-bedded and tidal-bedded, elongate tidal-sand bars and upper-flow regime sand flats with plane beds might overlie the tidal meanders. If the transgression were continuous, the estuary would begin to fill until sea-level highstand, when it would prograde seaward (Fig. 17). Dalrymple et al., (1992) suggest that when maximum transgression is reached, estuaries evolve into deltas by sediment infilling of the estuarine central-basin and progradation beyond the previous coastline (relative sea-level regression). Additionally, Dalrymple et al. (1992) suggest that scour surfaces, resulting from tidal-channel meandering, are typical at facies boundaries.

Figure 16. The Three Zones of a Tide-Dominated Estuary and Associated Facies.

Diagram showing the three zones of energy within a tidally-influenced estuary and the facies distribution resulting from this tripartite zonation. (From, Dalrymple et al., 1992)

Figure 17. The Evolution of a Tide-Dominated Estuary. Map-view of the evolution of a tide-dominated estuary during a complete T-R cycle and the migration of facies during that cycle (From, Dalrymple et al., 1992). Note the typical funnel-shape of the estuary.

Figure 18. Cross Section of a Tide-Dominated Estuary.

Cross-section of a tide-dominated estuary showing the migration of facies during a T-R cycle. (Modified from Dalrymple et al., 1992)

Tide-dominated estuaries typically have a funnel shape in map view (Dalrymple et al., 1992) (Fig. 17). Tidal range determines the extent to which various sediments and sedimentary structures will occur in a tide-dominated estuary (Dalrymple et al., 1992). Tide-dominated estuaries can develop in any of the three tidal-ranges, microtidal (tidal range <2m), mesotidal (2 – 4m), or macrotidal (>4m) (Boothroyd, 1978). However, the best known tide-dominated estuaries have macrotidal ranges, such as the Cobequid Bay and Salmon River of Canada (Dalrymple et al., 1992). In the case of macrotidal estuaries, the tidal sand bar and sand flats tend to comprise a much larger proportion of the estuarine deposits (Dalrymple et al., 1992).

Tidal Flats (Subtidal, Intertidal, and Supratidal Flats and Marshes)

Tidal flats are low gradient, ramp-like sites of deposition, present along coastal margins. The widths of tidal flats vary greatly depending on the range of tides and the strength of waves (Lewis and McConchie, 1994; Weimer, 1982). They may form under any climate, and may be comprised of any mineral content, and are associated with any number of depositional environments, including deltas and barrier islands (Weimer, 1982; Pettijohn et al., 1987; Davis, Jr., 1978; Lewis and McConchie, 1994). The intertidal flat has been defined as that region of a tidal flat bounded by mean low tide and mean high tide, whereas supratidal flats are those regions above the normal high tide, and subtidal flats are those regions below (Lewis and McConchie, 1994).

Tidal-flat environments show a decrease in grain size from coarse sand to mud proceeding from the subtidal zone through the intertidal zone to the supratidal zone (Weimer et al., 1982; Pettijohn et al., 1987; Davis, Jr., 1978; Lewis and McConchie, 1994). Coarse sand is normally deposited in the subtidal and low intertidal flat zones as a result of the winnowing effects of wave action and tidal currents. The relatively higher energy of the subtidal and lower intertidal zones reduces burrowing activity, which typically results in well-preserved bedforms, predominantly herringbone cross-bed sets (Lewis and McConchie, 1994; Weimer et al., 1982).

Due to tidal and evaporative effects, the upper and mid-sections of the intertidal and the supratidal regions tend to be inhospitable to most organisms. As a result, faunal diversity is seen to decrease from the subtidal zone to the upper tidal flat (Lewis and McConchie, 1994). Coarsest sand and gravel are found in tidal creeks, which

increase in proportion and decrease in size up-dip along the tidal flat (see section below).

Deposition of silt and mud increases with the subsequent decrease in tidal-current velocity landward across and up the intertidal flat. Clay and silt are typically deposited from suspension during times of slack tide, when the water is very still (Weimer et al., 1982). Bed-load sand is deposited during changing tides, both high and low. The repetitive deposition of sand and mud gives rise to bed-forms unique to tidal environments, including laminated, cross-bedded and cross-laminated sands with flaser, wavy, and lenticular bedding, as well as interference ripples and reactivation surfaces (Weimer et al., 1982; Lewis and McConchie, 1994). Additionally, soft-sediment deformation, including pillows, flame structures, and slumps, can result from rapid dewatering of unconsolidated sediments. Again, faunal diversity is low on the mid- to upper tidal flat, but bioturbation and trace fossils from adaptive species are not uncommon (Lewis and McConchie, 1994). Clay and silt are the only sediments deposited on upper tidal flats. The laminae of the upper tidal flat may be bioturbated by organisms tolerant of environmental extremes.

The region of a tidal flat above mean high tide is called the supratidal flat. In temperate to tropical climates, the supratidal flat is usually the location of a salt marsh (Weimer et al., 1982; Pettijohn et al., 1987; Davis, Jr., 1978; Lewis and McConchie, 1994). Water laden with suspended-load sediment inundates the salt marsh during tidal extremes or storms, when thin layers of mud are deposited (Davis, Jr., 1978). Both animal burrowing and root bioturbation are extensive in this area (Lewis and McConchie, 1994; Weimer et al., 1982; Davis, Jr., 1978). Thick deposits of root

bioturbated peat (coal) and black, organic-rich mud with massive and laminated beds typify the supratidal salt marshes (Lewis and McConchie, 1994; Weimer et al., 1982; Davis, Jr., 1978).

Salt marshes are extreme environments, lying at the boundary between marine and terrestrial conditions (Davis, Jr., 1978). Faunal assemblages of salt marshes are dependent on the width and location of the tidal flat, as well as the climate and the degree to which brackish waters mix with the fresh, surface and ground waters (Weimer et al., 1982; Davis, Jr., 1978). In temperate climates, modern marsh fauna consists primarily of shrubs, grasses, and algae that have an affinity for both brackish and fresh water (Lewis and McConchie, 1994). In tropical climates, modern salt-marsh vegetation may include several species of mangrove (Lewis and McConchie, 1994; Weimer et al., 1982; and Davis, Jr., 1978). In regions with low-energy tidal currents, salt-marsh vegetation may extend beyond the supratidal region to estuaries, delta channels, and lagoons (Davis, Jr., 1978; Weimer et al., 1982). Where tidal flow velocities are higher, unvegetated intertidal flats develop (Davis, Jr., 1978; Weimer et al., 1982).

Tidal Creeks and Tidal Creek Point Bars

Deposition in tidal flat subenvironments occurs through a series of interconnected tidal creeks, sourced by tidal currents in estuaries, bays, or the open oceans (Davis, Jr., 1978). Tidal creeks have a meandering form, where sinuosity is greatest on vegetated flats and the resultant drainage pattern is commonly dendritic (Davis, Jr., 1978). Pettijohn et al. (1987) report that tidal channels produce a fining-upward sequence with sedimentary structures that closely resemble those of a fluvial

environment (See Zone 3 and Zone 4 for a discussion of fluvial deposits). The main differences are the marine fossils and possible drapes found in the tidal creeks (Pettijohn et al., 1987).

Tidal creeks are widest and deepest in the subtidal to lower intertidal zones and tidal-current velocities within channels decrease with landward distance up the tidal flat. Lowest current velocities are found in channels of the upper intertidal flat and salt marsh/supratidal subenvironments. Additionally, the strength of the ebb tide may be greater than that of the flood tide, or vice versa, or they may be of equal strength. In each case, bedforms produced by such current flows will reflect any dominance or directional change in ebb or flood tide.

Clastic grain size is typically larger in channel creeks, than the adjacent tidal-flat subenvironment, but still fines landward. Grain size averages medium to fine sand in lower sections, fine sand to silt in lower to mid- intertidal flat, and silt to clay in the mid- to upper tidal-flat subenvironments. Only the finest clay is deposited in the supratidal zones. However, shell lags may be present throughout the length of a channel, deposition occurring in higher reaches as a result of unusually high tides or storm events.

Zone 3 (river-dominated deltaic distributaries and mouth bars)

A discussion of delta subenvironments is present below in the section on the deltaic model, where the focus will be on river- and tide-dominated deltas. Martino (1996) interprets the Zone 3 deltaic deposits to be the result of deposition in river-

dominated deltas. This contrasts with the importance given to tidal processes in Zones 1 and 2 of Martino's (1996) coastal-plain model. The distinction between the dominance of tidal and riverine process can be clarified with a more detailed look into the estuarine model of Dalrymple et al. (1992). According to Dalrymple et al. (1992), formation of estuaries (drowned river valleys) is favored by a balance between the influx of sediment by both tides and rivers and by a steady rise in sea-level (transgression). Delta formation is initiated at the maximum of the sea-level rise. Deltaic progradation occurs when sea-level stabilizes and sediment-laden rivers fill in estuaries of the former transgression. When estuaries are completely filled during the maximum transgression and when sediment influx continuously outstrips subsidence, delta progradation occurs. Deltaic sequences dominate the sea-level highstand. Deltaic progradation is followed by incision of alluvial channels into the former delta plain during the following sea-level low (regression) (Dalrymple et al., 1992). Deposition of incised valley fills (IVF) signals the initiation of an overlying marine transgression.

The dominance of river processes over tides contrasts the tide-dominated deposition within the estuaries of zone 2. Interestingly, the typical triangular diagram used to illustrate dominant processes controlling delta morphology and characteristics (Lewis and McConchie, 1994) places estuarine-embayed deltas adjacent to the broader heading of tide-dominated deltas (Figure 19). An example of an estuarine-embayed, tide-dominated delta is the Klang-Langat of Malaysia (see for instance, Coleman et al., 1970). Again, however, most workers, including Martino (1994, 1996) and Donaldson and Eble (1991), interpret deltaic sequences within these rocks to be the result of river-dominated processes.

Figure 19. Modern Delta Classification according to Dominant Process.

The Dominant process acting on a deltaic system may include river, tide, wave, or a combination of processes. (From Lewis and McConchie, 1994)

Zone 4 (meandering river channels)

Alluvial Channels

The alluvial channels of meandering streams migrate laterally across flood basins to form wide channel belts generally characterized by point-bar structures (Pettijohn et al., 1987; Visser, 1972; Cant, 1982). In outcrop, vertically stacked point bars are termed multi-story, and amalgamated single story point bars (sheet sands) are termed multilateral (Pettijohn et al., 1987). In other cases, point-bar sands may form isolated sand bodies within overbank facies (Pettijohn et al., 1987). Point bars are composed of

fining-upward sequences with a high degree of variance in paleodips of cross-bedding and cross-laminae (Pettijohn et al., 1987). However, bimodal paleocurrent directions should not be encountered in alluvial reaches of meandering rivers. Martino (1996) uses bimodal current directions to infer tidal processes and a tidal or estuarine setting for some Kanawha channel facies.

Lateral, low-dip ($\sim 5\text{-}15^\circ$) time-transgressive, bounding surfaces within point bar deposits are termed lateral accretion surfaces (Visser, 1972; Cant, 1982; Collinson and Thompson, 1989). The lateral accretion surfaces are sometimes highlighted in outcrop by the presence of mud (Smith, 1987)(See Fig. 20). These surfaces define individual sets of laterally accreting epsilon cross strata. An ECS consists of a fining-upwards succession (Pettijohn et al., 1987) that is generally one to five meters and bounded by erosion surfaces (Collinson and Thompson, 1989). Cross-beds and cross-strata dip perpendicularly to that of the ECS, indicating flow perpendicular to dip of the ECS (Collinson and Thompson, 1989). Ridge-and-swale topography develops from lateral migration of ECS (Farrell, 1987). Ridges, called scroll bars, are the surface expression of individual ECS (Visser, 1972; Cant, 1982).

A typical point-bar sequence begins with a discontinuous gravel lag atop an erosive channel base, overlain by planar and followed by trough cross-bedded sand, next overlain by ripple-laminated sand (Cant, 1982). Capping the fining-upwards sequence is vertically accreted, laminated, fine mud of the overbank facies (Cant, 1982). Clay clasts may also be present throughout the sequence (Pettijohn et al., 1987). The typical point-bar sequence may be erosionally truncated by the migration of overlying point-bar channels, which likewise may or may not be preserved in the rock

record (Smith, 1987). Soft-sediment deformation is also common in deposits of meandering streams and may result from a variety of processes, such as changes in flow conditions, overloading of sediments, and/or liquefaction (Collinson and Thompson, 1989).

Farrell (1987) interprets vertically accreted upper-point-bar muds to be part of the overbank facies. In any case, overbank deposits are discussed under Zone 5 below. Additionally, Shuster and Steidtmann (1987) suggest that the lateral and vertical distribution of point-bar facies within such overbank deposits is controlled by the rate of subsidence, if river type and avulsion rate remain constant. Shuster and Steidtmann (1987) interpret a relatively high proportion of overbank deposits to channel facies as an indication of relatively high subsidence rates. On the other hand, a relatively high proportion of channel facies to overbank deposits is interpreted to result from a relatively low subsidence rate (Shuster and Steidtmann, 1987).

Pettijohn et al. (1987) in defining the characteristics of meandering, braided, and anastomosing streams, interpreted many similarities between meandering and anastomosing streams types. Major differences between the two types are the large variance in paleocurrent-dip azimuths of meandering streams and the low variance in dip azimuth for anastomosing streams. The variance of dip azimuth relates directly to the high sinuosity of meandering streams and low sinuosity of anastomosing streams (Pettijohn et al., 1987). Finally, Lewis and McConchie (1994) and Pettijohn et al. (1987) note how the sandstone of meandering streams, estuarine channels, and tidal channels can be virtually identical in outcrop. Therefore, due care must be given to analysis of enclosing lithologies and facies associations in order to understand the genesis of the

channel sands. Lateral and vertical facies related to alluvial (meandering) channels are flood basins, crevasse channels, oxbow lakes, and swamps (described in Zone 5).

Laterally and vertically related facies of estuarine and tidal channels can be inferred from the discussion of Zone 2, above.

Smith (1987), recognizing the paucity of studies on point bars in modern depositional environments, proposed a three-fold classification for point bar deposits of meandering streams. Classification within Smith's (1987) model is dependent on the amount of tidal influence in the channel (Fig. 20)(see Zone 2, above). In Smith's (1987) classification, fluvial channels of the alluvial plain have the lowest mud content. Upper delta-plain or upper estuary channels within low-energy fluvial or micro-tidally-dominated settings have a greater percentage of irregularly spaced mud partings. Channels within meso-tidally dominated estuaries contain the greatest amount of mud partings as rhythmically bedded couplets of mud and sand in an overall fining-upward sequence (Smith, 1987). Smith (1987) also noted that the amount of mud increases downstream within point bars, especially in those of tide-influenced environments.

Figure 20. Classification of Epsilon Cross Strata.

Classification of ECS, dependent on percentage of fine-grained partings present. (from Smith, 1987)

Zone 5 Overbank Deposits (Interfluvial channel margins, lakes and swamps)

Both lateral and vertical distribution of Zone 5 subenvironments are dependent on the topography and water table within overbank paleoenvironments, where fluctuations in water table levels were related to changes in climate and/or sea level (Martino, 1996). Several successions are typical of overbank settings, including interbedded successions of levee deposits and channel sands, crevasse deposits and both levee and flood basin deposits, and oxbow lakes and flood basin deposits (Farrell, 1997). Aitken and Flint (1994) interpret thin (<0.4 meter), aerally restricted (2-3 km),

coals as deposits of backswamp environments. Splitting is not uncommon in such coal beds (Aitken and Flint, 1994).

Interfluvial Channel Margins

Interfluvial channel margins are commonly referred to as floodplains. A floodplain is a broad, topographically flat-lying region enclosing the main channel belt of a meandering river (Cant, 1982). Investigations of modern floodplains (Ray, 1976; Bridge, 1984; Farrell, 1987) have shown that the deposits form a mosaic of subenvironments, including levees, crevasse splays, lakes, swamps, and/or marshes.

Floodplain lithologies are characterized by thin beds (1-10cm) deposited from suspension during flood events, when floodwaters breach or overtop levees (Bridge, 1984). Mud of the floodplain may contain abundant root casts when deposited in temperate to tropical climates (Cant 1982). Martino (1996) interprets similar root-penetrated, laminated shales of the Kanawha Formation to be the deposits of clastic swamps. According to Grady (1998), the majority of both ancient and modern swamps were sites of clastic sediment accumulation with minor organic content. Martino (1996) describes these clastic-swamp environments as “forested wetlands with a mineral soil.”

Bridge (1984) notes a range of grain sizes for floodplain deposits, from fine-grained sand to clay, and grain size is dependent on the strength of the flood event as well as the sediment carried by the main channel. Generally, there is a reduction in grain size from deposits proximal to the main-channel to those distal to the main-channel (Bridge, 1984). Bed forms also are dependent on the location of the main-channel facies. Relatively small single-story channel forms (crevasse splays or

floodplain drainage channels) lie adjacent to the main channel and are composed of coarser-grained sediments (Bridge, 1984). On the other hand, sheet-like units are typically composed of more fine-grained sediments of the distal floodplain (Bridge, 1984).

Ray (1976) described a succession of overbank (floodplain) sedimentary features of the modern Mississippi River that range from ripple-drift laminated sands to trough cross-stratified sands. The depositional cycles of Ray (1976) are a result of frequent flood events in the Mississippi River floodplain. Ray's (1976) succession begins with horizontal to planar laminated, moderately to well-sorted silt and clay, deposited from suspension in quiet water settings, and overlain by ripple-drift laminated, moderately sorted silt. Formation of ripple-drift laminae results from excess sediment load relative to the strength of the current (Cant, 1982). Ripple-drift laminae are also a common bed form of meandering-river point-bar sequences (Cant, 1982). The ripple-drift laminae are overlain by small-scale, trough cross-laminated, well-sorted very fine sands deposited in a low-flow regime (Ray, 1976). Topping the succession are a variety of distorted laminae to massively bedded, bioturbated or root-mottled fine sands and clays. Ray (1976) also described scour-and-fill, and load-cast structures, and lenticular laminated fine sand to clay within the uppermost unit.

Farrell (1987) interpreted backswamp (floodplain) environments within the lower Mississippi River Valley using the classification of Krinitzsky and Smith (1969). Krinitzsky and Smith's (1969) classification has three main facies: 1) lacustrine; 2) poorly-drained swamp; and 3) well-drained swamp. Although somewhat of an

overgeneralization, this classification emphasizes the importance of those facies within a floodplain setting. Discussion of these facies is left for a separate section below.

Bounding the channel meander belts of Zone 4 are low, wedge-shaped ridges called levees (Cant, 1982). According to Farrell (1987), levee deposits become concentrated along the convex (erosional) side of the meander bends where the channel belt is fully developed. Although low topographic features, levees are very often the highest features in the floodplain, and so may show sedimentary features related to frequent subaerial exposure (Cant, 1982). Features typical of such exposure include abundant root casts, soil horizons, preserved organic material, mud cracks and rain-drop impressions (Cant, 1982).

Levee sediments are deposited during high discharge or flood stage of the enclosed channel belt (Farrell, 1987) as interbedded fine-grained, suspended-load sediments which dip away from the main channel. Rhythmites of sand and silt (Farrell, 1987) are deposited by frequent flood events. Fine sand and silt may be ripple cross-bedded or cross-laminated to parallel-laminated, whereas mud is laminated (Cant, 1982). The rhythmite of a levee deposit may sit on laminated, root-bioturbated clay of flood-basin origin (Farrell, 1987). Farrell (1987) also reports varying degrees of worm bioturbation in muddy sections of levee rhythmites of the Mississippi River. Levee deposits typically grade laterally into coarser sequences of the channel belt or crevasse-splay deposits (Farrell, 1987).

Crevasse splays form when levees are breached by flood-stage, sediment-laden currents (Cant, 1982). Crevasse deposits are channelform bodies, tongue-shaped in map view, flaring out from the main channel (Bridge, 1996; Visher, 1972; Cant, 1982).

With increasing distance from the main channel, crevasse deposits thin, taking on a sheet-like appearance (Bridge, 1984). According to Bridge (1984), crevasse deposits are coarser-grained (fine to very fine-grained sand) than other deposits of the floodplain, such as floodplain drainage channels (very fine-grained sand to silt). A typical crevasse deposit would consist of an erosive base, possibly overlain by a relatively thin coarsening-upwards of sediments deposited during rising flood stage. Deposition of a fining-upwards succession is attributed to a more prolonged period of waning flow (Bridge, 1984).

Aitken and Flint (1994) recognized crevasse channels within overbank sediments of the Breathitt Formation (Middle Pennsylvanian, of eastern Kentucky). The crevasse channels were described as single-story, minor channel-form bodies (100-563 meters wide and 5-13 meters thick)(Aitken and Flint, 1994). The channel-fill was comprised of siltstone, and/or fine- to medium-grained sandstone, and/or interbedded sandstone and siltstone with trough cross-bedding, current ripple lamination, lateral-accretion surfaces, and internal erosion surfaces. Aitken and Flint (1994) interpret other similar lithologies of the Breathitt as distributary channels or distal feeder channels. Likewise, Bridge (1984) reports that deposits of deltaic and alluvial facies may appear similar in the rock record. Bridge (1984) suggested differentiation of deltaic and alluvial overbank deposits can be made based on interpreted avulsion rates of the main channel belt. Gradual coarsening-upward sequences would typify deltaic sequences, whereas an abrupt change from a coarsening-upward sequence to a fining-upward sequence would be attributed to an alluvial setting (Bridge, 1984).

Lacustrine Deposits

Oxbow lakes are found throughout deposits of meandering alluvial systems (Cant, 1982). Formation of an oxbow lake begins when a river channel becomes too sinuous, and the high floodwaters breach the levee, cutting off the meander bend, straightening the channel. Gradually, the ends of the abandoned channel are plugged with sediment, isolating from the main flow to become an oxbow lake (Visser, 1972; Cant, 1982). Sediment is deposited in oxbows from suspension, forming a parallel-laminated, root-bioturbated, organic-rich clay plug within the meander belt (Visser, 1972; Cant, 1982). A series of these clay plugs help to keep the main channel within the center of the meander belt system (Cant, 1982; Lewis and McConchie, 1994; Visser, 1972).

Cannel coals are formed as wind blown spores and algae accumulate in stagnant deep ponds and oxbows distal from clastics (Gillespie et al., 1978; Grady, 1998, Blake (personnel communication, 1999)). Other sites in the meander belt system that may become sites of freshwater-lake deposition include extensive lengths of abandoned channels (due to upstream avulsion) and swales above laterally-accreting point bars (Cant, 1982).

Freshwater lakes on floodplains are frequently composed of homogeneous successions of fine-grained sediment (Lewis and McConchie, 1994). In the Kanawha Formation, Martino (1996) described successions of such deposits as planar-laminated, dark-gray shale with fine plant detritus, and minor partings of very fine sandstone with horizontal or lenticular current ripple bedding. According to Martino (1996), these successions result when the water table rises, drowning a planar swamp.

Farrell (1987) used Krinitzsky and Smith's (1969) classification of overbank deposits to define the lacustrine facies. As defined by Farrell (1987), the lacustrine facies includes well-bedded, reduced, dark clay with minor sand and silt and some shell beds. Aitken and Flint (1994) define a facies association of lacustrine deposits in the Breathitt Formation as light gray to gray siltstone with parallel and wavy laminae, some plant debris, and a sheet-like geometry.

Peat-forming Swamps

Coal-bearing sequences are a relative rarity in the rock record (Cecil and Renton, 1979; Donaldson et al., 1985; Grady, 1998), because there is a very narrow range of environmental conditions necessary for the preservation of peat (coal). However, as stated in Chapter 2, for the purposes of this study, coals are representative of a wet climate and a swampy (peat bog) depositional environment.

Delta Model Environments

Early studies on Pennsylvanian deposits of the central Appalachian foreland basin have focused on fluvio-deltaic environments. The early models of Ferm (1970, 1974, 1980) and Donaldson (1974, 1979) and Horne et al. (1978) postulated that sediments were deposited by a single, large river/deltaic system (flowing to the northwest) that, over time, prograded across the rapidly subsiding foreland trough (Southern Coalfield) onto the slower subsiding craton edge (Northern Coalfield). The modern Mississippi River Delta system was suggested as an analogue (e.g., Ferm, 1970, 1974). Later on, Donaldson (1979) suggested the Ganges and Indus River systems as modern analogues for the Pennsylvanian rivers. These models focused on coal deposits and three large-scale depositional facies within the system: alluvial-plain facies, upper-delta-plain facies, and lower-delta-plain facies.

The models of Ferm (1970, 1974, 1980) and Horne et al. (1978) interpreted a depositional continuum with carbonate offshore islands, barrier islands, and backshore bay-fills on the periphery of the lower-delta-plain. Donaldson (1974) originally interpreted barrier islands and back bays fringing the lower-delta-plain, and Donaldson et al. (1970) suggested the Guadalupe River delta (San Antonio Bay, Texas) as a modern analogue. However, Donaldson's (1979) model lacked the extensive barrier/back shore environments of Ferm's (1970) work and was an interpretation of Upper Pennsylvanian rocks in the Northern Coalfield. Tidal plain facies dominated the shoreline of Donaldson's (1979) delta model. Ettensohn (1980) re-interpreted the marine carbonate islands and marine shales as the erosional products of uplifted

Mississippian-aged rocks on the Waverly Arch in east-central Kentucky. Additionally, Wizevitch (1992), in an exhaustive study of the Lee Sandstone (Breathitt Group of Kentucky), found that the barrier island origin for the quartzose sandstones of previous models were not tenable as the sandstones appeared to be fluvial in nature. Marine shales, formerly interpreted as interdistributary bay-fills of limited areal extent (e.g., Horne et al., 1978), are now known to be extensive, basin-wide marine deposits with European correlatives, and are termed sea-fills by Chesnut (1989). According to Donaldson and Eble (1991), the scale of the Pennsylvanian deltaic systems is smaller than previously proposed (see, for instance, Donaldson, 1974), occupying only a third of the coastline, and deltas may have been important only during the regressive phase of an allocycle. Donaldson and Eble (1991) suggested the Texas coastal plain as an appropriate modern analogue for the scale of the Pennsylvanian deltaic systems.

Controls on sedimentation within the Appalachian Foreland basin include both allogenic processes, i.e., regional tectonic movements, eustatic sea-level changes, paleoclimatic variations, and autogenic processes, i.e., stream avulsion or local basement uplift (Donaldson and Eble, 1991). Such factors were discussed in the first two chapters. Formerly, Ferm (1970, 1974, 1980) and Horne et al. (1978) presented evidence for the importance of autogenic processes, concluding that such processes dominated the the Middle Pennsylvanian deposits. Currently, however, most workers agree that both autogenic and allogenic processes were at work during deposition, e.g. Donaldson and Eble, 1991. In fact, it is now believed that allogenic processes were the dominant control on deposition of these rocks (Donaldson and Eble, 1991).

Deltas

Lewis and McConchie (1994) defined a delta as a “complex mix of terrestrial to marine subenvironments created by a prograding deposit of sediment at the boundary between an alluvial system and the sea.” As emphasized by Pettijohn et al. (1987), the boundary between delta-plain deposits and up-dip alluvial-plain deposits can be difficult to locate in outcrop-scale studies, as it migrates variously over time. The complex interplay between sediment supply, basement subsidence, and changes in sea level greatly influence the location of this boundary (Pettijohn et al., 1987). Deltaic subenvironments include delta-plain deposits, such as fluvial-channel fills and levees, crevasse splays, freshwater lakes, floodplains, marshes; delta-front deposits, such as distributary-mouth bars, barrier islands, and shallow marine bays; and offshore muds and clays (Pettijohn et al., 1987; Tucker, 1993).

Overall, deltas are characterized as coarsening-upward sequences (Pettijohn et al., 1987), where offshore muds are overlain by distributary-bar sands, overlain by channel-fill sands (Coleman and Prior, 1982). However, as a wide variety of subenvironments comprise any given delta, there is an equally wide variety of possible successions that can form the local or outcrop-scale units of a delta deposit, including fining-upward units or coarsening-upward units capped by the seat-earth or coals of swamp environments (Pettijohn et al., 1987).

According to Coleman and Prior (1982), deltas commonly have a characteristic triangular shape when seen from above and, in cross-section, a wedge-shape. Deltaic thickness can range from tens to thousands of meters, while aerally, deltas can cover tens to thousands of square kilometers (Coleman and Prior, 1982). Modern deltas are

typically placed into one of three categories: river-, wave-, or tide-dominated; the classification is dependent on the dominant process influencing the delta shape and the deltaic subenvironments (Davis, Jr., 1978; Pettijohn et al., 1987; Tucker, 1993; Lewis and McConchie, 1994; Coleman and Prior, 1982). However, more than one process may act on a delta, and the less dominant process(es) may overshadow the predominant process on a local-scale (Pettijohn et al., 1987).

River-Dominated Deltas

River-dominated deltas form in areas with a low tidal range and minor marine influence. Interpretations of Pennsylvanian depositional environments within the central Appalachians have focused on river-dominated deltaic systems. Previously, workers assumed the Mississippi delta complex was a good modern analogue (e.g., Ferm, 1970, 1974). Currently, river-dominated deltaic environments are still envisioned for these Pennsylvanian rocks, although the Mississippi Delta is no longer accepted as the prototypical model (Donaldson and Eble, 1991; Martino, 1996). Recently, workers such as Donaldson and Eble (1991) interpret a coastal plain formed by the coalescence of deltaic deposits from many small rivers. Although the size of the Mississippi delta complex precludes it from being an appropriate modern analogue for the ancient Pennsylvanian rivers, the sediments and depositional environments of the Mississippi delta complex still provide a good analogue for many of the Middle Pennsylvanian deltaic sequences.

