[PS]Testing the Distributary Channel Model Against Predicted Changes in Fluvial Reservoir Geometry During Transitions From Low to High Accommodation Settings: Upper Pennsylvanian of the Central Appalachian Basin*

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Abstract

Models for distributary channel networks argue that rapidly aggrading systems that are presumably high accommodation will convert from low-accommodation single channel to distributary systems as they encounter the new conditions. If distributary channel systems are also bifurcating systems, it follows that channel size should reduce from low-accommodation to high-accommodation settings. Poorly drained floodplains with a lower energy regime and relatively high water table should record very high accommodation conditions and should particularly be susceptible to developing bifurcating distributary systems. We tested this hypothesis by comparing channel dimensions and lithofacies in high- vs. low- accommodation deposits in the Pennsylvanian strata of the Princess and Conemaugh Formations of eastern Kentucky. A valley complex 5–8 m thick typifies the low-accommodation setting with individual channel belts ranging from 0.75–1.5 m thick. Channels are highly amalgamated, are composed of fine to medium grained sands, and become heterolithic towards the top. Distributary channels, lake strata and smaller tie channels dominate the high accommodation floodplain settings. Distributary channels exhibit lateral accretion elements and are typically 1–3 stories, with individual channels being 0.4–1 m thick. Tie channels are 14–40 cm thick, very fine grained, and cross-cut floodplain lake strata. Thin, discontinuous, fine to very fine grain sand sheets connected to isolated tie channels represent pulses of deposition from channel propagation across the lake as a overbank sheet. Our data indicates a change in channel size, range of channel size, and channel geometry changes with an increase in accommodation state from low to high that is consistent with an upward change to a bifurcating system. This observation confirms the prediction of vertical change in geometry and size/size range of channels with change in accommodation state and supports the hypothesis that channels become bifurcated with sufficiently increased accommodation state. As well, the high accommodation condition is unpredictably well connected through tie channel propagation across the floodplain and distributary channel incision into these tie channel bodies and their overbank sands. Basin-fill models should thus consider the contingency that channel-belt reservoirs can change attributes with aggradation state and need not retain the sizes they possessed in the low-accommodation condition.

TESTING THE DISTRIBUTARY CHANNEL MODEL AGAINST PREDICTED CHANGES IN FLUVIAL RESERVOIR GEOMETRY DURING TRANSITIONS FROM LOW TO HIGH ACCOMMODATION SETTINGS: UPPER PENNSYLVANIAN OF THE CENTRAL APPALACHIAN BASIN

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Abstract

Models for distributary channel networks argue that rapidly aggrading systems that are presumably high accommodation will convert from low-accommodation single channel to distributary systems as they encounter the new conditions. If distributary channel systems are also bifurcating systems, it follows that channel size should reduce from low-accommodation to high-accommodation settings. Poorly drained floodplains with a lower energy regime and relatively high water table should record very high accommodation conditions and should particularly be susceptible to developing bifurcating distributary systems. We tested this hypothesis by comparing channel dimensions and lithofacies in high- vs. low- accommodation deposits in the Pennsylvanian strata of the Princess and Conemaugh Formations of eastern Kentucky.

A valley complex 5-8 m thick typifies the low-accommodation setting with individual channel belts ranging from 0.75-1.5 m thick. Channels are highly amalgamated, are composed of fine to medium grained sands, and become heterolithic towards the top. Distributary channels, lake strata and smaller tie channels dominate the high accommodation floodplain settings. Distributary channels exhibit lateral accretion elements and are typically 1-3 stories, with individual channels being 0.4-1 m thick. Tie channels are 14-40 cm thick, very fine grained, and cross-cut floodplain lake strata. Thin, discontinuous, fine to very fine grain sand sheets connected to isolated tie channels represent pulses of deposition from channel propagation across the lake as a overbank sheet.

Our data indicates that changes in channel size and channel geometry occur with an increase in accommodation state from low to high that is consistent with an upward change to a bifurcating system. This observation confirms the prediction of vertical change in geometry and size/size range of channels with change in accommodation state and supports the hypothesis that channels become bifurcated with sufficiently increased accommodation state. As well, the high accommodation condition is unpredictably well connected through tie channel propagation across the floodplain and distributary channel incision into these tie channel bodies and their overbank sands. Basin-fill models should thus consider the contingency that channel-belt reservoirs can change attributes with aggradation state and need not retain the sizes they possessed in the low-accommodation condition.

