SEDIMENTARY CONTROLS ON VALLEY INCISION IN THE MIDDLE TO UPPER PENNSYLVANIAN FILL OF THE CENTRAL APPALACHIAN BASIN

by

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ABSTRACT

The sedimentary fill of Middle to Upper Pennsylvanian strata in the central Appalachian Basin reveals complex sequence stratigraphy in predominantly fluvial strata. There are three major allogenic sedimentary controls: tectonism, climate change, and eustasy. All three controls can act on a basin at any one time, but they are not always independent. The effects of eustasy weaken up-dip as fluvial-dominant sequences see increasing influence from climate and tectonics. A more applicable fluvial sequence stratigraphic model that places focus on accommodation state rather than relative sea level is adopted, and tested in this study in order to determine the origin of valley incision within the Upper Breathitt Group and Lower Conemaugh Group rocks in the area of the Kentucky/West Virginia state line, and use this information to understand the relationship between sedimentary sequence controls and the fluvial system that filled the basin.

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INTRODUCTION

Serving as a holistic model for examining and dividing the sedimentary record, sequence stratigraphy incorporates both packages of sediment, and the surfaces between them on scales ranging from beds to sedimentary basin fills. Fluvial successions within the rock record, in the context of sequence stratigraphy, represent the coupling of upstream controls on sediment supply and the basinal controls on accommodation and preservation. It is important to keep in mind the interaction between base level changes and upstream controls, and how these interactions play a role in the subdivision and correlation of the sequence stratigraphic framework. This phenomenon can be seen on several outcrops displaying Pennsylvanian strata within the Central Appalachian Basin. More specifically, along Route 23 in Kentucky and Route 52 in West Virginia, the Upper Breathitt Group and Lower Conemaugh Group were recently excavated, exposing fresh surfaces that reveal their complex sequence stratigraphy. These outcrops exhibit an upward succession from upper delta plain to fluvial environments (Merrill, 1986). A typical sequence stratigraphic model for shallow marine settings uses unconformities as sequence boundaries; defining one sequence as deposits of one relative sea level cycle (Vail et al., 1977; Van Wagoner et al., 1988; Catuneanu, 2006). Aggradation and degradation of fluvial systems depend on the interaction between the rate at which accommodation is produced vs. sediment supply and energy flux of the depositional system (Miall, 2010; Martino, 2015). Accommodation space within this area was provided by subsidence and sea level rise. This combination of subsidence and sea level fluctuations produced basin-wide disconformities from eustatic-drawdown sequence boundaries between cycles (E.S. Belt et al, 2011).

There is little research on these strata, but notable exceptions are Thomas Arkle and others, Glen Merrill, and Ronald Martino. These authors measured sections of the Glenshaw

Formation in and around the study area (Arkle et al., 1979; Merrill, 1986; Martino et al., 1996; Martino, 2004). Most previous work done in the area is stratigraphically higher (e.g. Nadon and Kelly, 2004; Belt et al., 2011; Hembree and Nadon, 2011; Dzenowski and Hembree, 2012) or lower (e.g. Aitken and Flint, 1994; Aitken and Flint, 1996; Greb and Chesnut, 2009; Ney, 2015; Atkins, 2016) than the study area. Applying the traditional sequence stratigraphic model in the Northern and Central Appalachian Basin becomes problematic because this model assumes that facies architecture is overwhelmingly controlled by eustasy (e.g. Shanley and McCabe, 1994; Wright and Marriott, 1993; Richards, 1996). In the Northern and Central Appalachian Basin, other autocyclic or allocyclic factors, particularly climate, compete with eustatic control in sequence formation (Walker, 1992; Schumm, 1993; Shanley and McCabe, 1994). The purpose of this study is to analyze the stratigraphy of Upper Breathitt Group and Lower Conemaugh Group rocks in the area of the Kentucky and West Virginia state line and use this information to understand the relationship between sedimentary sequence controls and the fluvial systems that filled the basin. This study targeted the paleo valley fills and sought to assess and explain the origin of their incision.

Incised Valley Fills

Sequence stratigraphy has brought major attention to the research of incised valley systems within recent years. Incised valley fills are defined as elongate erosional features that are larger than a single channel and can range in size from 8 to 100 m thick (Dalrymple et al., 1994; Martino, 2015). Within an incised valley fill, the lowest story usually contains the coarsest grain size; grain size also tends to fine upward throughout the fill displaying higher frequency of heterolithic strata at the top. Under the widely accepted Exxon model, (e.g., Posamentier and Vail, 1990; Van Wagoner, 1988) incised valley fills mark unconformities during the lowering of base level associated with falling glacio-eustatic sea level (i.e. lowstand). This model offers two fundamental classes of incised valley fills: (1) valley fills associated with incision during sea level fall; and (2) those that are not related to sea level fall, but rather associated with inland tectonics or climate change (Dalrymple et al., 1994). These two simplistic classifications have remained the topic of much debate. Transgressions and regressions do not guarantee an overall change in a river's profile, and therefore do not always require an aggregational or incisional response (Schumm 1993; Wescott 1993). Alternatively, the further up dip a river's profile, the less influence sea level change has, and the tectonic and climatic processes begin to gain control (Blum, 1993; Shanley and McCabe, 1994). All incised valley fills within this study are found bounded by mature paleosols. The Upper and Lower Mahoning Sandstone incised valley fills are roughly 8-15 m thick, and sometimes separated by the Mahoning coal when the bed is not completely removed from paleo-valley incision. A second prominent valley fill is found in these outcrops, Saltsburg-Buffalo Sandstone, which ranged from 6 to 12 m thick. Holbrook (2001) used middle Cretaceous outcrops in southeastern Colorado to further study the concept of valley fills, which lead to the classification of four valley types. Under these outcrop conditions, we will be using the definition of a simple valley. Using this criteria, the valley fill will have more than two vertically stacked channel complexes, along with multistory stacking and amalgamation of the multistory channel belts (Holbrook, 2001).