The Mississippi delta is probably the most studied delta in the world. Both the lateral and vertical facies distributions of deltaic environments are well understood in

terms of the evolution of the delta and the processes whereby these sediments were deposited (see, for instance, Trowbridge, 1922, 1930; Fisk, 1961; Fisk et al., 1954). A good overview of the Mississippi delta complex is presented by Gould (1970) and forms the basis for this section. Gould (1970) discussed the delta in terms of broad depositional environments: alluvial-valley deposits, delta-plain deposits, and the subaqueous delta. According to Gould (1970), the Mississippi delta complex is composed of an onlapping sequence of fluvial, strandplain, and deltaic sediments deposited during a period of rising sea level (Late Quaternary) and overlying deltaic sequences deposited during the current sea-level stillstand (Recent).

In Recent times the Mississippi River has deposited sediments in five subdeltas, and the river is known to have taken at least two courses (Gould, 1970). The present-day Mississippi delta is a classic birdfoot delta with an elongate shape. Each of the four previous Mississippi deltas had a lobate shape in shallow regions of the continental shelf. The four distributaries of the modern birdfoot delta are prograding towards a relatively deepwater (shelf edge) region of the Gulf of Mexico. Clay- and silt-sized sediments comprise the greatest fraction (75%) of Mississippi delta deposits. The sand fraction is mainly deposited in distributary-mouth bars (Gould, 1970). The Po River delta of Italy is another example of a present-day, lobate, river-dominated delta (see Lewis and McConchie, 1994).

At the seaward limit of the birdfoot delta distributaries, mouth-bar sands are deposited in shallow water (Gould, 1970). Through seaward progradation, the distributary-mouth bars of the birdfoot delta have accumulated to form lunate sand bodies (15 to 20 mile long, 3 to 5 mile wide, and 30 to 120 foot thick) termed bar-finger

sands. The modern distributaries of the Mississippi delta maintain their courses with very little meandering or bifurcation. According to Gould (1970), bar-finger sands have a biconvex cross-sectional profile with gradational vertical and lateral contacts.

Bar-finger sands are composed of interbedded silty sand and sandy silt at the base. Sedimentary structures include basal trough cross-bedding or laminae, abundant plant debris and unidirectional planar cross-beds above. The upper section of a bar-finger consists of well-sorted, fine-grained sand, capped by fine sediments of the levee. These sand bodies grade laterally and overlie fine-grained sediments of the prodelta, delta front and interdistributary bay. The prodelta consists of massive, gray-colored clay beds that grade into interbedded silt and clay of the delta front (Gould, 1970). Ferm (1970) recognized deposits of bar-finger sandstones in his Allegheny Model for the Northern Coalfield.

Highly bifurcated networks of distributary channels with lobate delta forms characterize the four progressively older (Recent) deltas of the Mississippi River (Gould, 1970). These older deltas prograded across shallow regions of the inner continental shelf, where distributaries deposited coarse sediment (fine to medium sand) in mouth bars and spits (Gould, 1970). Bifurcation was a frequent response of distributaries when mouth-bar deposits plugged the channels. Once a channel mouth choked with sediment, the distributary would find a new course. Frequent bifurcation resulted in an amalgamated deposit of distributary-mouth bar sands termed a delta-front sheet sand (Gould, 1970). These sheet sands average 20 to 30 feet thick and are usually cross-bedded to cross-laminated. Individual distributary channels ranged from a quarter to a half-mile wide. The sheet sands grade up from underlying prodelta fines to fine sand

and silt. In some cases, burrowing was common enough to produce a mottled appearance. Sorting increases upwards and the sheet sands are well-sorted in upper sections. Marsh deposits of peat and organic muck cap the sheet sands (Gould, 1970).

Most of the fine sediment (silt and clay) carried by the Mississippi River is deposited seaward of mouth bars in areas of the prodelta and delta front (Gould, 1970). Sediments of the prodelta and delta front include interbeds of silty clay and clayey silt and coarsen upward to sand of the mouth bar. Bedding is thick to massive and sand interbeds are not uncommon (Gould, 1970). An assemblage of marine molluscs and foraminifers is common to this sequence.

In a study of the Po River delta in Italy, Nelson (1970) found thick accumulations of sand seaward of distributary mouth bars. Nelson (1970) suggested the thick-delta front sand deposits were a result of several factors that could be compared to the modern Mississippi delta. The most important factors were the greater sand load carried by the Po River, combined with relatively slow shelf subsidence, shallow water, and relatively high-river discharge velocities (approx. 1,500 cubic meters/second)(Nelson, 1970).

Fine-grained sediment also accumulates in depositional environments that are gradational to the distributary-mouth bars; they include levees, swamps, marshes, lakes, and bays. Gould (1970) classifies the latter settings as delta-plain facies. Other workers (e.g., Horne et al., 1978) would classify the marine environments under the narrow heading interdistributary bay-fill. As discussed previously, Chesnut (1989) suggested "sea-fill" as a better term for the regionally extensive Middle Pennsylvanian marine units (e.g., Dingess Shale Member of the Kanawha Formation).

Levee deposits are composed of laminated silt and clay interbeds that may be disturbed by root burrows. Levee deposits also contain scattered organic debris (Gould, 1970). Coarser-grained crevasse deposits are also typical within such environments (Coleman and Prior, 1982). The typical sedimentary associations of these deposits are identical to those discussed under interfluvial channel margins. The bay deposits discussed by Gould (1970) are not unlike floodbasin deposits in their lateral facies associations. The greatest difference may lie in the faunal distributions of the bay-fill, where marine- to brackish-water would preclude the establishment of fresh-water species. According to Gould (1970) brackish-water fauna are found throughout the delta-plain and include molluscs, gastropods, foraminifers, and ostracods. Finally, sequences of bay deposits overlie prodelta and mouthbar deposits and are capped by marsh sediments.

A final sedimentary sequence is the channel-sand sequence of the distributary channels. The channel deposits rest on an erosive base that cuts into underlying prodelta and delta-front sediments. It is composed of an upward-fining sequence of well-sorted and cross-bedded basal sand with layers of woody plant material. The channel sand contains no fauna and grades upwards into marsh deposits (Gould, 1970).

A depositional environment related to marine processes in the Mississippi delta complex is the chenier plain (Gould, 1970). The chenier plain is an extensive coastal plain (20-miles wide) covered by marsh deposits. The plain accumulated as a complex of littoral sand and mud, deposited by persistent westward longshore currents. As previously discussed, central Appalachian Pennsylvanian strata, formerly interpreted as

deposits of littoral environments, are now considered to be fluvial deposits. In any case, these deposits are more fully discussed in the later section context of a wave-dominated delta and marsh deposits.

Tide-Dominated Deltas

Cecil et al. (1985) suggested central Appalachian Middle Pennsylvanian coastal zones and estuaries were influenced by meso- to macro-tidal processes similar to those at work on the present-day Sunda Shelf. Examples of tide-dominated deltas are the compound delta of the Ganges and Brahmaputra Rivers in Bangladesh, the compound delta of the Klang and Langat Rivers of Malaysia, the Ord River delta of Australia, the Amazon River delta of Brazil, and the Fly River delta/estuary of Papua New Guinea. The structural setting of the Ganges and Indus Rivers (Pakistan) has been suggested as an appropriate modern analogue for the Middle Pennsylvanian central Appalachian region by Blake (personnel communication, 1999). Coleman (1969) and Bristow (1985) studied processes and sediments of the Brahmaputra River (Bangladesh) and recognized braided, meandering, and anastomosed sections of the river. Although the study of the Brahmaputra by Coleman (1969) is considered to be a landmark paper (Bristow, 1985), the wide variety of channel patterns are not representative of Middle Pennsylvanian depositional environments in the study area. Additionally, Cecil et al. (1992) suggested the coastal plain of Malaysia as an appropriate modern analogue for these Middle Pennsylvanian rocks. Therefore, for purposes of this study, the representative tide-dominated delta is the compound Klang-Langat delta. A study of the Klang-Langat by Coleman et al. (1970) provides the basis for this section.

The Klang-Langat delta is a compound delta formed by the accumulation of deposits from two, relatively small rivers on a coastal plain (Coleman et al., 1970). Delta morphology is predominantly controlled by macro-tidal conditions with an average range of 14 feet. Longshore drift exerts a low to moderate influence on the delta and it is attributed to the development of coastal-plain tidal flats northwest of the delta. Fluvial influence is confined to the network of tidal channels that also serve as distributaries. Important depositional environments within the Klang-Langat delta are tidal ridges, delta front, tidal flats, and swamps (Coleman et al., 1970; Keller and Richards, 1967).

The Klang-Langat delta is prograding into the Strait of Malacca on the Sunda shelf in tropical Southeast Asia (Keller and Richards, 1967; Coleman et al., 1970)(Fig. 21). The 805 km funnel-shaped strait has a narrow (64km wide) southern end connected to the South China Sea and a wider (257 km wide) northern end connected to the Indian Ocean (Keller and Richards, 1967). It is bordered by the Malay Peninsula on the northeast and Sumatra on the southwest. Muddy sand is the dominant sediment in the strait, and it is derived from the many small rivers that dissect the highlands of Sumatra and the Malay Peninsula (Fig. 21). Mud-sized sediment is typically associated with deposition near river mouths (Fig. 22).

Figure 21. Location of the Klang-Langat Delta System on the Malay Peninsula. Note the multiple river systems that drain the coastal plain of Malaysia (Modified from Coleman et al., 1970).

Figure 22. Facies of the Klang-Langat Delta.

Note the exaggerated nw-se trend of the deposits due to the strong nw-se tidal flow within the Malacca Strait. See Figure 23 for cross-section line A-A'. (Modified from Coleman et al., 1970).

The ridge-and-trough topography occurs adjacent to river mouths and was attributed to tidal currents in the strait (Keller and Richards, 1967). Flood tidal currents have velocities averaging 55 cm/second, and ebb tidal currents average 100 cm/second (Coleman et al., 1970). The ridges are composed of mud, and sand is present in the troughs (Keller and Richards, 1967). Sand deposition in lows is the result of higher tidal current velocities in the troughs. The ridge-and-trough topography described by Keller

and Richards (1967) is suggestive of tidal ridges that form in tide-dominated deltas. The tidal ridges of the Malacca Strait extend seaward from river mouths and, in some cases, flare out in a seaward direction (Keller and Richards, 1967). The ridges are up to 22 km long and approach 50 km in length. According to Wright (1978), tidal ridges are equivalent to distributary-mouth bars in river-dominated deltas. As a result, tidal ridges are major sites of sand accumulation in tide-dominated deltas. Additionally, Wright (1978) described sedimentary deposits of tidal ridges as dirty sand with bi-directional cross-bedding.

A network of interconnected tidal/distributary channels and tidal flats are located at the mouth of the Klang and Langat Rivers (Coleman et al., 1970) (Fig. 22). Fine-grained sediment of the northern Klang River flows into a funnel-shaped estuary known as the Klang Strait. The wide end of the estuary extends to the Malacca Strait in the north, parallel to the dominant northeast currents (Fig 22). The southern end of the estuary narrows into a series of tidal/distributary channels that flow in a southwest direction to the mouth of the Langat River and the Malacca Strait (Coleman et al., 1970). Tidal flats are located within the network of tidal/distributary channels. Tidal ridges, similar to those found in the Malacca Strait, develop with a northwest trend within the Klang Strait (Fig. 22).

A large tongue-shaped tidal flat, called Angsa Bank, also trends to the northwest and is located seaward of the Klang Strait and the southern tidal/distributary channel network (Coleman et al., 1970) (Fig. 22). Mangrove swamps are located on tidal flats bordering the strait. Fresh-water (peat) swamps develop in the higher elevations of

large tidal flats. These fresh-water swamps also dominate the landscape of the coastal plain behind the coastal mangrove swamps.

According to Coleman et al. (1970), river discharge rates vary with the two unequal monsoon seasons, and discharge is not normally very high or very low. The relatively slow flowing Klang and Langat Rivers carry a sediment load consisting of sand, silt and clay. Medium to very-fine-grained sand is the dominant component of the sedimentary mix, but very coarse sand is not uncommon (Coleman et al., 1970). Most sediment is carried through the southern end of the channel network into the Malacca Strait. Sandy tidal flats develop adjacent to the mouths of the tidal/distributary channels. The dominant northwest currents carry fine sediments to Angsa Bank and other tidal flats. The typical sedimentary sequence of this tide-dominated delta consists of basal offshore or nearshore sand and mud overlain, in turn, by delta-front sand, tidal-flat sand and mud, mangrove-swamp clay, and peat of the freshwater swamp (Coleman et al., (1970) (Fig. 23).

In the Klang-Langat delta, the delta front is essentially the region of steeply sloping tidal flats adjacent to channel mouths (Fig. 22). The delta front consists of medium- to thin-bedded and laminated sand to clayey sand with minor amounts of plant and shell debris (Coleman et al., 1970). Well-sorted sands of the tidal-flat and channel-mouth beaches overlie the delta-front deposits (Fig. 23).

Angsa Bank lies north of the delta-front deposits. Tidal-flat facies such as Angsa Bank are composed of fine-grained sediment, i.e., clayey sand to sandy clay (Coleman et al., 1970). The ramp-shaped tidal flats have an elevation of several feet due to the relatively high tidal range in the delta. Sediments reach the upper tidal flat through a

network of tidal creeks. Tidal-flat bedforms include parallel to lenticular laminae with lenses of organic matter. Burrowing is common within the tidal-flat, and a variety of mangrove species are present landward of the neap high-tide limit (Fig. 23).

Tidal/distributary channels contain a variety of sediments and structures because of the dual role they play in the delta (Coleman et al., 1970). Channels with relatively high discharge velocities contain deposits of well-sorted, fine to medium sand. Channels in relatively lower-energy settings are composed of poorly-sorted clayey sand with minor amounts of organic debris. Tidal/distributary channels become better established when vegetation is established on the tidal flats. Well established tidal channels form a meandering pattern. The tidal-channel point-bar sequence consists of channel sand overlain by fine-grained sediment of the mangrove swamp. Coleman et al. (1970) found the sediments and sedimentary structures of the tidal-channel point-bar deposits were identical to deposits of the low-tidal-flat facies.

Figure 23. Cross-Section Line A-A' from Figure 22.

Idealized facies model of the Klang-Langat Delta system showing lateral facies relations. Note how the water level mimics the topography. Compare with Fig. 14. (Modified from Coleman et al., 1970).

Mangrove swamps stretch from the high-tide mark landward on tidal flats of the Klang-Langat delta and the extensive Malaysian coastal plain (Coleman et al., (1970). Vast freshwater swamps lay landward of the coastal mangrove swamps and on higher sections of large tidal-flat islands in the Klang-Langat tidal-channel network (Fig. 21). The extensive freshwater swamps are similar to the domed peat swamps discussed by Grady (1992) and Donaldson et al. (1985) (see Fig. 14). According to Coleman et al. (1970), the peat reaches a maximum thickness of 20 feet in the center of the swamp and is thin to absent along the edges. Fresh water peat deposits overlie gray, root-bioturbated clay of brackish water mangrove swamps (Fig. 23). Coleman et al. (1970), suggested the gray-rooted clay of the mangrove-swamp facies is equivalent to the underclays of coal-measure deposits. Many other deltas in Borneo, Sumatra, and throughout Southeast Asia are similar to the Klang-Langat.

Wave-Dominated Deltas

Wave-influenced depositional environments are no longer accepted for Pennsylvanian deposits in the central Appalachians (see Ettensohn, 1980; Wizevitch, 1992). The purpose of this section is to cover the full spectrum of depositional environments that occur in wave-dominated deltas. Examples of modern wave-dominated deltas are the Rhone River delta of France, the Senegal River delta of Northwest Africa, and the Sao Francisco delta of Brazil (Wright and Coleman, 1973; Lewis and McConchie, 1994; Oomkens, 1970). According to Wright (1978), the Senegal River delta is the archetype for deltas influenced by extremely high wave energy with a dominant littoral drift. Similar marine conditions influence the Rhone

River delta (Oomkens, 1970). Likewise, the Sao Francisco delta is primarily influenced by high wave energy. Tidal effects are minimal in each of these deltas (tidal range of 20 cm in the Rhone, 2.5 m in the Sao Francisco, and 1.9 m in the Senegal) (Oomkens, 1970; Wright, 1978).

Wright (1978) described a typical sedimentary sequence for the Senegal delta. This sequence consists of laminated silt and clay of the shelf and prodelta overlain, in turn, by interlaminated sand, silt, and clay of the distal bar, overlain by medium sand and silt of the mouth bar and shoreface. Shoreface deposits were overlain by a channel-fill fining-upward sequence, overlain by a thick deposit of well-sorted beach sand. An equally thick deposit of well-sorted eolian dune sand tops the beach sands. Tidal-plain sand, silt, and clay cap the sequence. The southern longshore drift off the Senegal River delta sweeps the sandy mix southward, where it is deposited in beach barrier spits that parallel the coastline (Wright, 1978). The spits aggrade to the south until the river distributary becomes overextended. Then the distributary channel develops a new course upstream and the process begins anew. The delta plain, therefore, is composed of alternating abandoned barrier spits and channel fills.

Wright (1978) described a similar sequence for the Sao Francisco delta as found in the Senegal delta. However, the longshore drift is not as strong in the Sao Francisco delta. Therefore, the sequence lacks the channel-fill deposits that characterize the Senegal delta. Instead of alternating barrier spits and channel fills, the Sao Francisco consists of alternating beach ridge and swale fills. The swale fills consist of poorly sorted silt and shale with abundant root-bioturbation. According to Wright and Coleman (1973) the Sao Francisco delta consists of extensive, laterally continuous sheet sands.

With the exception of beaches and eolian dunes, the sedimentary structures and features within these wave-dominated deltas are similar to those in river- and tide-dominated deltas. Beach and dune deposits are found in river- and tide-dominated deltas, but they are not common, nor do they characterize such deltas. The beach and beach-ridge deposits of these deltas are composed of well-sorted, clean sand (Wright, 1978). Beach sand is deposited in planar beds with a low angle, seaward dip. Other common bedforms are multi-directional cross-laminae and landward-dipping cross-beds. Shell beds or clusters of shells are common. Associated eolian dunes of the upper beach also consist of clean, well-sorted sand. Dune sands have large-scale festoon cross-beds and small-scale tangential cross-beds. The top of the dune unit is heavily bioturbated by overlying tidal-plain vegetation.

Combination Deltas

Deltas, such as the modern Niger River delta of Nigeria and the Nile River delta of Egypt, have morphologies and facies distributions influenced by a combination of marine, fluvial, and tidal processes (Allen, 1970; Wright and Coleman, 1973). Beaches, tidal flats, and river-mouth bars are typical of these combination deltas. The shorelines of the Niger and Nile deltas are described as smooth and arcuate with slight seaward protrusions of river mouths (Wright and Coleman, 1973). Within these deltas, wave energy is high enough to prevent the river-mouth bars from protruding too far into the sea. Beach and/or barrier islands characterize the shorelines of these deltas. In the case of the Niger delta, the shoreline is almost entirely composed of beaches and beach ridges that are backed by a network of tidal creeks, tidal flats, and distributary

channels (Wright and Coleman, 1973; Allen, 1970). On the other hand, the Nile delta shoreline is composed of barrier islands and beaches that border lagoons, hypersaline tidal flats, and marshes.

The modern Niger delta has prograded over a relatively broad and steeply dipping continental shelf, accumulating a thickness of 10 to 100 meters (Allen, 1970). The Niger delta is highly symmetrical about a main axis. High-energy waves strike the delta from the southwest, and longshore currents sweep sediment away from the delta axis to the west and to the east. Mouth-bar sediments, carried by longshore currents, provide a source of renourishment to the marginal beaches. The beaches vary from 5 to 37 km in length and are 100s of meters to 12 km in width. Beach sediments are predominantly well-sorted clean sands. The main sedimentary structure is lamination and ripples are uncommon. Tidal creeks and distributary channels erode and rework sediments from the landward side of the beaches, leaving the advancing mangrove swamp and floodplain facies devoid of abandoned beach ridges (Allen, 1970).

An inner belt of mangrove swamps parallel the beach and beach-ridge network in the Niger delta (Allen, 1970). The vegetation is built upon a network of tidal flats with interconnected tidal creeks. Allen (1970) recognized three main elements within the mangrove environment; they are meandering tidal creeks, small upper-tidal-flat gullies, and tidal flats. The small-scale tidal-flat gullies drain the upper tidal flats and flow into the meandering tidal creeks. Likewise, the largest tidal creeks flow into distributary channels that Allen (1970) termed estuaries. Tidal flow occurs within the distributary channels and tides range from about one meter to three meters. Bottom sediments within the estuaries are both mud and sand, and bottom features include shoals and

deeps. The sediments and sedimentary structures of the meandering tidal creeks are typical point-bar deposits with a fining-upward sequence.

A vast floodplain is located behind the mangrove swamp belt in the Niger delta. Allen (1970) divided the floodplain into an upper section and a lower section. The elongate upper-flood-plain begins where the Niger River first bifurcates and stretches southward to where the floodplain widens greatly. There are three main distributaries within the upper flood plain. Upper-flood-plain distributaries are braided and separate areas of swamp and forested ground. River distributaries quickly bifurcate outward in the lower-flood-plain, forming a large triangle that gives the delta an arcuate shape. Distributary channels within the lower-flood-plain are meandering. Channel sediments range from fine to coarse sand, i.e., typical point-bar sequences. The channels are bounded by low (2-meter high) levees that grade laterally into fine-grained interdistributary deposits (Allen, 1970).

Distributaries cut 10-meter deep channels up to several hundred meters wide into the floodplain and swamp deposits (Allen, 1970). Seaward, the distributaries deposit sediments in U-shaped mouth-bars that range from 12 to 24 km in width (Allen, 1970). As discussed previously, the mouth-bar sediments are swept by littoral currents, in places forming spits or beaches. The subaqueous mouth-bar deposits grade seaward into prodelta deposits typical of wave- or river-dominated deltas.

Incised Valley Systems

According to Dalrymple et al. (1994) and Zaitlin et al. (1994), the extensive erosion surface associated with an incised valley system meets the established criteria

for a sequence boundary (e.g., a type 1 unconformity of Van Wagoner et al., 1990). Channels thought to be the product of incised valley systems can only be identified through regional studies. As the present study involves a series of closely spaced outcrops in a limited area, identification as incised valleys is not possible. However, recognition of several criteria presented by Zaitlin et al. (1994) can be used to infer the possibility of incised valley systems at the Birch River field site. Zaitlin et al. (1994) define an incised valley system as:

"A fluvially eroded, elongate topographic low that is typically larger than a single channel form, and is characterized by an abrupt seaward shift of depositional facies across a regionally mappable sequence boundary at its base. The fill typically begins to accumulate during the next base-level rise, and may contain deposits of the following highstand and subsequent sea-level cycles."

The definition implies that incised valleys are the product of a regional change in base level, i.e., relative sea-level fall or tectonic uplift, resulting in a reduction of accommodation space. In addition, Dalrymple et al. (1994) and Zaitlin et al. (1994) noted other factors that can cause fluvial incision, for example, increased discharge due to climatic change or stream capture. However, fluvially incised valleys created by these other factors do not form sequence boundaries.

The sedimentary successions that accumulated within these valleys are termed incised valley fills (IVF). The sediments of an IVF may have accumulated during a single sequence (simple valley fill) or may reflect several depositional sequences (compound valley fill), dependent on sediment supply rates and the depth of incision (Dalrymple et al., 1994). Valley filling typically occurs during the sea-level lowstand after incision or in the early stage of the next transgression. A transgressive surface

(sequence boundary) separates the lowstand sequence tract from the transgressive sequence tract. The top of the transgressive sequence tract is marked by the maximum flooding surface. According to Zaitlin et al., (1994), this surface may extend through the length of the incised valley fill or it may be undeveloped due to rapid sea-level fall. There may be several maximum flooding surfaces within compound valley fills (Zaitlin et al., 1994). Deposits of the highstand systems tract overlie the maximum flooding surface. A tidal ravinement surface, caused by tidal currents in seaward portions of the valley, is a diachronous boundary within the valley fill. A wave ravinement surface represents encroachment of the marine environment in a wave-dominated shoreline. This surface separates marine from estuarine and/or fluvial deposits, and it has a more regional extent than the tidal ravinement surface.

Because incised valley systems can cross physiographic and tectonic boundaries, Zaitlin et al., (1994) divided incised valley (IV) systems into piedmont IV systems and coastal plain IV systems. A piedmont IV system is defined as a fluvial eroded valley that originates in a hinterland and crosses a knickpoint. A coastal plain IV system does not cross a knickpoint and it is found along the low-gradient coastal plain. Additionally, the piedmont IV systems contain more immature and coarser-grained sediments than the fine-grained, recycled deposits of the coastal plain IV system (Zaitlin, et al., 1994).

Incised valley fills are usually composed of sediments deposited in fluvial, estuarine, and fully marine environments (Dalrymple, et al., 1994). Where sediment supply rates are quite high, the entire sequence or sequences may result from fluvial deposition. Zaitlin et al., (1994) divide incised valleys into three segments based upon

the processes and products that occur within the valley. Segment 1, the outer incised valley, is composed of fluvial and estuarine deposits of the sea-level lowstand and is overlain by transgressive sands deposited during the initiation of the next transgression. Segment 2, the middle incised valley, contains the most diverse facies assemblage. Facies of segment 2 range from fully marine to fluvial but are characterized by estuarine deposits. Depositional environments of segment 2 include barrier/inlet, central basin, and bayhead delta (see, for instance Dalrymple et al., 1992). Segment 3, the inner incised valley, is characterized by fluvial facies. Each segment shows a typical vertical facies succession, that can be predicted based upon the loss of accommodation space that occurs as the valley fills over time (Zaitlin et al., 1994).

Zaitlin et al. (1994) presented the following four criteria for recognizing incised valley systems: 1.) The valley is an erosional topographic feature and should truncate underlying beds, including any stratigraphic marker beds that may be present. 2.) The valley floor and sides represent a sequence boundary that may be overlain by a gravel lag and that can be traced (basinwide) to equivalent interfluvial features, i.e., soil horizons or other unconformities. 3.) IVFs represent a basinward shift in facies where landward facies overlie more distal deposits. 4.) Strata of the IVF onlap the sides of the valley walls.

Several recent studies (Archer et al., 1994; Kvale and Barnhill, 1994; Aitken and Flint, 1994) have shown IV systems developed during the Pennsylvanian Period in coal basins of the east and central United States. Archer et al. (1994) interpreted paleovalleys of the Douglas Group (Upper Pennsylvanian) of east Kansas as incised valley fills. These IV systems are described as simple incised valley fills of segment 1 in

the classification of Dalrymple et al. (1994). Likewise, Kvale and Barnhill (1994) interpreted development of incised valley systems in Lower Pennsylvanian strata of the Illinois Basin. These paleovalleys would also be classified as simple fill of segment 1. Finally, Aitken and Flint (1994) studied Breathitt Group (Pennsylvanian) paleovalleys in the central Appalachian basin of eastern Kentucky. These stacked IVFs are classified as compound fills deposited in fluvial segment 3.

The IVF's described by Aitken and Flint (1994) could serve as a comparison for this study, because a portion of the Breathitt Group is stratigraphically equivalent to the Kanawha Formation of West Virginia. Additionally, descriptions of Breathitt Group facies and lithologies are reasonably equivalent to the descriptions of coastal plain sediments by Martino (1996) for the Kanawha Formation. According to Aitken and Flint (1994), the Breathitt Group IVF deposits can be fit into five facies associations, although the dominant sedimentary component is fluvial sandstone. The five facies associations are 1) offshore siltstone and minor limestone, 2) mouth-bar interbedded sandstone and siltstone, 3) overbank interbedded fine-grained sediments, 4) minor (single-story) channels with three fill types, and 5) stacked major fluvial bodies composed of five fill types. The minor channels are composed of either siltstone, or fine- to medium grained sandstone, or most commonly, interbedded sandstone and siltstone (Aitken and Flint, 1994). The major stacked fluvial bodies are separated into 1) homogeneous facies, 2) heterogeneous facies, 3) tidally influenced facies, 4) draped laterally accreted facies, and 5) abandonment facies.

Aitken and Flint (1994) determined that maximum incision of paleovalleys occurred during the lowstand sequence set (LSS), when the fourth order sea-level curve

was superimposed on the falling limb of the third order sea-level curve. LSSs are composed of amalgamated sandstone bodies with a minor fine-grained component. The fine-grained sediments of the transgressive system tract (TST) and highstand system tract (HST) were mostly removed due to accentuated erosion of the superimposed cycles. The greatest portion of fine-grained sediment is preserved during the transgressive sequence set, or TSS, when the fourth order sea-level curve is superimposed on the rising limb of the third order curve. The TSSs were rarely capped by fine-grained marine siltstone. The marine siltstone marks the presence of marine flooding surfaces. (Parasequences are boundaries that mark non-regional changes in sea-level rise (Aitken and Flint, 1994).) Finally, Aitken and Flint (1994) described highstand sequence sets (HSSs) as transitional between the LSS and TSS. The fine-grained component of the HSS would be more abundant than in the LSS, but less than in the TSS.

Aitken and Flint (1994) could not identify the maximum flooding surface in the interval they studied, because there was no significant change to tidal facies in these segment 3 deposits. However, transgressive surface 'zones' are represented by the thickest and most widespread coals. The difficulty in finding such boundaries is documented by Dalrymple et al. (1994) and Zaitlin et al. (1994).