Purpose of Study and Introduction

• To test the hypothesis that channel belts become smaller, less connected and are associated with an increase in the relative proportion of overbank deposits as the system shifts from axial to distributary (e.g. Nichols and Fisher, 2007; Weissman 2012).

• Few such studies have attempted to relate observations of stacking of channel bodies with the nature of the adjacent floodplain environment (e.g. poorly drained vs. well drained) as it relates to accommodation

• This study presents an outcrop example from the Pennsylvania deposits of the Upper Breathitt Group and Lower Conemaugh Group in an area that provides excellent exposure of predominantly dip oriented sections of an axial and distributary fluvial succession.

Distributive Fluvial Systems

DFS are the result of sediment deposition that occurs when rivers exit the confinement of mountain valleys and become laterally mobile in broad sedimentary basins (Weissmann et al., 2010; Hartley et al., 2010). They are characterized by a radial pattern of channels from an apex of channel networks that evolve through channel bifurcation and avulsion.

DFS are roughly fan-shaped lobes of sediment that are convex upward across the system and concave upward down the system (Troeh,1965). This long-profile results as slope adjusts to transport the supplied sediment load (Stock et al., 2007). The steepness of the long-profile slope correlates with the size of the DFS (Stanistreet and McCarthy, 1993). DFS also have an intersection point where above which the river or alluvial system is incised in its floodplain and below which the river spreads out across the active sediment deposits.

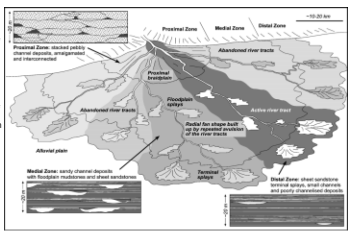


Fig. 1 Distributive Fluvial System (Modified from Nichols and Fisher, 2007).

Outcrops

Louisa 1A

Louisa 2B

Louisa 1C

Louisa 1B

Methods

This study is a combination of observations and measurements made in the field, large-scale panoramas, small-scale photos and statistical analyses. Outcrop analysis was conducted for 7 outcrops, which are exposed at different elevations labeled Louisa 1A, 1B, 1C and 2A, 2A_A, 2B and 3A along a 1 mi-long discontinuous exposure. For outcrops 1A/1B and 2A/2B the exposures are present on both sides of the road allowing for reflective analysis and a relative inference as to the orientation of the fluvial channels across a short distance.

1. Petrographic analysis of two coal beds that are present in the Louisa 2A and 2B outcrops to determine our location in the stratigraphic column

2. Vertical sections were measured for each outcrop and are used to correlate between outcrops.

3. Photos were taken along the entire length of each outcrop using Gigapan software and stitched together to create large-scale panoramas. The panoramas were used to create generalized lithofacies diagrams and architectural panels.

4. Smaller scale photos for lithofacies descriptions and sedimentary structures

5. Where possible, channel stories were measured to aid in the comparison of channel sizes between accommodation states. Complete channel stories can be discerned by the recognition of complete bar accretion surfaces. Complete bars are deduced by top-surface rollover (e.g., Mohrig et al. 2000) and associated levee or mud drapes at the tops of cannel fills. Or by documentation of a complete channel story-fill sequence in a vertical section

Location, Tectonic and Paleogeographic Setting

Several depocenters developed to the northwest of the orogenic belt. The central Appalachian Basin was one of these depocenters and is bounded by the thrusts of the orogenic belt to the east, by the Cincinnati Arch to the west and the Kentucky River Fault System to the north (Chesnut, 1991).

The Central Appalachian Basin is elongated in a NE-SW orientation (Fig. 1), with a structural hingeline that has the same orientation. The preserved axis of the basin is located southeast of the hingeline in southeastern Kentucky, which is where the Pennsylvanian strata is the thickest (Greb et al, 2013).