Cyclothems

Pennsylvanian cyclothems in North America, particularly within the Appalachian Basin, have been studied since the early 1930s. Cyclothems, which are cyclically alternating marine and non-marine sections (Wanless and Weller,1932; Davies et al.,1992), are easily recognized in the Middle to Upper Pennsylvanian Appalachian Basin (e.g. Busch and Rollins, 1984; Chesnut, 1992; Martino, 2004), making it possible to use sequence stratigraphy to interpret the sequences. These cyclothems are attributed to glacio-eustatic cycles that drove sequence formation (Busch and Rollins, 1984; Nadon and Kelly, 2004; Heckel, 2008). These cyclothems have been previously related to Gondwanan glacial-eustatic fluctuations in sea level that have an average duration of 400 kyr (Heckel, 2008; Martino, 2015). Cyclothems play a large role in understanding the complex sequence stratigraphy of the basin. Each cyclothem represents a sequence of widespread marine strata that is separated by terrestrial strata, usually including a paleosol (Joeckel, 1995; Heckel, 2008). The concepts of autocyclicity and allocyclicity are extremely powerful tools in stratigraphic analysis. Autocycles are produced by processes within sedimentary systems. This means, responses to autocyclic processes tend to be local and may range from millimeter-scale ripple migration to regional-scale events such as delta switching. Autocyclic processes also include processes like stream avulsion and meandering, and fluvial point-bar migration. Because effects are local and mainly involve changes in energy, autocyclic processes generally result in changes in the physical sedimentology. In contrast to autocycles, allocycles result from processes external to sedimentary systems that include tectonic activity, climatic change, and eustasy. Sedimentary responses to allocyclic processes may occur on geographic scales that range from basinal to global. Of the three allocyclic processes, tectonic and eustatic controls on sedimentation and stratigraphy have been studied far more extensively than have climatic controls. Tectonic events are the most random in time and space, whereas glacio-eustatic and climatic change commonly appear to have some degree of periodicity. Martino (2004) recognized eight complete cyclothems in the Glenshaw Formation.

Location of Outcrops

Between the towns of Prichard, West Virginia, and Louisa, Kentucky, along Kentucky State Route 23 and West Virginia State Route 52, five outcrops were chosen for this study. The outcrops are located within the Central Appalachian Basin. Three outcrops (K-2, K-3 and K-4) are along Route 23, and the other two outcrops (WV-1 and WV-2) are along Route 52. The coordinates for these outcrops are located in Table 1.

Table 1. Coordinates of outcrops in this study.

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

All five outcrops are located along the Big Sandy River, which marks the state line between Kentucky and West Virginia. The freshest road cuts are outcrops WV-1 and WV-2, making facies identification from a distance easiest on these outcrops. In comparison, on the Kentucky side, K-2, K-3, and K-4 are older and more overgrown. WV-1 is the highest outcrop in the stratigraphic section, and K-4 is the lowest outcrop in the stratigraphic section (Pechacek, 2018). An upward succession from upper delta plain to fluvial environments is displayed in these outcrops.

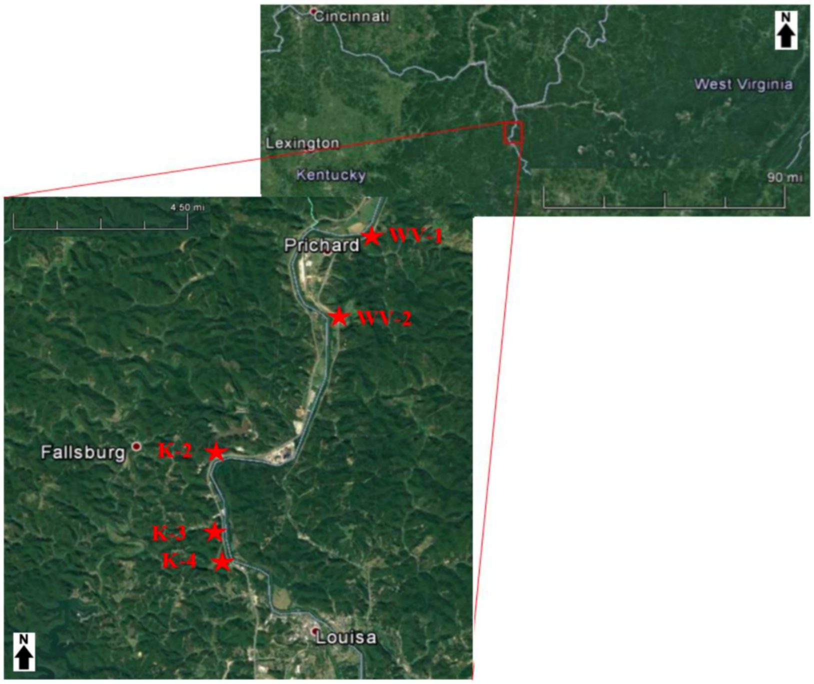


Figure 1. Location of outcrops along Kentucky State Route 23 and West Virgina State Route 52. Outcrops in Kentucky are denoted by “K”, and outcrops in West Virginia are denoted by “WV”. Images taken from Google Earth.

Stratigraphy of Outcrops

The outcrops collectively form a strike section of about 13 km of the Appalachian Basin, with about 25% exposure (Figure 2) (Pechacek, 2018). The distance from the northernmost outcrop to the southernmost outcrop is about 18 km along the Big Sandy River and 13 km in straight-line distance. About one-fourth of the distance from the northernmost outcrop to the southernmost outcrop is exposed when following the river with outcrops at various orientations. These outcrops expose Middle to Upper Pennsylvanian-aged strata.