Chapter 4

Descriptions of Architectural Elements

Blake (1997), Blake et al. (1989) and Martino et al. (1998) subdivided the Kanawha Formation into three divisions (for discussion purposes), the lower, middle, and upper, based upon major vertical changes in dominant lithology, coal-bed morphology, and degree of marine influence. The first named unit in the Birch River stratigraphic section is the #2 Gas coal. The #2 Gas (Appendix A, unit 17) is exposed 17.5 meters above the base of the Powell Mountain outcrop at the first road cut along U.S. Route 19 (south of Birch River). The #2 Gas is found at approximately the midpoint of Blake's (1997) middle division of the Kanawha Formation. The lower contact of the middle division is the base of the Betsie Shale Member and the upper contact, the base of the Winifrede Shale Member. However, based upon the criteria set forth by Blake (1997), it is more appropriate to include the Winifrede Shale in the middle division for the rocks at Powell Mountain. Therefore, for this study, the top of the middle division, Kanawha Formation will be the top of unit 44a laminated shale, siltstone, and sandstone (about 6 meters above the Winifrede Shale Member).

The upper contact for the upper division of the Kanawha Formation is the top of the Kanawha Black Flint and its non-chert, marine-influenced correlatives. Additionally, the coal bed split (Stockton "A" coal bed, unit 85 and sandstone unit 86) is lithologically more similar to the rocks of the upper division of the Kanawha Formation. Therefore, for this study, the top of the upper division, Kanawha Formation will be the top of the Stockton "A" coal bed. Stratigraphic thicknesses for the Birch River section are 136

meters for the partially exposed middle division and 65 meters for the entire upper division.

The upper 149 meters of exposure are assigned to the Allegheny Formation. There are no informal divisions for the Allegheny Formation. However, two trends were noted at Birch River. First, lithofacies of the Allegheny Formation tend to be laterally extensive, and second, the sandstone units coarsen upward throughout the exposure on Powell Mountain. That is, the lowest exposed Allegheny sandstone (unit 88) is fine-grained and the highest exposed Allegheny sandstone (unit 112) is conglomeratic. Additionally, as with the underlying upper division of the Kanawha Formation, multi-story channel sandstones dominate the Allegheny Formation.

The following discussion will be within the context of Blake's (1997) informal divisions, with the upper boundary of the middle division being the top of the laminated shale, siltstone, and sandstone unit 44a (above the Winifrede Marine interval, unit 44). Facies of the Kanawha Formation, middle division, will be described first. New facies or significantly different lithofacies will be described and interpreted successively for the Kanawha Formation, upper division, and the Allegheny Formation.

Lithotypes

Middle Division, Kanawha Formation

Type A Sandstone (Appendix A #'s 1, 9, 14, 15, 17, 18, 19, 21, 28, 29, 30, 44a)

This facies is composed of laminated sandstone and in some cases, siltstone, and shale. This sandstone type has a thickness range of 1.0- to 9.0-meters (Figs. 24, 25, and 26). Sandstone grain size varies from very fine to medium and is typically well sorted. Type A sandstones are generally laminated and may grade laterally into 1.0-

meter thick bed sets with sharp basal contacts. Primary bedding structures include horizontal and cross-lamination, as well as wavy, lenticular, and flaser bedding. Rare occurrences of herringbone cross-laminae and small-scale deformation structures (ball and pillow, distorted laminae) are found in thin units. Bedding planes may be littered with carbonaceous plant debris, siderite, and mica flakes.

(Left Picture)

Figure 24. Type A Sandstone, Outcrop Alpha.

Lowest sandstone is unit 1, Type A Sandstone, with bar form at base (Outcrop Alpha). Sandstone is fine to medium-grained with wavy to flaser bedding. The sandstone is overlain by unit 2, Type E Silty-Shale. These shale beds are root-penetrated. The tan-colored sandstone is unit 3, Type B (Burrowed) Sandstone. The basal sections of Type B Sandstones are homogenized due to extensive (worm) bioturbation. Jacob staff is two meters for scale.

(Right Picture)

Figure 25. Type A Sandstone, Outcrop Beta.

Interlaminated, wavy to flaser bedded sandstone and siltstone of unit 14. The section shown is a Type A Sandstone. Note limestone concretion to lower left of Jacob staff (Outcrop Beta).

Type A sandstones generally overlie other Type A sandstones, or shale or silty-shale units. Rarely, Type A Sandstones overlie Type B (Burrowed) sandstones or thin coal beds. Type A sandstones typically grade vertically into shale or silty-shale units.

At outcrop Beta, planar-shaped scour surfaces separate several Type A sandstone units. Also at outcrop Beta, a channel scour and/or paleosol divides successions of stacked Type A and Type B channel sandstones. Upper portions (1 to 3 meters) are more fine-grained and may be (root) bioturbated. Where (root) bioturbated, the sandstone may grade into a shale or seat earth that, in turn, underlies a coal bed. In other instances, the Type A Sandstone may be truncated by an overlying channel sandstone. Siderite lags, 50-cm thick, are common at the base of these channels. Shale rip-up clasts are rare and found only in the lowest sandstone within a succession. Large limestone concretions (2 to 10 meter wide and 1.5 meter thick) and discontinuous to continuous “beds” of cm-scale, nodular siderite are common in all units. Notable features of Type A sandstones are subtle (sand) bar forms (see Fig. 24) and an absence of marine fossils.

Figure 26. Type A Sandstone, Outcrop Gamma.

Wavy, flaser, and lenticular interlaminated siltstones and sandstones of unit 29, Type A Sandstone. Thin sand stringers commonly grade laterally from thin siltstone interbeds. Note the small-scale slump structure and the nodular siderite clasts present throughout the upper portion of the unit. (Outcrop Gamma)

Type B (Burrowed) Sandstones (Appendix A #'s 3, 5, 20)

Type B sandstones are composed of laminated to bedded sandstones with basal channel scour surfaces (see Fig. 27). Some bedded channel sections are “homogenized” due to extensive bioturbation. Sand-filled, vertical and horizontal traces are found throughout the homogenized sandstone sections of units 5 and 20. These traces are most visible on bedding surfaces. Total unit thickness varies from 4 to 10 meters (avg 6 m). In one exceptional instance, a Type B sandstone fills a 10-meter channel scoured into an underlying Type A sandstone (see Figure 56).

Figure 27. Type D Sandstone, Outcrop Gamma.

Type D (“U” shaped) sandstone, unit 24, cutting through the upper portion of unit 20, Type B (Burrowed) Sandstone (Outcrop Gamma). The unit 20 sandstone is part of the Campbell Creek Marine Zone. Note the ellipsoidal limestone concretions in the bottom of the sandstone unit (iron-stained). The Dingess Shale Member, unit 25 overlies the two sandstones at this exposure.

Grains range in size from coarse to fine sand, silt and mud. Siderite and mica flakes are common on bedding surfaces of units 3 and 5 and carbonaceous debris is common throughout unit 3. Ellipsoidal limestone concretions are scattered throughout units 3 and 5.

Type B sandstones are composed of well-sorted laminae where burrowing was not extensive. These laminated sandstones grade laterally into shale, siltstone, and sandstone interbeds that are 0.10 to 1.0 meters-thick. Sedimentary features of unit 5 and 20 include cross-laminae to lenticular laminae with sand and/or mud drapes. Bedding, in unit 3, is horizontal (low angle bed sets) to planar and/or trough cross-bedded. Epsilon cross strata occur on the lower part of Type B sandstone unit 3. Basal lags containing millimeter-sized nodular siderite clasts occur in units 3 and 5. The top 0.5 meters of the unit 5 Type B sandstone are (root) penetrated with stigmarian axes and grade into an overlying seat earth. The unit 3 Type B sandstone grades into a fining-upwards sequence of shaley-siltstones. Laterally across the face of outcrop Alpha, the unit 5 Type B sandstone fills a channelform scour that truncates the unit 3 Type B Sandstone. The unit 20 Type B sandstone grades into Type A sandstone.

Type C1 Shale (Winifrede Shale Member) (Appendix A # 44)

Type C1 shale is composed of laminated gray shale that is 1.0 meter thick (see Fig. 28). A single marine body fossil (unknown brachiopod species) was found in a “bluish-colored” horizon between outcrops Gamma and Delta. Additionally, M. Blake (personnel communication, 2001) reported that marine brachiopods and bivalves are common to this bluish horizon within the extents of the older road cut at Powell Mountain. The base of the Type C1 gray shale is marked by a siderite-rich layer. This siderite layer overlies a very thin and discontinuous coal. The Type C1 shale grades into Type A sandstone.

Figure 28. Type C1 Shale, Outcrop Gamma.

(Outcrop Gamma) Units 41 and 42, sandstone and shale units underlying shale of the Winifrede Marine Zone.

Type C2 Shale (Dingess Shale Member) (Appendix A # 25)

The Type C2 shale is composed of fissile and poorly laminated black shale that is up to 8.50 meters thick (see Fig. 29). This unit lies above a laterally continuous, sideritic lag approximately 0.10 meters-thick. Minor sandstone clasts are present throughout the lag. This sideritic lag lies over an undulose scour surface that truncates a (1 cm-thick) coal.

Figure 29. Type C2 Shale and Type A Sandstone, Outcrop Gamma.

Bottom unit is upper section of Dingess Shale Member, unit 25, Type C2 Shale. The shale is grades into a seat earth that is overlain by a thin Type F Coal Bed, unit 27, Cedar Grove Coal Bed (covered in picture). The tan sandstone above the Dingess is unit 28, Type A Sandstone. (Outcrop Gamma)

Vertical burrows are found locally. Measured sections from the old Route 19 road cuts report linguloid brachiopods (Reppert, 1976). According to Martino et al., (1998), invertebrate fossils are locally common in the lower portions of black shale facies and include, brachiopods, bivalves, cephalopods, gastropods, and echinoderms. The unit is typically homogeneous both laterally and vertically, although the color changes from dark black to gray laterally (see Fig. 29). Additionally, ellipsoidal limestone concretions occur in the upper 4.0 meters of the shale. Nodular siderite is found as clasts and in several diffuse bands. The unit 25 shale grades into a Type E (root) bioturbated shale (unit 25a) that is, in turn, overlain by a thin (15 cm) coal.

Type D (Multi-story) Sandstone (Appendix A #34, 41)

Type D sandstone ranges from 13 to 14.50 meters-thick and starts as a sandstone body lying above a scour surface. The basal scour underlying the Type D Sandstone, unit 34, eroded a 4 meter-thick section of underlying fine-grained lithologies.

Type D sandstone is medium to coarse-grained and is composed of planar- and trough-cross beds. Grains are typically well sorted, although sediment grain size fines upward within individual channel features from medium to fine grained. Mica flakes, carbonaceous debris, siderite grains, and coal partings mark laminae.

Epsilon cross bedding is only visible in the upper third of unit 34. The lower section of unit 34 displays massive bedding. The Type D sandstone, unit 41, contains cut-and-fill sandstone bodies not seen in unit 34. These stacked channel-form features are tens of meters wide and up to 14 meters thick (see Fig. 30). Various thicker channels (10 to 14 meters) grade vertically and laterally into laminated fine-grained sandstone, siltstone, and shale, and rarely, coal.

Bed sets (0.50 to 2-meters thick) may contain thick lag deposits of clay/shale clasts, locally imbricated. Soft-sediment deformation structure is rare. A basal lag deposit containing imbricated coal clasts, plant clasts and impressions (Calamities), and siderite clasts is found about two meters above the main basal scour surface in unit 41 (see Fig. 31). Such clasts are found, to a lesser degree, throughout the stacked channels of unit 41. The main basal scour is located over a thick (1.45 m) coal bed. Type D sandstone grades both vertically and laterally into a succession of siltstone, shale, a thick seat earth (5 m-thick) and a thick coal (see Fig. 31 and 32).

Figure 30. Type D Sandstone, Outcrop Gamma.

(Outcrop Gamma) Type D Multi-story Sandstone unit 41. This sandstone is composed of stacked channel sandstones. Individual channels contain planar bedded to trough cross-bedded sets. Jacob staff is two meters for scale.

Figure 31. Flow Structure in Type D Sandstone, Outcrop Gamma.

(Outcrop Gamma) Basal flow structure in unit 41, Type D Multi-story Sandstone. Sedimentary structure contains coal and fossil plant clasts and siderite clasts.

Figure 32. Type E Fine-Grained Units, Outcrop Gamma.

Upper silty-sandstone and shale section (Type E fines) overlying unit 34, (Type D - Single-story Sandstone), in turn, overlain by Type F Coal Bed,

unit 40 (Chilton Coal Bed) (Outcrop Gamma). Basal portion of another Type D multi-story sandstone is seen in bench at top of photo.

Type D (“U”-Shaped) Sandstone (Appendix A # 24)

A large-scale channel fills a 10 meter deep “U”-shaped channel in underlying Type A sandstone, unit 21 and Type B sandstone, unit 20. The Type D (“U”-shaped) sandstone is approximately 50 meters-wide and has a “U”-shaped cross-sectional appearance. Several smaller (>2 m-thick, >2 m-wide) wedge-shaped sandstone bodies and thin (>1 cm-thick) coals lie adjacent to the channel scour. The main (“U”-shaped) channel sandstone is composed of several stacked lens-shaped or channel-form bed sets (0.5 to 1.0 m-thick), in which bedding ranges from laminar to planar bedded. Sand grain size varies within individual bed sets from very fine to coarse-grained and sorting is good. The sand coarsens laterally from the margin into the channel. This increase in grain size is accompanied by an increase in bed thickness from lamination to bedded sets. A lag deposit of millimeter-sized siderite and clay/shale clasts and plant debris within a fine-grained matrix is located in the channel. Carbonaceous debris and thin shales mark bedding surfaces within the bed sets. Upper bed sets are composed of fine-grained sandstone and grade vertically into very-fine-grained sandstone and further into siltstone. The overlying siltstone grades both laterally and vertically into shale. The top of the main channel sandstone and the top of the wedge-shaped sandstone bodies are marked by a laterally extensive scour surface that angles down through units 21 and 20. This scour surface marks the base of the Dingess Shale Member, unit 25 (Type C2 Shale).

Type E Shale (Appendix A #'s 8, 22, 25a, 31, 33, 35, 42)

Type E shales typically underlie or overlie thin (0.01m to 0.30m) Type F coals or Type A sandstones. In other instances the shale may be bound by a scour that is

overlain by Type D sandstone or the shale may grade up from a Type D Sandstone. One Type E shale, unit 25a, grades up from a Type C2 shale. Shale color ranges from black to light gray and these shales often show a vertical gradational color change from black near the coal to light gray at the top. Unit thickness ranges from 0.30 to 5.00 meters. These shale beds are laterally extensive across the measured section, but may have variable thickness. Thickness changes may be due to erosion by streams from above (Type D sandstones) or from grading laterally into overlying Type A or Type D sandstones. No marine fossils were found within Type E shales. The shales show good fissility where not disturbed by (root) bioturbation.

Type E Siltstone/Shale (Appendix A #'s 2, 4, 10, 12, 13, 38)

Type E silty-shale is associated with Type A sandstone and Type B sandstone. Laminated silty-shale units grade up from laminated Type A sandstones or Type B sandstones. The unit 13 silty-shale grades into laminated Type A sandstone. Other related units include thin coals and underclays and other Type E silty-shales. Individual units vary in thickness from 0.10 to 5.0 meters. Type E silty-shales may show a vertical gradation in color from black to dark gray to medium gray. Scattered nodular siderite clasts and diffuse siderite beds are common. Some silty-shale units are (root) bioturbated and contain many fossil roots (stigmarian axes). Ellipsoidal limestone concretions are found at the base of the unit 4 silty-shale.

Another Type E silty-shale, unit 38, is composed of interbeds of shale and laminated siltstone. The interbeds are not gradational, except where there is a vertical lithology change into a seat earth, unit 39. The underlying lithology is a thin Type F coal. The unit 39, silty-shale, varies in color from dark- to medium- to light-gray. The

lightest-gray laminae contain fine-grained sand and may be described as sandy-siltstone. Nodular siderite is common throughout this unit.

Figure 33. Type D Sandstone overlying a Type F Coal Bed, Outcrop Gamma.
(Outcrop Gamma) View of top unit 40, Type F Coal Bed (Chilton Coal Bed) and the base of unit 41, Type D Multi-story Sandstone.

Type F Coal Bed and Seat Earth (Appendix A #'s 6, 7, 11, 16, 23, 26, 27, 32, 36, 37, 39, 40, 43, 45)

Type F coal beds range in thickness from 1.0 cm to 1.45 m. These coals have vitreous luster and blocky fracture (See Fig. 33). One coal contains a shale parting that is up to 0.25 m-thick. Thicker coals have an undulating upper surface, possibly the result of differential compaction from overlying Type D channel sandstone or from erosion. Thinner coals have variable lateral continuity. Thicker coals are laterally continuous. All Type F coals overlie root-penetrated seat earths. The seat earths have a thickness range of 0.03 to 3.0 meters. Lithologies overlying coals include Type A sandstone, laminated black to light gray shale, silty-shale, and Type D sandstone. The

roof shales are not root-bioturbated, as are the underlying seat earths (See Fig. 34, below).

Figure 34. Type F Coal Bed, Outcrop Alpha.

Thin coal is unit 7, Type F Coal Bed (No.2 Gas Coal Bed). The underlying unit is 6, underclay. (Outcrop Alpha). The coal bed, unit 7, is overlain by unit 8, shale. The shale is, in turn, overlain by Type A sandstone.

Type F coals are most commonly bright-banded with minor dull bands. In some cases, vitrain material may form as discontinuous laminae throughout a dull coal. All Type F coals show blocky fracture.

Upper Division, Kanawha Formation

Type D (Multi-Story) Sandstone (Appendix A # 50, 86)

Type D (Multi-Story) sandstones range from 11.0 to 13.5 meters thick and are comprised of multi-story, cut-and-fill channel sandstone (see Fig. 35-37). This sandstone is light to medium gray and has bed sets that are approximately 0.35 meters thick. Type D sandstone has an erosive, undulose base with a maximum incisement of 7.00 meters. Underlying strata include Type A sandstone, Type C1 shale, Type E shale and Type F coal.

The Type D (Multi-Story) sandstone unit 50 is located along the base of outcrop Delta, where it disappears into the ground to the south. Maximum visible channel widths are 150-meters for the thickest units. Sand grain-size ranges from fine to coarse, but individual beds are typically well sorted. Some bed sets contain shale interbeds near the base. These interbeds may contain nodular siderite. Trough cross bedding is common within the lower section and changes upward into planar cross-bedding to planar cross-lamination higher in the section.

Individual channels within the unit 50 Type D sandstone grade up from bedded coarse- or medium-grained sand into fine-grained sand with wavy lamination. In one channel, the fine-grained sandstone grades vertically into medium-grained sandstone, then fine-grained sandstone, then medium-grained sandstone yet again. These grain size variations are accompanied by vertical changes in bedding. That is, fine-grained sandstone is planar laminated and medium-grained sandstone is planar bedded. Bedding surfaces of upper laminae are littered with carbonaceous debris, siderite grains, and mica flakes. These materials are found to a lesser extent on bedding

surfaces lower in the channel. The upper 1-meter of the sandstone contain stigmarian axes with carbonized rootlets that extend into the overlying Type E fine-grained unit (sand-siltstone). No other fossils were found within this sandstone.

The unit 86 Type D (Multi-Story) sandstone, lies in the middle of a coal bed split, unit 85. The channel thalweg cut down through the lower coal split and into another 5 meters of underlying shale and silty-sandstone interbeds. This light-gray sandstone is fine-grained and well-sorted. Laminated bedding planes are covered with finely disseminated organic debris and mica flakes. Lateral-accretion surfaces can be traced laterally for many ten's of meters. The sandstone grades laterally and vertically into a 0.50 meter-thick (or less) zone of shale. The shale is gray with abundant carbonaceous debris, and root-bioturbated. Millimeter-sized siderite clasts are found in the sandstone, but not in the shale section. This sandstone and shale unit pinches out laterally (south) into the adjacent coal bed (Stockton "A" Coal Bed). The sandstone and shale unit is laterally continuous, but thins away from the main channel in the opposite direction (north). The upper shale section is overlain by the upper coal bed split (Stockton "A" Coal Bed).

Figure 35. Type D Sandstone, Outcrop Delta.

Lower part of photo includes unit 50, Type D Multi-story sandstone (Outcrop Delta). These sandstones cut through Type C1 shale (Winifrede Marine Zone) at the north end of outcrop Delta. Overlying strata are fine-grained floodplain deposits.

(Left Photo)

Figure 36. Limestone Concretion in Type D Sandstone, Outcrop Delta.

Large limestone concretion in the upper portion of unit 50, Type D Multi-story sandstone (Outcrop Delta).

(Right Photo)

Figure 37. Type D Sandstone and Type E Fine-Grained Units, Outcrop Delta.

The lower two meters, behind Jacob staff, are top of unit 50, Type D Multi-story sandstone. Unit 50 sandstone grades vertically into fine-grained floodplain deposits (Outcrop Delta).

Type D (Single-Story Channel) Sandstone (Appendix A # 76)

The Type D (single-story) sandstone is similar to the Type D (multi-story) sandstone described above. The sandstone unit 76 is 6.00 meters thick. Sand grain-size varies from medium to coarse and grains are well-sorted. No channel-form bodies were found. This unit is trough cross-bedded lower in the section and planar cross-bedded higher in section. However, massive bedding is generally dominant throughout this light gray colored sandstone. Overlying an undulose basal scour surface, the sandstone contains a basal lag consisting of Calamities stems, siderite clasts, and rare meter-long, thin (<1 cm-thick) coal rip-ups. The underlying lithology, unit 75, is a Type E roof shale. The unit 75 roof shale is slightly truncated by the overlying Type D

sandstone. Several bed sets comprise the basal lag; lags are not found higher than 2.0 meters from the basal scour. Generally, the Type D (single-story) sandstone is very hard and resistant, but where mica flakes cover the bedding surfaces it breaks readily into thin flags. Carbonaceous debris and siderite grains are also common on bedding surfaces throughout the unit. The unit becomes fine-grained toward the top, where it is laminated. The upper laminated part contains stigmairian axes and finely disseminated carbonaceous debris. This sandstone grades vertically into Type H seat earth that is, in turn, overlain by a Type H cannel coal.

Figure 38. Type D Sandstone overlain by Type E Fine-grained Units and Type F Coal Beds, Outcrop Delta.

Unit 76, Single-story, Channel sandstone grading into fine-grained deposits (Outcrop Delta). The overlying strata include unit 77, Type E Shale, unit 78, Type G Cannel Coal, unit 79, Type E Shale, and unit 80, Type E Fining-upwards sequence.

Type E Fine-grained unit (Fines-upward) (Appendix A #'s 51, 56, and 80)

The Type E, fine-grained unit (FUS) is composed of a fining-upward succession of sandstone and siltstone or siltstone and shale. Type E fine-grained unit ranges from 0.30 to 1.25 meters thick and fines upwards from Type E, medium-grained, sandstone

or Type G (undulating) sandstone. Bioturbation (root) locally has destroyed bedding. Root impressions are found throughout this unit, becoming more densely spaced upward in the section where bioturbation was greatest. Carbonaceous debris and mica flakes are also common throughout unit 51 and become concentrated higher in the section where the unit is siltier. The upper 0.50 meters of unit 51 contain thin (<1 cm-thick) and laterally discontinuous coals. FUS unit 51 grades into a thin seat earth that, in turn, underlies a Type F coal bed. Diffuse bands of siderite are found sporadically throughout the unit 56 FUS. Unit 56 grades into a Type E coarsening upward succession of fine-grained sandstone.

Type E Fine-grained unit (coarsens-upwards) (Appendix A #'s 56-57, 62-63-64, and 67-68)

This fine-grained unit is composed of a coarsening upward succession (CUS) that ranges from 0.45 to 1.80 meters thick. The unit may grade up from Type G sandstone (units 56-57) or it may overlie a Type F coal (units 62-63-64 and 67-68). Fine-grained heterolithic units intergrade from shales into siltstones and fine sandstones. One set of Type E (CUS) units, (units 56 and 57), is root-bioturbated and contains occasional diffuse siderite bands. Shaley units overlying coal beds are light to medium gray. Beds are generally medium to thick bedded. Siderite clasts may be found scattered throughout such units. These units have sharp uneven upper contacts, are variously truncated and are overlain by Type G sandstones or they may grade into Type F seat earth.

Type E (Heterolithic) Sandstone, Siltstone, and Shale (Appendix A # 83)

The Type E heterolithic unit is composed of 4.0 meters of gray, interbedded medium to very fine-grained sandstone, siltstone, and shale (see Fig. 39). Sandstone

grain-size is generally fine-grained. The unit grades up from an underlying gray to black shale that, in turn, overlies a coal zone. The fine-grained sections are primarily laminated and the sandstones are laminated to cross-laminated. Both mica flakes and carbonaceous debris cover bedding planes. Nodular siderite concretions form discontinuous layers throughout the interbeds. The interbedded laminae are continuous locally and planar- to wavy-bedded on a large scale. Some sections contain mixed sets of very fine-grained and fine-grained sandstone. Meter-sized limestone concretions are common in the upper section and coarser fractions contain some siderite inclusions. Root casts commonly extend through the upper portion of this unit. The interbedded sandstone, siltstone, and shale grades into seat earth.

Figure 39. Type E Fine-Grained Units, Outcrop Delta.
(Outcrop Delta) Laminated to cross-laminated, interbedded siltstones and sandstones of unit 83. Note the elongate limestone concretion (iron stained) above the Jacob Staff and the undulose bedding.

Type E (Roof) Shales (Appendix A #'s 47, 49, 54, 71, 75, 79)

Type E shales are associated with thin coal beds. Units 75 and 79 overlie cannel coals. Type E shales vary in color from light gray to black. Shale color typically varies vertically, and the shale is darkest adjacent to one of the underlying thin coal beds. The light gray shales are sometimes weakly consolidated and are better termed clayey-shales. Centimeter-sized diffuse bands of siderite are common throughout. Laminae of shales may be destroyed by root-bioturbation; stigmarian axes are generally present. The shale beds may coarsen vertically and contain a small fraction of silt or sand;

however, they still have a shaly character. These shale units vary in thickness from 0.40 to 2.0 m. The shales are typically laterally extensive, unless truncated by overlying channel sandstone units. Unit 54 is composed of interbedded shale and siltstone with discontinuous coals and carbonaceous debris throughout the unit. Where not truncated by overlying Type D or Type G sandstones, the Type E roof shales may grade into Type F seat earth or type H (canneloid) shale or Type E heterolithic fine-grained deposits.

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Figure 40. Type E Fine-Grained Units and Type G Sandstone, Outcrop Delta.

Type F Coal Bed & Seat Earth (Appendix A # 45a-46, 47a-48, 52-53, 58-59, 61, 65-66, 70, 81-82, 84-85)

Type F coal beds range from 0.10 to 1.75 meters in thickness. These coals are dull to vitreous and have a blocky to laminated character. Type F coal beds are typically overlain by Type E roof shale. Other Type F coals overlain by Type G (undulating) sandstone or may grade into Type E (CUS) shale or Type E (FUS) shale or Type E heterolithic sandstone, siltstone, and shale. Generally, these coal beds are laterally and vertically continuous. Rarely, the coals may be of varying lateral thickness when overlain by Type E (FUS) silty-shale. Additionally, one coal bed (unit 48) is truncated by overlying Type D sandstone (unit 50). Other associated lithologies are Type D (single-story) and Type G sandstones. Typically, seat earths that range from a few centimeters to 1.50 meters thick underlie these coals. These seat earths vary from gray to black. One seat earth (unit 58) is composed of interlaminated siltstone, shale and discontinuous coals. Type F seat earths may grade up from a variety of lithotypes including: Type C1 shale, Type E roof shale, Type E (FUS) silty-sandstone, Type E (CUS) sandstone, and Type G (undulating) sandstone.

Coal units 66 and 82 are interbedded with thin shale and /or clay interbeds. The thickest coal beds contain shale partings from 0.01 to 0.30 meters and the coals range from 0.04 to 0.30 meters. Thicker shale interbeds are rich with plant debris and are root-bioturbated. More commonly, the shale interbeds are from 1 cm to 2 cm-thick. Often the thickest coal beds will lie at the top and /or bottom of the unit. The shale interbeds are clayey and light gray in color. Some coal layers contain thin, mm-scale,

discontinuous fusain layers mineralized with clay. The coal interbeds are blocky to faintly laminated and have dull luster with discontinuous, vitrain layers throughout.

Unit 85 is composed of two coals separated by a Type D sandstone, unit 86. This coal is vitreous to dull and displays blocky fracture. Laterally (at the southern end of outcrop Delta) the Type D sandstone pinches out along a channel-shaped scour and the two separated coals merge to become one 80-cm thick coal. Where separated, the lowest coal contains a 15-cm thick clayey, dark gray shale. The lowest coal overlies seat earth. The overlying Type D sandstone erosionally truncates the lower coal and the seat earth. The lower coal does not reappear lateral to the channel cut. The higher coal is laterally extensive.

A 1.20 meter-thick seat earth lies under the lower of the two coals mentioned above. The lowermost (0.70 to 1.0 m) section of seat earth is gray in color and is separated from overlying black seat earth (0.20 to 0.50 m) by a single, thin (1cm-thick), diffuse band of nodular siderite. Nodular siderite is scattered throughout the lower gray seat earth. The lower gray seat earth is laterally continuous and it grades vertically from underlying Type E heterolithic sandstone, siltstone and shale. Laterally, the seat earth is overlain by Type D sandstone. Where the Type D sandstone is present above the seat earth, it locally removed the upper black shale by erosion. Further away from the area of truncation (towards the merge of the coals), the Type D sandstone grades laterally into a series of shale and silty-sandstone interbeds and the black shale appears to “grade” into the split coals.