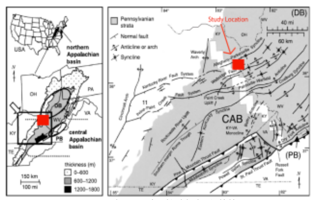


Fig. 2 Location and structure map of central Appalachian basin (Modified from Greb and Martino, 2005).

Fig. 3 Paleogeographic map (Modified from Blakey)

Louisa 2A

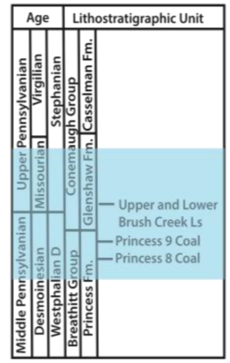
Louisa 3A

Louisa 2A_A

Stratigraphy

The stratigraphic nomenclature of Middle to Upper Pennsylvanian strata is shown in (Fig. 4) and the formations of interest for this study are highlighted in blue. In general, Pennsylvanian strata in eastern Kentucky can be divided into (1) a Lower Pennsylvanian section (2) a Middle Pennsylvanian section containing more laterally extensive coal beds, and lacking quartzarenites; and (3) an Upper Pennsylvanian section characterized by thinner coals (Princess No. 8 and Princess No. 9 coals) and thicker claystones that represent the Glenshaw Fm. Of the Conemaugh Group. The Middle Pennsylvanian section is broken up by widespread, marine shale members and that coarsen upward into fluvio-deltaic sandstones (Aitken and Flint, 1994).

Table 1. summarizes the primary facies associations encountered at our outcrop. They are based on lithology, vertical and lateral relationships and primary sedimentary structures. The major facies association for the Upper Breathitt Group and Lower Conemaugh Formation in our interval is interpreted as being deposited in an alluvial plain (Martino, 2005).



Coal Analysis

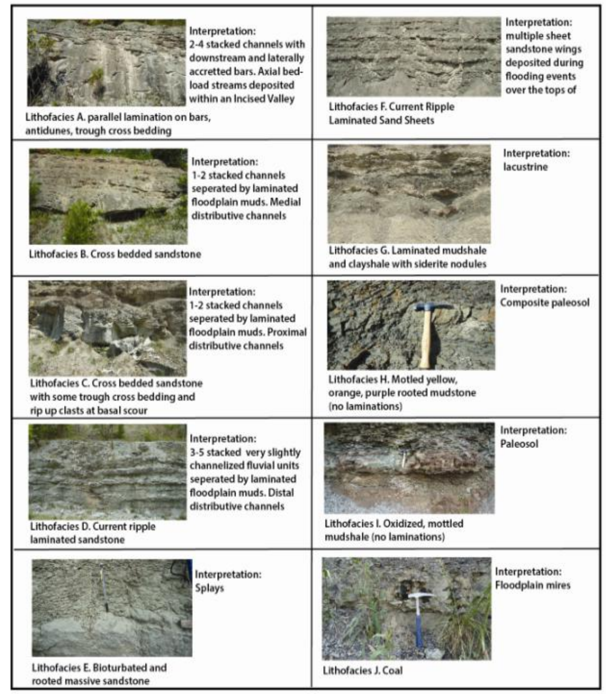
Geochemistry

Sample Thickness (inches)	2	4.5	6	17
Coal Bed	Princess	Princess	Princess	Princess
Name	# 9	# 8	# 8	# 8
KGS Sample ID	3175	3176	3177	3178
Moisture	4.24	6.23	6.35	8.81
Volatile matter, dry	15.07	29.97	19.08	36.75
Ash Yield, dry	60.18	35.27	58.74	10.55
Fixed Carbon, dry	24.75	34.76	22.17	52.7
Total Carbon, dry	28.48	49.92	28.73	71.56

Palynology

KY Route 23				
Princess Formation #8 and #9 Coal Beds				
Latitude: 38,06,13				
Longitude: 82,37, 38				
Samples collected 08/01/2013				
along KY Route 23, south of Ashland, KY				
Sample Thickness (inches)	2	4.5	6	17
Coal Bed	Princess	Princess	Princess	Princess
Name	# 9	# 8	# 8	# 8
KGS Sample ID	3175	3176	3177	3178
Total Lycopsid Trees	19.2	10.8	17.2	43.6
Total Small Lycopsids	0	0	0	0
Total Tree Ferns	20.8	83.6	74.4	50.8
Total Small Ferns	0.8	0.4	3.6	1.2
Total Calamites	13.6	3.6	3.6	4
Total Seed Ferns	0.8	0	0	0
Total Cordaites	43.2	0	0	0
Total Unknown Affinity	1.6	1.6	1.2	0.4