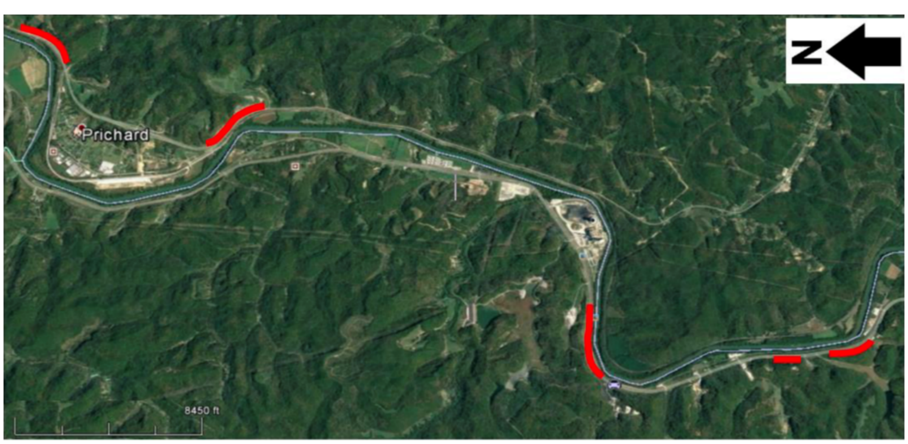


Figure 2. Location of outcrops (rotated 90 degrees to the left from **Figure 1**) showing the outcrop exposure within the study area. Images taken from Google Earth.

The boundary between the underlying Breathitt Group and the overlying Conemaugh Group is the Princess #9 coal bed. The Conemaugh Group consists of the lower Glenshaw Formation and the upper Casselman Formation, which are separated by the Ames Limestone. The Glenshaw Formation is well exposed in the study area, while only the basal portion of the Casselman Formation is visible. The last marine transgression into the study area is represented by the Ames Limestone. This last marine transgression filled the Appalachian Basin (Merrill, 1988). K-2, K-3, and K-4 all contain the top-most portion of the Princess Formation of the Breathitt Group, and approximately the bottom half of the Glenshaw Formation of the Conemaugh Group. WV-2 contains a majority of the Glenshaw Formation. WV-1 contains most of the Glenshaw Formation, and the lowest portion of the Casselman Formation of the Conemaugh Group.

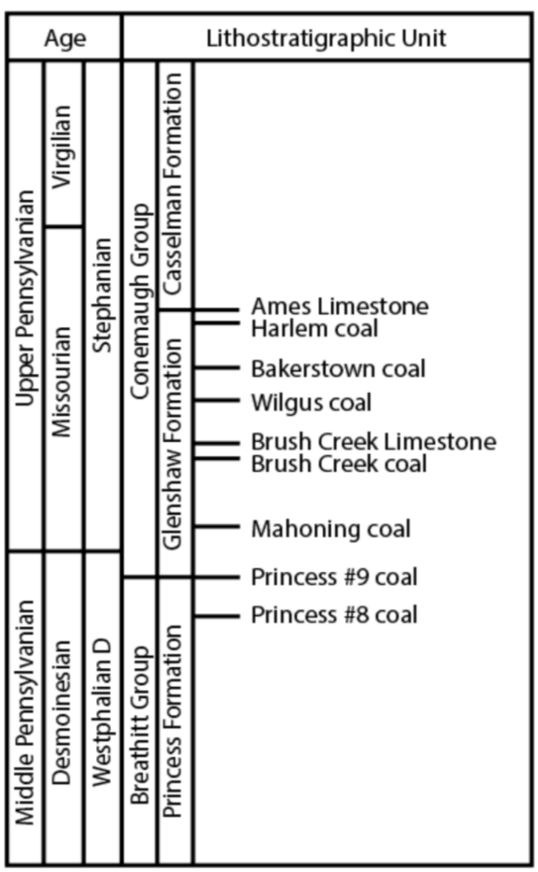


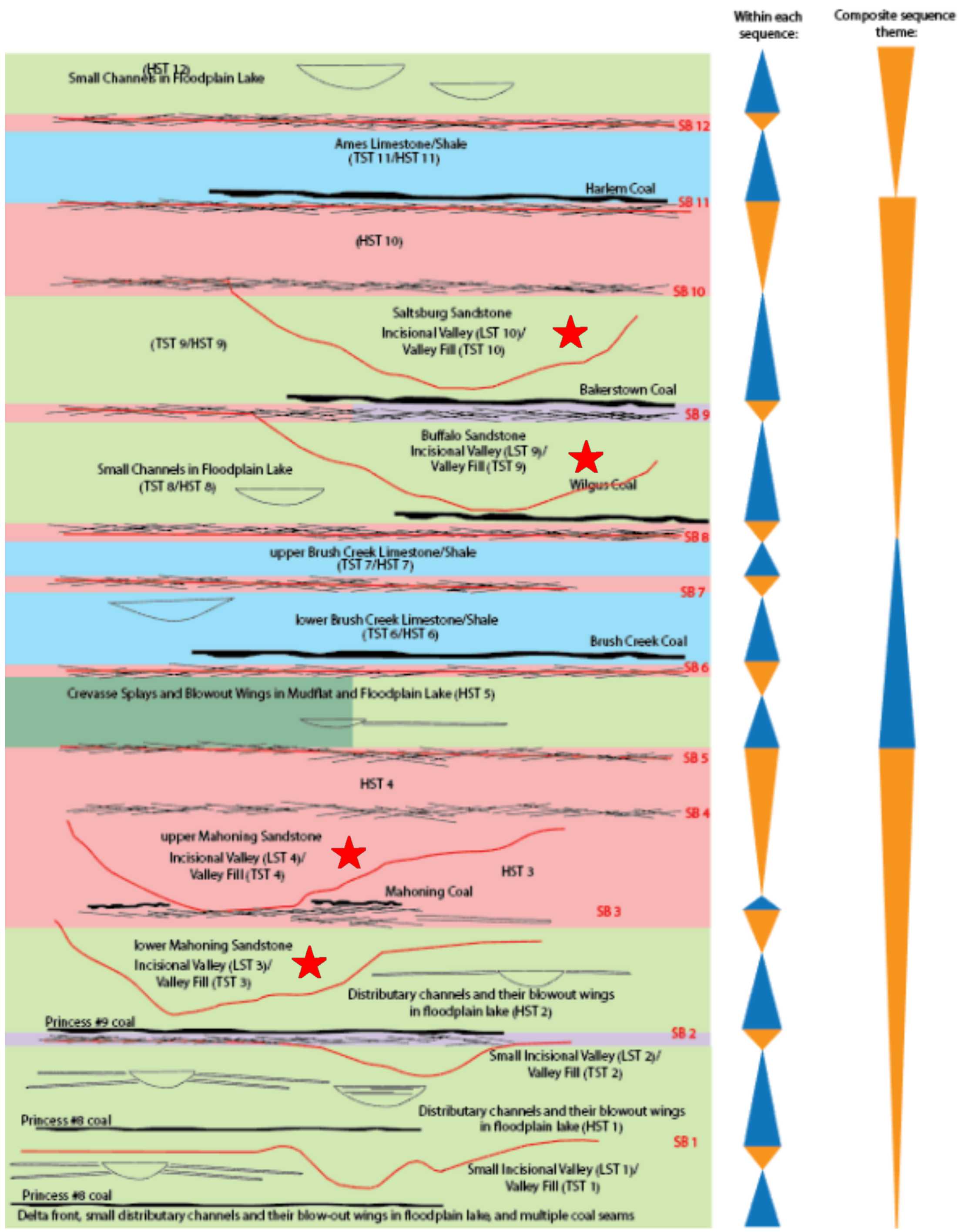
Figure 3. Stratigraphic Section of units in Middle and Upper Pennsylvanian strata within the Central and North Appalachian Basin (modified from Martino et al., 1996; Greb et al., 2004).