Figure 41. Type F Coal Beds and Type D Sandstone, Outcrop Delta. (Outcrop Delta) The two coal beds visible in the picture unite into one seam (Stockton "A" Coal Bed) in the outcrop to the south, Outcrop Epsilon.

Figure 42. Normal Fault, Outcrop Delta.

(Outcrop Delta) Southern end of outcrop. Unit 85 (Stockton "A" coal bed), the split coal is visible in the middle of the photo. A normal fault is also visible at the same level as the split coal; note the graben like structural feature. The fault has a maximum vertical throw of 1.30 meters at unit 85. Compare with Fig. 62.

Figure 43. Type D Sandstones, Outcrop Delta.

Southern end of outcrop Delta. Top of unit 76, Single-story Sandstone visible at bottom right in photo. Overlying deposits in first two benches are units 77-82, shale and coal lithologies. The third and fourth benches are comprised of units 83-86. These units include Type E Interbedded Sandstone, Siltstone, and Shale, Type E Shale, Type F Coal (Split), and Type D Sandstone.

Type G (Undulating) Sandstone (Appendix A #'s 55, 60, 69)

Type G sandstones are composed of wedge or channel-shaped sandstone bodies that range from 0.25 to 1.60 meters (see Figs. 44 and 45). All Type G sandstones have an undulating basal scour surface with decimeter-scale relief. Underlying lithologies include Type E roof shale or Type F coal or Type E (CUS) siltstone. Type G sandstones are typically composed of poorly-sorted, fine-grained and light-gray sand. Bedding varies from massive to laminated. Type G sandstones fine laterally and vertically into sandy-siltstone, siltstone, and shale interbeds. Siltstone/shale interbeds are commonly laminated; coarser interbeds are wavy- to cross-laminated. Mica flakes and carbonaceous debris are common to abundant on bedding surfaces, particularly in the upper interbedded sections. Diffuse bands of nodular siderite and millimeter-sized siderite clasts are common throughout this facies. Discontinuous siderite layers average 0.10 meters thick. The interbedded sections may grade into heterolithic siltstone and shale that, in turn, underlie a Type F coal bed. Another Type G sandstone grades into silty-shale (units 55-60). One Type G sandstone, unit 60 has an uneven upper surface that is capped by a Type F coal.

Rarely, fossil trees (Calamities) are found in growth position within thicker Type G sandstone intervals. Locally, (1.00) meter-sized lycopod stumps are found in basal parts of the Type G sandstone (Fig. 45). These lycopod stumps are rooted in underlying finer-grained units, below the basal scour surface. Most of the Type G sandstones are extensively root-bioturbated and stigmarian axes are common throughout.

(Left Photo)

Figure 44. Type G Sandstones and Type F Coal Beds, Outcrop Delta.

(Outcrop Delta) Mixed fine-grained deposits. Deposits display lateral continuity and are composed of Type E fine-grained units and Type G sandstones.

(Right Photo)

Figure 45. Lycopod Stump in a Type G Sandstone, Outcrop Delta.

(Outcrop Delta). Stacked Type G sandstones and overlying thin coal beds, units 59 through 75, capped by a Type E Single-story Sandstone, (unit 76). Note the large lycopod stump in center of photo.

Type H (Canneloid) Shale (Appendix A # 72)

Type H shales are black and contain a high amount of carbonaceous material.

This variety of shale might be better termed a carbonaceous claystone, as only the thickest laminae (<0.01 m) are visible. Type H canneloid shale grade up from Type E roof shale. This shale type is very hard and has an uneven or “conchoidal” fracture. A thin (0.10 m-thick) bed of light-gray colored, Type E shale was found within the lower portion of the canneloid shale. This shale type is 0.70 meters thick and is laterally extensive where exposed. Type H canneloid shale grades into Type H seat earth, that is, in turn, overlain by Type H cannel coal.

Type H (Cannel) Coal Bed and Seat Earth (Appendix A #'s 73-74, 77-78)

Type H coals average 0.28 meters thick and range from 0.20 to 0.35 meters.

These coals have a blocky to cannel character and are dull to vitreous. The coals are composed of interbeds of blocky coal and cannel coal. The blocky layers are vitreous. The cannel layers are dull and tough with faintly visible laminae. The cannel layers have conchoidal fracture, although breakage along laminae (fissility) is also displayed. The units as a whole are laterally extensive and are overlain by light to medium gray, Type E roof shales. The cannel coals are underlain by black to gray-colored seat earths. These Type H seat earths are laterally continuous and may contain carbonaceous material on bedding planes, as well as laterally continuous layers of siderite. Lithotypes underlying the Type H seat earths include Type H canneloid shale and Type D sandstone.

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Figure 46. Type E Fine-Grained Units, Outcrop Delta.

North end of outcrop Delta. Picture shows the lateral continuity of these units across the face of the outcrop (units 53-75). Type D Multi-story sandstone occurs at the base of the outcrop. Unit 76, Type E Single-story sandstone is visible in the middle of the outcrop.

Allegheny Formation

Type D (Multi-story Channel) Sandstone (Appendix A #'s 91, 96, 100, 104, 110)

Allegheny Formation sandstone facies are composed of multi-story channel sandstones that are up to 35.00 meters-thick (see Figs. 49 and 50). Sand grain-size varies from fine to coarse and higher units (units 100 and 110) contain basal conglomeratic sandstones. Average grain-size is coarse and color varies from white to gray. Channel thalwegs contain meter-thick lag deposits of siderite, coal, and shale clasts with minor tree debris in units 91, 96, and 104. These cut-and-fill sandstones are separated from underlying coal and shale facies by scour surfaces. One exceptionally-thick unit (unit 91) fills a cut at least 15.35 meters into underlying sandstone, siltstone, shale, and coal beds.

Carbonaceous debris and mica flakes mark wavy to uneven (laminated) bedding planes overlying many lag deposits. Sandstone bed sets are dominated by massive bedding, but are also composed of trough to planar cross-beds and epsilon cross-beds. Vertical successions follow a general fining-upwards trend. Massive beds tend to fine upwards from pebbles to coarse, medium, or fine-grained sandstone. These sandstones, in turn, grade upwards through silty-sandstone and sandy-siltstone and shale. One channel sandstone grades vertically into a thin (0.40 m-thick), fissile, dark black shale. Sandstones may grade laterally and/or vertically into such fine-grained zones. A 12.00 meter-thick channel sandstone contains an excellent exposure of large-

scale soft-sediment deformation. The exposure of deformed beds is approximately 8 meters-thick, representing most of the channel succession (see Fig. 50).

(Previous Page; Upper Picture)

Figure 47. Type D Sandstone, Outcrop Epsilon.

(Outcrop Epsilon) Photo of siderite lag deposits in sandstone unit 91, Type D (Multi-story Channel) sandstone. The combined thickness of the lag deposits is approximately 2 meters. Unit 85 (Stockton "A" coal bed) is visible below the sandstone in this picture. The unit 91 sandstone truncated the entire unit 88, Type K Sandstone.

(Previous Page, Lower Picture)

Figure 48. Type D Sandstone, Outcrop Epsilon.

(Outcrop Epsilon) Photo shows coal rip-ups in the lower portion of unit 91, Type D (Multi-story Channel) sandstone. The coal rip-ups are continuous for up to several meters in length, but are typically quite thin, on the order of several centimeters.

(Picture Below)

Figure 49. Type D Sandstone, Outcrop Epsilon.

(Outcrop Epsilon) Base of outcrop is channel sandstone, unit 91, Type D (Multi-story Channel) sandstone. Unit 91 is approximately 15 meters-thick. Overlying the unit 91 sandstone are similar successions of sandstone, siltstone, shale and coal.

Figure 50. Soft-Sediment Deformation in Type D Sandstone, Outcrop Epsilon.

(Outcrop Epsilon) Soft Sediment deformation in sandstone beds of unit 104. Log casts were also found within upper bedsets of the unit 104 sandstones (not visible in photo).

Figure 51. Type D Sandstones, Outcrop Epsilon.

(Outcrop Epsilon) Type D (Multi-story Channel) sandstones of the Allegheny Formation. Note the cut-and-fill structure of these sandstones.

Type E (Coarsening-upwards) Sandstone, Siltstone, Shale (Appendix A #'s 92)

The Type E (CUS) unit is composed of a coarsening-upward succession of silty-shale, siltstone, sandy-siltstone and fine-grained sandstone. Generally, this unit will grade up from underlying Type E coaly shale. Lateral to the Type E coaly shale, this fine-grained lithology overlies a Type D sandstone. Here, a basal scour surface separates the Type D sandstone from the underlying Type E (CUS) lithotype. Adjacent to this zone, another overlying Type D sandstone further erodes the underlying fine-grained lithologies as well as the underlying Type D sandstone body.

Type E (CUS) unit thickness ranges from 2.70 to 3 meters. Diffuse bands of nodular siderite may mark the gradational boundary between Type E fine-grained lithologies and underlying Type E coaly shale. Nodular siderite clasts and diffuse bands of nodular siderite are common throughout. These fine-grained lithologies are medium to dark gray. They are laminated and contain mica flakes and finely disseminated carbonaceous debris throughout. The fine-grained sandstone section may contain abundant root casts (stigmarian axes), especially towards the top of the unit. The Type E (CUS) unit is overlain by Type F seat earth that is, in turn, overlain by Type F (blocky) coal.

Type E (Fining-upwards) Sandstone, Siltstone, Shale (Appendix A # 97, 101, 105, 107-108, 111)

Type E fine-grained lithologies typically grade from underlying Type D sandstone and, rarely, overlie Type J (channel-fill) shale (unit 108). This lithotype is composed of laminated silty-sandstone or sandy-siltstone or silty-shale or shale. Unit 108 is composed of flint clay and rooted claystones. Type E (FUS) fine-grained units are black to gray and range from 2.90 to 7.60 meters in thickness. Root casts may be present

throughout the lithotype unit. Where present, the root casts extend up to 1.5 meters into the underlying Type D sandstone. This unit is laterally extensive, except where cut by overlying Type D sandstone. The E (FUS) unit may grade vertically into Type F seat earth or Type J Shale. Other overlying lithotypes include Type K (conglomeratic) sandstone, Type F interbedded coal and shale.

Unit 101 is composed of gray, wedge-shaped, laminated, fine-grained sandstone that overlies a sharp basal scour above Type D large-scale channel sandstone. This wedge-shaped lithology grades laterally from sandstone to siltstone to shale. The unit pinches out laterally into the same large-scale channel sandstone it overlies. Lateral to the pinch out, the unit thins considerably. In this section the unit is composed of laminated silty-shale beds covered in plant debris. Silty sections are fossiliferous, containing an abundance of plant debris on bedding surfaces. Bedding surfaces of sandy sections are covered in mica flakes. Up to 1 meter of the upper portion is root-bioturbated. This unit grades vertically into Type F seat earth that, in turn, underlies Type F (Interbedded) Coal and shale.

Type E (Coaly) Shale (Appendix A # 90)

This 40 cm-thick shale grades up from very-fine-grained sandstone and siltstone beds. The shale is very dark-black with a fissile or coaly character. It is non-descript shale with very little lateral variation. The shale is erosionally truncated by overlying Type D sandstone. Lateral to the scour surface, the shale is separated from overlying Type E (CUS) silty-shale by a diffuse band of nodular siderite.

Type E (Roof) Shale (Appendix A # 95, 103)

Type E roof shale ranges in thickness from 0.10 to 1.75 meters. It is composed of black to gray shale or silty-shale sometimes containing siderite layers. These shales overlie Type F Coal. Type E roof shales are truncated by the basal scour surface of overlying Type D large-scale channel sandstones.

Type F Coal Bed and Seat Earth (Appendix A #'s 93-94, 98-99)

Type F (blocky) coals are 1 meter-thick on average. These coals are blocky and lie above Type F seat earth (see Fig. 52). The coals are homogeneous (no partings) and display even bedding. They are vitreous to dull and, rarely, iridescent. Type F (blocky) coals are laterally extensive, except where completely truncated by overlying Type D channel sandstone. The upper surface, where not eroded may be capped by thin black shale. In other cases, the upper bounding surface is an overlying channel scour from Type D sandstone. The underlying Type F seat earths are 0.10 meters thick. Typically the Type F seat earths grade up from silty-sandstone.

Type F (interbedded) coals are underlain by Type F seat earth or some other rooted zone. Decimeter-thick gray shale may also be interbedded within multiple bedded coal zones. Other coal bed partings include thin (1cm-thick) black, unconsolidated clay and fine-grained clastics. Individual coal beds are dull to vitreous or banded and vary in thickness from as small as 1 cm to as thick as 0.90 meters. Overlying lithotypes include Type E roof shale or partial erosion and the basal scour of a Type D sandstone.

Figure 52. Type F Coal Bed, Outcrop Epsilon.
(Outcrop Epsilon) Unit 99, Type F Coal. Note the blocky character of the coal bed. Coal bed overlain by unit 100, Type D (Multi-story Channel) sandstone.

Figure 53. Type D Sandstone Overlying Type F Coal Bed, Outcrop Zeta. (Outcrop Zeta) Unit 109, Type F (Interbedded Shale and) Coal overlain by unit 110, Type D (Multi-story Channel) sandstone. Unit 109 coal bed is the Lower Kittanning. Thickness variations in this coal bed are due to compaction.

Figure 54. Type D Sandstone and Type F Coal, Outcrop Zeta.

(Outcrop Zeta) Unit 102, Type F (Interbedded Shale and) Coal. The upper shale beds are truncated by the overlying Type D (Multi-story Channel) sandstone. Coal bed is the Upper No. 5 Block (unit 102).

Type I (Channel-fill) Shale (Appendix A # 106)

This shale fills small channel-shaped cuts in the top of underlying Type D sandstone. The thickest channel is 5 meters. Lateral to this channel, the shale fills much smaller channel shapes. Type I shale is fissile, dark gray to black, and contains minor plant detritus and rare coal clasts. Type I shale is a flint clay. Bedding surfaces mimic the channel shapes. Diffuse bands of nodular siderite are present throughout. Additionally, several lens-shaped and meter-sized limestone concretions are found in the top 1-meter of the shale. This shale type grades vertically into Type E (CUS) silty-

shale. Laterally, the Type I shale is bound by the channel-shaped scour that the shale fills.

Type J (Large-scale, Conglomeratic, Channel) Sandstone (Appendix A # 112)

Type J sandstone is composed of 9.0 meters of massive-bedded sandstone with faint channelforms throughout. This laterally extensive sandstone overlies a Type E (FUS) shale. Sand grain size fines upward from pebble-sized to coarse-grained sandstone. The sand grains are light gray to white. These millimeter-sized clasts are predominantly quartz pebbles, although mud/shale clasts and coal clasts are also found rarely in 1-meter-thick horizontal planar beds. These pebbles form a widespread lag deposit at the base of the sandstone (conglomerate). Where not as concentrated, the clasts are supported in a coarse-grained sand matrix. Sorting improves vertically, and the unit is well-sorted near the top where it is a coarse-grained sandstone. This sandstone contains planar cross-bedded to massively bedded sandstone with several faint channel-forms. There are no other lithotypes above this unit at outcrop Zeta. This was the last unit studied.

Type K Sandstone (Appendix A # 87, 88, 89)

Type K sandstone is composed of interbedded fine-grained sandstone, very-fine-grained sandstone, and siltstone. These interbeds are planar to wavy laminated and alternate from medium gray to light gray to white. The color variation corresponds to a change in grain size, where the white layers are composed of very-fine-grained sandstone and the gray layers, fine-grained sandstone or siltstone. The alternation of grain size and color help show the wavy bedding in the sandstone. These wavy beds/laminae vary from 30 centimeters to 5 centimeters thick. Mica flakes and finely

disseminated carbonaceous debris are scattered throughout the sandstone.

Additionally, diffuse bands of nodular siderite are found every 5 to 10 cm throughout the sandstone. The total thickness of units 87, 88, and 89 is approximately 11 meters.

The base of this sandstone is comprised of a thin and weakly consolidated zone of clayey-sandy-siltstone. This thin zone is laterally continuous, but has variable thickness, generally less than 10 cm. This section caps the Type F, upper coal bed (split) found in the upper division of the Kanawha Formation. The upper 1-meter of this sandstone is composed of weakly consolidated, very-fine-grained sandstone. This section of sandstone is heavily (root) bioturbated (stigmarian axes). Grading up from the (root) bioturbated sandstone section is Type E (coaly) shale.

Chapter 5

Interpretations of Depositional Environments

The following discussion will use middle and upper divisions for the Kanawha Formation described at the beginning of Chapter 4. Descriptions of depositional environments of the Allegheny Formation will follow in the same format as a separate section. Interpretations are presented for each set of stratigraphically related lithologies. A synthesis of events leading to the development of the Birch River section will be presented in the following chapter.

Middle Division, Kanawha Formation

Facies A – Estuary Margin

The combination of sedimentary structures and features, lithotypes, and laterally related facies is suggestive of a marginal estuarine setting. The Type A Sandstones were likely to have formed as lower-intertidal sand flats along the margin of estuaries. Laterally and vertically related lithologies were deposited in coastal upper-intertidal mudflats and swamps adjacent to the sand flats.

According to Martino (1994, 1996) and Brownridge and Moslow (1991), the formation of wavy, lenticular, and flaser bedding is suggestive of an environment with alternating relatively strong and weak currents and where both mud and sand were available. Current velocities must have varied to allow for the deposition of sandstone and siltstone/shale in alternating laminae. Furthermore, shale and siltstone laminae were likely deposited from suspension during periods of slack tide, while sandstone laminae were deposited during the flood or ebb tide (Brownridge and Moslow, 1991).

Development of each bedding type, flaser, wavy, and lenticular, is an indication of the overall strength of the tidal currents and availability of sand. Where flaser bedding developed, current energies were relatively high. Where lenticular bedding forms, tidal current energies were relatively low, and wavy beds form somewhere in the middle (Lewis and McConchie, 1994). Therefore, as wavy bedding characterizes the Type A Sandstones, tidal current energies within these subtidal zones were moderate. Rare occurrences of small-scale deformation structures, such as ball and pillow and distorted laminae, are a result of dewatering of mud layers overlain by more dense sand layers (Miall, 1987).

Subtle (sand) bar forms were likely to have developed along the margins of an estuary by tidal currents moving over the sand flat. The presence of a low-angle bar form that lacks any internal scour surface suggests the bar formed in a relatively stable area. Bed sets within the bar form become thicker and more sandy along the flank and into the channel. According to Fraser (1989), the paucity of mud within the bar and adjacent channel suggest the water was in constant flow.

The flat erosive base of these sandstones is evidence of a ravinement or erosion surface. Such scours within Type A Sandstones may have developed from relative sea level rises within the inner zone of the estuary. Scouring would have occurred when estuarine and / or tidal channels migrated further updip into the estuary due to the relative sea level rise (Dalrymple et al., 1992). Both Type A Sandstone and Type B Sandstone overlie scour surfaces. Where Type A Sandstone overlies a scour, it is probable conditions returned to the pre-sea level rise state, as it is suggested these sandstones formed in the inner zone of an estuary.

Finally, the lack of marine and / or freshwater fossils within these Type A Sandstones suggests salinity conditions were extreme. A likely cause may be the variation in salinity within a zone of mixed fresh, brackish, and / or marine waters. As it is possible for tidal influence to extend upstream into the fluvial reaches of an estuary (Dalrymple et al., 1992), poor water quality may also extend into the alluvial reaches. In this case, a lack of any fauna within the Type A Sandstones suggests they were deposited within the inner reaches of a tidally influenced estuary (Dalrymple et al., 1992).

Siderite nodules are strewn throughout and are found as continuous to discontinuous beds throughout the Estuary Margin sediments. The presence of discrete clasts within the estuarine sandstones is most likely the result of erosion of the surrounding floodplain sediments. Regarding the nature of the diffuse siderite beds, siderite is thought to form at an early stage, prior to or during initiation of diagenesis and forms in both freshwater and marine environments (Mozley and Wersin, 1992). As a result, the mere presence of siderite is not evidence in support of a single depositional setting.

Decimeter-scale micritic limestone nodules are found throughout Type A Sandstones. These structures may have formed from early diagenetic processes, such as the precipitation from groundwater (Milliken, 1998). The limestone concretions have sharp boundaries and faint horizontal laminae. These faint laminations appear to be contiguous with laminae adjacent to the concretion. Milliken (1998) analyzed the oxygen isotope values of limestone concretions in fluvial sandstones of the Breathitt and Lee Formations in the central Appalachians (including West Virginia). Milliken (1998)

found that the isotope values did not support concretion formation within marine waters. The contiguous laminations as well as the analysis of Milliken (1998) suggest the limestone concretions are not eroded clasts from the floodplain, but were formed *in situ* during early diagenesis.

Facies B – Estuarine Channels

Taken together, the channel-shaped basal scours, as well as the size of the scours, the sedimentary structures and other features, and the lateral facies associations suggest that these sandstones formed in subtidal, meandering estuarine channels. The lithotypes of Facies B are quite similar to those of Facies A, and the depositional environments of these facies are undoubtedly related. The main difference here is in the presence of vertical worm burrows (*Skolithos*), extensive (non-plant) bioturbation, lateral accretion surfaces, and large-scale, channel-shaped basal scours.

According to Martino (1994, 1996), estuarine channels may appear similar to fluvial or distributary channels in outcrop. Martino (1994, 1996) suggests the presence of wavy, lenticular, and flaser (ripple) bedding, reactivation surfaces, bipolar paleocurrents, bioturbation and laterally related facies are indicative of estuarine channels. Martino (1994, 1996) recognized such deposits of the Kanawha Formation in many outcrops of southern West Virginia.

Regarding the burrowing organisms, it is possible that the salinity of the marine waters was near normal so as to provide the organisms a temporarily hospitable habitat or that sedimentation was slow enough to allow these burrowing organisms time to colonize the sediments. The *Skolithos* ichnofacies is generally accepted as an indication of an intertidal setting. The set of sedimentary characteristics including wavy,

lenticular and flaser bedding is also suggestive of a tidal setting. The presence of channel-shaped basal scour surfaces marked by lag deposits of shale clasts and siderite nodules and epsilon cross strata with a fining-upwards succession suggests channels scoured across the lower intertidal to subtidal zone (Facies A) (Dalrymple et al., 1992). Lateral accretion surfaces, basal lags, and the fining-upwards succession suggest these were meandering channels (Jackson, 1976). Laminated bedding is an indication of an overall low energy system.

Type B (Burrowed) Sandstones are interpreted to be the shallow, subtidal deposits of estuarine channels. Where Type B Sandstone overlies a scour, the erosion may have been caused by the migration of such channels across the estuarine system. This would result in channel-shaped scour surfaces throughout these deposits (Dalrymple et al., 1992).

Facies C – Estuarine Lagoon

Type C1 Shale (the Winifrede Shale Member) was likely to have been deposited in a middle estuary (lagoon) seaward of the typical Type A Estuary Margin succession. A single marine brachiopod was found within this shale type. Normally a single brachiopod fossil would not be enough evidence to support a marine interpretation. However, according to Blake (personnel communication, 2001) there were additional brachiopod, bivalve, pelmatazoan, coral, and bryozoan fossils within several yards of the outcrop at the older road cut in the blue-colored horizon (unit #45). Blake (personnel communication, 2004) also reports the presence of a ravinement surface beneath the Type C1 shale between Outcrops Gamma and Delta. This fossil

assemblage suggests that the depositional environment of the shale was, at least temporarily, hospitable to a limited range of marine organisms.

Type C2 Shale (the Dingess Shale Member) was most likely deposited in the offshore zone or in a deep low within an estuary lagoon created during a (relative) sea level rise. Evidence for a marine depositional setting includes the underlying transgressive sideritic lag with sand clasts, the dark black, organic-rich coloring of the shale, and the presence of burrows in the lowest section. The siderite and sand clasts were likely concentrated during shoreface retreat.

The Dingess black shale contains diffuse bands of siderite and scattered meter-sized limestone nodules. In the past, workers have used the presence of siderite nodules to argue for a fresh-water setting (Mozley and Wersin, 1992). However, as discussed previously, such nodules form in both marine and freshwater environments and are typically the result of diagenetic processes (Mozley and Wersin, 1992).

Wignall (1991) presented the “Expanding Puddle Model” for the development of black shales in epicontinental basins. According to Wignall’s model, puddles of anoxic water develop on the bottom of the epicontinental sea and result from density stratification due to variation in salinity and/or temperature. Wignall (1991) suggests these puddles of anoxic water expand onto shallow platforms during transgressions. Wignall (1991) also points to the presence of a lag over a laterally extensive scour surface underlying the black shales, as well as the underlying shallow water facies. Such successions are found in many epicontinental basins worldwide (Wignall, 1991) and include the Birch River Type C2 Shale.

M. Blake (personnel communication, 2001) reported the inarticulate brachiopod *Lingula* from the same unit at a nearby outcrop. The presence of *Lingula* and vertical burrows also suggest a marine depositional environment. Moreover, the shale is composed of thin mudstone laminae with rare vertical worm burrows near the base (Blake, personnel communication, 2001). The lack of a diverse marine fauna may be a function of fluctuating salinity. Other factors may include rapid sedimentation, turbid bottom waters or dysaerobic-oxygen levels at depth (Wignall, 1991).

Finally, the Dingess Shale Member lacks any fossil roots, which would be expected if the mud were deposited in an anoxic, marsh or lake setting. The black shale grades vertically into root-bioturbated dark to medium gray shale. The root-bioturbated gray shales are indicative of a coastal marsh. This suggests the Dingess Shale Member is characterized by offshore marine or deep estuary lagoon shales that grade into coastal, freshwater marsh deposits.

Facies D – Meandering Stream

The combination of bed forms, structures and features, combined with fining-upward grain size and lateral facies associations are suggestive of a meandering fluvial channel. The fining-upward in grain size is accompanied by a progression of bed types from trough and /or planar cross-bedding to laminated. These sandstones are capped and grade laterally into siltstones and/or shale that is, in turn, overlain by coal. According to Miall (1988), the presence of lateral accretion surfaces (epsilon cross strata) is suggestive of deposition in either meandering- or anastomosing- or braided-stream deposits. Lateral accretion surfaces are indicative of a channel system with high sinuosity (Miall, 1988).

The amalgamation of basal channel-shaped scours and channel-fills create a so-called “cut-and-fill architecture”. The cut-and-fill channelform architecture of the sandstones combined with basal lags containing shale clasts suggests the meander cutbanks eroded back and forth across the fluvial plain. Analysis of paleodips for the Type D Sandstones revealed preferred orientations to the southeast, southwest, and northeast (see Appendix D). The wide distribution of paleodips also suggests high sinuosity within the channel belt (Miall, 1988). Since regional paleodip is to the north-northwest (Arkle, 1979), it should be expected that the dominant paleodip would also be to the north-northwest. Martino (1996) reported a dominant paleodip to the northwest in deposits of the Kanawha Formation of southern West Virginia with subordinate paleocurrents to the south, southeast, and east. Martino (1996) suggested the variations in paleocurrent could be accounted for by several factors including:

“... (1) high sinuosity channel systems, (2) local deflections in channel orientation caused by contemporaneous faulting of the coastal plain (Ferm and Weisenfluh, 1989), (3) the radiating pattern of distributaries in the delta plain and (4) flow reversals associated with subtle tidal influence...”

Hydraulic flow within high sinuosity channels is typically slow (Allen, 1965), and deposition of fine- to medium-grained sandstone is suggestive of such low- to moderate-energy conditions. Imbrication of some clasts and lag deposits indicate the occurrence of a unimodal flow direction within the channel deposits (Lewis and McConchie, 1994).

The bottommost channel sandstones are missing the upper portion of the fining-upwards successions due to lateral migration of channels across the fluvial plain. In the uppermost sandstone, laminated shales with abrupt basal contacts overlie Type D Sandstone and are suggestive of floodplain deposits that filled channel cutoffs and/ or

oxbow lakes (Ghosh, 1987). Such fine-grained channel-fills were preserved in these sections due to a change in the depositional pattern within the last channel cycle, such as avulsion (Ghosh, 1987).

Facies E and F – Floodplain / Swamp

Organic-rich, fining-upwards successions of siltstone, shale, and coal overlie subtidal deposits of Facies A and contain sedimentary features suggestive of deposition in coastal and / or estuarine wetlands and swamps (Dalrymple et al., 1992). The fining-upwards indicates the tidal flats were prograding. Evidence for deposition in wetlands and swamps includes stigmarian axes, paleosols, and thin coals. According to Dalrymple et al. (1992), vegetation tolerant of environmental extremes may colonize the upper tidal and intertidal flats in a low energy, tide-dominated estuary or coast. Laterally related facies suggest these wetlands existed along the margins of an estuary. The presence of a thin (~0.20m), laterally extensive gray shale over the thin coals signal the change from peat swamp to clastic swamp or floodplain, possibly brought on by a subtle change in sea level or by channel migration.

Type B (Burrowed) Sandstones grade vertically into siltstones and shales deposited in wetlands bordering the estuary. According to Dalrymple et al., (1992), estuarine tidal meanders grade laterally and vertically into marsh sediments. The presence of stigmarian axes and rootlets within some Type B siltstones and shales suggests these sediments were deposited in vegetated wetlands.

Shale overlying the Types C1 and C2 shale is root-bioturbated (stigmarian axes), particularly the top several meters. The presence of stigmarian axes in units overlying shale that bears marine body fossils indicates the area gradually shallowed and was

then the site of an estuarine, vegetated wetland. Lithologies overlying the upper, root-penetrated shale include both coal and shale deposited in swamps bordering an estuary.