Lithofacies Associations



Lithofacies Interpretations

Facies Association A

Interpretation: This facies is interpreted as an Incised Valley Fill with channel fill and bar deposits of axial or low-sinuosity streams with high-energy flows. The lack of floodplain deposits and lateral accretion elements within the main body of the Incised Valley Fill indicates that infilling occurred by vertical accretion in axial streams.

Facies Association B

Interpretation: Facies association B is interpreted as a proximal distributary system with channels that exhibit decreasing discharge down flow distally from the apex of the distributive system. In their entirety they are fan shaped bodies that following the model proposed by Nichols and Fisher (2007) in that flow radiates from a linear apex. However, the source channel could not be determined within our outcrops. The stratigraphic architecture is aggradational with little evidence of deep incision by base level fall. The sizes of individual channels and their dimensions are variable and are interpreted to be deposits of both braided and meandering streams with an increasing amount of lateral amalgamation in the meandering flows.

Facies Association C

Interpretation: This facies is interpreted as a more proximal part of the system than the channels and channel fill elements related to facies association B. From thalweg to channel fill the unit is 2.5 meters with the channel measuring 1 m. There are rip up clasts at the base of the lateral accretion elements, which point to a high-energy flow.

Facies Association D

Interpretation: Facies association D was deposited as crevasse splays ranging from high to low energy flooding events. This facies is interpreted to be the splays related to flooding events from the channels associated with the incised valley fill of facies association A. Higher energy flows resulted in larger (30-45 cm) sand bodies with tractional, unidirectional flows as interpreted from cross-beds. Lower energy flooding events resulted in smaller (7-28 cm) splays where the only sedimentary structures observed are climbing ripples.

Facies Association E

Interpretation: These sandstone sheets are interpreted as crevasse splays. The rooting in the lower splay indicates sub aerial exposure and the presence of siderite cement indicates oxidation. The occurrence of rooted horizons and the complex interbedding of the sand sheets with laminated siltshale indicate intermittent deposition. Both units also thin considerably, which points to waning energy away from the levee breach.

Facies Association F

Interpretation: This lithofacies is interpreted as blow out wings coming out of a larger channel of facies association C. and spreading out as sand sheets in a poorly drained to standing water floodplain. The lateral continuity of the laminated siltshales and mudshales in the layers below and above the sand sheets as well as the lack of well-developed paleosols suggests a lacustrine environment. The different extents of the wings indicate flood pulses of varying magnitude as the system aggraded.

Facies Association G

Interpretation: This lithofacies is interpreted to be a shallow proximal floodplain lake due to the known proximity of the channel belt from which the blow out wings of facies association F was sourced. The laminations are blocky because there wasn't enough time in between flooding events for fine laminations to develop.

Facies Association H

Interpretation: These are interpreted to be composite paleosols deposited near an ephemeral floodplain lake. The soils represent temporary emergence and then subsequent re-drowning of the lacustrine system. These cyclical fluctuations in lake level are evident by the multiple levels of roots such as lycopods like stygmaria, which tried to keep pace with sedimentation and point to an unsteady rate of pedogenesis.

Facies Association I

Interpretation: These represent a well drained floodplain and are interpreted to be vertisols or ardisols and represent significantly more exposure time than the paleosols of facies association H. Exposure is interpreted to have occurred on interfluves of the incised valley fill drainage areas associated with facies A.

Facies Association J

Interpretation: The relatively low ash content and thickness of the Princess # 8 coal suggests development in laterally extensive, raised and long-lived peat mire (McCabe, 1984). This is interpreted to occur when base level was high enough to raise the water table to ground level. The higher ash content in the Princess #9 coal is technically interpreted as a carbonaceous or coaly shale and is interpreted to have been deposited close to active fluvial systems in the backswamp areas.

