Facies Architecture and Comparative Study of 2 Fluvial Systems in Sequence 1, Ferron Notom Delta, Utah

By

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Abstract

Knowledge of fluvial architecture is an essential tool for hydrocarbon exploration. Reservoir size and shape, along with internal porosity/permeability distribution, is often associated with channel pattern. Therefore understanding the factors that control channel pattern and dimensions is essential to the hydrocarbon recovery and overall paleoenvironmental reconstruction.

In this study, outcrop dimensions (width/thickness) and spatial distribution patterns of isolated and amalgamated channel belts will be obtained and compared. This will be done by collecting vertical measured sections along with paleocurrent measurements in order to construct a cross section demonstrating the orientation and extent of the channel belts.

The geometry of the preserved sand bodies will be compared to existing models which associate sandstone/mudstone ratio and degree of channel belt amalgamation in terms of subsidence, accumulation, avulsion frequency, and channel migration rate, allowing prediction of dominant variables controlling deposition of the bodies to be made.

Internal bedding geometry of channel belts will be done to determine bar style associated with braided or meandering rivers. This will allow the idea of river plan-form controlling net-to-gross ratio to be tested along with determining any systematic change stratigraphically between or within channel belt clusters.

The ultimate goal is to provide outcrop analog data which include dimensions and distribution patterns of isolated and amalgamated channel belts in order to improve models and correlations in subsurface fluvial stratigraphy in areas with sparse data.

Introduction

Understanding and predicting the architecture of fluvial systems is very valuable, especially for hydrocarbon exploration. Some of the biggest reservoirs in the world lie within fluvial systems, such as Prudhoe Bay in Alaska, Minas Field in Sumatra, and Gippsland Basin in Australia, Travis Peak Formation in Texas (Davies et al., 1991). Reservoir volume and connectivity are influenced by the plan-view and migration behavior of the river (translation vs. expansion), making it an important aspect for reservoir analysis (Donselaar and Overeem, 2008; Davies et al., 1991). Therefore, knowledge and understanding of fluvial architecture may be used as a tool for predicting interconnectivity and quality of subsurface reservoirs.

The dimensions of fluvial channel belts have received much less attention than their internal structure, despite the fact that many subsurface analyses draw upon the geometry of suitable fluvial analogues (Gibling, 2006). Fluvial systems are complex and highly variable due to their response to even minimal changes. Geomorphic factors that are responsible for shaping channels include discharge, slope, sediment grain size and load, channel margin composition and strength, and factors related to the local geological history (Gibling, 2006). As changes in regime occur, a channel tends to adjust by changing its width or sinuosity, with adjustment in channel width being a prominent response to discharge fluctuations (Gibling, 2006). Bristow and Best (1993) and Gibling (2006) introduced models showing that different channel geometries are dependent on the balance between different factors. In the single-story channel model, the relationship between channel aggradation rate and bank migration rate determines the geometry of the body (Fig. 1). Because the width of channels is sensitive to short term discharge variation, many channels are likely to widen and show lateral accretion over time (Gibling, 2006). In the multistory model, the interactions of reoccupation frequency and avulsion periodicity are also involved. Reoccupation is likely to generate vertical stacking of the body (Fig. 2), whereas avulsion periodicity represents the formation of new channels on an unconfined plain and leads to channel belt expansion and amalgamation (Fig. 2) (Gibling, 2006). Once channel dimensions are obtained they can be compared to theoretical models to determine possible factors that control channel belt dimensions.

Some fluvial stratigraphy models suggest that fluvial architecture is controlled by changes in base level when the river is linked to the sea. Two different models proposed by Shanley and McCabe (1993) and Wright and Marriott (1993) illustrate more or less the same concept with a minor disagreement in the placement of the isolated fluvial deposits. Shanley and McCabe (1993) suggest that during the lowstand systems tract, when base level is low, there are amalgamated fluvial channel deposits (Fig. 3). During the transgressive systems tract, when base level is rising, there is the presence of tidally influenced fluvial deposits (Fig. 3), whereas in the highstand systems tract there is an increase in the rate at which accommodation is created, characterized by fine grained flood basin strata and isolated, high sinuosity fluvial channels (Fig. 3) (Shanley and McCabe, 1994). The model introduced by Wright and Marriott (1993) suggest that during the lowstand systems tract, there are amalgamated fluvial channel deposits (Fig. 4). This is followed by an increase of accommodation rate which favors storage of floodplain sediments, resulting in isolated channels during middle to late transgressive systems tract (Fig. 4). A reduction in accommodation during the highstand systems tract results in higher rates of floodplain reworking and the rejoining of some channel bodies (Fig. 4). Although the 2 models show some differences, what they do have in common is where fluvial amalgamation occurs, which is within the lowstand systems tract.

All previously discussed theoretical models allow the comparison and prediction of sandstone/mudstone ratio and degree of channel belt amalgamation to be made in terms of variables such as subsidence, accumulation rate, channel migration rate (which controls channel belt width), and avulsion frequency (which controls channel belt cluster), allowing a better understanding of factors controlling channel belt dimensions.

Earlier fluvial stratigraphy models, such as the one presented by Friend (1983), suggested that net-to-gross is a function of river plan-form, in which there are only 2 end members, braided or meandering (Fig. 5), where braided systems are sand dominated and meandering systems are mud dominated. This model however has been proven to not always be accurate and research has shown the presence of both braided and meandering within the same system may occur, therefore plan-form cannot be determined from this model alone. Internal bedding geometry of channel belts can be used to determine bar style associated with channel type. The relationship of the internal bedding geometry with respect to paleoflow direction will either demonstrate lateral accretion associated with meandering systems, or downstream accretion (bidirectional down lap in strike view) associated with braided systems (Fig. 6). This will allow the idea of river plan-form controlling net-to-gross ratio to be tested, along with determining any systematic change stratigraphically between or within channel belt clusters.

This study evaluates the floodplain vs. channel belt architecture and internal facies architecture in mud-prone alluvial strata of the Ferron Notom Delta in Central

Utah. Previous sequence stratigraphy studies allow an evaluation of the change in fluvial style, along with stacking of channel belts within this framework. The focus of this research includes the following; first, obtain and compare isolated and amalgamated channel belt dimensions (width/thickness) and spatial distribution patterns from cross section. Second, compare preserved sand body geometry to previously discussed theretical models to predict dominant variables controlling channel belt dimensions. Third, determine internal bedding geometry of channel belts to distinguish bar styles associated with braided or meandering systems. This will allow the idea of river plan-form controlling net-to-gross ratio to be tested and to determine any systematic change stratigraphycally between or within channel belt clusters.

Fluvial Systems

Fluvial or alluvial deposits are created by rivers, streams of flowing water in a channel, transporting sediment to a topographically low region. They have been recorded in the rock record to have occurred in various continental settings and under various climatic conditions (Wright and Marriott, 1993). According to Bridge (2006), there can be two main types of channel patterns, single channels which may be meandering or straight and multiple channels known as braided or anastomosed. Both channel patterns can be present in different parts of the river simultaneously, and are thought to be controlled by a range of different factors, such as discharge, slope, grain size, amount and kind of sediment load, bed roughness, and even bank stability due to vegetation (Davies and Gibling, 2010). Bridge (2006) suggests that it is predominantly controlled by channel forming discharge and slope, in which an increase in braiding correlates with an increase in channel discharge and slope (Fig. 7).