Lateral to the scour-based, fine-grained channel-fills of the Type D Sandstone, the upper portion of the epsilon cross strata grade into laminated sandstone, siltstone and shale typical of upper point bar and overbank facies (Farrell, 1987; Ray, 1976; Bridge, 1984). Alternation of shale, siltstone, and sandstone partings suggest the fluvial plain was exposed to episodic flood events where a variety of fine-grained detrital material was available (Ghosh, 1987). Coal bed splitting, fossil roots (stigmarian axes), and variation in color from light to dark gray suggest the floodplain had at least two swamp phases. Thin clay partings within the lowest section of the thickest coal may represent a flood event during which time the swamp was temporarily inundated by higher than average waters.

Upper Division, Kanawha Formation

The following facies interpretations are quite similar to those described for Facies D – Meandering Stream, Facies E – Floodplain, and Facies F - Swamp. However, the facies described here reflect a change from coastal plain for the middle division of the Kanawha Formation to alluvial plain for the upper division. That is, the estuarine facies that characterize the middle division of the Kanawha Formation (estuary margin, estuarine channel, estuary lagoon) are not found within the upper division of the Kanawha Formation. Blake (1997) interpreted a similar change in facies during his study of the Kanawha Formation in southern West Virginia.

Facies D – Meandering Stream

The sandstones of Facies D are composed of medium- to coarse-grained sandstone with a range of bedding features and facies associations that are suggestive of deposition in a meandering fluvio-deltaic channel system. The sandstones of this facies association are similar to those described for Facies D in the middle division of the Kanawha Formation. Key similarities are the fining upwards succession, sand grain size, epsilon cross strata and a range of bed forms including trough cross beds and laminae. The multi-story sandstones of this facies display a cut-and-fill architecture, which is indicative of a channel belt with high sinuosity (Miall, 1988). Paleodip azimuths for the two sandstones of this facies type display a predominant northwest direction with lesser trends to the northeast and southeast (see Appendix D). The northwest trend fits with the regional dip to the northwest and the northeast (Arkle, 1979).

The sedimentary structures and features of sandstone unit 86 are indicative of a meandering fluvial system. Epsilon cross-strata together with a fining-upward trend and the laterally related facies are indicative of point-bar deposits (Jackson, 1976). The fine-grained sand that composes this sandstone suggests this stream had relatively low current velocities (Allen, 1965). The laterally enveloping coal bed indicates the meandering channel cut through a swamp bordering the alluvial plain (Greb et al., 1999).

Facies E, F and G – Floodplain and Levee / Swamp / Crevasse

Lithologies of facies Association E, F, and G represent a variety of deposits including floodplain and levee, swamp/peat bog, and crevasse channel/splay, respectively. Light to dark gray, interlaminated shale and siltstone with fossil roots

(stigmairian axes) and thin, discontinuous coals are typical lithologies of such an environment (Ray, 1976; Bridge, 1984; Farrell, 1987). The fine-grained sediments were deposited during frequent flood events (Farrell, 1987). Evenly interbedded fine-grained units with wavy-shaped internal scour surfaces were deposited on the upper surfaces of a levee during waning flood stage. The wavy-shaped scours are the result of more high-energy floodwaters rushing across the levee surface (Farrell, 1987).

Stigmairian axes are evidence the floodplain was the site of a forested wetland (Martino et al., 1998). The coal deposits are indicative of a swampy depositional environment.

One sandstone contains buried lycopod stumps and rarely *Calamities* preserved in growth position. The combination of a single, thin (1.0 m) sandstone with internal decimeter-size “wave-like” bed forms overlying an uneven or undulating basal scour plus buried lycopods and *Calamities* in growth position suggests rapid flooding events occurred episodically in these forested wetlands (Ghosh, 1987). Such an event would occur in a floodplain where a river breaks or overtops the levee, as in a crevasse channel or splay (Ghosh, 1987). The thickness of the sandstone, the relative coarseness of grain-size and the undulating bedforms suggest the waters that deposited the crevasse sandstone were of relatively high velocity, probably proximal to the main channel belt (Ghosh, 1987).

Facies H – Freshwater Lakes

Cannel coals are a specific type of coal thought to form in anoxic freshwater lakes with a high algal content and/or from accumulations of wind blown spores (Hutton and Hower, 1999). The extensively root penetrated gray shales that underlie and

overlie both the cannel coals and the canneloid shale indicate the surrounding wetlands were vegetated. The lack of shale partings within the coals suggests the lakes were protected from clastic influx (Martino et al., 1998). Possibly, the levees of these freshwater bodies may have been sufficiently elevated to provide a temporary barrier from sediment-laden floodwaters or the lakes may have been located enough distance from the channel belt.

According to Grady (1998), canneloid shales form in clastic topogeneous swamps. These clastic swamps may grade laterally into more protected swamp environments such as planar topogenous and/or elevated ombrogenous swamps. The appearance of the canneloid shale is similar to that of the cannel coal. Based on the results of a proximate analysis by D. Brown (personnel communication, 2001), this shale is carbon-rich or 31.5% carbon. This analysis suggests the carbonaceous shale was deposited in a freshwater body that was exposed to episodic influx of sediment-laden waters. This swamp was most likely too close to the channel system for coal to form.

Allegheny Formation

Facies of the Allegheny Formation are similar to those of the upper division of the Kanawha Formation and include Facies D – Meandering Stream, Facies E - Floodplain, and Facies F – Swamp. Other facies of the Allegheny Formation include Facies J Channel-fill, Facies K – Conglomeratic Sandstone, and Facies L – Heterolithic (Estuarine) Sandstone. This combination of laterally related facies is suggestive of an alluvial plain to coastal plain setting with one instance of a possible estuarine setting.

Facies D – Meandering Stream

This facies type is composed of multi-story sandstones deposited in meandering fluvial-channel belts, similar to the sandstones of Facies D in the middle and upper divisions of the Kanawha Formation. These sandstones are also medium- to coarse-grained with a range of bedding features, including epsilon cross beds, an upwards-fining trend in grain size, and cut-and-fill architecture. As in the previously mentioned facies, the combination of these sedimentary features and structures, as well as the laterally related facies, are indicative of a meandering fluvial-channel system (Miall, 1988).

Incision into underlying lithologies, including thick coals (1.5 m) and underlying cut-and-fill sandstones, is as much as 15.0 meters (see unit 91, Appendix A). Miall (1988) believes maximum fluvial incision occurs where stream gradient is low (i.e., high sinuosity channels) and where the energy of the system goes into eroding underlying sediments rather than into carrying the coarser-grain bed load.

Paleodip azimuths for these sandstones show a dominant flow to the northeast with subordinate flow to the north and lesser flow to the west, southeast, and south (See Appendix D). Such variation in paleodip azimuths indicates these fluvial systems had a high sinuosity.

Slumping or large-scale soft-sediment deformation (Figure 1d.) suggests the channels migrated rapidly over previous channel deposits (Allen, 1965). The cut-and-fill architecture of the sandstones illustrates that the channel cut through older portions of the fluvial system. Lag deposits containing siderite, clasts of coal and shale and tree debris within channels are further evidence the channel belts cut through fine-grained,

floodplain sediments (Allen, 1965). Bed sets show the typical sequence of bed forms found within meandering channel deposits. That is, a fining-upwards trend is accompanied by a change in bed forms from massive to trough cross-bedded to planar cross-bedded to laminated (Allen, 1965; Jackson, 1976). The uppermost bed forms within the sandy channel fill are wavy with drapes of carbonaceous debris and mica flakes marking the upper surface of laminae. These fine-grained sediments were deposited in the low-energy setting on the inner margin of meander bends (Jackson, 1976). Lateral facies associations are suggestive of floodplain deposits (see section below).

Facies E, F, and I – Floodplain / Swamp / Channel-Fill

Lithologies of facies E, F, and I represent a variety of deposits present at various distances from the channel belt and include floodplain, abandoned channels, and freshwater swamp. These facies are typified by light to dark gray and black shale interlaminated with siltstone, fine-grained sandstone and minor, thin to discontinuous coals with fossil roots (stigmarian axes).

In some cases, the upper portions of Type D Sandstones are truncated by well-developed channel-shaped scours. After channel abandonment, these channel-shaped scours were filled with fine-grained sediments of Facies I, black to dark gray shale (compare with Farrell, 1987).

More often, Type D Sandstone fines upward into siltstone, shale, and fine-grained sandstone interbeds. These fining-upwards successions may be capped by coarsening upwards successions. Where grain size fines upward, the channel belt

moved in a direction away, and where a coarsening in grain size, the channel belt was approaching the aforementioned facies (Bridge, 1984; Ghosh, 1987). In any case, such deposits accumulate through vertical accretion in a floodplain adjacent to the channel.

Laminated fine-grained sediments that overlie Type D sandstones were deposited as overbank fines in a floodplain setting, Facies E (Farrell, 1987). These fine-grained sediments were carried into the floodplain by floodwaters that overtopped the levee. The fines settled from suspension after floodwaters retreated and left ponded water on the planar floodplain surface. As discussed previously, the presence of stigmarian axes suggest the floodplain was the site of a forested wetland. The presence of coal indicates a swampy depositional environment. The flint clays and rooted claystones are soil horizons.

A lateral and vertical fining-upwards trend, as well as the presence of a wedge-shaped basal scour, are indicative of deposition proximal to the channel belt in a channel cut-off (Bridge, 1984; Ghosh, 1987). The fining-laterally (50-meters) and fining-upward trends are a result of the reduction in current energies (of floodwaters) away from the channel belt (Bridge, 1984). That is, the coarsest grained sediments were deposited nearest the channel margin and the finely disseminated carbonaceous and micaceous debris settled from suspension when the floodwaters receded. The presence of organic debris as well as the stigmarian axes atop the succession also suggest the site was covered by a forested wetland.

Facies J – Conglomeratic Sandstone

This sandstone was deposited in a relatively high-energy fluvial system. The presence of a thick basal lag and the overall coarseness of the sandstone unit are

indicative of a high-energy setting (Allen, 1965). Moreover, a lack of fine-grained partings within the quartz-rich conglomeratic sandstone suggests the fluvial system was high-energy. Sporadic clasts of coal, shale, and mud indicate that floodplains surrounded this high-energy fluvial system (Allen, 1965). The paucity of internal scour surfaces within these coarse grained sandstones may be a result of the lack of fine-grained sediments that help to distinguish bedding surfaces (Allen, 1965). Extensive avulsion across the alluvial plain would also result in the destruction and or removal of such fine-grained sediments. Finally, the presence of a quartz-rich pebble lag at the base of this sandstone and the diagnosis of a relatively high-energy fluvial setting suggest an increase in stream gradient.

Facies K – Heterolithic (Estuarine) Sandstone

This alternately laminated very fine-grained and fine-grained, wavy bedded sandstone was deposited in the abandoned alluvial length of a tide-influenced estuary. The unit accumulated as a thick, laterally extensive section of siderite-rich sandstone with abundant carbonaceous and mica flake drapes. This unit does not fit any previously described facies associations for the Birch River section.

According to Blake (personnel communication, 2002), similar alternately laminated very fine-grained and fine-grained sandstones have been described in other studies of Middle Pennsylvanian strata of southern West Virginia. These rock units do not fit within the typical tidal facies models presented for other bounding architectural elements of these sections, as the strata lack any mud partings. Blake (personnel

communication, 2002) has referred to these similar lithologies as tidal laminites. Two scenarios may explain the complete lack of mud within this 10.0 m thick section.

The first scenario is a lack of mud within the system. In the tripartite estuarine model of Dalrymple et al., (1992), sand is deposited in the relatively higher energy fluvial reach, along the estuary margins and at the seaward edge of the estuary and mud is deposited in the low energy middle section. In this model, if the fluvial system carrying the sediment load into the estuary were abandoned, sand would be carried and deposited by tides in the fluvial end with little to no mud input into the system. The lack of fossil fauna can be explained by varying salinity in the isolated abandoned fluvial reach with extensive freshwater runoff into the water body a result of the everwet, tropical climate. Furthermore, the predominance of wavy bedding suggests a tidal setting (Middleton, 1991; Brownridge and Moslow, 1991), where the cyclical alternation of fine-grained and very fine-grained sandstone may have developed from variations in tidal current energies (Middleton, 1991).

A second scenario is constant flow of the water column as in a fluvial channel system (Johnson and Levell, 1995). Wavy bedding has been related to point bar deposition in fluvial systems (Miall, 1988). Evidence in favor of a fluvial setting includes channel scours, cross bedding, and a fining-upwards in grain size. However, none of the supporting evidence for a fluvial system, other than wavy bedding, was found.

Chapter 6

Interpretation of the Birch River Section

Basic concepts and terminology of sequence stratigraphy can be used to describe the Birch River section. However, the cause of sea level rise and fall, whether allogenic or autogenic, cannot be determined through the study of a single outcrop. Therefore, the role of relative transgression and relative regression are discussed as they pertain to the architecture of this stratigraphic section.

Middle Division, Kanawha Formation

The frequency with which estuarine-facies were deposited during the middle division, Kanawha Formation, at Birch River, suggests this was a period of overall relative sea-level rise. Several fluvio-deltaic to coastal-plain facies are overlain by restricted-marine or marine strata at Birch River. According to Blake (1997) and Martino (1998), the three marine shales, the Campbell Creek Marine Zone, the Dingess Shale, and the Winifrede Shale Member, were deposited basinwide during periods of glacioeustatic sea-level rise. Blake (1997) correlated these marine units with similar European lithologies. Analysis of the architectural elements comprising Outcrops Alpha, Beta, and Gamma (Figs. 56 – 60) reveals several episodes of possible (relative) marine transgression of rocks of probable estuarine origin followed by progradation of coastal swamp and/or wetland and subtidal, upper estuarine facies.

Strata underlying and including the Campbell Creek Marine Zone are divided by several scour surfaces, with no less than three planar-shaped and one channel-shaped scour identified (Fig. 57). The lowest planar-shaped scour separates sedimentologically equivalent Type A sandstones (Estuary Margin). The second planar scour truncates a

paleosol that is up to 1.0 meter-thick and is overlain by a third Type A sandstone (the lower portion of the Campbell Creek Marine Zone). A channel-shaped scour truncates this third Type A sandstone. The channel-shaped scour is filled by Type B sandstone (Estuary Channel) (the upper portion of the Campbell Creek Marine Zone) that grades into a fourth Type A sandstone that grades further into a Type E shale. The shale overlying the fourth Type A sandstone is capped by yet another planar-shaped scour surface.

Each scour surface marks a transitional period during which one or several factors led to a time of nondeposition (a change to relatively higher-energy conditions in the estuary, change in depositional rate, and relative change in sea level). Because paleosols and coals are soil horizons that form at or above sea level, the truncation of a paleosol or coal followed by deposition of estuarine strata is a good indication of a relative rise in sea level. Therefore, it is likely there were at least two periods of sea level rise during the deposition of the units underlying and overlying the Campbell Creek Marine Zone. The first occurred when the paleosol was truncated by overlying Type A sandstone. The second occurred at the boundary between the Type E shale below the fourth planar-shaped scour and the Dingess Shale Member. A thin (<1cm) discontinuous coal was found at Outcrop Alpha, between the top of the Type E shale and the bottom of the Dingess Shale. The lowest section of Dingess Shale contains scattered worm burrows (marine), and the dark Dingess Shale at Birch River passes upward into light-gray colored deposits of the low-lying coastal swamp and floodplain.

The siderite lag with minor sandstone clasts at the base of the Dingess black shale may be a result of the (relative) rise in sea level and subsequent encroachment of

the epeiric sea upon the former coastal plain. Such flooding may have resulted in the creation of a widespread ravinement surface that is overlain in succession by a siderite lag deposit and transgressive sandstone (Martino, 1994, 1996; Martino et al., 1998; Blake, 1997). Such transgressive sands were deposited in the nearshore zone during the former regression and were reworked during the ensuing shoreface retreat (Martino, 1996). Marine flooding may also produce a siderite lag overlying a thin coal and/or tidal-creek channel-fills (Martino, 1994, 1996; Martino et al, 1998; Blake, 1997). This suggests the planar-shaped scour surface underlying the sideritic lag at the base of the Dingess Shale is, in fact, a ravinement surface.

The Dingess Shale grades into a Type E shale that, in turn, grades into a seat earth. The seat earth underlies a thin coal bed. This thin coal bed is followed by at least ten meters of floodplain deposits. This succession of facies may indicate a relative sea level-fall. The sandstone deposits of a meandering river cap this succession (see Figs. 58 and 59).

The Type D - Meandering River facies is composed of single-story and stacked, multi-story sandstones (Figs 59 and 60). The basal scour of large-scale sandstones formed when the alluvial channels incised into the former coastal or floodplain deposits during a (relative) sea level stillstand. Progradation of the coastal plain was followed by infilling of these channels by alluvial deposits, including fluvial sandstones, floodplain siltstones and shales and (relatively) thick coals.

The Winifrede Shale, part of Facies C – Estuary Lagoon, overlies Type A sandstone (Estuary Margin) (Figs. 59 and 60). The Type A sandstone, in turn, grades up from Type D (Multi-story, fluvial) Sandstone. This particular progradation of facies is

similar to that discussed in the previous paragraphs for the Campbell Creek Marine Zone and is suggestive of a (relative) sea-level rise. During this time it is likely the sea encroached upon the coastal plain, either due to a change in sedimentation rate or a slowing of basement subsidence or climatic variation (Dalrymple et al., 1992).

(Next Page)

Figure 55. Location of Outcrops at Birch River Study Area.

Field site map of Birch River, showing locations of outcrops “Alpha”, “Beta”, “Gamma”, “Delta”, “Epsilon”, and “Zeta”.

Locations of outcrops studied at Powell Mountain, near town of Birch River,
Nicholas County, West Virginia. Outcrops are labeled: "Alpha", "Beta",
"Gamma", "Delta", "Epsilon", and "Zeta".

Modified From NE/4 Widen Quadrangle (USGS 7.5 Minute Series)

Figure 56. Illustration of Outcrop Alpha.

Units in green are part of Facies A – Estuary Margin. Units in blue are part of Facies B – Estuarine Channels. Unit in purple is part of Facies C – Estuarine Lagoon. Units in black are part of Facies F – Swamp.

Figure 57. Illustration of Outcrop Beta.

Units in green are part of Facies A – Estuary Margin. The blue unit is part of Facies B – Estuarine Channels. Unit in purple is part of Facies C – Estuarine Lagoon. The paleosol is part of Facies E – Floodplain.

Figure 58. Illustration of Outcrop Gamma – North End.

Unit in yellow is part of Facies D – Meandering Stream. These triangular-shaped sandstone bodies are thought to have formed by compaction into the underlying muddy substrate. The small “U”-shaped channel (unit 24) is located to the right of this section (not shown). Unit in purple is part of Facies C – Estuarine Lagoon with basal transgressive (sideritic) lag.

Figure 59. Illustration of Outcrop Gamma – Middle Section.

Units in green are part of Facies A – Estuary Margin. Unit in brown is part of Facies E – Floodplain. Units in yellow are part of Facies D – Meandering River. Units in black are part of Facies F – Swamp.

Figure 60. Illustration of Outcrop Gamma – South End.

Unit in green is part of Facies A – Estuary Margin. Unit in brown is part of Facies E – Floodplain. Units in yellow are part of Facies D – Meandering River. Unit in black is part of Facies F – Swamp.

Upper Division, Kanawha Formation

The lowest fluvial sandstone within the Upper Division, Kanawha Formation marks the change from primarily estuarine and/or marine to dominantly fluvial (Fig. 60). There is one estuarine lithofacies found above the Winifrede Shale Member in the upper division of the Kanawha Formation. The Kanawha Black Flint equivalent, the upper bounding lithology of the Kanawha Formation, was reported at this series of outcrops (Blake, personnel communication, 2001). As discussed previously, Reppert (1979) suggested the Kanawha Black Flint was deposited in a restricted bay. However, the typical Kanawha Black Flint of White (1891, reported in Reppert, 1979) was not found within the new outcrop exposures at Birch River. That is, there were no marine fossils found within the KBF equivalent at Birch River. The KBF at Birch River is interpreted as a Type A sandstone, part of Facies A - Estuary Margin.

Strata directly overlying the Winifrede Shale Member include lithologies deposited in flood-plain and swamp environments. These floodplain deposits and the underlying Winifrede Shale Member are truncated by Type D (multi-story) sandstone. The distribution of facies within the upper division of the Kanawha Formation suggests deposition proximal to the paleoshoreline along the coastal to estuarine setting of the Winifrede Shale. A sedimentary succession of estuarine-to-marine strata overlain by fine-grained, flood-plain rocks, all of which are truncated by fluvial sandstone, is suggestive of a relative sea level fall and subsequent progradation of the paleoshoreline (see Fig. 61).

Both multi-story and single-story fluvial sandstones are overlain by lithologies typical of floodplain facies in the Upper Division of the Kanawha Formation at Birch River. These fluvial sandstones grade into the fine-grained sandstone, siltstone, shale

and coal deposits of the floodplain. Such successions are typically truncated by other fining-upwards successions deposited during crevasse events. These crevasse deposits are evidence that the channel belt was approaching the Birch River site (Ghosh, 1987). Sections of fine-grained deposits with interbedded coals that overlie the crevasse and fluvial sandstones indicate the channel belt was moving away from the Birch River site (Ghosh, 1987) (see Appendix B, Fig. E). Cannel coals and the canneloid shale are further evidence of a freshwater (lake) setting in a floodplain environment.

The coal bed split, units 85 and 86, formed when a fluvial channel meandered across a peat bog, truncating a large section of the underlying fine-grained deposits as well as the peat. Subsequently, the channel filled and the meander belt moved away from the swamp. As the channel retreated, the swamp vegetation encroached upon the sandy channel-fill, leaving a peat deposit atop the former fluvial channel (see Fig. 62).

Figure 61. Illustration of Outcrop Delta – North End.

Unit in green is part of Facies A – Estuary Margin. The base of unit 50 (in yellow) marks the start of the upper division of the Kanawha Formation, as described at Birch River. Units in yellow are part of Facies D – Meandering Stream. Units in brown are the deposits of Facies E – Floodplain, Facies F – Swamp, G – Crevasse, and H – Freshwater Lakes. These lithologies display great lateral continuity in this approximately 0.50 mile-long outcrop Delta. Unit 46 is a coal bed, part of Facies F – Swamp.

Figure 62. Illustration of Outcrop Delta – South End.

Units in brown are part of Facies E – Floodplain, Facies F – Swamp, and Facies G Freshwater Lake. Units in yellow are part of Facies D – Meandering Stream. According to M. Blake (personnel communication, 2001), the top of the Kanawha Formation (the Kanawha Black Flint) is between the top of Unit 82 and the bottom of Unit 83. The Allegheny Formation: Units in yellow are part of Facies D – Meandering Stream. Unit in orange is part of Facies K Heterolithic (Estuarine) Sandstone. Unit in brown is part of Facies E – Floodplain. The normal faults that cut through this section are thought to be a result of post-depositional processes related to the formation of the Enon anticline (Blake, personnel communication, 2000).

Allegheny Formation

Lithologies of the Allegheny Formation at Birch River were deposited within the alluvial plain of a coastal region that experienced several instances of relative sea-level fall accompanied by relatively large-scale fluvial incision. The majority of the Allegheny Formation at Birch River is composed of stacked successions of channel and flood-plain lithologies with large-scale basal scours that approach the scale of incised valley-fill deposits (>15.0 meters). Other notable features include a possibly, tidally deposited (estuarine?) sandstone, and an overall coarsening-upward sequence in grain-size

terminating with a coarse-grained sandstone / conglomerate which caps the Birch River section.

After the formation of the coal bed split (units 85 and 86; uppermost unit of the Kanawha Formation at Birch River), the locale underwent a brief period of relative sea-level highstand. This coal bed split is overlain by a thick (~10.0 meter) section of interbedded wavy-laminated, fine- and very fine-grained sandstone deposited in the abandoned alluvial valley of a possibly, tide-influenced estuary, Type K – (Estuarine) Sandstone.

The upper section of the Type K (Estuarine) Sandstone is root-bioturbated and overlain by coaly shale. This succession suggests a clastic swamp overlay the area after the channel was filled (Grady, 1998). The presence of the root-bioturbated zone and the coaly shale over the (Estuarine) sandstone is suggestive of a slowing or ending of sea-level rise at that time period. Finally, the coaly shale coarsens vertically into interbedded shale, siltstone, and fine-grained sandstone of the flood plain, suggesting the channel belt was then approaching (Ghosh, 1987).

Next, a thick, single-story channel sandstone cut through the floodplain lithologies and the (Estuarine) sandstone down to the top of the coal bed split (Fig. 63). The visible “valley” walls and the underlying possibly, estuarine sandstone are an indication this thick, single-story sandstone may be a fluvial, incised valley-fill deposit. The channel sandstone contains a thick basal lag of clasts and tree debris from upstream, including siderite clasts, shale clasts, fossilized tree trunks and coal rafts. Chunks of the coaly shale can be seen along the edge of the channel sandstone and at

the upper margin of the channel bank. Once the IVF channel was abandoned, the sandstone was overlain by a progradation of the flood-plain lithologies.

Descriptions and interpretations of the uppermost successions at Birch River are suggestive of episodic relative sea-level falls. These upper outcrops are composed of several successions of stacked, multi-story channel sandstones that grade into typical flood-plain deposits composed of siltstone, shale, and overlying thick coals (see Figs. 63-65). Each succession shows some truncation from overlying channel sandstone units. In several instances, erosion was deep enough to truncate the underlying, cohesive peat deposits and cut into the next underlying channel system. Where not eroded, the coals may be capped by overlying multi-story channel sandstones. In other cases, a section of shale beds may be found between the coal and the overlying sandstone. The flint clays and rooted claystones formed as soil horizons.

In the top several successions, the channel sandstones show an overall increase in grain-size (see Figs. 66 and 67). Unit 100 sandstone is medium-grained, unit 104 sandstone is medium to coarse-grained, and unit 110 sandstone is coarse-grained to pebble-sized and unit 112 is very coarse-grained to pebble-sized.

Figure 63. Illustration of Outcrop Epsilon – North End.

Unit 88 (in orange) is part of Facies K - Heterolithic (Estuarine) Sandstone. Units in brown are part of Facies Association E – Floodplain. Units in yellow are part of Facies D – Meandering Stream. Black units are coals.

Figure 64. Illustration of Outcrop Epsilon – Middle Section.

Unit in orange is part of Facies K - Heterolithic (Estuarine) Sandstone. Units in brown are part of Facies E – Floodplain. Units in yellow are part of Facies D – Meandering Stream. Black units are coals.

Figure 65. Illustration of Outcrop Epsilon – South End.

Units in brown are part of Facies E – Floodplain. Units in yellow are part of Facies D – Meandering Stream. Unit 110 is part of Facies D – Meandering Stream. Unit in black is part of Facies F – Swamp.

Figure 66. Illustration of Outcrop Zeta – North End.

Units in brown are part of Facies E – Floodplain. The units below unit 109 are part of Facies E – Floodplain and Facies I – Channel-fill. Units in yellow are part of Facies D – Meandering Stream. Unit 112 (in red) is part of Facies J – Conglomeratic Sandstone.

Figure 67. Illustration of Outcrop Zeta – South End.

Units in The brown units, 105, 107, and 108 are part of Facies E – Floodplain. The brown unit 106 is part of Facies I - Channel-fill. Other brown units are part of Facies E – Floodplain. Units in yellow are part of Facies D – Meandering Stream. Unit 112 is part of Facies J – Conglomeratic Sandstone. Unit 112 is the uppermost unit described at the Birch River outcrops.

Figure 68. Illustration of Depositional Environments Interpreted for the Birch River Section. Sketch is based on field study and interpretations of sedimentary structures and features made during the current study. Facies are representative of probable depositional environments for both the Kanawha Formation and the Allegheny Formation.

Figure 69. Stratigraphic Column of the Birch River Section.

Lithologies based on sedimentary descriptions from this study. See Appendix B for more detailed strat columns and Appendix A for outcrop notes.

Chapter 7

Conclusions

Sedimentary descriptions and facies interpretations of the Birch River section suggest the Coastal Plain model of Martino (1996) is a better fit than the previous delta-plain and alluvial-plain models of Ferm (1970, 1974), and Donaldson (1974, 1979) and others (see, for instance, Horne et al., 1978). Of special significance to Martino's (1996) model are the presences of tidally influenced estuarine facies within the middle division, Kanawha Formation. Delta mouth-bar and distributary channels are conspicuously absent from the facies interpretations of this complete section.

Six facies were interpreted for the middle division, Kanawha Formation. These facies are Estuary Margin, Estuarine Channels, Estuarine Lagoon, Meandering Stream, Floodplain, and Swamp. Estuary Margin facies are composed of laminated, flaser bedded sandstones and silty-shale units, with gradations into seat earths and thin coal beds. Stigmarian axes are common in units underlying the thin coals. Estuarine Channels contain "homogenized" to laminated, (wavy bedded) sandstones with localized concentrations of ichnofossils, including *Skolithos*. Estuarine Channel sandstones truncate underlying sandstones of the Estuary Margin Facies Association. The Estuary Lagoon Facies Association is composed of gray to black shale beds with trace and body fossils common in basal portions. Meandering Stream sandstones are both single and multistory. These sandstone units are capped by pointbar silty-shales and overbank/swamp shales and coal beds. Floodplain and swamp facies are composed of root-bioturbated gray to black shales with overlying thin coal beds.

The upper division, Kanawha Formation is composed of five facies. These Associations are Meandering Stream, Floodplain, Swamp, Crevasse, and Freshwater Lakes. Meandering Stream facies of the middle division are also composed of both single and multistory sandstones. Such deposits are capped by point-bar siltstones and shales. Wedge-shaped sandstones with undulating basal surfaces are common crevasse deposits. Additionally, the floodplain and swamp facies are also composed of root-bioturbated gray to black shales with overlying thin coal beds. Freshwater Lake facies are composed of thin channel coal beds and channeloid shales. Within the floodplain facies are levee deposits composed of interbedded sandstone, siltstone, and shale with large-scale wavy bedding. Overlying the levee deposits is a coal bed that is split by a large, channel sandstone.