Pechacek (2018) analyzed the stratigraphy of these five specific outcrops, and resulted in interpreting eleven complete sequences, and two partial sequences (Figure 4). Where present, coals, paleosols, and marine limestones are generally laterally continuous stratigraphic markers. Coals were used primarily for correlation in Pechacek's (2018) study. The coals used for correlation included the Princess #8, Princess #9, Mahoning, Brush Creek, Wilgus, Bakerstown, and Harlem coals. The marine limestones used for correlation included the Brush Creek Limestone (upper and lower) and the Ames Limestone. Figure 4 reveals the composite section created in Pechacek's (2018) study, and the overall transgressive and regressive cycles associated with each sequence. For these strata, a sequence starts with a locally low water table and fluvial incision (Aitken and Flint, 1995). At this time, rivers running across a coastal floodplain incise valleys (Wright and Marriott, 1993; Shanley and McCabe, 1994). On interfluves, the topographically high spots, a lack of sediment input and low water table promote soil formation (Aitken and Flint, 1994). The degree of soil formation directly depends on the amount of time it remains exposed. A sequence boundary forms at the scoured base of the incisional valley and on the tops of the paleosols created on the interfluves (Vail et al., 1977; Martino, 2004). Next, as the water table begins to rise locally, the fluvial system aggrades within the incised valley. Channel-belt amalgamation within the valley is caused by the vertical and lateral avulsion of the channels flowing out to sea. On the interfluves, soil formation continues (Wright and Marriott. 1993; Shanley and McCabe, 1994). As the water table continues to rise, the incised valleys finish filling, and the standing water on the interfluves fill the floodplains, which promotes peat production (Busch and Rollins, 1984). The accumulation and buildup of peat indicates rising sea level, which is named a flooding surface in the traditional sequence stratigraphy model (Martino, 2004).

Sequence boundaries in the Northern and Central Appalachian Basin are marked by scours below incised valley fills, and paleosols formed during periods of little to no deposition in the interfluves between the incised valley fills. Basin-ward facies shift at the beginning of a new sequence is marked by a basal peat that tops most of the paleosols. Generally, the sequence boundaries are laterally continuous throughout the study area. Incised valley fills cut through some sections of the sequences, causing missing pieces. This can be seen at the top of the Princess Formation of the Breathitt Group, the entirety of the Glenshaw Formation of the Conemaugh Group, and at the very base of the Casselman Formation of the Conemaugh Group (Pechacek, 2018). The red stars indicate the incised valley fills that were studied in detail for this paper.

Each of the sequences Pechacek (2018) defined are interpreted as glacially-driven cyclothems on scales of 100 ka years or less. Smaller-scale cyclothems are represented by well-drained deposits (i.e. floodplain mudflats, crevasse splays, and well-drained paleosols). Sea level did not cause the local water table to rise, which allowed deposits to remain well-drained at this time. Conversely, poorly-drained deposits (i.e. floodplain lakes, coals, and poorly-drained paleosols) represent a cyclothem with a larger sea level rise, which promoted a much greater water table rise. The marine limestone deposits are associated with these larger scale cyclothems. Three marine incursions are noted within the strata: the lower Brush Creek Limestone, the upper Brush Creek Limestone, and the Ames Limestone. The marine incursions most commonly occur above the well-drained paleosols. This argues for an imprint of a still larger cycle on the short-term glacial cycles.

The sequences observed combine to record composite sequences. The sequences record regressive and transgressive cycles (Figure 4). Each sequence discretely contains a drying up trend (late highstand/ lowstand or regression) followed by a wetting up trend (transgressive/ early highstand or transgression). These drying and wetting upward patterns also manifest across multiple sequences. Sequences 1 through 4 are part of an overall drying up trend marked by floodplain lake deposits and a poorly drained paleosol topped by well-drained paleosols indicative of longer periods of valley incision. The valleys in sequences 3 and 4 mark the first of the incised valleys recognized in the study area. The highstand deposits for sequence 5 is indicative of a switch back to a wetting up trend. Sequences 6 and 7 are dominantly wetting up, consisting of two marine incursions. This set of sequences represents a significant period of flooding. Drying up begins again as the other two incised valleys form in sequences 9 and 10. These composite cycles likely record longer-term transgressive/regressive cycles superimposed on the shorter-term glacial cycles.