During flood stage in channels, there is development of bars, which are formed by accretion of smaller bed forms such as dunes and ripples. A bar is a bed form whose length is proportional to local channel width and whose height is proportional to channel depth (Bridge, 2006). The smaller scale bars accrete to form larger scale features known as composite or compound bars. Depending on the location of a compound bar in the channel, they are known as point bars or braid bars. Channels are characterized by these compound bar features, since their geometry, spatial distribution, and migration within the channel controls the over all plan view geometry (Bridge, 2006). Point bars are attached to the side of the channel and laterally accrete towards the cutbank (Fig. 8). Helical flows transport the eroded cutbank sediment along the bottom and deposit it on the laterally accreting point bar. The helical flow gradually loses momentum up the point bar slope and results in a lateral deposition onto the point bar surface (Donselaar and Overeem, 2008). On the other hand, braid bars are located in the center of the channel causing the helical flow to split. The two helical flows begin to accrete laterally on both sides of the bar, creating a mound like features (Fig. 9). These grow in height and migrate downstream by erosion along the bar head and deposition along the bar tail (Bridge, 2006). Both systems migrate by deposition on compound bars, the key difference is that braided patterns have a frequent occurrence of braid bars bounded by coeval channels and of confluence regions bounded by coeval side bars (Bridge, 2006).

Adjacent to the channel is a strip of land which is normally flooded, known as the floodplain. Floodplains are made up of alluvial ridges (high areas) and flood basins (low areas). Within the alluvial ridge, there will be channels (active or abandoned), levees, crevasse splays, and crevasse channels (Bridge, 2006). Levees are wedge shape ridges adjacent to the channel that are formed during flood events. As the channel floods and overtops its banks, water spills onto the floodplain decreasing velocity and depositing sediment. Sediments are coarser near the channel margin and become finer away from the channel, but have an overall coarsening upwards sucession. After numerous flooding events, levee height is increased, increasing the elevation of the channel to the floodplain, therefore increasing channel instability, which could lead to an avulsion, but exact factors controlling avulsions are still debated (Aslan et al., 2005; Aslan et al., 2006; Tornqvist and Bridge, 2002). During floods, larger channels may breach or cut into the levee surface allowing deposition of sediment in the floodplain. These are known as crevasse channels. Crevasse channels behave like distributary systems, splitting into smaller channels as they move away from the main trunk channel and depositing fan shape mounds of sediment called crevasse splays (Fig. 10) (Bridge, 2006). Crevasse splays behave similar to deltas in the sense that they prograde towards the floodplain after every flood event, typically forming a coarsening upwards succession. The floodplain deposits may also be used to determine the environment at the time of deposition, such as paleosols, coals, and desiccation cracks. Caliche and redbeds can indicate an arid environment, whereas plant material, gleysols, and coals may indicate a humid environment. All this is key information which can be used to interpret and reconstruct the ancient environment of deposition depending on channel migration, changes in floodplain channels, avulsions, tectonics, progressive deposition and erosion (Bridge, 2006).

Fluvial deposits in ancient outcrop examples can be characterized and recognized by several different observations. Deposits have an erosional undulating base with a fining upwards succession. Channel bodies can be single-storey or multistorey (Fig. 11), where storeys are separated by scour surfaces (Friend et al., 1979). Single-storey bodies may be asymmetric or symmetric and depending on the fill they may be concentric or asymmetric (Fig. 11). Asymmetric fill implies bank attached bars which accrete laterally, while concentric fill represents the progressive filling of the channel by deposition on its floor and accretion banks (Gibling, 2006). Channel wings may also be present and can be relatively wide (Fig. 11), they may be a part of the channel body or may represent natural levee and crevasse splay deposits, distinct from the channel fill (Gibling, 2006). Deposits may also be multistorey if they are vertically stacked, or they may be multilateral if they coalesced laterally (Fig. 11) (Gibling, 2006). Channel bodies can be succession-dominated, where storeys form reasonably complete channel fills (Fig. 11) or they can be erosion-dominated, where the body contains abundant erosional surfaces (Fig. 11) (Gibling, 2006).

The previously discussed material will be applied to the study outcrop, allowing a better understanding and interpretation of the system and environment of deposition to be made. The architectural elements and their accretion/migration, discussed above, will assist in determining the channel patterns present along the outcrop. The floodplain elements will be used to identify possible levees and crevasse splays/crevasse channels and their extent along the outcrop, therefore determining the nature of margin of the floodplain and the channel. Channel bodies, storeys, and fills will be used to identify the overall geometry of the fluvial deposits and to better understand how the system changed as it went from what appears to be an isolated channel belt to an amalgamated channel belt.

Regional Geology

The Ferron Sandstone Member of the Mancos Shale formation is middle Turonian to late Santonian in age, and was deposited as a series of deltaic complexes that prograded into the Western Interior Seaway (Fig. 12). The Western Interior Seaway joined the Gulf of Mexico with the Northern Boreal sea, dividing the North American continent in two. This was a shallow sea with faunal assemblages indicating a water depth of 250 to 300 meters (Kauffman, 1984). It was about 1600 km wide and extended around 4800 km from the Gulf of Mexico to present day Arctic Ocean (Kauffman, 1984). The western margin deposited eastward thinning clastic wedges composed of sediment derived from the mountains of the Sevier Orogeny to the west, creating the Vernal Delta Complex, Last Chance Delta Complex, and the Notom Delta Complex (Fig. 12) (Gardner, 1995; Garrison and van den Bergh, 2004; Li et al., 2010; Zhu, 2010). The paleolatitude of the area in the Cretaceous was around 45° N (Fig. 13) with a humid to subtropical climate within a "greenhouse" cycle (Ryer and Anderson, 2004).

The southernmost lobe (Notom Delta Complex) (Fig. 12) first prograded into the Henry Mountains Basin around 91.25 Ma and then stopped around 90.7 Ma due to a regional river avulsion, which shifted towards the North, forming the Last Chance Delta in the Castle Valley area (Gardner, 1995; Garrison and van den Bergh, 2004). Zhu (2010) Argon dated sanidine crystals found in the bentonite beds at the base of the delta and indicated the progradation and deposition to have initiated at about 91.25 ± 0.77 Ma. The Ferron Sandstone is a fluvio-deltaic deposit that belongs to the Mancos Shale Formation.

The Tununk Shale Member lies below, and the Bluegate Shale Member sits above the Ferron (Garrison & van den Bergh, 2004). Peterson and Ryder (1975) divided the Ferron into a lower and upper unit, where the lower unit is considered to be of shallow marine deposits and the upper is predominantly fluvial deposits. Zhu (2010) and Li et al (2010) constructed a regional sequence stratigraphy of the Ferron Notom Delta where 43 parasequences, 18 parasequence sets, and 6 sequences were identified (Fig. 14).

Study Area

The outcrop is located near Sweetwater Creek (Fig. 15) in south-central Utah, U.S.A, between the towns of Hanksville and Caineville, near Steamboat point. The exposures consists of several near vertical cliffs ranging from 10 m to 15m in height exposed along the wash allowing the comparison of two channel belt systems. Regional stratigraphic work of the Ferron Notom Delta by Zhu (2010) and Li et al (2010) identified 6 sequences, where fluvial deposits in sequence 1are the main focus (Fig. 14).