The Allegheny Formation is composed of the following six facies: Meandering Stream, Floodplain, Swamp, Channel-fill, Conglomeratic Sandstone, and Heterolithic (Estuarine) Sandstone. The Heterolithic (Estuarine) Sandstone is composed of (flaser bedded) interlaminated very fine to fine-grained sandstone with no apparent trace or body fossils. This sandstone is found in the basal section of the Allegheny Formation. The Meandering Stream facies sandstones dominate exposures of the Allegheny Formation at Birch River. Sand grain-size increases vertically from individual sandstone units from medium to coarse-grained to pebble-sized. Fine-grained, point bar deposits typically cap the sandstone beds. In one case, black shale beds filled channel-forms in upper meandering stream deposits (Channel-fill facies). Floodplain deposits are composed of coarsening upward and/or fining-upward successions. Channel belt

proximity and/or movement were inferred based on the architectural placement of these successions. Conglomeratic sandstones cap the Birch River exposures.

The Birch River section shows an overall progradation in facies from marginal marine to alluvial occurred over time from the lowest unit of the middle division Kanawha Formation to the highest unit of the Allegheny Formation. The pattern of facies migration within the complete section is best described using Martino's (1998) coastal plain model, which emphasizes the evolution of coastal plain facies spanning sea level rise, sea level highstand, sea level fall, and sea level lowstand (Blake, 1998).

Analysis of the entire section reveals instances of both relative sea level rise and relative sea level fall occurred throughout the immediate region of Birch River during the late Middle Pennsylvanian. The middle division, Kanawha Formation is characterized as a period of relative sea level rise, wherein estuarine and /or marine deposits, including the Campbell Creek Marine Zone, the Dingess Shale Member, and the Winifrede Shale dominated the section. During the relative sea level stillstand the estuaries filled-in and the coastal plain migrated across the former estuaries. Evidence for this progradation of facies is the meandering stream deposits that overlie the estuarine and/or marine deposits.

Meandering stream, floodplain, and swamp deposits are common within the upper division, Kanawha Formation and the Allegheny Formation at Birch River. The thick accumulation and internal truncation of these alluvial deposits suggests the period was dominated by relative sea level falls followed by coastal progradation.

References Cited

- Aitken, J.F., and Flint, S.S., 1994. High Frequency Sequences and the Nature of Incised-Valley Fills in Fluvial Systems of the Breathitt Group (Pennsylvanian), Appalachian Foreland Basin, Eastern Kentucky. In: Dalrymple, R.W., Boyd, R., and Zaitlin, B.A., (Editors), *Incised-Valley Systems: Origin and Sedimentary Sequences*. SEPM Special Publication, 51; p. 353-368.
- Allen, J.R.L., 1965. A Review of the Origin and Characteristics of Recent Alluvial Sediments. *Sedimentology*, vol. 5, no. 2, p. 91-191.
- Allen, J.R.L., 1970. Sediments of the Modern Niger Delta: A Summary and Review. In: J.P. Morgan (Editor), *Deltaic Sedimentation Modern and Ancient*. Society of Economic Paleontologists and Mineralogists, Special Publication Number 15; p. 138-151.
- Archer, A.W., Lanier, W.P., and Feldman, H.R., 1994. Stratigraphy and Depositional History Within Incised Paleovalley Fills and Related Facies, Douglas Group (Missourian/Virgilian; Upper Carboniferous) of Kansas, U.S.A. In: Dalrymple, R.W., Boyd, R., and Zaitlin, R.W., (Editors), *Incised-Valley Systems: Origin and Sedimentary Sequences*. SEPM Special Publication 51; p. 45-60.
- Arkle, Thomas Jr., Beissel, Dennis R., Larese, Richard E., Nuhfer, Edward B., Patchen, Douglas G., Smosna, Richard A., Gillespie, William H., Lund, Richard, Norton, C. Warren, Prefferkorn, Herman W., 1979. The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States- West Virginia and Maryland: United States Geological Survey, Professional Paper 1110 D; p. D1-D35.
- Arndt, H.H., 1979. Middle Pennsylvanian Series in the proposed Pennsylvanian System Stratotype. In: Englund, K.J., Arndt, H.H., and Henry, T.W., (Editors), *Proposed Pennsylvanian System Stratotype, Virginia and West Virginia*. AGI Selected Guidebook Series, no. 1, p. 73-80.
- Beerbower, J.R., 1969. Interpretation of Cyclic Permo-Carboniferous Deposition in Alluvial Plain Sediments in West Virginia: *Geological Society of America Bulletin*, v. 80; 9, p. 1843-1847.
- Blake, B.M., Jr., 1992. Stratigraphy of the Lower and Middle Pennsylvanian Series in West Virginia. In: C.B. Cecil and C.F. Eble (Editors), *Paleoclimate Controls on Carboniferous Sedimentation and Cyclic Stratigraphy in the Appalachian Basin*. U.S. Geological Survey Open File Report, 92-546; p. 102-114.
- Blake, B.M., 1997. Revised Lithostratigraphy and Megafloral Biostratigraphy of the New River and Kanawha Formations (Pottsville Group: Lower and Middle Pennsylvanian) in Southern West Virginia. Unpublished Master's Thesis, West Virginia University, Morgantown, WV; p. 1-159.
- Blake, B.M., Jr., 1998. Coal Geology, Paleobotany, and Regional Stratigraphy of the Middle Part of the Kanawha Formation, Southern West Virginia. *Coal Division Field Trip Guidebook, Southeast Section*, Geological Society of America; p. 1-113.
- Blake, B.M., Fedorko, N., III, Loud, E.I., McClelland, S.W., Repine, T.E., and Keiser, A.F., 1989. Coal Availability Study in West Virginia. In: AAPG Eastern Section Meeting; Abstracts. American Association of Petroleum Geologists, Bulletin, vol. 73, no. 8; p. 1030.
- Bridge, J.S., 1984. Large-scale facies sequences in alluvial overbank deposits. *Journal of Sedimentary Petrology*, v. 54; p. 583-588.

- Bristow, C.S., 1985. Brahmaputra River: Channel Migration and Deposition. In: Ethridge, F.G., Flores, R.M., and M.D. Harvey (Editors), *Recent Developments in Fluvial Sedimentology, Contributions from the Third International Fluvial Sedimentology Conference*. SEPM Special Publication 39; p. 63-74.
- Boothroyd, 1978. Mesotidal Inlets and Estuaries. In: Davis, R.A., Jr. (Editor), *Coastal Sedimentary Environments*, Springer-Verlag, New York, NY: p. 47-51.
- Brownridge, S., and Moslow, T.F., 1991. Tidal Estuary and Marine Facies of the Glauconitic Member, Drayton Valley, Central Alberta. In: Smith, D.G., Zaitlin, B.A., Reinson, G.E., and Rahmani, R.A., (Editors), *Clastic Tidal Sedimentology*. Canadian Society of Petroleum Geologists, Memoir 16; p. 107-122.
- Busch, R.M., and Rollins, H.B., 1984. Correlation of Carboniferous Strata Using a Hierarchy of Transgressive-Regressive units. *Geology*, v.13, n.8; p.471-474.
- Cant, D.J., 1982. Fluvial Facies Models. In: (editors) Scholle, P.A., and Spearing, D., *Sandstone Depositional Environments*. American Association of Petroleum Geologists, Memoir 31; p. 115-138.
- Cecil, C.B., 1990. Paleoclimate Controls on Stratigraphic Repetition of Chemical and Siliclastic Rocks: *Geology*, v. 18; p. 533-536.
- Cecil, C.B. and Renton, J.J., 1979. Coal Composition Relationships in Support of a Chemical Model. In: A.C. Donaldson, M.W. Presley, and J.J. Renton (Editors), *Carboniferous Coal Short Course and Guidebook*, W. Va. Geol. Surv., B37 (3); p. 103-128.
- Cecil, C.B., Stanton, R.W., Neuzil, S.G., Dulong, F.T., Ruppert, L.F., and Pierce, B.S., 1985. Paleoclimate Controls on Late Paleozoic Sedimentation and Peat Formation in the Central Appalachian Basin (U.S.A.). In: T.L. Phillips and C.B. Cecil (Editors), *Paleoclimatic Controls on Coal Resources of the Pennsylvanian System of North America*. *International Journal of Coal Geology*, 5; p. 195-230.
- Cecil, C.B., Eble, C.F., Fedorko, N., Blake, B.M., and Grady, W.C., 1992. Paleoclimate Controls on Carboniferous Sedimentation and Cyclic Stratigraphy in the Appalachian Basin: Field Trip Guide Book, West Virginia Geologic and Economic Survey; p. 38-43 and p. 102-116.
- Chesnut, D.R., 1989. Pennsylvanian rocks of the eastern Kentucky coal field. In C.B. Cecil and C. Eble (Editors), *Carboniferous Geology of the Eastern United States*. Field Trip Guidebook T143; p. 57-60.
- Chesnut, D.R., 1994. Eustatic and Tectonic Control of Deposition of the Lower and Middle Pennsylvanian Strata of the Central Appalachians: Tectonic and Eustatic Controls on Sedimentary Cycles, *SEPM Concepts in Sedimentary and Paleontology* #4; p. 51-64.
- Coleman, J.M., 1969. Brahmaputra River, channel processes and sedimentation. *Sedimentary Geology*, Special Issue, 3 (2); p. 137.
- Coleman, J.M., Gagliano, S.M., and Smith, W.G., 1970. Sedimentation in a Malaysian High Tide Tropical Delta. In: J.P. Morgan (Editor), *Deltaic Sedimentation Modern and Ancient*. Society of Economic Paleontologists and Mineralogists, Special Publication Number 15; p. 185-197.
- Coleman, J.M., and Prior, D.B., 1982. Deltaic Environments of Deposition. In: (editors) Scholle, P.A., and Spearing, D., *Sandstone Depositional Environments*. American Association of Petroleum Geologists, Memoir 31; p. 139-179.

- Collinson, J.D., and Thompson, D.B., 1989. *Sedimentary Structures*, 2nd Edition. Unwin Hyman Inc., London, UK; p. 1-17, 37-182.
- Dalrymple, R.W., Zaitlin, B.A., and Boyd, R., 1992. Estuarine Facies Models: Conceptual Basis and Stratigraphic Implications: *Journal of Sedimentary Petrology*, 62; 6; p. 1130-1146.
- Dalrymple, R.W., Boyd, R., and Zaitlin, B.A., 1994. History of Research, Types and Internal Organization of Incised-Valley Systems: Introduction to the Volume. In: Dalrymple, R.W., Boyd, R., and Zaitlin, R.W., (Editors), *Incised-Valley Systems: Origin and Sedimentary Sequences*. SEPM Special Publication 51; p. 45-60.
- Davis, R.A., Jr., 1978. Beach and Nearshore Zone. In: Davis, R.A., Jr. (Editor), *Coastal Sedimentary Environments*, Springer-Verlag, New York, NY: p. 47-51.
- Donaldson, A.C., 1974. Pennsylvanian Sedimentation of Central Appalachians: The Geological Society of America Special Paper 148; p. 47-78.
- Donaldson, Alan C., 1979. Depositional Environments of the Upper Pennsylvanian Series: The American Geological Institute Selected Guidebook Series No. 1, Proposed Pennsylvanian System stratotype Virginia and West Virginia; p.123-31.
- Donaldson, A.C., Martin, R.H., and Kanes, W.H., 1970. Holocene Guadalupe Delta of Texas Gulf Coast. In: J.P. Morgan (Editor), *Deltaic Sedimentation Modern and Ancient*. Society of Economic Paleontologists and Mineralogists, Special Publication Number 15; p. 107-137.
- Donaldson, A.C. and Shumaker, R.C., 1981. Late Paleozoic Molasse of Central Appalachians: Geological Association of Canada, Special Paper 23, Sedimentation and Tectonics in Alluvial Basins; p. 99-123.
- Donaldson, A.C., Renton, J.J., and Preisey, M.W., 1985. Pennsylvanian Deposystems and Paleoclimates of the Appalachians. In: T.L. Phillips and C.B. Cecil (Editors), *Paleoclimatic Controls on Coal Resources of the Pennsylvanian System of North America*. International Journal of Coal Geology, 5; p. 167-193.
- Donaldson, A.C., and Eble, C.F., 1991. Pennsylvanian Coals of Central and Eastern United States: The Geological Society of America, The Geology of North America, v. P-2, Economic Geology, U.S.; p. 523-546.
- Ettensohn, F.R., 1980. Alternative to Barrier-Shoreline Model, Kentucky: Summary. Geological Society of America, Bulletin 91 (I), no. 3; p. 130-135.
- Fail, R.T., 1997. A Geologic History of the North-Central Appalachians, Part 2: The Appalachian Basin from the Silurian through the Carboniferous, *American Journal of Science*, v. 297, summer; p. 729-761.
- Farrell, K.M., 1987. Sedimentology and Facies Architecture of Overbank Deposits of The Mississippi River, False River Region, Louisiana. In: (Editors) Ethridge, F.G., Flores, R.M., and Harvey, M.D., *Recent Developments in Fluvial Sedimentology, Contributions from the Third International Fluvial Sedimentology Conference*. SEPM Special Publication, 39; p. 111-120.
- Ferm, J.C., 1970. Allegheny Deltaic Deposits. In: J.P. Morgan (Editor), *Deltaic Sedimentation Modern and Ancient*. Society of Economic Paleontologists and Mineralogists, Special Publication Number 15; p. 246-255.
- Ferm, J.C., 1974. Carboniferous Environmental Models in Eastern United States and their Significance: The Geological Society of America, Special Paper 148; p. 79-95.

- Ferm, J.C., 1980. Exploration Model for Pennsylvanian Upper Delta Plain Coals, Southwest West Virginia. *American Association of Petroleum Geologists Bulletin* 64 (6); p. 938-941.
- Ferm, J.C., and Weisenfluh, G.A., 1989. Synsedimentary Faulting in the Coal Measures of Eastern Kentucky. *Geological Society of America, 1989 Annual Meeting, Abstracts with Programs*, vol. 21, no. 6; p. A52-A53.
- Fisk, H.N., 1961. Bar-finger sands of the Mississippi delta. In: *Geometry of Sandstone Bodies: Tulsa, Oklahoma*, American Association of Petroleum Geologists; p. 29-52.
- Fisk, H.N., Kolb, C.R., and Wilbert, L.J., 1954. Sedimentary framework of the modern Mississippi delta. *Journal of Sedimentary Petrology*, v. 24; p. 76-99.
- Fraser, G.S., 1989. *Clastic Depositional Sequences; Processes of Evolution and Principles of Interpretation*: Prentice Hall, Englewood Cliffs, NJ; p. 1-459.
- Gillespie, W.H., Clendening, J.A., and Pfefferkorn, H.W., 1978. Plant Fossils of West Virginia. *West Virginia Geological and Economic Survey, Educational Series* (Morgantown, WV), no. 3A.
- Ghosh, S.K., 1987. Cyclicity and Facies Characteristics of Alluvial Sediments in the Upper Paleozoic Monongahela-Dunkard Groups, Central West Virginia: In F.G. Ethridge, R.M. Flores, and M.D. Harvey (Editors), *Recent Developments in Fluvial Sedimentology, Contributions from the Third International Fluvial Sedimentology Conference*. SEPM Special Publication 39; p. 229-239.
- Grady, W.C., 1998. Coal Geology, Paleobotany, and Regional Stratigraphy of the Middle Part of the Kanawha Formation, Southern West Virginia. *Coal Division Field Trip Guidebook, Southeast Section*, Geological Society of America; p. 1-113.
- Gould, H.R., 1970. The Mississippi Delta Complex. In: Morgan, J.P. (Editor), *Deltaic Sedimentation, Modern and Ancient*. SEPM Special Publication 15; p. 3-30.
- Greb, S.F., Eble, C.F., and Hower, J.C., 1999. Depositional History of the Fire Clay Coal Bed 9 (late Duckmantian), Eastern Kentucky, USA. *International Journal of Coal Geology*, vol. 40, no. 4, p. 255-280.
- Horne, J.C., Ferm, J.C., Caruccio, F.T., and Baganz, B.P., 1978. Depositional Models in Coal Exploration and Mine Planning in Appalachian Region. *American Association of Petroleum Geologists Bulletin* 62 (12); p. 2379-2411.
- Howell, D.J., and Ferm, J.C., 1980. Exploration Model for Pennsylvanian Upper Delta Plain Coals, Southwest West Virginia: *American Association of Petroleum Geologists Bulletin*, 64; 3; p. 938-941.
- Hutton, A.C., and Hower, J.C., 1999. Cannel Coals; Implications for Classification and Terminology. In: Hower, J.C., and Eble, C.F., (Editors), *Applied Topics in Coal Geology*. *International Journal of Coal Geology*, vol. 41, no. 1-2, p. 157-188.
- Jackson, R.G., II, 1976. Depositional Model of Point Bars in the Lower Wabash River. *Journal of Sedimentary Petrology*, vol. 46, no. 3; p. 579-594.
- Johnson, H.D., and Levell, B.K., 1995. Sedimentology of a Transgressive, Estuarine Sand complex; the Lower Cretaceous Woburn Sands (Lower Greensand), Southern England. In: Plint, A.G., (Editor), *Sedimentary Facies Analysis; a Tribute to the Research and Teaching of Harold G. Reading*. *International Association of Sedimentologists, Special Publication*, vol. 22; p. 17-46.

- Keller, G.H., and Richards, A.F., 1967. Sediments of the Malacca Straits, Southeast Asia. *Journal of Sedimentary Petrology*, v. 37; p. 120-127.
- Krinitzsky, E.L., and Smith, F.L., 1969. Geology of Backswamp Deposits in the Atchafalaya Basin, Louisiana. U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report S-69-8: Vicksburg, Mississippi; p. 26.
- Kvale, E.P., and Barnhill, M.L., 1994. Evolution of Lower Pennsylvanian Estuarine Facies Within Two Adjacent Paleovalleys, Illinois Basin, Indiana. In: Dalrymple, R.W., Boyd, R., and Zaitlin, R.W., (Editors), *Incised-Valley Systems: Origin and Sedimentary Sequences*. SEPM Special Publication 51; p. 45-60.
- Lewis, D.W. and McConchie, D., 1994. *Practical Sedimentology*, 2nd Edition: Chapman & Hall, New York, NY; p. 24-39; 91-103.
- Link, P.K., 1996. *Basic Petroleum Geology*, 2nd Edition: Oil & Gas Consultants International, Tulsa, Oklahoma.
- Martino, R.L., 1994. Facies Analysis of Middle Pennsylvanian Marine Units, Southern West Virginia: The Geological Society of America, Special Paper 294; p. 69-86.
- Martino, R.L., 1996. Stratigraphy and Depositional Environments of the Kanawha Formation (Middle Pennsylvanian), Southern West Virginia, U.S.A.: *International Journal of Coal Geology* 31; p. 217-248.
- Martino, R.L., 1998. Coal Geology, Paleobotany, and Regional Stratigraphy of the Middle Part of the Kanawha Formation, Southern West Virginia: Coal Division Field Trip Guidebook, Southeast Section, Geological Society of America; p. 1-113.
- Miall, A.D., 1987. Recent Developments in the Study of Fluvial Facies Models: In F.G. Ethridge, R.M. Flores, and M.D. Harvey (Editors), *Recent Developments in Fluvial Sedimentology*, Contributions from the Third International Fluvial Sedimentology Conference. SEPM, Special Publication 39; p. 1-9.
- Miall, A.D., 1988. Reservoir Heterogeneities in Fluvial Sandstones; Lessons from Outcrop Studies. *American Association of Petroleum Geologists, Bulletin*, vol. 72, no. 6, p. 682-697.
- Middleton, G.V., 1991. A Short Historical Review of Clastic Tidal Sedimentology. In: Smith, D.G., Zaitlin, B.A., Reinson, G.E., and Rahmani, R.A., (Editors), *Clastic Tidal Sedimentology*. Canadian Society of Petroleum Geologists, Memoir 16; p. ix-xv.
- Milliken, K.L., 1998. Carbonate Diagenesis in Non-marine Foreland Sandstones at the Western Edge of the Alleghanian Overthrust Belt, Southern Appalachians. In: Morad, S., (Editor), *Carbonate Cementation in Sandstones; Distribution Patterns and Geochemical Evolution*. International Association of Sedimentologists, Special Publication 26; 87-105.
- Mozley, P.S., and Wersin, P., 1992. Isotopic Composition of Siderite as an Indicator of Depositional Environment. *Geology*, vol. 20, no. 9; p. 817-820.
- Nelson, B.W., 1970. Hydrography, Sediment Dispersal, and Recent Historical Development of the Po River Delta, Italy. In: Morgan, J.P., (Editor), *Deltaic Sedimentation; Modern and Ancient*. Society of Economic Paleontologists and Mineralogists, Special Publication Number 15; p. 152-184.
- Oomkens, E., 1970. Depositional Sequences and Sand Distribution in the Postglacial Rhone Delta Complex. In: Morgan, J.P., (Editor), *Deltaic Sedimentation; Modern and Ancient*. Society of Economic Paleontologists and Mineralogists, Special Publication Number 15; p. 198-212.

- Pettijohn, F.J., Potter, P.E., and Siever, R., 1987. Sand and Sandstone, 2nd Edition. Springer-Verlag, New York, NY; p. 97-135.
- Presley, Mark W., 1979. Lower Pennsylvanian (Pottsville to Conemaugh) Alluvial to Delta-plain Facies Shift Through Time, Central Appalachians, 9th International Congress on Carboniferous Stratigraphy and Geology; p. 393-406.
- Pritchard, D.W., 1967. What is an estuary? In: Lauff, G.H., editor, Estuaries. A.A.A.S. Publication 83, Washington, D.C.; p. 3-5.
- Ramsbottom, W.H.C., 1979. Rates of transgression and regression in the Carboniferous of NW Europe. Journal of the Geological Society of London, 136; p. 147-153.
- Ray, P.K., 1976. Structure and Sedimentological history of the overbank deposits of a Mississippi River point bar. Journal of Sedimentary Petrology, v. 46; p. 788-801.
- Reger, D.B., Price, W.A., Tucker, R.C., Sisler, J.D., and White, I.C., 1921. Nicholas County Reports: West Virginia Geological and Economic Survey; p. 18-90, 91-104, 105,107, 134-151, 185-240.
- Reppert, Robert S., 1979. Kanawha Black Flint: Its Occurrence and Extent in West Virginia: The American Geological Institute, Selected Guidebook Series No. 1, Proposed Pennsylvanian System Stratotype Virginia and West Virginia; p. 109-11.
- Ross, C.A., and Ross, J.R.P., 1985. Carboniferous and Early Permian Biogeography. Geology, v. 13: p. 27-30.
- Scotese, C.R., 1986. Phanerozoic Reconstructions: a New Look at the Assembly of Asia. Univ. Texas Inst. Geophys. Tech. Rep., 66. Paleooceanographic Mapping Project Progress Rep., 19-1286.
- Shuster, M.W., and Steidtmann, J.R., 1987. Fluvial-Sandstone Architecture and Thrust-Induced Subsidence, Northern Green River Basin, Wyoming. In: (Editors) Ethridge, F.G., Flores, R.M., and Harvey, M.D., Recent Developments in Fluvial Sedimentology, Contributions from the Third International Fluvial Sedimentology Conference. SEPM Special Publication 39; p. 279-285.
- Smith, D.G., 1987. Meandering River Point Bar Lithofacies Models: Modern and Ancient Examples Compared. In: (Editors) Ethridge, F.G., Flores, R.M., and Harvey, M.D., Recent Developments in Fluvial Sedimentology, Contributions from the Third International Fluvial Sedimentology Conference. SEPM Special Publication, 39; p. 83-91.
- Trowbridge, A.C., 1922. Preliminary geologic report on the Mississippi delta (unpublished report): U.S. Army Corps of Engineers, New Orleans District.
- Trowbridge, A.C., 1930. Building of Mississippi delta: American Association of Petroleum Geologists Bulletin, 14; p. 867-901.
- Tucker, M.E., 1993. Sedimentary Rocks in the Field, 2nd Edition: John Wiley & Sons Ltd., West Sussex, England; p. 141.
- Vail, P.R., Mitchum, R.M., Jr., Thompson, S., III, and Sangree, J.B., 1977. Seismic Stratigraphy and Global Changes of Sea Level; Parts 1-7. In: (Ed.) Payton, C.E., Seismic Stratigraphy; Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists, Memoir 26; p. 51-143.
- Van Wagoner, J.C., Mitchum, R.M., Campion, K.M., and Rahmanian, V.D., 1990. Siliciclastic Sequence Stratigraphy in Well Logs, Cores, and Outcrops: Concepts of High-resolution Correlation of Time

- and Facies. American Association of Petroleum Geologists, Methods in Exploration Series 7; p. 55.
- Veevers, J.J., and Powell, C. McA., 1987. Late Paleozoic Glacial Episodes in Gondwanaland Reflected in Transgressive-Regressive Depositional Sequences in Euramerica. Geological Society of America Bulletin, 98: 475-487.
- Visher, G.S., 1972. Physical Characteristics of Fluvial Deposits. In: Rigby, J.K., and Hamblin, W.K. (Editors), Recognition of Ancient Sedimentary Environments. SEPM Special Publication 16; p. 84-97.
- Wanless, H.R., and Shepard, F.P., 1936. Sea level and climatic changes related to late Paleozoic cycles. Geological Society of America Bulletin, 47; 1177-1206.
- Weimer, B.J., Howard, J.D., Lindsay, D.R., 1982. Tidal Flats and Associated Tidal Channels. In: Scholle, P.A. and Spearing, D., (Editors), Sandstone Depositional Environments. AAPG, Memoir 31; p. 191-245.
- White, I.C., 1891. Stratigraphy of the Bituminous Coal Field of Pennsylvania, Ohio, and West Virginia. U.S. Geological Survey Bulletin, 65; p. 212.
- Wignall, P.B., 1991. Model for Transgressive Black Shales? Geology, vo. 19, no. 2; p. 167-170.
- Wizevitch, M.C., 1992. Sedimentology of Pennsylvanian quartzose sandstones of the Lee Formation, central Appalachian Basin: fluvial interpretation based on lateral Profile analysis. Sedimentary Geology, 78; p.1-47.
- Wright, L.D., 1978. River Deltas. In: Davis, R.A., Jr. (Editor), Coastal Sedimentary Environments, Springer-Verlag, New York, NY: p. 47-51.
- Wright, L.D., and Coleman, J.M., 1973. Variations in Morphology of Major River Deltas as Functions of Ocean Wave and River Discharge Regimes. American Association of Petroleum Geologists Bulletin 57 (2); p. 370-398.
- Zaitlin, R.W., Dalrymple, R.W., and Boyd, R., 1994. The Stratigraphic Organization of Incised-Valley Systems Associated with Relative Sea-Level Change. In: Dalrymple, R.W., Boyd, R., and Zaitlin, R.W., (Editors), Incised-Valley Systems: Origin and Sedimentary Sequences. SEPM Special Publication 51; p. 45-60.

Appendix A.