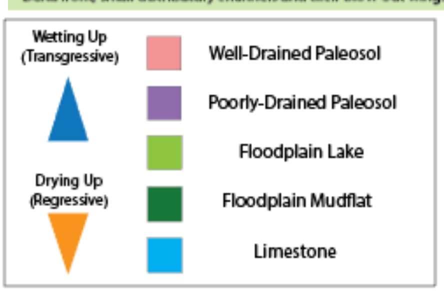


Figure 4. Composite section created from vertical sections measured in Pechacek (2018), indicating sequences of transgressive (wetting up) and regressive (drying up) cycles. Shows units as they are exposed from south to north on a strike section. Stars indicate the incised valley fills studied in detail.

Lithofacies Assemblages

The outcrops along State Highway 23 and State Highway 52 between Prichard, West Virginia, and Louisa, Kentucky, contain ten lithofacies. Table 2 summarizes the physical characteristics of these lithofacies and offers interpretations. The lithofacies observed here are grouped into four genetically related lithofacies assemblages: ***channel-belt***, floodplain lake, floodplain mudflat, and delta front (Pechacek, 2018). Furthermore, these lithofacies assemblages combine to make up three super-assemblages: ***valley fill***, poorly drained floodplain, and well-drained floodplain. For this study, the only lithofacies assemblage and super-assemblage analyzed in detail are the channel-belt and valley fill assemblages. Lithofacies descriptions and assemblages were created and taken with the guidance of Pechacek (2018).

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

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

Table 2. Lithofacies identified in outcrop.

Lithofacies	Lithology	Structures	Fossils	Interpretation
Cross-laminated Sandstone	Very fine to coarse grained sandstone	Planar laminated and trough cross bedded, commonly near base of sandstone scour, concave up channel form geometry, vertical and lateral accretion surfaces, local mud rip up clasts, local gravel layers. Sets range from only cm thick up to several m thick	Rare plant fragments	Migrations of ripples and dunes
Ripple- laminated sandstone	Very fine to medium grained sandstone	Ripple laminations, local climbing ripples, commonly get clay and silt partings less than one cm thick, local siderite beds and nodules, commonly exhibits concave up channel form or sheet geometry. Beds range from one cm to one meter thick.	Common plant fragments	Migration of ripples in low to moderate flow
Planar- laminated sandstone	Very fine to medium grained sandstone	Horizontal laminations, commonly with clay and silt partings less than one cm thick, commonly exhibits sheet geometry. Beds range in thickness from one mm to two m thick.	Common plant fragments	High energy flow or tidally influenced deposits.
Heterolithic sandstone, siltstone, and mudstone	Ranges from muddy siltstone to medium grained sandstone, occurs in alternating beds	Planar laminations, ripple laminations, commonly exhibits concave up channel form geometry, or sheet geometry thickness ranges from 0.5-10 m	Common plant fragments	Unstable flow conditions
Laminated siltstone and mudstone	Ranges from siltstone to mudstone	Planar laminations, siderite nodules, sheet geometry, commonly occurs in thick sections, gradational contact with floodplain mudflat deposits	Root balls and tree stumps	Subaqueous accumulation of settled suspended load
Bioturbated siltstone and mudstone	Ranges from siltstone to mudstone	Siderite nodules, commonly occurs in thick sheets, exhibits gradational contact with floodplain lake deposits	Plant fragments, burrowing, rooting, heavily bioturbated	Subaerially exposed settled suspended load
Well- drained paleosol	Red and grey mudstone or siltstone	Blocky, hackly, peds and slickensides, local siderite beds and nodules, sheet geometry that thins and thickens laterally, sharp contact with underlying sandstone facies, gradational contact with mudflat facies	Rooting	Well drained/oxidized paleosol indicating long periods of subaerial exposure
Poorly- drained paleosol	Grey, purple, and yellow mudstone and siltstone, locally with very fine-grained sandstone	Mottled, blocky, hackly, peds and slickensides, local siderite beds and nodules, sheet geometry that thins and thickens laterally, gradational contact with mudflat or floodplain lake facies	Rooting, bioturbated	Poorly-drained paleosol indicating a simple soil with a short subaerial exposure and frequent saturation
Coal	Coal and carbonaceous shale locally with organic-rich siltstone partings	Laminated sheets that thin and thicken laterally. Coal seam generally less than 80 cm thick, siltstone partings are up to 2 m thick.	Rooting, plant fragments	Peat swamp, mire (histosol)
Limestone	Grey to red wackestone to packstone and shale	Thin-bedded sheet geometry. Beds usually less than 75 cm thick, laminated shale beds up to 1.5 m thick.	Brachiopods, crinoids, bryozoans, and other shell fragments	Shallow marine, with periods of oxidation

Paleogeographic and Tectonic Setting

The Appalachian Basin is a foreland basin that extends from Quebec to Alabama, covering an area of about 536,000 km2 (Ettensohn, 2008). The basin formed in response to multiple orogenic events, including the Acadian, Taconic, and the Alleghenian orogenies. The basin is commonly divided into three regions: Northern, Central, and Southern. The study area sits on the boundary between the Northern and Central regions. The Central Appalachian Basin lays between the Cincinnati Arch to its northwest and the Appalachian fold and thrust belt to its southeast, oriented in the northeast-southwest orientation (Figure 5).