Within sequence 1, Li et al (2010) recognized 2 valley fills which demonstrate a vertical change in facies and fluvial style, associated with changes in water discharge, sediment load, and slope. In the older valley 2, fluvial style appears to have always been meandering. In contrast to the younger valley 1, which shows a vertical change in fluvial style, from braided at the base to single thread meandering then back to a low sinuosity river system. The sandstone at the base of the valley was interpreted as a lowstand fluvial deposit because it is highly amalgamated and exhibits a high sandstone/mudstone ratio. The highstand fluvial deposits were observed to have a low sandstone/mudstone ratio and the presence of isolated and non amalgamated channel and channel belts with an abundance of fine grain sediment associated with floodplain/overbank deposits (Li et al., 2010). This research will focus on the fluvial deposits in the top most part of valley 1 in sequence 1, the isolated channel belt and the overlying amalgamated sheet like fluvial deposit, interpreted as the highstand fluvial facies by Li et al. (2010). Integration of cross section (Fig. 16), bedding diagrams, and paleocurrents may address plan-form in order to determine and understand changes in fluvial system and possible control on net-to-gross.

Methodology

Data collected in the field during a three month period included vertical measured sections and hundreds of highly detailed photos. Data for the vertical measured sections was collected using a hand lens, grain size card, Brunton compass, tape measure, Jacob staff, and a rock hammer. Detailed vertical measured sections measured grain size, sedimentary structures, paleocurrent direction, preserved dune heights, and trace fossils. The measured sections were then scanned and digitized and a cross section was created using the transgressive Bluegate Shale Member as a datum to hang the measured sections.

Hundreds of highly detailed photos were taken of the cliff faces using a gigapan and camera. These photos were then merged together using Adobe Photoshop software and Gigapan Software to create photo mosaics. Measured sections were then superimposed on the photo mosaic using Adobe Illustrator, and correlated to create bedding diagrams of the fluvial architecture. Surfaces were then ordered using the techniques of Miall (1992).

Paleocurrent measurements will be analyzed and compared to photo mosaics and internal bedding diagrams to determine paleoflow and direction of bar accretion in the channel belts, therefore providing plan-form. Thickness of sand body can be obtained from vertical measured section/cross section. Width can be determined using simple trigonometry as long as paleocurrent measurement, outcrop orientation, and apparent channel belt width data is available.

Proposed Research

Having identified the outcrop to be of fluvial deposits, my focus will be to analyze the fluvial and facies architecture of both channel belts. Dimensions (width/thickness) and distribution patterns will be obtained and compared from the cross section. Once dimensions of the preserved sand bodies are obtained they will be compared to theoretical models that associate sandstone/mudstone ratio and degree of channel belt amalgamation in terms of subsidence, accumulation, avulsion frequency, and channel migration rate, to determine possible factors that control channel belt dimensions. The idea that river plan-form controls net-to-gross will be tested by determining bar style from the internal bedding geometry of the channel belts, along with any systematic change stratigraphically between or within channel belt clusters.

The ultimate goal of this study is to provide outcrop analog data which include dimensions and spatial distribution patterns of isolated and amalgamated channel belts in order to improve models and correlations in subsurface fluvial stratigraphy.

Figures

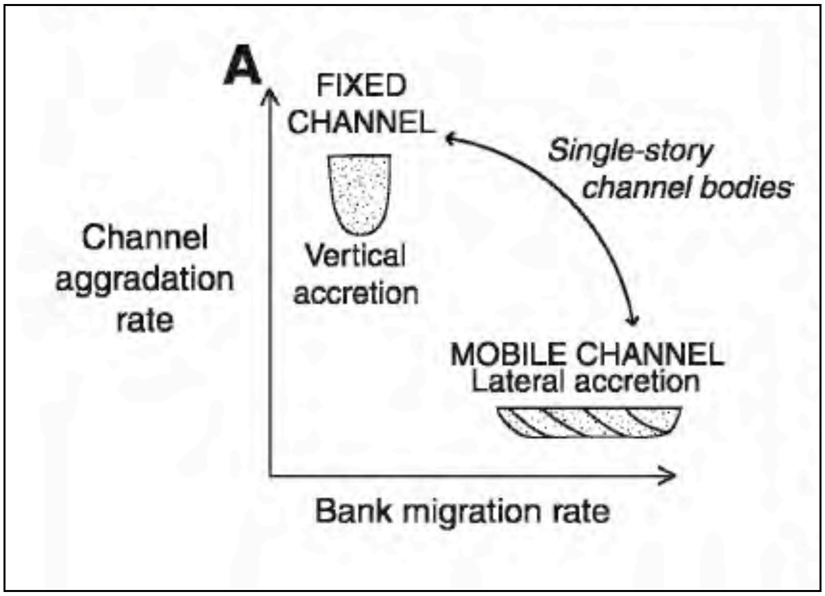

Figure 1—Model showing factors controlling geometry of single-story channel bodies. (Gibling, 2006)

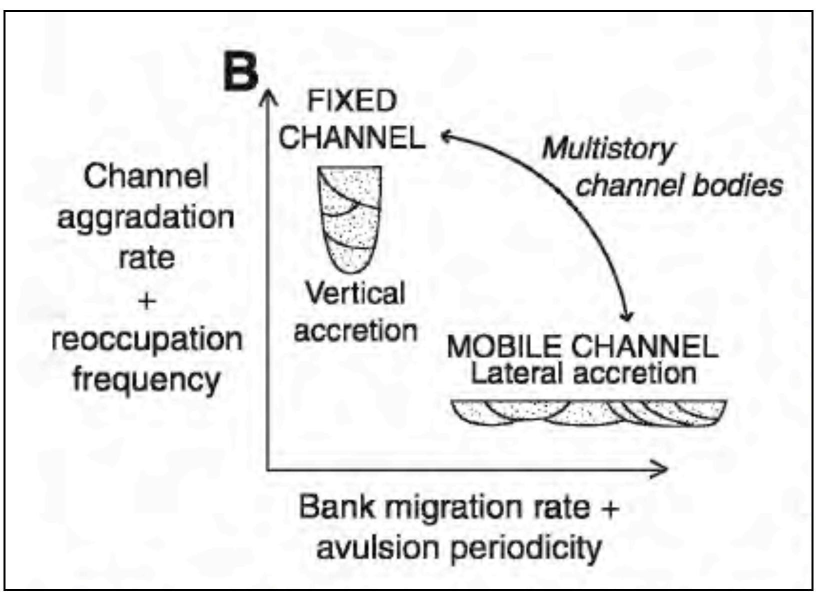

Figure 2—Model showing factors controlling geometry of multistory channel bodies. (Gibling, 2006)