Outcrop Descriptions (Oldest to Youngest)

Outcrop Alpha		Middle Division, Kanawha Formation		
<u>Unit #</u>	<u>Lithology</u>	<u>Description</u>	<u>Unit Thickness (meters)</u>	<u>Cumulative Thickness (meters)</u>
1.)	Sandstone	Laminated, fine to medium grained sand, light to medium gray in color. Sorting is good within bed sets. Bed sets are one meter thick on average and contacts are sharp. Mica flakes and carbonaceous debris drape bedding surfaces. Laminae are commonly horizontal, cross-laminated, wavy, discontinuous, and flaser with silty interbeds. A low angle bar form dips gently to the north at the base of the outcrop. Bed sets thicken into the trough adjacent to the bar form and thin atop the bar crest. Bed sets within the bar thicken in the middle and pinch out on flank.	8.00	8.00
2.)	Silty-Shale	A silty-shale grades up from the sandstone unit 1. The shale unit is black to dark gray in color and contains scattered debris on bedding, <i>Stigmara</i> . The color lightens vertically from dark gray to light gray. Thin, diffuse siderite layers are interbedded with the light gray shale layers. Laterally, this silty-shale unit is completely eroded away and capped by the sandstone unit 2.	5.00	13.00
3.)	Sandstone	This sandstone disconformably overlies unit 1 and unit 2. This unit fills a channel that is incised more than 10-meters into units 1 and 2. Siderite, mica, plant, silt, and clay grains were noted. Large, ellipsoidal limestone concretions (> 1.0 meter) occur throughout unit 3. Several siderite clast lags are present in channel-form at the north end of outcrop Alpha. At least three beds with Epsilon Cross-Strata (ECS) are present in unit 3. Sand grain size changes follow an upwards-fining trend within individual large-scale bed sets. Bed sets have sharp basal contacts. Bed sets are massively bedded ("homogenized") deposits of medium-grained, poorly sorted, light-gray sands. Where bedding is undisturbed by bioturbation, large-scale cross beds and planar beds are visible.	10.00	23.00
4.)	Shaley-Siltstone	This unit fills the upper portion of the channel that incised through units 1 and 2. The unit 3 sands grade into this shaley-siltstone. Unit 4 is light gray in color and contains carbonized root traces; rooting has disturbed bedding. Nodular siderite clasts are found scattered throughout unit 4. Several ellipsoidal limestone concretions (> one meter-thick) are found at the base of this shaley unit. The top ten centimeters of unit 4 are heavily root-bioturbated dark gray shale. Unit 4 thins where it laps onto the channel margin and thickens into the channel thalweg. On the upper channel margin it is completely composed of shale.	4.00	27.00

5.)	Sandstone	The shale and shaley-siltstone of unit 4 and the sandstone unit 3 are truncated by an overlying channel sandstone. The irregularly shaped (undulose), sharp base of the sandstone is marked by a siderite lag and many root impressions (<i>Stigmara</i>) and sand-filled, vertical burrows. The sandstone is fine to very-fine grained and light to dark gray in color. There are a few ellipsoidal limestone concretions (> one meter thick) present throughout the unit. Bedding is typically massive (no bedding) to laminar (cross to lenticular). Where bedding is visible it may be distorted along the basal edge, where nodular siderite is most common. Sand-sized siderite grains and mica flakes are common on most bedding surfaces of the unit 5 sandstone. Stigmarian axes are present in the top of this sandstone.	3.90	30.90
6.)	Underclay	The top of sandstone unit 5 grades into a very thin underclay (0.0 to 0.10 m-thick) containing stigmarian axes.	0.10	31.00
7.)	Coal (No. 2 Gas Coal Bed)	Vitreous, and blocky coal bed. This coal bed is evenly bedded and laterally continuous at outcrop Alpha.	0.30	31.30
8.)	Shale	A shale bed with a sharp base overlies the unit 7 coal bed. This (fissile) shale lightens in color vertically from black to light gray. The shale is laterally continuous, but has variable thickness. The unit 8 shale grades into the overlying unit 9 sandstone. This shale contains no fossils.	0.35	31.65
9.)	Sandstone	This sandstone is fine-grained, well sorted, and light gray in color. Bedding is massive to (planar) laminated. For example, thin-thick bed sets are massive to planar laminated. Where bedding is apparent, bedding surfaces are littered with sand-sized siderite grains and mica flakes. This sandstone is laterally continuous, where visible at outcrop Alpha. The upper two-meters of unit 9 are root-bioturbated and contain scattered nodular siderite clasts.	3.00	34.65
10.)	Silty-Shale	The upper 1.0 to 0.5 meters of the unit 9 sandstone grade into siltstone and shale at the top. This unit is heavily root-bioturbated.	1.00	35.65
11.)	Unnamed Coal	A thin coal bed overlies the root-bioturbated unit 10. This coal is vitreous, blocky, and laterally extensive. At outcrop Alpha the coal is 0.05 meters-thick and at outcrop Beta it is 0.12 meters-thick.	0.12	35.77
Outcrop Beta		Middle Division, Kanawha Formation		
12.)	Silty-Shale	At outcrop Beta, unit 12 is composed of interlaminated, centimeter-thick, dark gray silty-shale beds and diffuse siderite bands.	0.50	36.77
13.)	Siltstone	The percentage of silt in unit 12 increases vertically, until at 0.5	0.10	37.27

		meters above base, unit 12 has graded into a planar laminated siltstone. This siltstone is 0.10 meters thick and grades vertically into sandstone.		
14.)	Sandstone	This sandstone is very fine to fine-grained and light gray in color. Sandstone is laminated (predominantly trough to planar cross laminated). The laminae are distorted in some instances and may be draped with finely disseminated carbonaceous debris and fine siderite grains and mica flakes. Nodular siderite masses (0.20x0.05m) are found scattered throughout the sandstone. The top of this 1.60 meter-thick section is marked by a (planar) scour surface. This scour surface is laterally extensive across the face of outcrop Beta.	1.00	37.37
15.)	Sandstone	This unit starts as a 1.1 meter-thick section of bedded to laminated and graded sandstone beds that overlie a planar-shaped scour surface. The basal contact of the bedded sands is abrupt with underlying laminated sands. These bedded sands lack the carbonaceous debris and siderite grains found on the laminated sand surfaces. The bedded sands may only appear to be bedded due to a lack of the fine-grained material. The bedded sands are light gray and the laminated sands are medium gray. Sand grain size is fine to very fine throughout. Laminae are ripple-bedded. Laminae may also be distorted or disturbed (flow rolls, upturned laminae and lenses) higher in this unit. These bedding features are similar to those seen in the unit 1 sandstone (i.e., flaser, horizontal, and x-laminae, as well as small-scale flow structures; ball and pillow laminae, and rare herringbone x-beds not seen in unit 1). A thin (0.05 meter-thick), diffuse siderite bed lies below a scour surface at the top of this unit.	1.10	38.47
16.)	Paleosol	Laterally, to the south (at outcrop Beta), the upper scour surface of unit 15 cuts away most of a paleosol that grades up from the unit 15 sandstone. This paleosol is up to 1.0 meter thick, accounting for almost half of the thickness of the unit 15 sandstone. At outcrop Gamma, the scour surface is marked by ellipsoidal limestone concretions (up to 10.0 m long x 2.0 m thick). The limestone concretions are almost extensive enough to form a distinct bed. These concretions are found at or just above the same stratigraphic level as the scour surface.	1.0	39.47
17.)	Sandy-Shale	At outcrop Beta, the above mentioned scour surface (and paleosol) is overlain by a planar laminated shale/sandstone. Diffuse bands of siderite are found throughout the unit. This succession begins as a thin (0.05 meter-thick), gray, laminated sandy-shale.	0.05	39.52
18.)	Sandstone (Campbell Creek Marine Zone)	Scattered nodular siderite clasts and a few shale clasts mark the gradational boundary from the sandy-shale of unit 17 to very fine-grained silty-sandstone, unit 18. Where the paleosol, unit 16, is present, the overlying siderite bed is continuous and up to 0.20 meters-thick. The silty-sandstone is dark to medium gray in color. Many limestone concretions are present throughout unit 18.	8.95	48.47

		These LS concretions are ellipsoidal in shape and are several meters in diameter.		
19.)	Siltstone (Campbell Creek Marine Zone)	Unit 18 grades into a dark gray, laminated siltstone that varies from 0.50 to 1.0 meters in thickness. *Units 17, 18, and 19 have variable thickness due to the presence of an extensive scour surface. At the south end of outcrop Beta, the 10.00 m-thick section of units 17, 18, and 19 has been completely truncated by a channel-shaped scour surface. In the middle of outcrop Beta, the erosion was less extensive, leaving almost a full meter of the bottom of this unit.	1.0	49.47
20.)	Sandy-Silty-Shale (Campbell Creek Marine Zone)	This unit lies above the scour surface mentioned in unit 19. Unit 20 is composed of laminated, silty-shale with very fine to fine-grained sand-filled lenses and horizontal burrows. Approximately 0.50 meters above the scour surface, this unit becomes sandier and is homogenized by burrowing. Bedding is only faintly visible as disturbed laminae. More discernible are the many horizontal trails (or traces).	5.0	54.47
21.)	Silty-Sandstone	Unit 20 grades vertically into 5.0 meters of light-gray, well-sorted, interlaminated fine-grained sandstone and siltstone. Diffuse siderite bands are present throughout this silty-sandstone.	5.0	59.47
22.)	Shale	1.0 meter of unfossiliferous shale grades up from the unit 21 Silty-Sandstone. The gradational boundary is marked by a siderite horizon. Other, more discontinuous sideritic layers are present throughout the shale.	1.0	60.47
23.)	Coal (Williamson Coal Bed (??))	At the top of unit 22, outcrop Alpha is a very thin (< 1cm thick) laterally continuous coal bed. This coal bed is not found at outcrop Beta.	0.01	60.48
Outcrops Beta & Gamma				
<u>Unit #</u>	<u>Name</u>	<u>Description</u>	<u>Unit Thickness (meters)</u>	<u>Cumulative Thickness (meters)</u>
24.)	Sandstone	At the north end of outcrop Gamma a large-scale channel (10 meters thick) cuts through the upper shale section of units 21 and 20, and originates just below at the same apparent stratigraphic level as the (Williamson) coal bed found at outcrop Alpha. Laterally, the basal channel disconformity marks the base of the overlying Dingess Shale Member. The main channel is composed of well-sorted, light gray, fine-grained, thinly laminated and typically horizontal planar-bedded sandstone with minor amounts of nodular siderite. These fine-grained laminations comprise larger-scale (1.0 meter thick) lens-shaped bed sets in the center and south end of the channel. In the center of the channel sandstone grain size increases, coarsening laterally to the north end, where millimeter-sized lag deposits are found. The lag deposits are composed of siderite clasts, clay and/ or shale clasts and some unidentified plant material in a medium to fine-grained matrix. Bedding features change laterally from laminae at the south end to planar cross and horizontal beds at the north end	10.00	70.48

		<p>(ECS). Bedding is made more obvious by carbonaceous flakes and/ or thin shales (where an abundance of carbonaceous material) on bedding surfaces. Near the top of the channel the fine-grained sands grade vertically into very-fine grained sands, which grade further into silts and still further, both laterally and vertically into shales.</p> <p>Similar sandstone lithologies are found laterally to the south at outcrop Gamma just below this same disconformity. These sandstone bodies are “check-shaped” and smaller than the large-scale channel (less than two meters-thick). Thin coals are found locally between these smaller-scale sandstone bodies just below the disconformity.</p>		
25.)	Shale (Dingess Shale Member)	<p>A laterally extensive ravinement surface separates the Williamson coal bed (unit 23), where present, and/or the shale (unit 22) near the top of the Campbell Creek Marine Zone (unit 20), where the Williamson Coal is not present, from the Dingess Shale Member. This ravinement surface was found at each outcrop where the Dingess and Campbell Creek were visible. Above the ravinement surface is a sideritic lag deposit (0.05 to 0.10 m-thick) with minor sandstone clasts. Sitting atop the lag deposit is homogeneous, thick, dark black shale. This shale grades laterally, (to the south), into a gray shale. The shale is extremely fissile, with nodular siderite forming diffuse bands throughout the shale thickness. Several ellipsoidal limestone concretions (> 1.0 meter thick) are found in the top 4 meters of the unit. Burrows are found locally near the base of the shale. M. Blake (2001, personnel communication) reports that <i>Lingula</i> could be found in the old U.S. Route 19 road cut; however, this report could not be verified in the new road cut. .</p>	8.50	78.98
25a.)	Shale	<p>This shale unit grades up from the Dingess Shale Member. It is a gray shale that is heavily bioturbated by rooting. This shale grades into underclay, unit 26. A (unconsolidated) clay bed is found below the underclay at outcrop Gamma.</p>	2.00	80.98
26.)	Underclay	<p>This gray, underclay grades up from the underlying shale/clay, unit 25a. It is laterally extensive and varies from 0.05 to 3.0 meters thick.</p>	3.0	83.98
27.)	Coal (Cedar Grove Coal Bed)	<p>Thin, laterally continuous, banded, blocky coal bed. Vitreous material forms thin, discontinuous layers throughout the coal.</p>	0.15	84.13
28.)	Sandy-Silty-Shale	<p>Unit 28 begins as a thin (0.05-meter thick), light gray, weakly consolidated, clayey-shale above the coal of unit 6b. This clay zone rapidly grades into 1.40 meters of interlaminated wavy to flaser (shale) bedded, fine-grained sands, "banded" siderite, and siltstones with mostly discontinuous, planar horizontal laminae.</p>	1.45	89.83
29.)	Silty-Shale	<p>The interlaminated beds of unit 28 grade into 1.50 meters of a silty-shale, where fine-grained sands give the shale a flaser to</p>	1.50	91.28

		lens-shaped, discontinuous bedding structure. Small-scale soft sediment or flow-type structures are locally common in this zone. In the middle of this zone the silty-shale is very heterogeneous both laterally and vertically. Stringers of fine-grained sandy-silt or shale grade (coarsen) from the shale laminations. These stringers are both small-scale laminations and larger-scale bed forms, 10 to 20-cm thick. No fossils were found.		
30.)	Sandy-Siltstone	The 1.50-meter thick unit 29 grades into a 5.70-meter thick medium-gray sandy-siltstone. Diffuse bands of nodular siderite, discrete nodular siderite clasts and ellipsoidal limestone concretions (> 1 meter) are found throughout this siltstone.	5.70	92.78
31.)	Shale	The 5.70 meter-thick siltstone grades into a heavily (root) bioturbated section of shale (underclay). Although bioturbated, the shale still exhibits fissility.	1.50	94.28
32.)	Unnamed Coal	Overlying the shale of unit 31 is a thin (2cm-thick), dull, highly weathered (Fe-stained) coal. This coal is laterally and vertically homogeneous and continuous.	0.02	94.30
33.)	Shale	Unit 33 is a thin (30cm-thick), medium gray, (fissile) shale. This shale is truncated by the overlying channel sandstone (unit 34). No fossils were found.	0.30	94.60
Outcrop Gamma				
<u>Unit #</u>	<u>Name</u>	<u>Description</u>	<u>Unit Thickness (meters)</u>	<u>Cumulative Thickness (meters)</u>
34.)	Sandstone/Shale	A thick succession of channelform sandstones fill an undulating to channel-shaped scour through units 28-33. The channel scoured out, as much as, 4 meters of the highest shale, coal and siltstone. The sandstone is medium to coarse-grained with planar horizontal and x-beds. Lateral accretion surfaces are visible locally at the top of the unit. Clay (unconsolidated) and/ or shale clasts form local lag deposits in bed sets. Soft sediment deformation is found a few meters above the base of the channel-shaped scour. Laminae are visible due to the presence of carbonaceous and mica flakes on the bedding planes. The sandstone is more planar bedded in the upper section. Thickness of unit 34 varies from a minimum of 13.00-meters to a maximum of 16.90-meters.	13.00	107.60
35.)	Shale	The unit 34 sandstone grades into a 1.10- to 5.00-meter thick, light gray, root-bioturbated, highly weathered shale. Nodular siderite is present throughout the 5.00 meters of shale.	1.10	108.70
36.)	Underclay	Where the shale of unit 35 is 5.00-meters thick, at a point 1.60 meters above the sandstone of unit 34, the shale grades into a 3-cm thick dark-gray shale.	0.03	108.73
37.)	Unnamed Coal	The thin underclay of unit 36 underlies a 3-cm thick, mostly dull, but slightly vitreous, laminated, and blocky coal.	0.03	108.76

38.)	Shale	Overlying the coal is a series of interlaminated dark, medium, and light gray shales, silty-shales, and laminated, fine-grained sandy-siltstones. This unit is 3.34-meters thick.	3.34	112.10
39.)	Underclay	A 0.50 meter-thick, gray underclay grades up from the shale of unit 38. No bedding is visible due to extensive root-bioturbation. This unit underlies the next coal bed, unit 40.	0.50	112.60
40.)	Coal (Chilton Coal Bed)	A coal bed with a 0.25-meter thick shale section located 0.15-meters from the base of the coal, overlies the shale of unit 39. The coal is vitreous, blocky, and slightly iridescent in the upper 0.5-meters. The shale is dark-gray, and varies from 10 to 25 cm's thick. A 1.05 meter-thick coal caps the shale. Sitting disconformably above the coal is the channel sandstone of unit 41. The upper surface of the coal is uneven and is capped by a scour surface.	1.45	114.05
41.)	Sandstone/ Shale	<p>A scour surface represents the boundary between this multi-story "channel" sandstone and the underlying Chilton Coal Bed (unit 40). At least 4 scour surfaces were recognized between the base of unit 41 and the overlying unit 42 shale. At the base of unit 41, coal and plant clasts and siderite pebbles form a series of lag deposits in the sandy matrix. The largest lag is found in a bed set 2.0 meters above the Chilton Coal Bed (unit 40). The coal and plant clasts and siderite pebbles typically lie parallel to bedding, imbricated. These clasts are <1cm-thick and from 5 to 10cm's long. Casts of plant axes with coalified bark are common. Lens-shaped shale clasts (with minor clay and siderite inclusions) were found in higher sections of the unit, with no apparent imbrication.</p> <p>Sandstone unit 41 is an extremely heterolithic (laterally and vertically) sandstone. Where more complete, individual channels grade vertically into 0.50-meter thick, dark-gray shales with thin bands of nodular siderite. These shale components may contain thin, <10cm-thick, discontinuous coal beds near the top. Channel sandstones are composed of 0.50-meter thick, planar-bed sets with internal trough x-bedding or planar horizontal bedding. The channel sandstones grade laterally and vertically into shale interbeds. The presence of shale interbeds is dependent on the formation and size of channels. The largest channel sand cuts through almost the entire thickness of unit 41 and grades vertically and laterally into a series of shale, silt, and sand interbeds, each 0.10 to 1.00-meter thick. Within channels, sand grain size varies from fine to medium, but individual bed sets are typically well sorted. However, at least one channel shows lateral gradation in grain size from shale to mixed fine-grained sand and silty-shale. In this instance the laminae do not lap channel margins, rather the laminae drape the channel bottom. Throughout the section, bedding and/or laminae are well pronounced due to the presence of mica and/or carbonaceous and/or iron (siderite) flakes on the bedding surfaces. Where enough carbonaceous material was deposited, thin (<1cm-thick) coals formed on bedding surfaces (compressed plant stems?).</p>	14.45	128.50

42.)	Shale	The upper 0.50 meters of unit 41 grade into root-bioturbated sandstone and shale that fill a channel form. This shaley unit appears to grade into the overlying fine-grained sands of unit 44 in some areas. Locally, a very thin coal bed, unit 43, overlies the shale. Most of the contact between units' 42, 43, and 44 is hidden under cover at the top of the overlying bench.	0.50	129.00
43.)	Unnamed Coal	A thin (5cm to 0cm-thick), laterally discontinuous coal sits between the dark-gray shale of unit 42 and the shale of unit 44.	0.05	129.05
44.)	Shale (Winifrede Shale Member)	A siderite-rich layer marks the base of this gray shale. M. Blake (personnel communication, 2003) reports that marine bivalves, and brachiopods, and crinoids were common to a blue-gray horizon within this shale at the old U.S. Route 19 road cut. M. Blake (personnel communication, 2003) also reported the same fossils are located within the new road cut, between outcrops Gamma and Delta. However, upon further investigation, the author was unable to find any marine fossils within this unit. This unit grades into unit 44a. This unit is present between outcrops Gamma and Delta.	1.00	130.05
44a.)	Shale, Sand & Siltstone	Grading up from the shale of unit 44 is a 6.70-meter thick, laterally and vertically continuous and homogeneous sequence of light-gray shale, interlaminated with light-gray to white, fine-grained sands and silts, with flaser, cross and lenticular laminae.	5.70	135.75
Upper Division, Kanawha Formation				
45.)	Shale (Seat Earth)	The 5.70 meter-thick section of unit 44a grades into a 5.00-meter thick, dark-gray shale. The dark-gray shale is root-penetrated and underlies the next coal bed of unit 46.	5.00	140.75
<u>Unit #</u>	<u>Name</u>	<u>Description</u>	<u>Unit Thickness (meters)</u>	<u>Cumulative Thickness (meters)</u>
46.)	Coal (Winifrede Coal Zone)	Overlying the shale of unit 45a is a dull to vitreous, thin, blocky and laterally and vertically continuous coal bed.	0.20	140.95
47.)	Shale (Seat Earth)	This shale is light to medium-gray with diffuse bands of siderite. Although many fossil roots (stigmairian axes) can be found throughout the shale, the laminations are still visible.	0.50	141.45
47a.)	Shale	The unit 47 gray shale grades into a black shale. This shale section is composed of thinner laminae than those found unit 47. This upper black shale underlies the next coal bed, unit 48. This unit is not found at outcrop Delta; it is only at outcrop Gamma. A large-scale channel visible in outcrop Delta, unit 50, has truncated this unit.	1.50	142.95

48.)	Coal (Winifrede Coal Zone)	This unit is a dull to vitreous, blocky, and laterally extensive coal bed at outcrop Gamma. It is not found at outcrop Delta. A large-scale channel visible in outcrop Delta, unit 50, has truncated this unit.	0.55	143.50
49.)	Shale/Clay	The coal bed of unit 48 underlies a 0.02-meter thick black shale. This thin black shale grades into a 1.80-meter thick, weakly consolidated, light gray clayey-shale. At 1.50-meter's thickness, the clayey-shale becomes more tan and contains a larger proportion of nodular siderite and diffuse siderite bands than in the lower portion. The shale also coarsens in this interval; although it remains a clayey-shale, the unit has more silt and fine sand within this interval. This unit is not found at outcrop Delta; it is only at outcrop Gamma. A large-scale channel visible in outcrop Delta, unit 50, has truncated this unit.	1.82	145.32
Outcrop Delta				
<u>Unit #</u>	<u>Name</u>	<u>Description</u>	<u>Unit Thickness (meters)</u>	<u>Cumulative Thickness (meters)</u>
50.)	Sandstone	<p>Unit 50 is composed of two large-scale channels; the larger is 11-meters thick and at least 150-meters wide, at outcrop Delta. This channel sandstone scoured completely through units 49, 48, 47, 46, 45, and at least 2.00-meters into the upper portion of unit 44. Unit 50 is composed of medium-grained, well-sorted, gray sandstone. Trough cross bedding is common lower in section and planar cross bedding to cross-laminae are common higher in section. Discontinuous shale beds are interbedded with sandstone beds at the base of some cross-bed sets. The shale beds contain nodular siderite and mica flakes are abundant on most bedding surfaces. No fossils were found in this lower channel-fill sandstone.</p> <p>This lower channelform, visible at outcrop Delta, is partially truncated by a large-scale channel filled with sandstone. This channel is 6.0 meters in thickness and cuts through a portion of the 11-meter thick sandstone. This “smaller” channel is inaccessible for close inspection. However, it appears to contain similar sedimentary structures to those found in the lower, larger channel sandstone.</p> <p>Above the two channelforms of unit 12 are two laterally extensive zones (0.25 m-thick, ea.) of fine-grained, very micaceous, wavy-bedded sandstones. A 0.50-meter thick section of massive bedded, medium-grained sandstone separates these two wavy-bedded zones. Additionally, a 1.50-meter thick section of massive bedded, medium-grained sandstone lies above the higher wavy-bedded zone.</p> <p>The upper 1.0-meter of unit 50 contains stigmarian axes that extend into the overlying silty-sandstone of unit 51.</p>	13.50	158.82

51.)	Siltstone/ Sandstone (FUS)	A sandy-siltstone grades from the upper unit 50 sandstone. The unit is bioturbated by rooting. Deposits of carbonaceous and mica debris become more extensive towards the top of the unit. No bedding or laminae are visible in this unit. Thin (<1cm-thick), discontinuous coals are found in the upper 0.50-meters of this unit.	1.25	160.07
52.)	Shale (Seat Earth)	Unit 51 grades into a thin shale, unit 52, that underlies the next coal bed of unit 53.	0.05	160.12
53.)	Unnamed Coal	Thickness of the coal bed varies laterally from 0.35 to 0.50-meters. The coal is blocky, vitreous to dull, and laterally continuous.	0.50	160.62
54.)	Silty-Shale (Roof Shale)	Light-gray, (root-bioturbated) and interbedded siltstones and shales overlie the coal bed of unit 53. Thin (<1cm-thick) laterally discontinuous, vitreous and blocky coals and carbonaceous (plant debris) are found throughout the interbedded silts and shales. Siderite nodules are also found throughout the unit. In some sections, the siderite nodules coalesce to form individual layers several cm's thick.	0.40	161.02
55.)	Sandstone	This cross-laminated sandstone has a channel-shaped, abrupt lower contact with the underlying unit 54 siltstone and shale interbeds. Mica and carbonaceous material are common on bedding surfaces. Additionally, fossil plant stems and tree trunks (Calamities) are found sporadically throughout the sandstone. Some tree fossils are subvertical with fossil roots extending downward into unit 54. The upper portion of the sandstone contains laterally discontinuous layers of nodular siderite, 10 cm-thick. Where siderite is present, the sandstone appears bioturbated, as fossil roots are also found in these locales.	1.25	162.27
56.)	Silty-Shale (FUS)	Unit 56 grades from the sandstone of unit 55 and is composed of a 0.30 meter-thick silty-shale with sporadic, diffuse bands of siderite. This unit is root-bioturbated and the roots extend upwards through units 57 and 58.	0.30	162.57
57.)	Sandstone (CUS)	The unit 56 silty-shale grades into a 0.25 meter-thick, very fine-grained sandstone.	0.25	162.82
58.)	Silty-Shale (Seat Earth)	The unit 57 sandstone grades into 0.25 meters of interbedded silts, shales and thin (<1cm-thick) discontinuous coals.	0.25	163.07
59.)	Unnamed Coal	This coal is dull and laterally continuous. The bottom 0.06 meters are finely laminated, while the upper 0.04 meters are blocky.	0.10	163.17
60.)	Sandstone	A well-sorted, fine-grained, light-gray, laminated sandstone. The sandstone contains thin (<1cm-thick) discontinuous coal partings and has carbonaceous material on the bedding planes. The over and underlying contacts of the sandstone are abrupt (erosive) and uneven (wedge-shaped).	0.25	163.42

61.)	Unnamed Coal	This coal bed is laterally continuous, blocky and dull.	0.30	163.72
62.)	Shale (CUS)	Overlying the coal of unit 61 is a thin 0.10 to 0.20 meter-thick light-gray shale.	0.20	163.92
63.)	Siltstone (CUS)	The shale of unit 62 grades into a 0.10 meter-thick siltstone.	0.10	164.02
64.)	Sandstone (CUS)	Unit 64 is fine-grained, poorly sorted sandstone that overlies the siltstone of unit 63. The sandstone contains undulating bed forms and is (wavy) laminated with carbonaceous material on the bedding surfaces. This sandstone portion has an abrupt contact with the lower siltstone. Laterally discontinuous silt and shale partings are present throughout the sandstone. A lycopod stump is found locally within the sandstone section.	1.50	165.52
65.)	Silty-Shale (Seat Earth)	Grading from the sandstone unit 64 is a 0.30 meter-thick, root-bioturbated, medium-gray silty-shale. Nodular siderite and fossil roots are found throughout the entire thickness of units 62, 63, 64, and 65.	0.30	165.82
66.)	Coal (Coalburg Coal Zone)	This coal bed is interbedded with thin (1 to 2cm-thick), medium-gray shale partings. The coals are blocky and dull with banded vitreous layers; vitreous layers being locally continuous. The dull coal layers and shales are predominantly discontinuous. The thickest coal layers (approx. 0.08 meters-thick) are at the bottom and top of the unit, where the uppermost coal layer is laterally continuous.	0.50	166.32
67.)	Shale (CUS)	Unit 67 is a 0.25 meter-thick, light-gray shale that overlies the unit 66 coal.	0.25	166.57
68.)	Shaley-Siltstone (CUS)	Unit 68 is grades up from the shale of unit 67 as silty-shale and finally as siltstone which is 0.20 meters-thick. The silty-shale section contains nodular siderite.	0.20	166.77
69.)	Silty-Sandstone	Overlying the siltstone of unit 68 is a 1.60 meter-thick, very fine-grained, medium-gray, well-sorted, cross-bedded sandstone. This sandstone portion is very similar to the sandstone of unit 64; that is, it contains an abrupt basal surface and is composed of undulating bed forms. Several meter-sized (One measured 1.40 meters in thickness) lycopod stumps are found within the lower section of this sandstone. These stumps are seated in the underlying shale, siltstones and coals below and distort locally the bedding of all overlying lithologies. Small coal and shale partings shoot up the edges of the lycopod stumps. Fossil roots become more prevalent in the upper half of the sandstone. Siltstone interbeds gradually occur with higher frequency from bottom to top, while the beds of both lithologies thin correspondingly. The last siltstone of unit 69 underlies the next coal, unit 70.	1.60	168.37