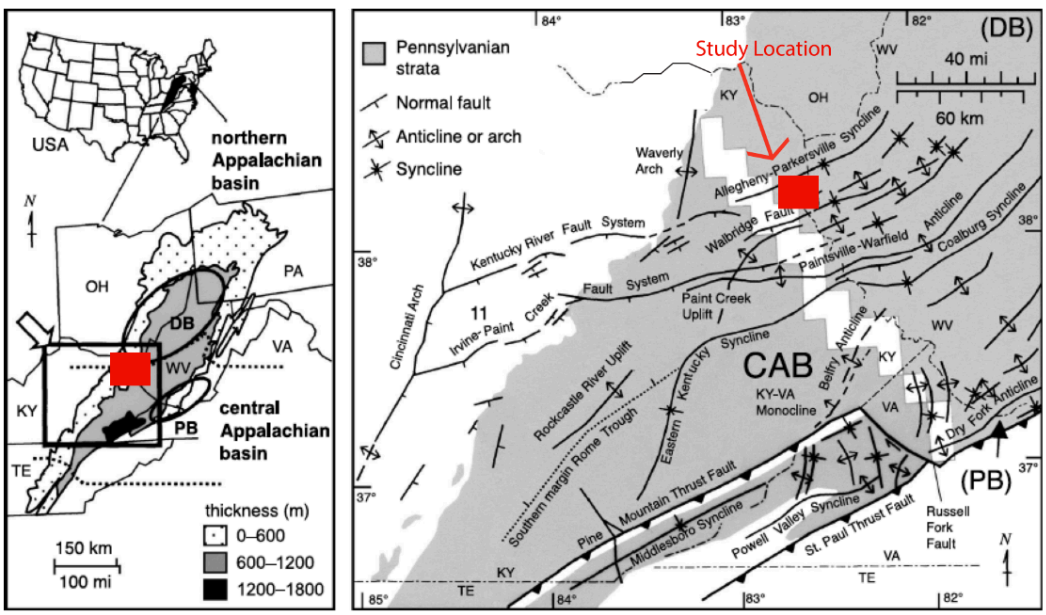


Figure 5. Location of the Central Appalachian Basin, in reference to study area, showing major structures: CA, Cincinnati Arch; KRF, Kentucky River Fault Zone; IPCF, Irvine-Paint Creek Fault Zone; HL, hinge line (modified from Greb et al., 2004).

During the Middle to Late Pennsylvanian, the most recent orogenic event, the Alleghenian, caused thrust-loading from the crustal collisions associated with the closure of the Rheic Ocean. The crustal collision of Laurasia (present-day Europe, Asia, and North America) into Gondwana (present-day Africa, South America, Antarctica, Australia, and India). The thrust-loading induced basin subsidence and provided sediment accommodation space for these strata (Martino, 2015). The accommodation space provided in the Late Pennsylvanian was generally less than provided in the Early-Middle Pennsylvanian due to decrease in the rate of tectonic subsidence. The subsidence was greatest in the foredeep of eastern West Virginia and decreased northwestward toward the cratonic platform in Ohio and Kentucky (Martino, 2015). Tectophases, transgressive-regressive cycles lasting several million years, resulted from tectonic loading and relaxation. The glacio-eustatic transgressive-regressive cycles occur at a much higher frequency and are embedded into the tectophases (Busch and Rollins, 1984; Heckel, 1994; Martino, 2016).

There were at least eight transgressions during the deposition of the Glenshaw Formation (Martino, 2004), and Pechacek (2018) concluded as many as eleven complete sequences. Only the distal edges of the shallow Late Pennsylvanian Midcontinent Sea (LPMS) reached the basin during these times as indicated by the thin marine deposits (Heckel, 1995). Source areas for the Central Appalachian rocks substantially changed throughout Pennsylvanian time. In the Early Pennsylvanian the major sediment source was from the northern cratonic platform in Ohio and Kentucky by axial river systems that carried coarse fluvial sediments (Chesnut, 1991). A transition of sediment source occurred during the Middle Pennsylvanian, while the Alleghenian orogenic event increased to the southeast. Sediment began sourcing from the mountains and transported northwestward across the basin floodplain (Aiken and Flint, 1994).

Paleoclimatic Setting

During the Pennsylvanian, a glacial time when the Earth was an ice house, the Central Appalachian basin drifted northward and was positioned within a few (5 to 10) degrees south of the equator by the Late Pennsylvanian. The basin was rotated about 40 clockwise from its current location (Greb et al., 2009). The northward drift of the basin caused a transition in climate. The late Middle and Late Pennsylvanian had significantly less rain fall than the Early to Middle Pennsylvanian (Greb et al., 2009). The climate fluctuated between humid subtropical and semiarid (Martino, 2015). Aridity was greatest during the deposition of the Glenshaw Formation (Martino, 2015). As Laurasia and Gondwana collided, atmospheric circulation patterns were redirecred noth of the mountains (Tabor and Montanex, 2002).

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

Rivers draining the Alleghenian Orogen flowed west and north across West Virginia (Martino, 2017). A large scale paleoflow analysis was not conducted in this study but paleoflow was collected in the field by the general direction of cross-bedding and bar accretion within the outcrops and compared against previous studies in and around the study area. Previous work (Donaldson et al. 1985; Martino, 2004) documented a north-northwest paleoflow, which is consistent with our field findings. Deposits that indicate transgressions and regressions of the LPMS also influenced the climate (Heckle, 1995). Local coal beds within the Breathitt Group also indicate moisture was reaching the basin. When the LPMS was at high stand, coal beds were deposited, and when the sea was at lowstand deltaic and terrestrial environments dominated the basin and well-drained soils developed (Heckle, 1995). The changes in climate affect water and sediment influx throughout the fluvial system, which caused variations in the thickness of channel belts.

METHODS

This study is a combination of observations and measured sections completed in the field, architectural analysis of the outcrops using photography from a DJI Phantom 4 Pro+ drone, and the fulcrum approach to assessing source-to-sink mass balance. Five road cuts were selected along Kentucky State Route 23 and West Virginia State Route 52 along an approximately 13-kilometer discontinuous exposure. These exposures are labeled K-2, K-3, K-4, WV-1, and WV-2. The same five outcrops were used in Pechacek (2018), which provided the foundational data for the overall lithofacies interpretations and sequence stratigraphic correlation. Each outcrop exposes parts of the Princess Formation, Glenshaw Formation, and Casselman Formation, and collectively encompass the uppermost Princess Formation through the lowermost Casselman Formation. Measured sections were taken in the field of each valley fill. K-3, K-4, and WV-2 exhibited one main valley fill, while K-2 and WV-1 each exhibited two. At least two measured sections were taken of each valley fill, where possible, in order to gain a vertical and lateral variation of the lithofacies within the fill. These lithofacies were compared and correlated with Table 2. Digital photos were taken at each outcrop using a DJI Phantom 4 Pro+ drone. Using the drone photography, valley fill architecture was mapped for each outcrop. The drone photography provided a clear, laterally extensive view of each outcrop and associated incised valley fills, allowing the measurement of architectural elements such as channel story depth and width to be measured.