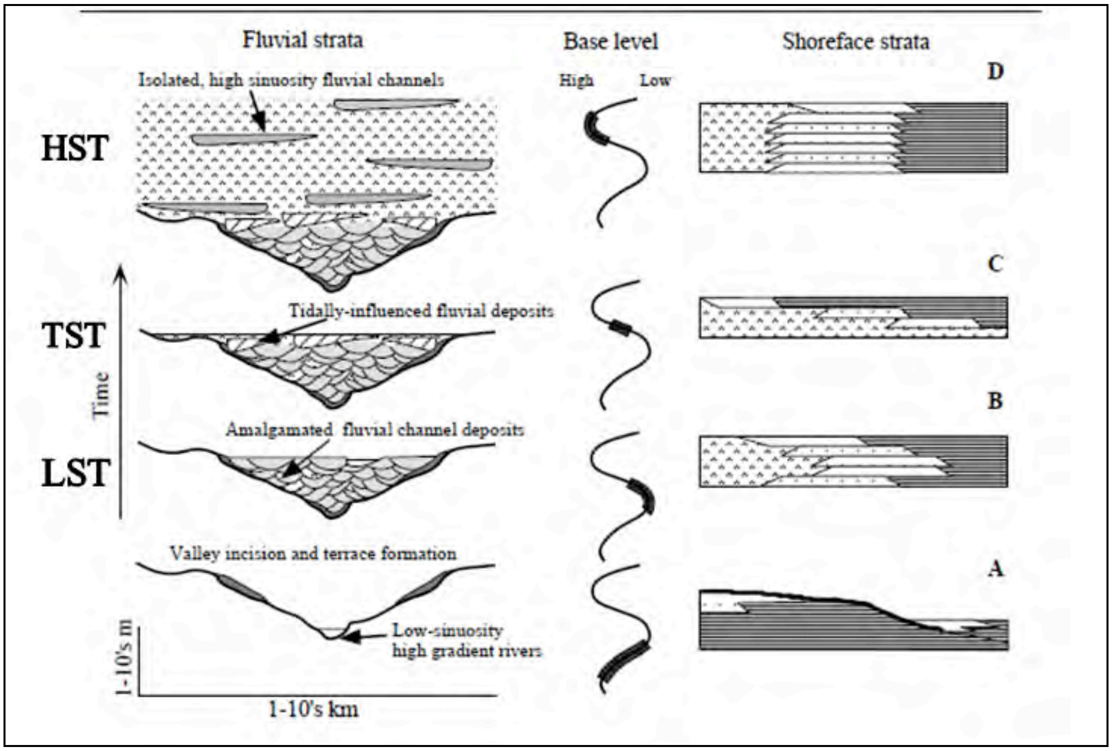

Figure 3—Diagram illustrating fluvial architecture as a function of base level change. (Shanley and McCabe, 1993)

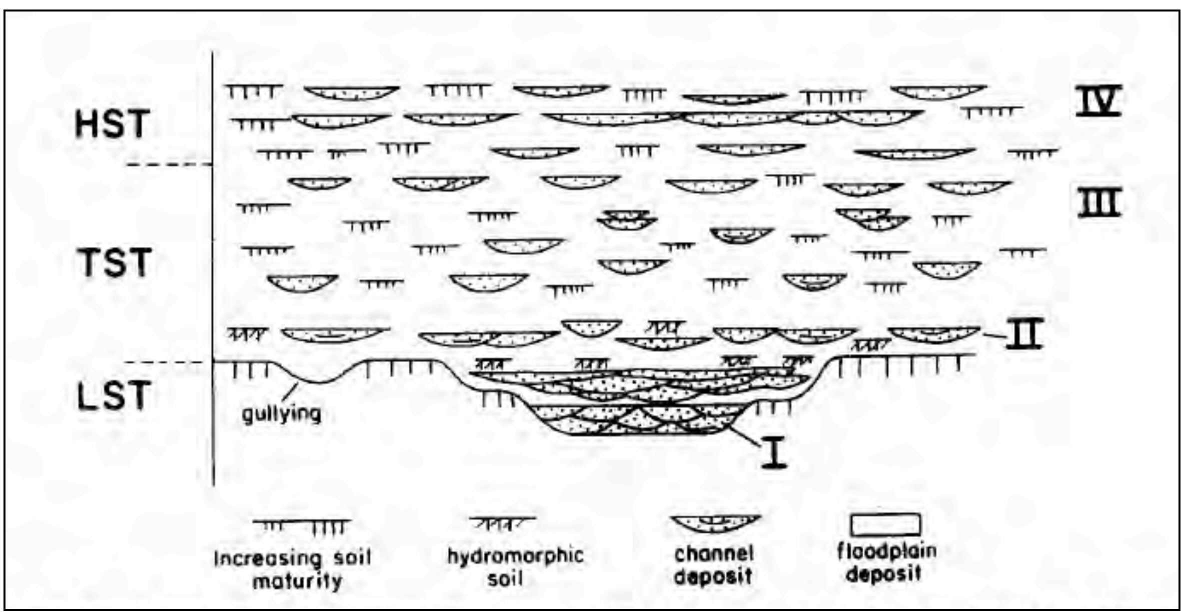

Figure 4—Diagram illustrating simple architecture model for fluvial sequence deposited during base level fall-rise. (Wright and Marriott, 1993)

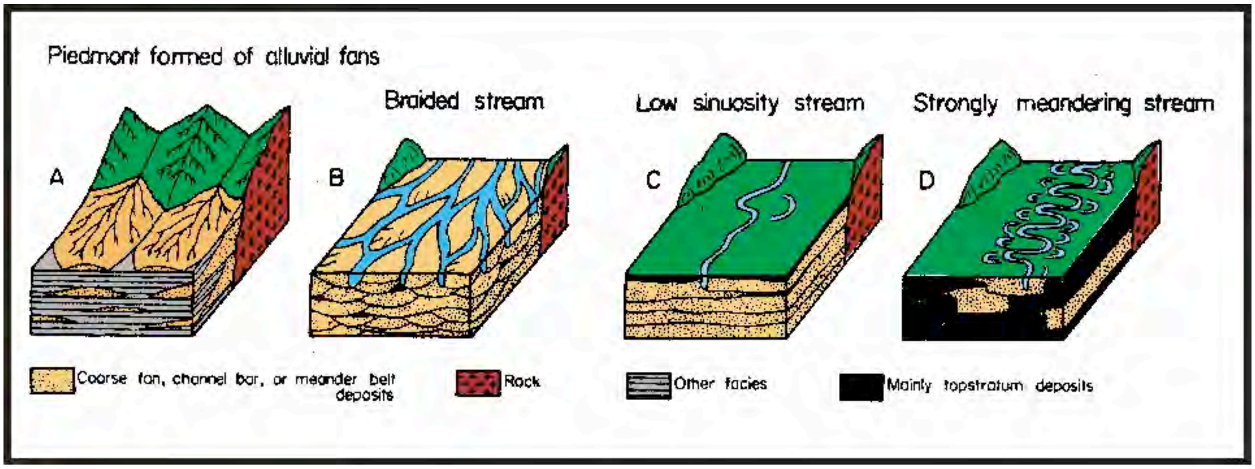

Figure 5—Early fluvial stratigraphy models suggesting net-to-gross is controlled by river plan-form, only 2 end members. (Friend, 1983)