70.)	Unnamed Coal	This coal bed is blocky and dull. A 0.05 meter-thick clayey-shale layer is found in the middle of the coal.	0.30	168.67
71.)	Shale	This shale is medium-gray and extensively root-bioturbated, with fossil roots exposed throughout. The shale has a gradational upper contact.	0.60	169.27
72.)	Canneloid Shale	Grading from the shale of unit 71, this (canneloid) shale is dark-black, and extremely hard with uneven fracture. It might be more appropriately termed a claystone; only the thickest laminae (>1cm) are visible. Above the first 0.10 meters of the black (canneloid) shale is a 0.10 meter-thick layer of light-gray, finely laminated, (unconsolidated) clay. Another 0.50 meters of the dark-black (canneloid) shale cap this layer of (unconsolidated) gray-clay.	0.70	169.97
73.)	Shale (Seat Earth)	The dark-black (canneloid) shale of unit 72 grades into a fissile light-black to medium-gray shale. This shale contains as many as ten laterally continuous layers of nodular siderite. These layers average 0.02 meters-thick. At the base of this shale is a layer of discontinuous siderite. This shale is heavily bioturbated by rooting; fossil roots are clearly visible. This shale underlies the coal bed of unit 74.	1.20	171.17
74.)	Unnamed (Cannel) Coal	This coal varies from cannel to blocky. The bottom 0.10 meters is a cannel coal which grades into 0.05 meters of a vitreous, blocky coal, then grades back into another 0.05 meters of the cannel coal. The cannel coal portions are dull, hard and have faint laminae with conchoidal fracture. The unit is laterally continuous, where exposed.	0.20	171.37
75.)	Shale	Unit 75 is a medium to light-gray, laminated (fissile) shale. Extensive and continuous layers of nodular siderite are found throughout the shale. The uncovered section of this shale is 1.50 meters-thick. The shale is not accessible for closer inspection. The overlying sandstone unit 76 has truncated the upper section of this shale.	1.50	172.87
76.)	Sandstone	This "channel" sandstone is medium to coarse-grained, light-gray, and well-sorted, with trough and planar x-beds and sub-rounded grains. Bedding varies from cross-bedded and planar to massive throughout the sandstone section. The sandstone is laterally continuous with a sharp, uneven basal contact. The sandstone is extremely tough. Where the sandstone is weak, mica flakes coat bedding surfaces. Much of the x-bedding is visible due to the presence of iron, carbonaceous and/or mica flakes on the bedding surfaces. Coal stringers and coal clasts can be found locally. Most are less than 0.01 meters-thick and laterally discontinuous. These coals are found throughout the sandstone x-beds. Individual x-beds vary in thickness from as much as one meter to as small as a few centimeters, with an average of 0.35 meters. Basal lag deposits are common within the sandstone. These lags	6.00	178.87

		are composed of compressed, sand-filled Calamities tree trunk casts with thin coalified barks. Millimeter-sized siderite clasts are mixed in with the Calamities casts at the base of the sandstone. The siderite clasts are probably rip-up clasts from the shale below. None of the fossil Calamities casts were found in growth position and none were found higher than 2.00 meters from the base of the sandstone. At the top of the sandstone are several laterally discontinuous bedding planes composed of dark-black shale to silt-sized grains of mica and carbonaceous material with little to no quartz. The bedding planes are uneven laterally and do not show the x-bedding found in the main sand body. The sand grains fine upwards, becoming fine-grained at the top, where the sandstone is laminated. Here, about 1.00 to 0.50 meters from the top, the sand is heavily root-bioturbated. Again, the bedding surfaces are visible due to an abundance of carbonaceous material. The fossil roots extend 0.20 meters below this heavily bioturbated zone. There are no obvious scour (channel) surfaces within the exposed section of unit 76. The top of the unit 76 sandstone is marked by an abrupt gradation into the shale of unit 77.		
Outcrops Delta & Epsilon				
<u>Unit #</u>	<u>Name</u>	<u>Description</u>	<u>Unit Thickness (meters)</u>	<u>Cumulative Thickness (meters)</u>
77.)	Shale (Seat Earth)	Grading up from the sandstone of unit 76, this medium-gray shale is heavily root-bioturbated. It is laterally and horizontally homogeneous and laterally continuous. Minor amounts of carbonaceous material are found on bedding surfaces.	0.35	179.22
78.)	Unnamed (Cannel) Coal	Overlying the shale of unit 77, this coal is predominantly dull and tough with fissile to conchoidal fracture along the lower half. A thin (< 0.01 meter-thick), blocky, vitreous layer runs through the middle of the coal. The upper half of the coal is tough, blocky and dull with conchoidal fracture. It is a cannel coal.	0.35	179.57
79.)	Shale	Overlying the cannel coal of unit 78 is 0.50 meters of medium-gray shale, layered with nodular siderite. The shale is laterally continuous and grades vertically into unit 80. Additionally, the surface trace of a normal fault can be seen at the south end of outcrop Delta. This fault appears from a covered section, adjacent to where the exposure of unit 79 begins. This normal fault cuts through several tens of meters into the overlying units and has a maximum vertical throw of 1.30 meters. The fault shows 0.50 meters of vertical throw through unit 79-81.	0.50	180.07
80.)	Sandstone-Siltstone-Shale	Unit 80 is composed of fine-grained sandstone, siltstone, and shale. These graded beds are laterally continuous with fossil root casts throughout. This unit has stacked, cm-thick, laterally continuous bands of nodular siderite. Fossil root casts extend through the nodular siderite. Towards the top of the unit the lithology is predominantly shale. Here the shale is heavily root-bioturbated. Carbonaceous and mica flakes are extensive throughout the unit. This unit grades laterally into a light-gray,	2.25	182.32

		fine-grained sandstone interbedded with siltstones. The sandstone is x-laminated		
81.)	Shale (Seat-Earth)	Unit 80 grades into and is capped by a thin (< 0.03 meter-thick) medium to dark-gray, laminated shale (seat-earth). The seat-earth is laterally continuous, but varies in thickness. The upper layers of the seat-earth are black and underlie the next coal bed, unit 82.	0.03	182.35
82.)	Interbedded Coal and Shale (Stockton Coal Zone; Kanawha Black Flint equivalent)	Overlying the seat-earth of unit 81, unit 82 is composed of a series of interbedded coals and shales. The coals range in thickness from 0.30 to 0.04 meters, and the shales from 0.30 to < 0.01 meters. The coals are blocky and dull to vitreous. The lowest coal is 0.30 meters thick and contains thin (<0.01 meter-thick), dark-black, highly organic, discontinuous layers of unconsolidated sediment throughout. This coal layer is overlain by a light-gray, 0.30 meter-thick, laminated shale. The shale is full of plant trash; leaves, roots, small stems are found on the bedding surfaces. Rooting disturbed the shale laminae. This shale grades into a thin coal, (<0.10 meters-thick), with faint laminae. Above this thin coal is a zone of loosely consolidated, medium-gray, clayey-shale. Above this clay zone is another 0.30 meter-thick laminated coal. This coal is blocky along the bottom and more fissile at the top and does not contain the organic rich layers in found in the lower 0.30 meter-thick coal. Again the coal layer grades into a loosely consolidated, medium-gray, clayey shale, this time 0.20 meter-thick. This clayey-shale, then grades into a 0.07 meter-thick, laminated, vitreous, blocky coal. Once again, the coal grades into a clayey-shale, the same as the previous, but 0.03 meters-thick. Then, the final coal of the sequence, a thin (0.04 meter-thick), laminated, blocky, vitreous coal grades abruptly from the clayey-shale below and into a seat-earth above. The seat-earth is composed of < 0.01 meters-thick, dark-black, organic-rich, unconsolidated sediment. This seat-earth grades into the overlying sequence of silty-shales. According to Blake (personnel communication, 2000) the top of unit 82 and the bottom of unit 83 is the Kanawha Black Flint equivalent.	1.75	184.10
83.)	Interbedded Sandstone, Siltstone, and Shale (Kanawha Black Flint equivalent)	The upper seat-earth of unit 82 grades into a sequence of interbedded siltstones, shales, and fine-grained sandstones. The lithologies are laminated to x-laminated and are interbedded with additional layers of nodular siderite. The individual layers are not laterally continuous, but are laterally extensive and wavy on a large-scale. The large-scale wavy forms fill internal wavy-shaped scour surfaces. At approximately 1.00 meter from the top of the unit are several lens-shaped limestone concretions. The concretions average 0.20 to 0.30 meters thick and 1.00 to 3.00 meters in width. They are laterally extensive, but not continuous. Root casts are common in the upper half of the sequence. Laterally, (to the northeast), the interbeds grade from silt to shale. Vertically, the sequence grades into the overlying shale of unit 84.	4.00	188.10
84.)	Shale (Seat Earth)	The sand-silt-shale unit 83 grades into a friable, gray shale. The shale contains minor siderite inclusions and sparse root casts. The shale is present across the length of the outcrop, but it is not	1.20	189.30

		laterally continuous. To the northeast, this unit grades vertically into a dark-black shale. In some locales, a thick, nodular siderite layer separates the gray and black shales. The black shale is laterally continuous, except where eroded by the unit 86 channel sand. A scour surface lies between the black shale and the overlying channel sand of unit 86. To the southwest, the gray shale underlies the coal bed of unit 85.		
85.)	Coal (Stockton "A" Coal Bed)	At the southwest end of outcrop Delta, this coal splits into two coal beds, separated by the shale and channel sandstone of unit 86. At outcrop Epsilon, this coal is one thick coal bed, 0.80-meters thick, with no unit 86 present. At outcrop Delta, the lower coal bed consists of a 0.15 meter-thick, blocky, vitreous to dull, coal. This coal is overlain by a 0.15 meter-thick, clayey, light-black shale that is capped by another, 0.10 meter-thick, vitreous to dull coal. Next, these lower coal are overlain by the shale and channel sandstone of unit 86. Capping the unit 86 sand and shale is the upper coal bed of unit 85. This coal is 0.49 meters-thick, and vitreous to dull and blocky.	0.80	190.10
86.)	Shale/ Sandstone	This large-scale channel sand truncates the underlying shale of unit 84 and the lower coal of unit 85. It is 6.30 meters thick, where the deepest erosion occurred. Outside of the channel, the sandstone pinches out within 50.0 meters to the south and 200.0 meters to the north. The channel sand is light-gray, fine-grained, and well-sorted with sub-rounded grains. The portion of channel that truncates into unit 84 and 85 has well-developed bedding (lateral accretion) surfaces. The bottom 0.50 meters are laminated and overlain by 1.00 meters of massive bedding, overlain by laminae and again overlain by 1.00 meters of massive bedding. Laminated bedding is clear where organic material is abundant on bedding planes. The top 0.50 meters become "fissile" and in some places, the sandstone has graded into shale. This shale is light to medium-gray, full of organic material and fossil roots. In some places the fossil roots where abundant enough to have disturbed the shale laminae (root-bioturbated). Additionally, minor organic inclusions have been coalified. Siderite nodules, found in the top of the sandstone, are not found in the shale. However, the fossil roots extend through the shale into the top of the sandstone. Above the main channel, the shale layers grade laterally into sandstone lenses. Individual sandstone and shale beds can be traced laterally and vertically into the overlying bench. Sandstone beds grade laterally to the southwest into shale that pinches out at the southwest end of outcrop Delta. The sandstone thins to the northwest, but is laterally continuous for several hundred yards across the outcrop.	10.18	200.28
		Allegheny Formation		
87.)	Sandy-Siltstone	Unit 87 is a weakly consolidated zone of a clayey/sandy-siltstone that overlies the coal of unit 85. This clayey-sandy zone is laminated and laterally continuous, but has variable thickness.	0.10	200.38

88.)	Sandstone	Grading up from the sandy-siltstone of unit 87, unit 88 consists of interbedded fine and very fine-grained, but well-sorted, and planar-laminated, light to medium-gray, laterally continuous, heterogeneous sandstone and siltstone. Mica and carbonaceous flakes are present throughout the unit. The unit has bands of laterally continuous, nodular siderite every 0.05 to 0.10 meters. Where the unit is composed of very fine-grained sands, it is of a lighter color, almost white. Where it is composed of fine-grained sands, it is a gray, light to medium in color. The differing grain sizes and corresponding color changes give the sandstone a wavy, banded appearance. These bands are as much as 0.30-meters thick, but average from a few to 0.05-meters thick, being found approximately every 0.10-meters up the outcrop. Samples of both grain types do not react with dilute HCL acid, except for some weak bubbling on fresh surfaces. No fossils.	9.90	210.28
89.)	Sandstone	Grading up from unit 88 is a weakly consolidated, very fine-grained, medium-gray, and heavily root-bioturbated sandstone.	0.85	211.13
90.)	(Coaly) Shale	Grading from the sandstone unit 89 is a thin, dark-black, fissile (coaly) shale. The shale contains no fossils.	0.40	211.53
Outcrop Epsilon				
91.)	Large-scale Channel Sandstone	This large-scale channel sandstone truncated the underlying units, 90, 89, 88, and 87, and rests disconformably atop the Stockton "A" coal bed, unit 85. This unit is composed of well-sorted, medium-grained sand. Plant casts (trunks) and roots are rare. The sandstone is exposed in outcrop as a channel shape in cross-section. The channel bottom is approximately 48 meters wide. The base of the channel sandstone is composed of a thick lag deposit. The lag consists of a several discontinuous layers of nodular siderite that are 0.40 meters-thick. Above the lag are uneven to wavy laminated bedding planes marked by an abundance of organic material. The laminae are laterally continuous for several meters. The organic material is made up of coal, plant clasts, and carbonaceous and mica flakes. Above this organic-rich zone is another layer of unevenly bedded siderite clasts, approximately 10 to 20 cm-thick. Above this second siderite-rich zone, the sandstone is massively bedded with sporadic, discontinuous zones of siderite clasts. Several meters higher, the siderite clasts become much larger and are yet more discontinuous, being no longer associated with any sort of bedding. Meter long rafts of the coaly-shale, unit 90, lie along the top of the channel margin on the southern edge of the exposure. Channel sandstone, unit 91, is partially overlain by the fine-grained deposits of unit 92 along the southern channel margin. Adjacent to the channel margin, the upper portion of this sandstone has been eroded away by an overlying channel sandstone, unit 96. The boundary between unit 91 and unit 96 is visible as an irregular, channel-shaped scour surface.	15.35	226.88

92.)	Silty-Shale, Silty-Sandstone (CUS)	Grading from the black (coaly) shale of unit 90, a thin (cm-thick), diffuse band of siderite marks the gradational boundary from black shale into a medium gray, iron-stained, silty-shale. This shale also lies over a section of the channel sand, unit 91. This occurs at that point where the channel truncates the underlying (coaly) shale, unit 90. The contact between units 91 and 92 is sharp. Bands of laterally continuous nodular siderite are found throughout this 0.30-meter thick silty-shale. This lithology grades into a 2.70-meter thick, silty-very fine-grained sandstone that is laminated, and medium to dark gray in color, with mica and carbonaceous flakes on bedding surfaces. This section also contains the continuous bands of nodular siderite seen in the lower silty-shale. Laminae are best visible lower in section, clarity becoming progressively worse towards the top of section, where the laminae are completely destroyed by root-bioturbation. The sequence is not homogeneous, as vertical and horizontal changes in lithology occur; lithologies vary from silty-sand to sandy-silt.	3.00	229.88
93.)	Seat Earth	The silty-sands and sandy silts of unit 92 grade into a light gray shaley seat earth. This unit underlies a coal bed.	0.10	229.98
94.)	Coal (Little No. 5 Coal Bed)	This coal bed is iridescent to vitreous, and blocky. It is laterally continuous and evenly bedded.	0.90	230.88
95.)	Shale	Where not truncated by the overlying sandstone of unit 96, a thin black shale overlies the coal of unit 94.	0.10	230.98
96.)	Large-Scale Channel Sandstone	A scour surface marks the boundary between this multi-story channel sandstone and the underlying units 95, 94, 93, 92, and 91. A basal lag can be seen in the base of the unit 96 sandstone, above the sandstone of unit 91. This lag contains coal rafts, coal pebbles, shale clasts, and scattered siderite pebbles in the lowest 1.0 to 2.0 meters of the unit. This sandstone is light to medium gray and predominantly medium-grained. Sorting and grain size vary between bed sets and range from coarse- to fine-grained and poor- to well-sorted. Layers of silty-shale, from 1 to 10 cm-thick, separate bed sets. A few of these silty-shale partings contain thin lenses of poorly-sorted, medium-grained sandstone, and clasts of coal and nodular siderite, and thin coal laminae, ~1 cm-thick. These shale partings may be lens-shaped. Individual channel forms vary in width and height. The sandstone is composed of cut and fill structures (channel forms). Basal lag deposits (0.50-0.20 m-thick) of nodular siderite clasts, chunks of coal, coalified plant debris and shale clasts in a coarse-grained matrix are found within some bed sets (1.00-0.50 m-thick). A few log casts were found approximately 5.0-meters from the base of the unit. Sorting within most bed sets is good and is consistent throughout the exposed section of unit 96. Only near the top of the unit does the grain size begin to fine-upwards into fine-grained sand to silt to shale of the overlying unit 97. Bedding is visible within channel forms due to the presence of dark-colored laminae. These dark colored laminae are made so by thin layers of coalified organics	18.00	248.98

		or carbonaceous and mica flakes on bedding surfaces. Trough cross bedding is dominant within this sandstone, although planar cross beds massive bedding were also found. Distorted bedding (flow and roll structures) was found in a few lower channel forms. One channel (thalweg) contains a shale lens, approximately 7 meters-wide by 4.5 meters-high. The shale lens lies within the middle of the channel and is “sandwiched” by underlying and overlying sandstone beds. Lateral accretion surfaces (or Epsilon Cross Strata - ECS) are clearly visible as bed sets that follow the channel forms.		
97.)	Silty-Shale (FUS)	This silty-shale grades up from the underlying channel sandstone of unit 96. The unit is dark black, laminated, and contains abundant root casts (stigmairian axes). The root casts extend through the whole of unit 97 and another 1.50 meters into the top of the underlying channel sandstone, unit 96. This shale unit appears to be laterally extensive, except where it has been truncated by the overlying channel sandstone, unit 100.	2.90	251.88
98.)	Seat Earth	The silty-shale of unit 97 grades into a thin seat earth that contains at least one fossil stigmairian axis. The sandstone unit 100 has truncated this unit.	0.10	251.98
99.)	Unnamed Coal	This coal bed is blocky and dull. It is laterally extensive along the northern exposure of outcrop Epsilon. The overlying channel sandstone, unit 100, has truncated this coal bed.	0.80	252.78
100.)	Large-scale Channel Sandstone	This large-scale, multi-story channel sandstone is composed of light gray, medium grained sandstone. Cut and fill structures can be seen throughout the exposed section. Several channels within the cut and fill structures are composed of planar bed sets (0.5 to 1.0 meters thick) with basal scour surfaces and thin lag deposits. Trough cross bedding is common within bed sets. Elsewhere in the exposure of unit 100, one channel form contains a thick (2 meter) lag of white to light gray, coarse-grained sand, shale, siderite clasts and mica flakes. This thick lag deposit pinches out to the north and is truncated to the south by an overlying channel form. The main basal scour of unit 100 truncates the underlying fine-grained deposits of units' 99, 98, and 97. This basal scour also cross cuts the channel forms of the underlying channel sandstone, unit 96. The scour surface is irregular on a small scale, and channel-like on a large-scale. A discontinuous, 0.40-meter thick lag deposit is found above the main basal scour of unit 100. This lag consists of clasts of siderite and quartz and small coal stringers (0.30 meters x 0.05 meters). Bedding planes within the uppermost 1.5 meters of sandstone 100 are littered with carbonaceous and sideritic plant detritus. Additionally, this section contains many coal clasts and plant clasts coated in coal. The coal clasts are 1 cm-thick and are discontinuous. The top of sandstone 100 is marked by a laterally extensive scour surface that underlies the fine-grained deposits of units 101 and 101a.	25.00	277.78

101.)	Sandstone-Siltstone-Shale (FUS)	Shale sits disconformably above sandstone unit 100, at outcrops Epsilon and Zeta. At outcrop Zeta, the shale grades laterally (north to south) from the edge of the outcrop into a silty-shale, shaley-silt, siltstone, and finally into a fine-grained sandstone. This unit pinches out to the south, where it is adjacent to the underlying sandstone of unit 100. The overall shape of unit 101 is that of one-half a large-scale channel-fill (at Outcrop Zeta). The silty sections are fossiliferous, containing an abundance of plant debris and the sandy sections contain mica flakes on the laminated bedding surfaces. The laminae are laterally continuous. The top 1.00-meters of the unit is root-bioturbated and the color is medium-gray throughout. At outcrop Epsilon, the unit is 1.0 meters-thick and composed of shaley-silt. At Epsilon, the unit is also dark-gray in color and full of plant detritus, visible on bedding surfaces. This unit appears to be laterally continuous to the north, at outcrop Epsilon. However, it is not continuous to the south of outcrop Zeta.	2.30	280.08
Outcrops Epsilon & Zeta				
<u>Unit #</u>	<u>Name</u>	<u>Description</u>	<u>Unit Thickness (meters)</u>	<u>Cumulative Thickness (meters)</u>
101a.)	Seat Earth	This medium-gray shale grades up from units 100 and 101.	0.20	280.28
102.)	Coal (Upper No.5 Block Coal Bed)	Unit 102 is composed of interbedded coals and shales. Above the shaley seat earth of unit 101a is a 0.45 meter-thick, vitreous and blocky coal. This coal is next overlain by 0.30 meters of a laminated, dull to vitreous coal with unconsolidated, organic-rich (black), "dirt" layers and discontinuous, thin shale (> 1.0 cm) interbeds. The top half of the 0.30 meter-thick coal layer is mostly coal, with one, thin shale layer. Above this coal layer is a 0.25 meter-thick layer of medium-gray shale. At the top is a 0.20 meter-thick layer of more interbedded coals and shales. Within this layer there are four coals, the thickest 0.05 meters and the thinnest 0.01 meters. All coals are vitreous and blocky. Coal and shale layers are laterally continuous, where not eroded by channel sandstone, unit 104. Laterally, unit 102 is wavy to uneven, likely due to compaction from the overlying sandstone unit 104.	1.30	281.58
103.)	Shale/ Siltstone	This unit overlies the coal of unit 102. In most locales, this unit has been eroded away by the overlying sandstone of unit 104. Where present, unit 103 is composed of interbedded light to medium-gray shales and siltstones with nodular siderite layers. It is laterally and vertically discontinuous- due to the erosive action of the overlying channel sandstone(s). This unit is also wavy to uneven, as with unit 102.	1.75	283.33
104.)	Large-scale Channel Sandstone	Unit 104 lies disconformably above units 103 and 102. It is composed of a massive to planar-bedded channel sandstone. The sandstone is poorly-sorted, coarse-grained, and white to medium-gray in color. Organic matter, (grains) are common throughout the unit with additional, minor inclusions of weakly to unconsolidated coals and organic-rich (black) mud and shale. The channel sands form cut-and-fill structures. Planar beds	14.00	297.33

		<p>separate zones of massive bedding. The planar beds are discontinuous laterally and vertically. In some places, the planar beds are highlighted by the presence of coal clasts and coal-coated tree clasts on bedding surfaces.</p> <p>At the southern side of outcrop Epsilon, bench #4, is an excellent exposure of beds that have undergone large-scale soft-sediment deformation (sloughing). The contorted section of sandstone beds is as much as 10 meters thick. Casts of several logs can be seen in the upper most portion of the disturbed bedding.</p> <p>Across the face of the outcrops, the bedding changes from trough to cross-bedded in the south, to massive-bedding northward, and again to cross-bedded even further northward. At outcrop Zeta, the top of unit 104 is present as a fining-upwards succession, overlain by an uneven, erosive, to gradational (laterally variable) surface. The fining-upwards zone grades upwards from coarse, massive bedded sands to planar bedded fine-grained sand and into the fine-grained sediments of unit 105.</p>		
105.)	Sandstone-Siltstone-Shale (FUS)	Unit 105 grades up from the upper fine-grained sands of unit 104. It is composed of sandy-silt, siltstone, silty-shale. The sandy-silt is gray and contains nodular siderite throughout. This unit grades into the shale of unit 106. Laterally, this fining-upwards zone is not present. Where missing, the fining-upwards zone is marked by a pronounced channel-shaped scour that is filled by the shale of unit 106.	3.0	300.33
106.)	Shale	The thickness and composition of this unit varies greatly, both laterally and vertically. Above the unit 104 fine-grained sandstone, unit 106 is 5.20 m-thick and overlies a channel-shaped scour. It is composed of dark gray to black, flint clay with minor plant detritus on the bedding surfaces and discontinuous layers of nodular siderite. Several lens-shaped, meter-sized limestone concretions are found in the top meter of the shale (25 cm-thick, 5 m-long). The top one meter of this shale grades into unit 107. The deepest shale-filled channel is 5.0 meters-thick. This shale contains rare coal clasts. Within the channel-shaped features, the bedding or laminae generally mimic the channel shape. Unit 106 is discontinuous laterally, because the shale filled in channels created by the cut-and-fill sands of unit 104.	5.20	305.53
107.)	Sandstone (FUS)	Above the channel-fill section of unit 106, a 4 meter-thick, fine-grained sandstone lies disconformably above the shale. This sandstone grades laterally into the unit 105 sandy-silt, siltstone and silty-shale.	4.0	309.53
108.)	Sandy-Siltstone (FUS)	Above the unit 107 fine-grained sand and the unit 105 sandy-silt is a 5.00 meter-thick zone of interbedded fine-grained sand, silt, and flint clay with gradational contacts. The zone begins with a sand, grades into a flint clay, and grades finally into a silty-fine-grained sand. Sand and silt beds are massive; the flint clay is fissile. This zone is laterally continuous, but variable in thickness. The middle sandstone ranges from 1.0 to 0.5 meters-	5.00	314.53

		thick. The top 0.5 meters of the zone contain abundant root clasts. The unit 109 coal lies above this root-bioturbated zone.		
109.)	Coal (Lower Kittanning Coal Bed)	Above unit 108a is a 0.70 meter-thick, dull to vitreous, laterally continuous, wavy, coal with a thin, (0.05 meter-thick), shale parting near the top. Thin (< 0.10 meter-thick) partings of shaley-coal grade laterally 2.00 meters out from the coal. Between these shaley-coals and the more pure coal are several sand stringers. In some locales, the thin top shale thickens to 0.15 meters. In those same areas, The 0.15 m-thick shale grades into another shale that is 0.25 meters-thick.	1.05	315.58
110.)	Sandstone	This is a trough to planar x-bedded to massively bedded sandstone composed of several channel-forms. The x-beds vary from small to large-scale, but are predominantly large-scale. The sandstone is light gray to white and full of pebbles, becoming a conglomerate in some locales. The pebbles can be anywhere in the sandstone, but are most abundant towards the bottom. The pebbles are rounded, as found in a mountain stream, predominantly quartz, (minor mud or shale clasts found in horizontal, planar beds), and form a lag deposit. Above the lag deposit the sandstone has trough cross beds. The sandstone is very coarse-grained at the bottom, fining upwards to become fine-grained, with sub-angular grains. The unit has graded bedding on a massive-scale. It is poorly sorted along the bottom and well sorted at the top. Minor inclusions of coal clasts are found in the lower section (below 1.00 meters). This sandstone is homogeneous, that is, there are no shale partings.	17.30	332.88
111.)	Shale (FUS)	This shale unit is mostly covered by a talus slope. It consists of gray to dark gray shale that grades up from the underlying sandstone.	7.60	340.48
112.)	(Conglomerate) Sandstone	Bedding is not obvious in this quartz conglomerate. It is a massive bedded sandstone composed of several channel-forms. The sandstone is light gray to white and full of pebbles. It is a conglomerate throughout several meters of the basal section. The pebbles are found throughout the thickness of the sandstone. The clasts are rounded, as found in a mountain stream, predominantly quartz, however, minor mud or shale clasts are found scattered throughout. The sandstone is very coarse-grained above the conglomeratic zone. No coal clasts were found in the unit. This sandstone is homogeneous, that is, there are no shale partings.	9.00	349.48

(Total thickness of measured section is 349.98 meters or 1,147.93 feet)

Appendix B.

Stratigraphic Columns

(Following Pages)

Figures A-D. Stratigraphic columns illustrating the middle division of the Kanawha Formation, as described at Birch River field site.

Figure D. Stratigraphic column showing the upper division of the Kanawha Formation and a portion of the Allegheny Formation at Outcrop Delta.

Figures D-G. These stratigraphic columns illustrate the Allegheny Formation, as described at Birch River field site.

LEGEND

Figure A

Figure B

Figure E

Figure F

Figure G

Appendix C

Strike and Dip of Cross Beds

Unit #

5b.)	Strike: 20° W of N Dip: 16°, SW	Strike: 90° due E Dip: 24°, due N	Strike: 5° E of N Dip: 30°, SW	Strike: 15° E of N Dip: 19°, NW	Strike: 61° E of N Dip: 14°, NW
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7.)	Strike: 40° E of N Dip: 13°, SE	Strike: 45° W of N Dip: 12°, NE	Strike: 90° due E Dip: 9°, due S	Strike: 65° E of N Dip: 26°, SE	Strike: 25° E of N Dip: 15°, SE
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8.)	Strike: 50° E of N Dip: 12°, SE	Strike: 40° W of N Dip: 20°, NE	Strike: 9° W of N Dip: 2°, SW	Strike: 32° W of N Dip: 13°, SW	Strike: 0° due N Dip: 21°, due E
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12.)	Strike: 2° W of N Dip: 19°, NE	Strike: 55° E of N Dip: 15°, SE	Strike: 56° E of N Dip: 6°, NW
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16.)	Strike: 27° W of N Dip: 27°, NE	Strike: 78° E of N Dip: 16°, NW	Strike: 48° E of N Dip: 24°, NW	Strike: 10° E of N Dip: 28°, NW
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17c.)	Strike: 72° W of N Dip: 3°, SW
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18.)	Strike: 8° W of N Dip: 2°, SW	Strike: 39° W of N Dip: 4°, SW
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19.)	Strike: 12° E of N Dip: 2°, SE
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20.)	Strike: 81° E of N Dip: 18°, NW	Strike: 80° W of N Dip: 17°, NE	Strike: 75° W of N Dip: 16°, NE
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21.)	Strike: 62° W of N Dip: 8°, SW	Strike: 55° E of N Dip: 11°, NW	Strike: 25° W of N Dip: 11°, NE	Strike: 4° W of N Dip: 25°, SW	Strike: 13° E of N Dip: 21°, NW
	Strike: 83° E of N Dip: 4°, SE	Strike: 61° W of N Dip: 17°, NE	Strike: 46° E of N Dip: 9°, SE	Strike: 18° W of N Dip: 2°, NE	Strike: 75° W of N Dip: 2°, NE
	Strike: 31° E of N Dip: 8°, SE				

22.)	Strike: 0° due N Dip: 24°, E	Strike: 26° E of N Dip: 9°, SE	Strike: 4° W of N Dip: 28°, NE	Strike: 28° W of N Dip: 27°, NE	Strike: 1° W of N Dip: 31°, NE
	Strike: 75° E of N Dip: 9°, SE	Strike: 63° W of N Dip: 22°, NE	Strike: 25° E of N Dip: 9°, SE		

23.)	Strike: 81° E of N Dip: 11°, NW	Strike: 6° W of N Dip: 20°, NE	Strike: 30° E of N Dip: 29°, NW	Strike: 80° E of N Dip: 11°, SE	Strike: 16° E of N Dip: 3°, SE
	Strike: 53° W of N Dip: 6°, NE	Strike: 75° W of N Dip: 6°, SW			

Strike and Dip of Normal Fault through Units:

16c.)	Strike: 40° E of N Dip: 54°, NW
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