A combination of field samples, measurements, and architecture analysis were used in the fulcrum approach. The fulcrum approach works on the assumption that in order for sediment to move from a source to its sink, it must pass through a cross sectional point. Estimating the amount of sediment passing through this 'fulcrum' point allows for the mathematical estimation of sediment moving from the source to sink (Holbrook, 2016). Bank full channel depth and width were estimated directly from channel story thickness. Complete channel stories were determined from outcrop by identifying a complete story-fill sequence by the vertical progression from basal thalwag fill, to lower channel fill or bar section, to an upper bar or channel-fill abandonment profile (Holbrook, 2006). Complete channel stories can also be discerned by the recognition of complete bar accretion surfaces. Complete bars are deduced by top-surface rollover and associated levee or mud drapes at the tops of cannel fills. Sediment samples were taken from the thalwag fill, or basal part of the central channel fills, as representative grain size samples for bank full bed load and are used in calculations of sediment and water discharge. The grain size hand samples collected in the field were converted into thin sections. A point-count analysis was performed on each sample to determine the average grain size cumulative curve. Average channel depth (d_m) is considered to be one-half bank full thalwag depth (d_t). Grain size (D) and channel depth can be used to estimate paleoslope (S), and average flow velocity (U). Channel width (w_e) can be measured directly from outcrop when available, otherwise it is estimated. Both channel and belt width can be checked against graphical field relationships of thickness vs. width as well (Gibling, 2006; Blum et al., 2013; Holbrook, 2014).

The estimation of slope, and documented paleo shoreline allows for the determination of backwater length for these rivers.

RESULTS

Valley Fill Architecture

The fluvial strata were measured and described for facies characteristics, and they were examined for complete bar and channel-fill sequences within each section. Channel systems lack complex braid-bar elements or large lateral accretion elements, but they do have muted versions of each, with lateral accretion elements more common. Channels are judged to be generally simple, relatively straight, single channels with some minor braiding. Width is approximated at the average width between simple single-thread and fully braided channel systems (Holbrook, 2016). The incised valley fill complex consists of stacked channel-fill, bar, downstream and lateral-accretion elements. The bars and channels amalgamate both laterally and vertically. The nature of the valley scour varies from being a sharp contact with the underlying coal, to incising completely through the coal. In any given vertical section of the incised valley assemblage, there are between 2-4 stacked channel stories. Intensive amalgamation within the confined valley has resulted in an incomplete preservation of these channel fill elements, which makes assessment of full channel dimensions difficult. The ability to recognize and measure complete bar and channel fill stories is limited in the lowermost portion of the incised valley fill deposits. There are greater than 10 channel fills observed laterally and between 2-5 in any given vertical section, which decrease in size going up in the section.

Channel Fill Element

Channel fill elements contain single and multistory bodies of cross-laminated sandstone, ripple-laminated sandstone, planar-laminated sandstone, heterolithic sandstone, siltstone, and mudstone lithofacies. Channel fills are marked by a sharp basal scour and a concave up channel form geometry. This assemblage includes the architectural elements associated with the laterally and vertically accreted bars, also includes the valley scour, channel scours, channel fill and uppermost channel contacts. A single-story channel fill averages 1.2 m and ranged from cm scale to a little over 2 m, and multistory fills reach maximum heights of 12 m. A typical channel fill exhibits a sharp basal scour into underlying strata, most commonly floodplain lake or floodplain mudflat. The fill fines upward within a story and are commonly interbedded with, or capped by siltstone, shale, and occasionally coal. The sandstone often transitions upwards into heterolithic sandstone and siltstone/mudstone fill. Conglomeratic channel lag deposits are sometimes present with siderite, limestone, coal spar, and vein quartz pebbles. The lower portions of the fills are typically trough cross-stratified with sets from 20 to 50 cm thick and topped by ripple-laminations followed by planar laminations. Compound cross-stratification is also present reaching heights from 1.5 to 5 m thick. The fining upward trend and sequence of sedimentary structures indicates waning flow as the channel fills. Channel belts are multistoried and were deposited in single channel, axial, low sinuosity river that avulsed and aggraded within a valley.

Bar Element

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

Fulcrum Method Results

The fulcrum approach applied here attempts to use paleohydrologic measurements from preserved channel fills and bars to reconstruct the amount of sediment passing through a basinal cross section over time. Channel discharge parameters are calculated for the channels, and the results of these calculations are summarized in Table 3.

Table 3. Paleohydrologic and discharge estimates from outcrop channel fills.

Channel	Banfull Thalweg Depth (m).	Bankfull Channel Depth, Hbf (m).	Bankfull Channel Width, Bbf (m).	Grain Size (D16, D50, D84, D90) (mm)	Slope (S)	Average Velocity (m/s)	Water Discharge Qbf (m3/s)	Bedload Discharge. Qtbf (m3/s)	Sediment Load Discharge* Qss
K-2	1.76	0.88	18	0.2, 0.49, 0.95, 1.0	0.001708875	1.54	26	0.035	0.088; 0.016
K-3	1.87	0.935	23	0.26, 0.56, 1.2, 1.3	0.001838118	1.64	38	0.054	0.158; 0.021
K-4	1.47	0.735	17	0.24, 0.53, 1.1, 1.2	0.00221302	1.54	21	0.036.	0.084; 0.013
WV-1	1.93	0.965	24	0.09, 0.17, 0.22, 0.24	0.000537866	0.90	23	0.010.	0.051; 0.009
WV-2	1.93	0.965	24	0.25, 0.55, 1.1, 1.2	0.001749171	1.61	41	0.055.	0.161; 0.021

Slope is a dependent variable and adjusts to the discharge and grain size available. Grain sizes were relatively small, with a D50 in the Wentworth ‘‘fine sand’’ range (Table 1). This suggests that slopes, and overall energy for these systems, was low, which would drive the discharge calculations toward below-average values compared to other channels of these depths. This small grain size could, however, reflect a lack of larger grains in the available supply because of longitudinal size sorting rather than low competence related to the low slopes.