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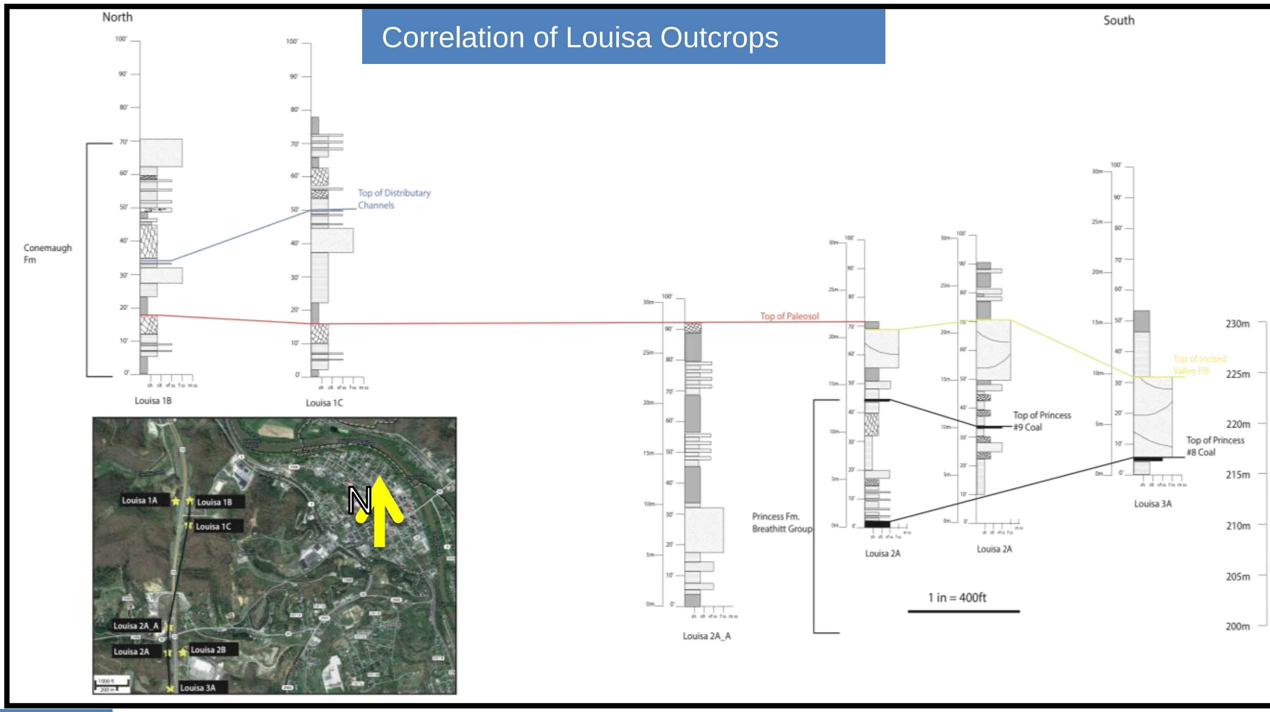
TCU ENERGY INSTITUTE

FRG ERG Fluvial & Eolian Research Group

Sedimentary Structures

Correlation of Louisa Outcrops

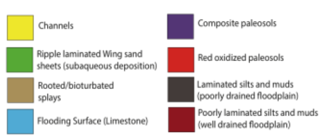


Paleoflow

Calculation method	Frequency
Class interval	30°
Filtering	deactivated
Data type	unidirectional
Rotation amount	0°
Population	101
Maximum percentage	23.8%
mean percentage	7.92%
standard deviation	341.12°
Vector mean	10.3°
Confidence interval	0.66

Fluvial and deltaic channels consist of channel form bodies with unimodal paleoflow as indicated by cross-bedding. The mean flow direction is toward the north-northwest, which is away from the Alleghanian orogen and consistent with fluviodeltaic reconstructions of earlier workers (Arkle, 1974; Donaldson, 1979; Donaldson et al. 1985). Local flow directions range from west to northeast; such variability is likely in high-sinuosity channel systems and radiating deltaic distributaries. Channel sandstones commonly exhibit large-scale bar accretion surfaces that commonly dip at a high angle (e.g., 70–908) with respect to the paleoflow directions indicated by internal cross-strata, a feature that is common in meandering channel systems. Mud-filled channels resulted from avulsion and channel deactivation. In meandering systems, this produces oxbow lakes (Martino, 2004).