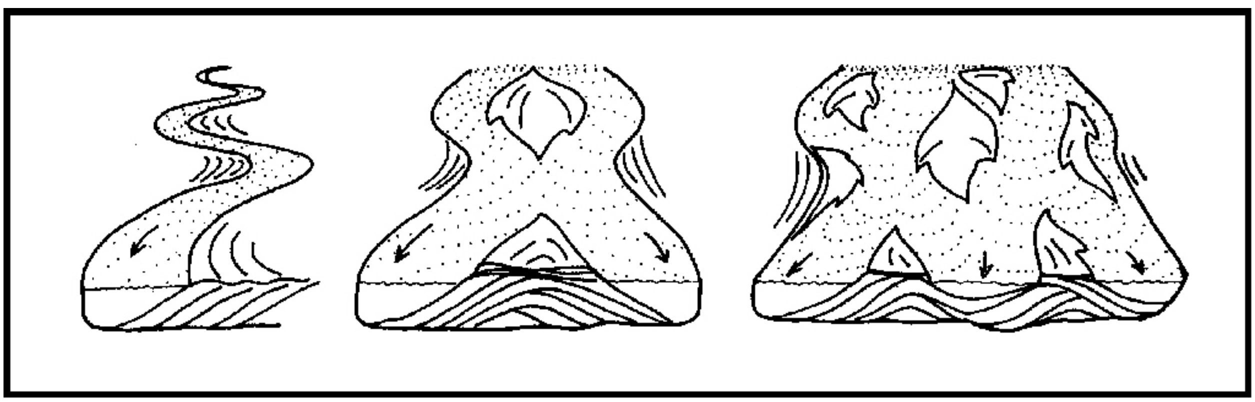

Figure 6—Correlation of cross-sectional geometry of beds (bedding diagram) allowing interpretation of bar and channel type. (Galloway and Hobday, 1996)

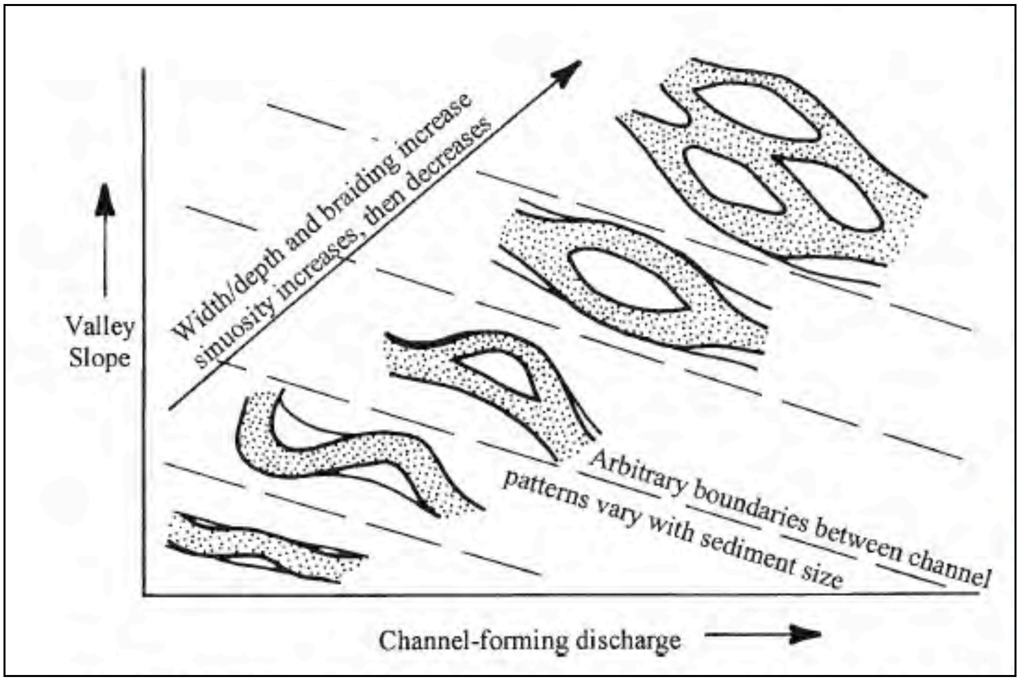

Figure 7—Diagram illustrating varying channel patterns depending on channel forming discharge and valley slope. (Bridge, 2006)

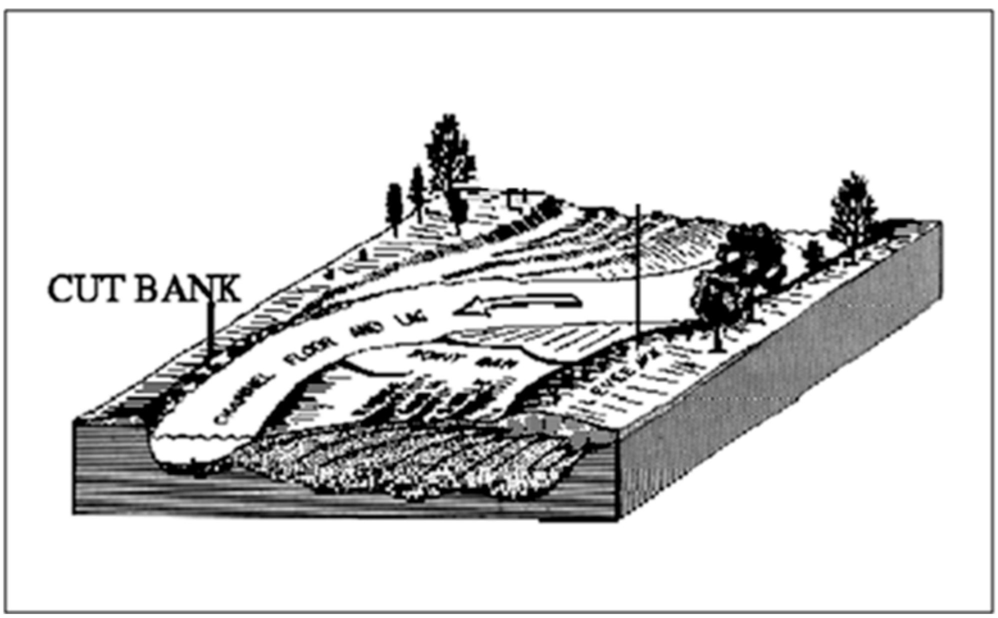

Figure 8—Model of meandering fluvial system with laterally accreting pointbars. (Mikes and Geel, 2006)

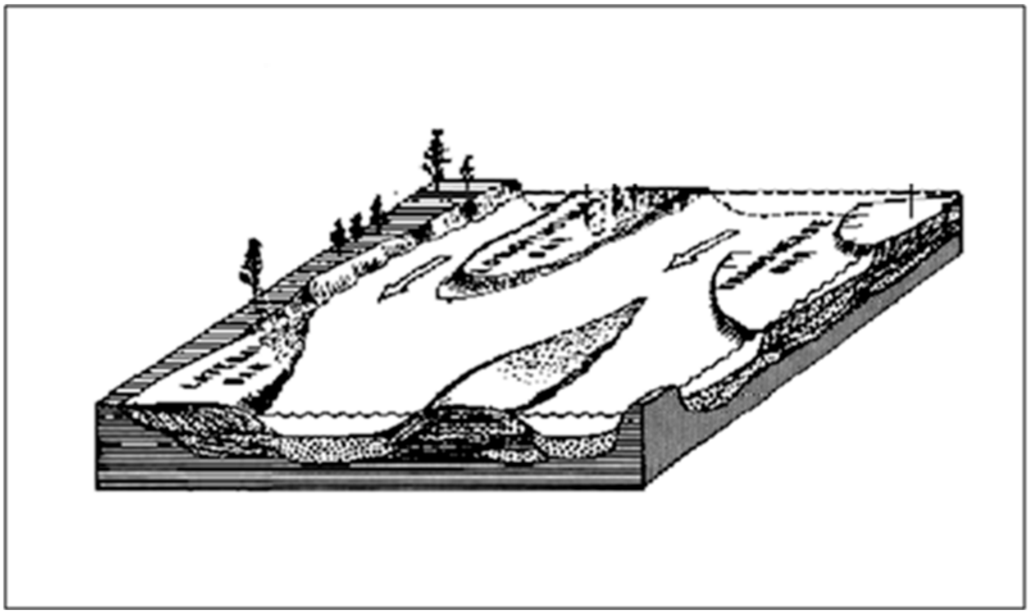

Figure 9—Model of braided fluvial system with mound like braid bars. (Mikes and Geel, 2006)