DISCUSSION

A backwater profile forms in a channel where the depth is raised above the normal depth of flow and the effects are felt upstream. The backwater length is the distance upstream before normal depth is re-established. The calculation of backwater effects is important because it enables the determination of the upstream influence of works in a river channel. In land drainage systems, the backwater length tends to be long making the extent over which water levels are affected important. Backwater length can be calculated by 0.7*(bankful channel depth/slope). Table 4 shows the backwater lengths for these channels.

Table 4. Backwater lengths.

Channel	Bankfull Channel Depth, Hbf (m)	Slope (S)	Estimated Backwater Length
K-2	0.88	0.001708875	360.471
K-3	0.935	0.001838118	356.070
K-4	0.735	0.00221302	232.487
WV-1	0.965	0.000537866	1255.889
WV-2	0.965	0.001749171	386.183

The paleo shoreline ranged from approximately 30 to 150 kilometers from the study area during maximum transgressions of the marine units deposited in the study area (Busch and West, 1987; Chesnut, 1994; Martino, 2015). Sea influence is known to have the ability to propagate tens to hundreds of kilometers up dip (Blum and Törnqvist, 2000) putting the study area reasonably within a backwater length of the coast (Table 4). Therefore, it is plausible that sequence formation in the study area was responsive to sea level changes. Finally, the existence of incised valleys within the study area indicates that the river system was trying to decrease its slope. This infers that stream power consistently exceeded sediment supply in the system and that the ambient slope was steeper than the equilibrium slope of rivers (Holbrook et al., 2006).

Controls on Relationship Between Discharge and Sediment Supply

There are three major allogenic sedimentary controls: tectonism, climate change, and eustasy. All three controls can act on a basin at any one time, but they are not always independent. The two fundamental differences when discussing allogenic sedimentary controls are upstream and downstream controls. Tectonics and climate control upstream processes. Climate controls fluvial discharge, vegetation cover, and has major influence of sediment supply. Tectonics control regional slope and relief of the source area, which affects the level of sediment load. Eustasy, or sea level change, controls downstream processes. At, or close to sea level in shallow marine environments, base level is the most important control. Fluvial sandstone layers composed of amalgamated channel belts that lie above erosional sequence boundaries are generally categorized as lowstand systems tract. Sequence boundaries within the Conemaugh Formation generally follow these criteria. They are thought to have formed during falling base level and are marked by high relief unconformities at the base of incised valleys and strongly developed paleosols on the interfluves. They developed during glacio-eustatic lowstands associated with the expansion of Gondwana ice sheets (Martino, 2004).

Base-Level Buffers and Buttresses

Holbrook et al. (2006) introduced the concepts of buttress and buffer valleys to account for longitudinal changes in fluvial facies and architectural upstream from a coastline (Miall, 2014). A buttress is some fixed point that establishes the downstream control on a fluvial graded profile. In marine basins, base level is sea level, and in inland basins base level will be lake level. The buffer zone represents the available instantons preservation space for the fluvial system. The lower limit is set by the maximum depth of local channel scour, and the upper buffer limit is the height to which the river can aggrade under the prevailing conditions of discharge and sediment load. Upstream controls like climate and tectonics primarily determine spacing trends between these upper and lower buffers.

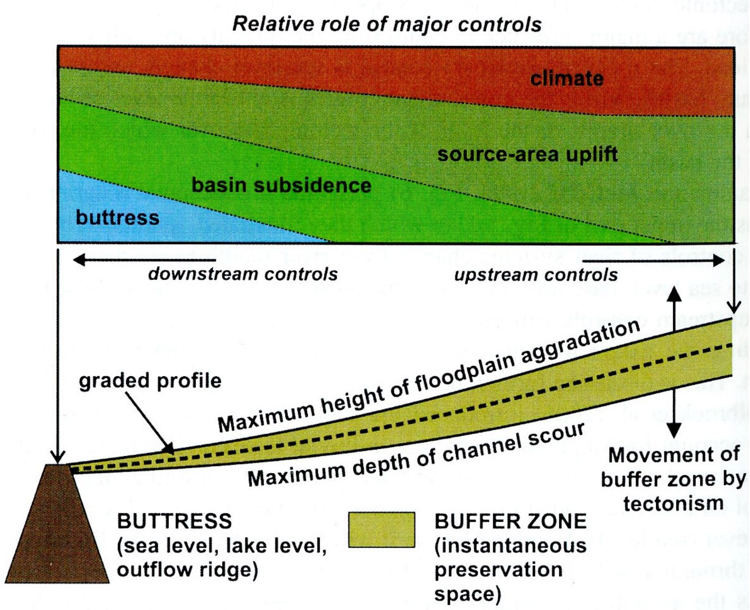


Figure 7. Allogenic controls on a fluvial system. The relative roles of the major depositional controls are based on Shanley and McCabe (1994); the diagram is intended to suggest how the balance between upstream (tectonic, climatic) and downstream (Base-level) controls changes from river mouth to source. The buttress and buffer concepts are based on Holbrook et al. (2006). Figure taken from Miall (2014).

The valleys in this study area are interpreted as buttress valleys, and the base level is sea level. As sea level changes, the profile of the river will adjust to accommodate this change. The buttress valleys fit the traditional sequence stratigraphic model because, as mentioned before, the base level is sea level, and the fluvial systems incised in response to their base level changes. When the sea level regressed, the valleys incised along their drainage

CONCLUSIONS

- Sequence stratigraphic models could be improved through the modification of shifting buffers in response to shifting of a buttress (i.e., sea level). This approach integrates upstream base-level controls with primarily downstream-oriented models. This permits the capture of architectural complexities within high frequency incision-aggradation cycles due to the increase of influence of upstream controls like climate and tectonics.

- The backwater length is influencing these river systems at this point in the Central Appalachian Basin, which supports traditional sequence stratigraphic models.
- These sequences generally follow the sequence stratigraphic model for a fluvial setting. They appear to record buttress valleys, which incised during sea level fall along slopes steeper than the preferred river profile.

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