Legend for Lithofacies map



Generalized Lithofacies Diagrams

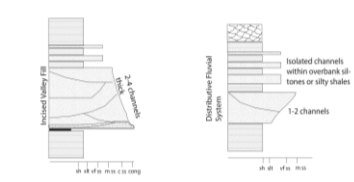
Generalized facies diagrams were constructed to aid in visualizing the nature of the lithofacies relationships. The vertical sections from the cross-section above (elevation above sea-level) give a relative idea to how these outcrops relate in a vertical sequence. The Princess #9 coal is the contact between the Breathitt Group and Conemaugh Group. About 8m above this coal is the amalgamated channels of the incised valley complex. We interpret the well drained interfluves from the base of the Louisa 1A, 1B and 1C outcrops to be the time equivalent floodplain of the axial channels that were confined within the valley from the Louisa 2A, 2B and 3A outcrops. There is a substantial change in the size, geometry, stacking patterns and drainage of the correletable floodplain going up through the section which we interpret to reflect an increase in accommodation, a leveling of the slope in the alluvial plain, and a transition to distributary from axial channels.

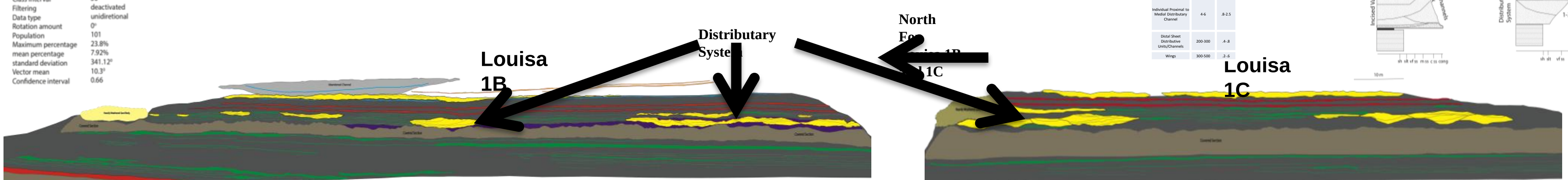
Quantitative Analysis

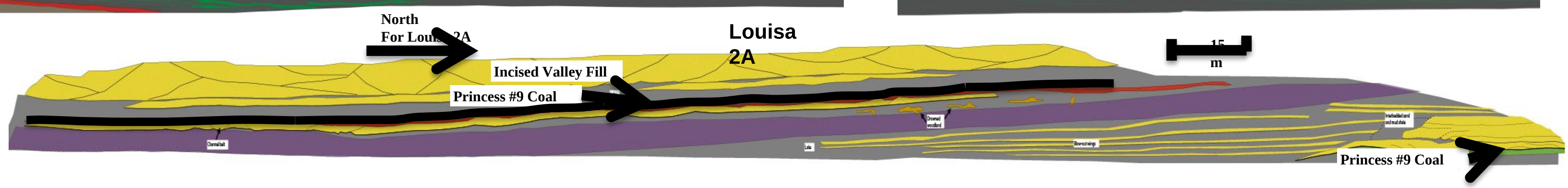
Channel Assemblage	Width (meters)	Thickness (meters)
Amalgamated Axial Channel Complex Confined within Valley	200-350	7-11
Individual Channel within Amalgamated Valley Complex	15-60	1.5-4
Clustered Proximal to Medial Distributary System	300-500	2-4
Individual Proximal to Medial Distributary Channel	4-6	.8-2.5
Distal Sheet Distributive Units/Channels	200-300	.4-.8
Wings	300-500	.2-.6

Schematic Logs

Representative vertical sections going through the amalgamated channels within an incised valley (lower left) and through the medial channels of the distributive system. In the IVF there are 2-4 stacked channel belts with conglomerate scour bases. They fine upwards where the fill becomes increasingly heterolithic. The distributive channels were never observed to have more than 2 channels in communication and the sequence is capped by more isolated single body channels separated by laminated poorly drained mudstones.







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Architectural Analysis

Incised Valley Fill Assemblage

The incised valley fill complex consists of stacked channel belts with the following main elements; channels, bars, 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 of facies association J to incising down through the coal. In any given vertical section along the valley complex, there are between 2-4 stacked channel belts.