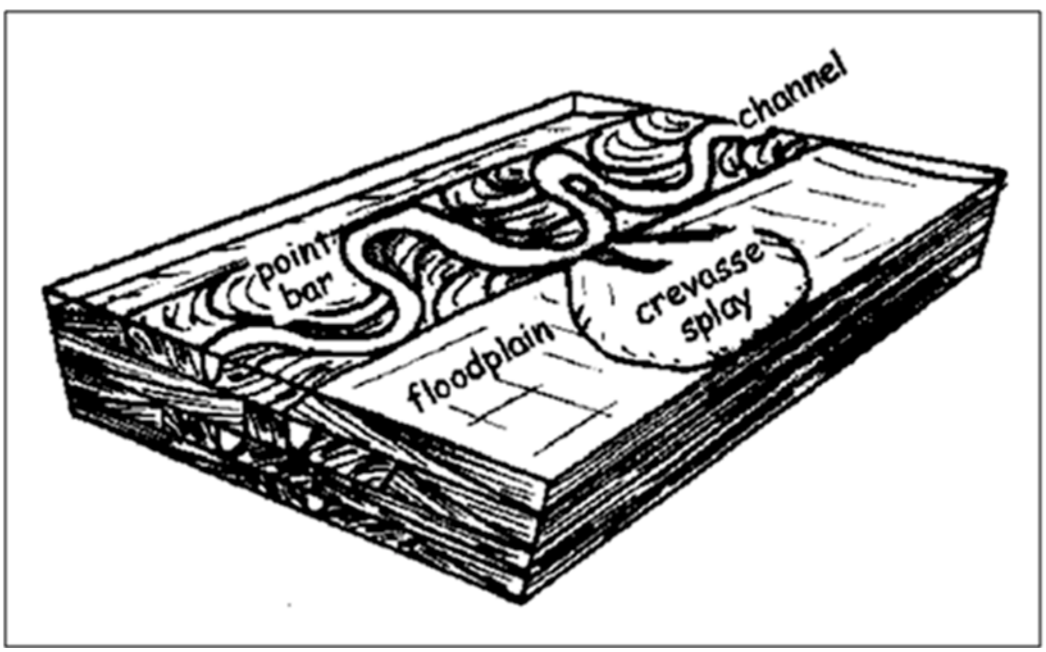

Figure 10—Model demonstrating floodplain crevasse splay. (Mikes and Geel, 2006)

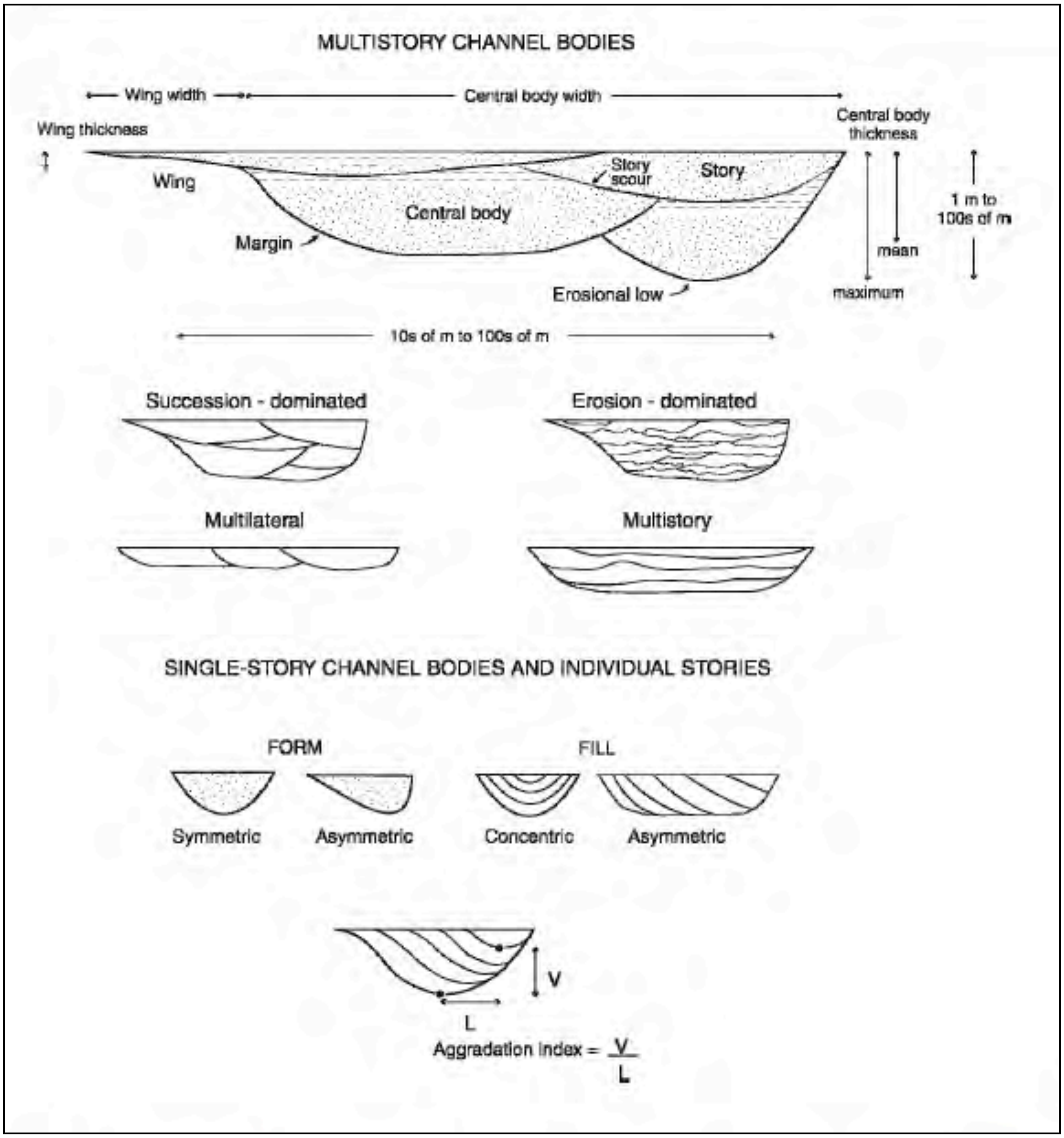

Figure 11—Terminology for describing the geometry of channel bodies. (Gibling, 2006)

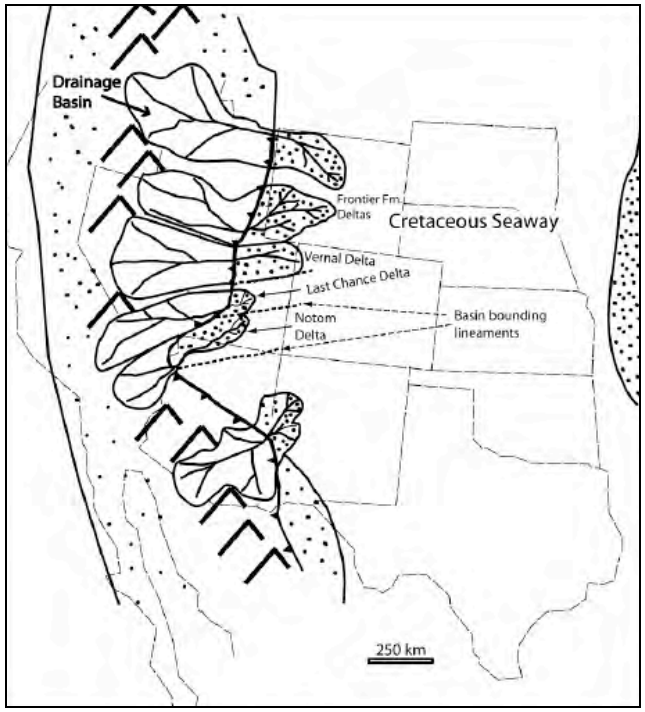

Figure 12—Paleogeographic map of mid-Cretaceous clastic wedges, Notom Delta shown. (Bhattacharya and Tye, 2004)

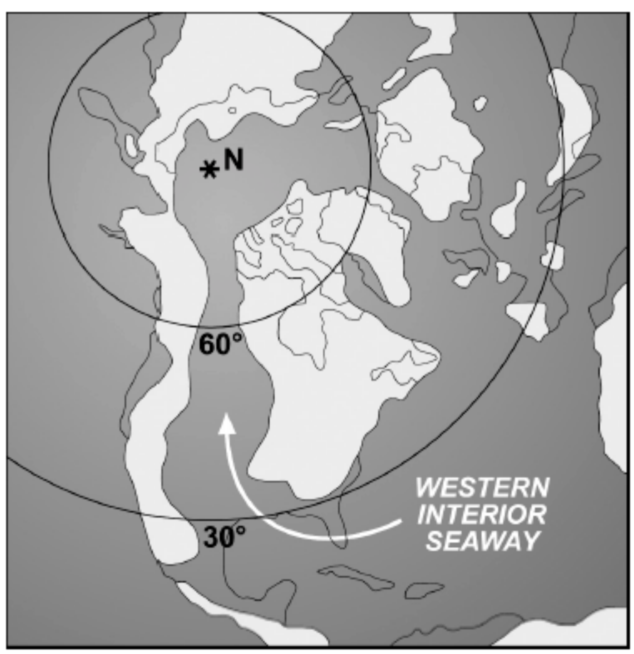

Figure 13—Paleogeography of Western Interior Seaway diving North America in 2 during early Turonian. (Ryer and Anderson, 2004)

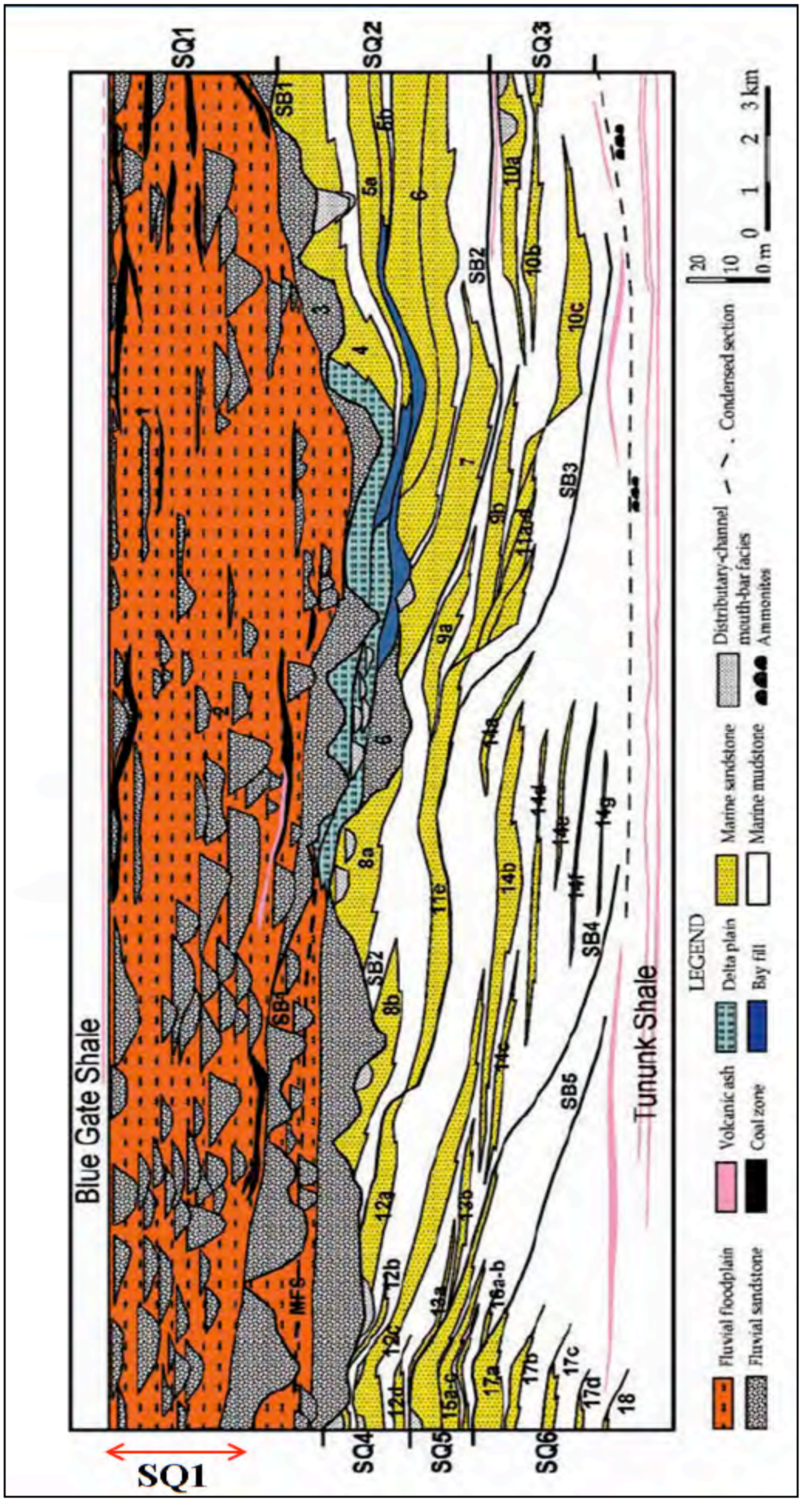

Figure 14—Regional sequence stratigraphy of Ferron Notom Delta oblique to depositional dip view. (Li et al., 2010)