Element 1: Bars

Interpretation: Based on the internal sets of parallel laminations, the bars were formed by bedload bedforms indicative of flows of varying energy. Lower plane beds produced parallel laminations and anti-dunes formed during supercritical flow. Multiple flooding events smeared individual units bars into compound bars that are reflected by an increase in the angle of the parallel laminations along the bar face.

Element 2: Channels

Interpretation: These channels record the incising, infilling, avulsing and depositional cycle of multiple channel belts within an incised valley complex. Sandy channel fill elements are adjacent to lateral accretion elements and divert around migrating side attached bars. Lateral accretion elements are the most common, which is often indicative of lateral point bar growth. However, these bar elements from field observations are always less than twice the width of the associated and adjacent channel fills. Following Holbrook, 2001 this argues for within channel belt avulsion over lateral bar growth as the channel migrating mechanism. In addition, the channel fills are generally symmetrical in a concave up shape in strike-oriented sections such as figure 10.

Channel belts are multi-storeyed and were deposited in single channel, axial, low sinuosity river that avulsed and aggraded within a valley.

Distributive System Assemblage

The distributive system assemblage consists of three main elements: channel fill elements (both sandy filled and abandoned), bars and wings. The channels and bars amalgamate both laterally and vertically. The wings extend laterally from the tops of channels. There are no more than two stacked (connected) channels in an given vertical sequence and in some case there are 3 channels in a vertical section, but with the uppermost channel being isolated within overbank deposits.

Element 1: Bars

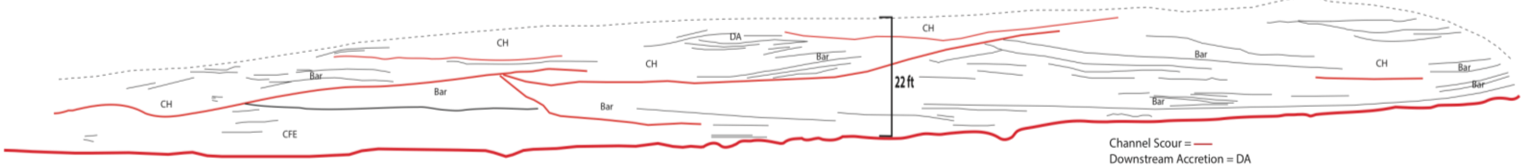
Interpretation: These complex bars with multiple bar elements are interpreted to reflect lateral migration of side-attached bars of medial distributary channels. Bedform and bar migration occurred in laterally mobile bedload streams and are characterized by a high proportion of trough cross sets that suggest migration of dunes.

Element 2: Channels

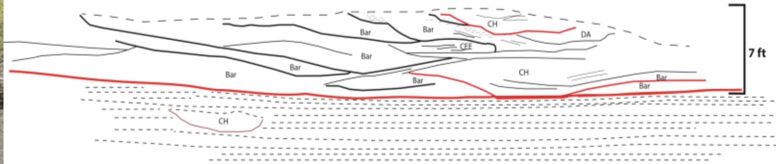
Interpretation: These channels and channel fills are interpreted to represent bifurcation, avulsion and abandonment of channels associated with a medial distributary system. There is abundant coarse material in most channels, many of which are laterally equivalent. However, abandoned channels are filled with mud. The different channel fill elements suggest that flow was highly variable. Field observations point to some periods of avulsion, where one channel was abandoned and the flow was diverted to a new path, while other observations suggest contemporaneous channel deposition via bifurcation.

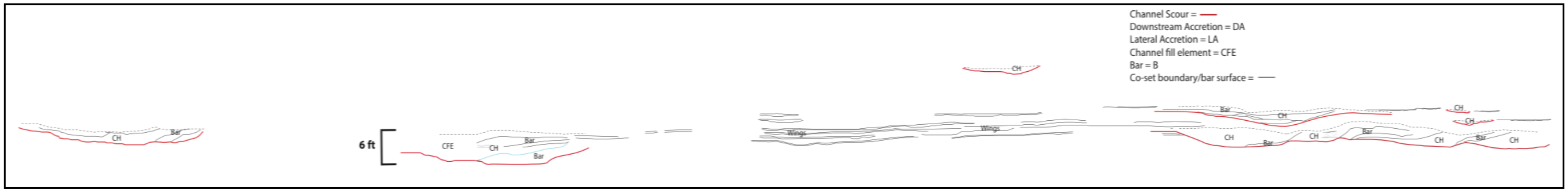
Element 3: Wings

Interpretation: This is interpreted as over-levee sedimentation during aggradation of the system from within the adjacent distributary channels during flooding events. Multiple wing sand units separated by silt- to mudshale indicate multiple pulses of flooding that expelled the sand out of the channel and into the floodplain. The nature of the floodplain indicates poorly drained conditions where there was standing water or possibly ephemeral lakes.



Channel Scour =
Downstream Accretion = DA
Lateral Accretion = LA
Channel fill element = CFE
Bar = B
Co-set boundary/bar surface =





Discussion

The models for Distributive Fluvial Systems argue for thicker channel belts to exist within confinement closer to the source and adjacent to a well-drained floodplain where paleosol development is common (Weissman, 2010). This observation is confirmed in the Louisa outcrops. There is a noticeable decrease in channel body size as the system goes from confinement to distributive. As the system continues to advance, a point is reached where incision is replaced by system aggradation. The channels avulse and bifurcate and this represents a decrease in sand body amalgamation and an increase in mud : sand ratio. Standard sequence stratigraphic models (e.g. Shanley and McCabe, 1994) represent these higher accommodation channel bodies as being isolated within overbank muds. In our study section we are observing much more sand interconnectedness by blow out wing processes that occur during flooding events. As channels continue to advance across the alluvial plain they commonly incise into the wings from previously deposited distributary channels.

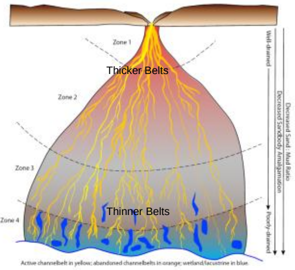


Fig. 4 Distributive Fluvial System exhibiting reduction in channel size and increase in number of channels moving away from apex (Modified from Weissman, 2010)).

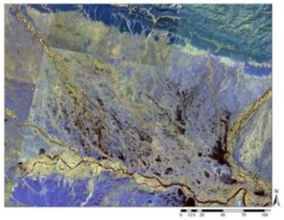


Fig. 5 Satellite map of a DFS (Modified from Weissman, 2010)).

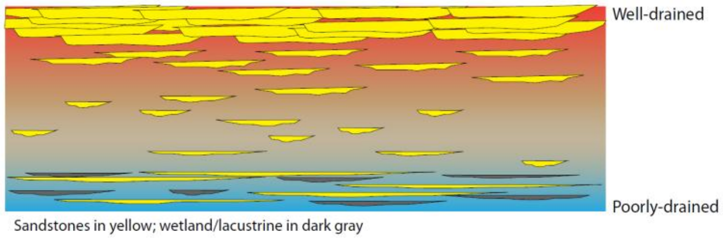


Fig. 6 DFS model showing channel stacking nature with nature of floodplain Modified from Weissman, 2010)).

Conclusions

- A change in channel belt morphology is evident in the study area and is due to an increase in terrestrial accommodation space in the alluvial plain
- Major stacked fluvial bodies (Facies association A.) are multistory and multilateral in nature. This facies incises into underlying overbank deposits and is interpreted as the result of rapid sedimentation from high-energy flows. The almost complete lack of lateral accretion elements and overbank deposits indicates that infill was the result of vertical accretion in a low sinuosity river
- There is an increase in lateral accretion elements as accommodation space increases and as energy in the system declines. Facies association B. and C. represent deposition in a high accommodation setting and commonly cut into poorly drained overbank facies. Cross-bedding and current ripple laminations are present. This facies associations represents distributary channels with some degree of nodal movement of the major distributary apex up-dip.
- There is a change in the nature of the floodplain environment as accommodation space increases. This change is most notably in the transition from a well-drained, oxidizing floodplain with reddish paleosols to a poorly drained floodplain characterized by well laminated mudshales and clayshales deposited under standing water environments.

References

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