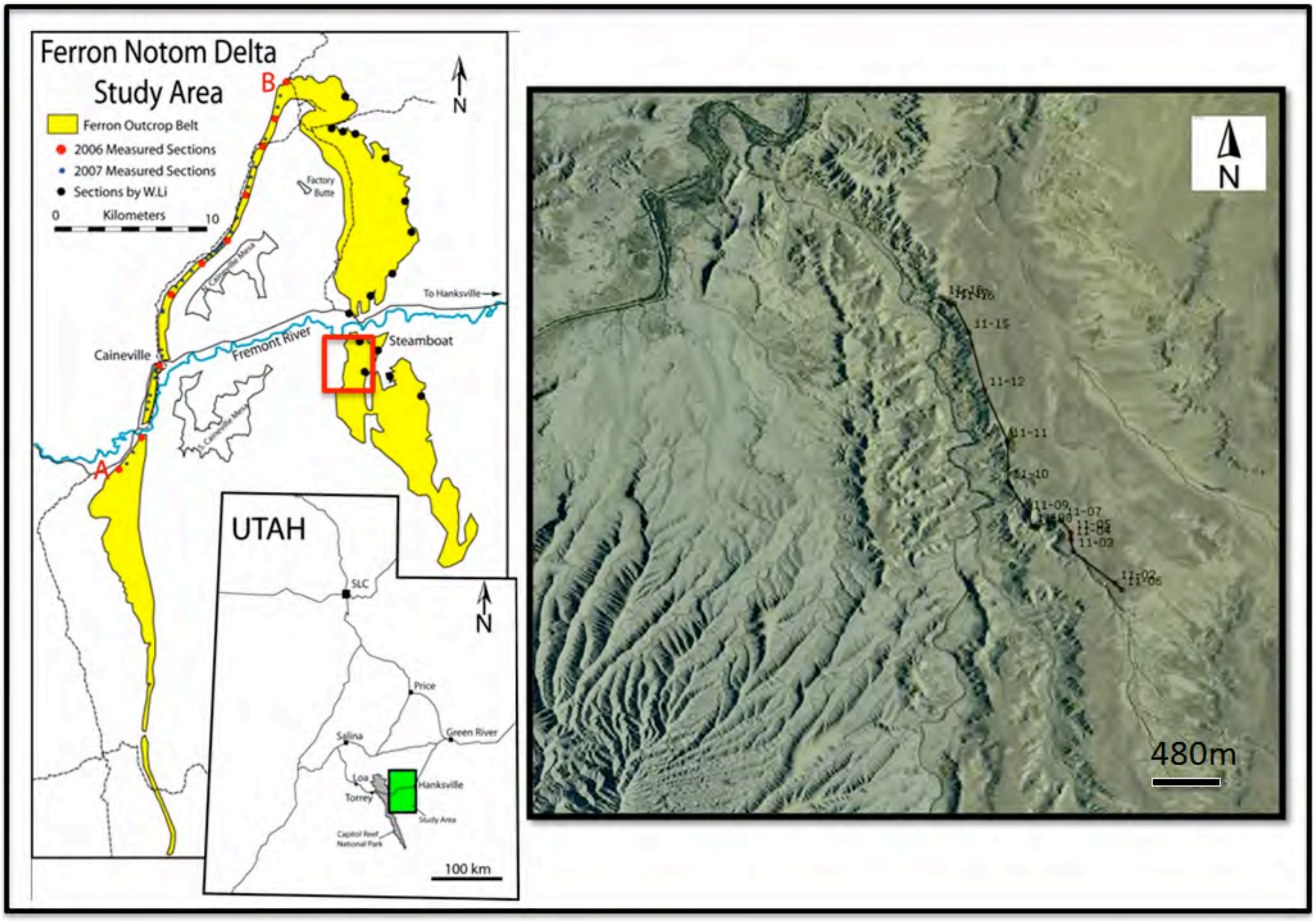

Figure 15—Map showing the location of the study area and the position of vertical measured section.

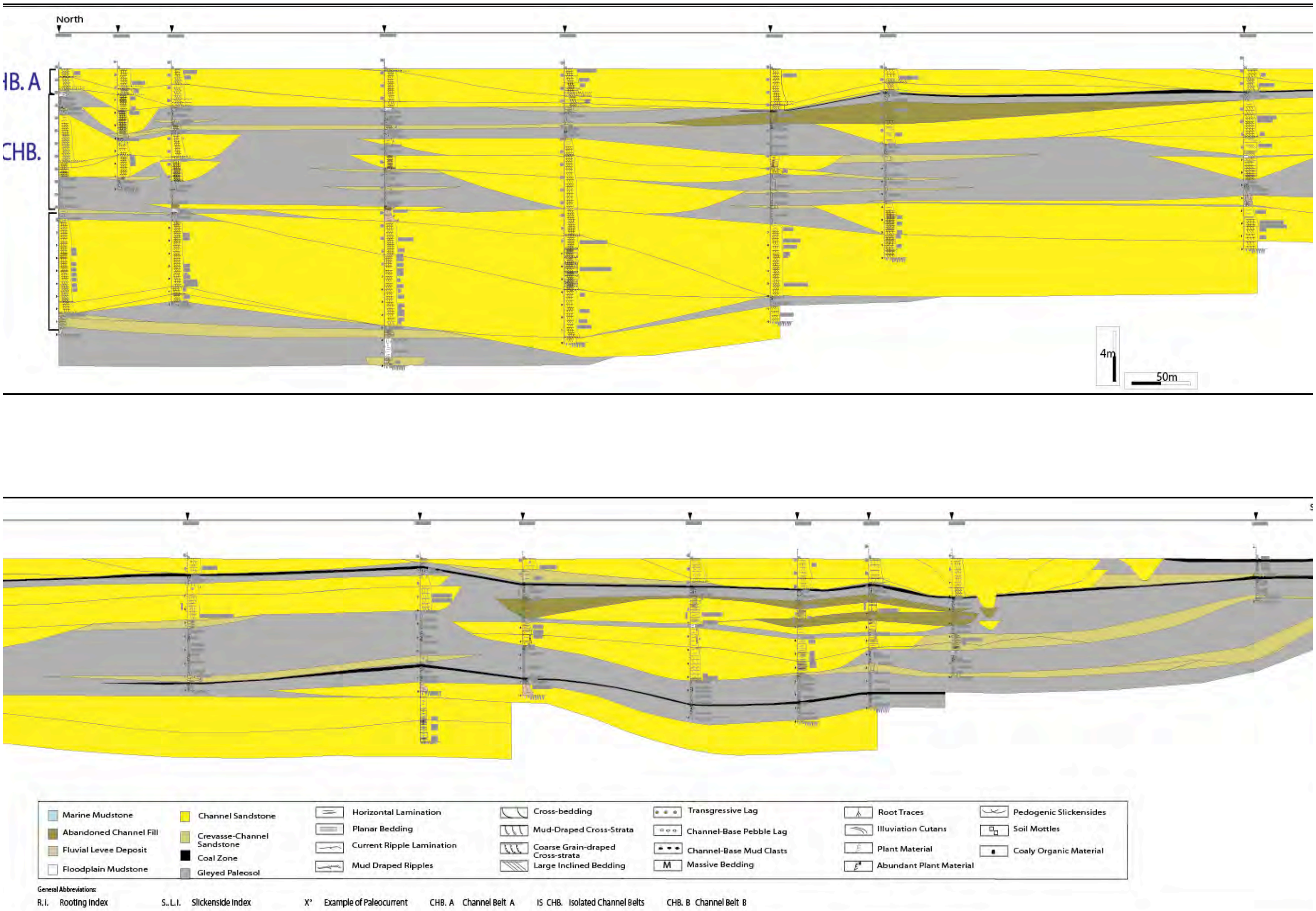

Figure 16—Cross section showing the amalgamated channel belt (CHB. A) and isolated channel belt (IS CHB). Also shows the locations of the vertical measured sections.

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