FACIES ARCHITECTURE AND CONTROLS OF A FLUVIAL SYSTEM, FERRON NOTOM DELTA, UTAH, USA

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Abstract

There are 4 models that have been hypothesized to explain channel-belt organization in ancient fluvial systems 1) avulsion processes create clustered channel-belts with random geometry, 2) channel-belt organization is related to net to gross, wherein the cross sectional geometry of fluvial systems can be attributed to changing accommodation and sediment supply, 3) channel-belt organization is controlled by sequence stratigraphy in which a fall in base level creates lateral confinement and amalgamated clusters within valleys, and 4) fluvial systems can be self-organized by autocyclic processes, producing non-random stratigraphy, dominated by avulsion clusters.

The aim of this research is to test these models by examination of fluvial deposits of the Late Cretaceous (Turonian) Ferron Sandstone Member, within the Mancos Shale Formation in Central Utah, along Sweetwater Wash, where the alluvial stratigraphy of the upper part of the Ferron is particularly well-exposed. Detailed cross sections, based on measured sections, walking out beds, and photopans, will show the proportion of channel belt, floodplain, and overbank splays and crevasse channels, which will address the degree of amalgamation of the channel-belts. Geostatistical methods will be used to determine whether channel-belts are organized in a random or non-random pattern, as well as addressing the length scales at which possible channel belt clusters occur. Previous sequence stratigraphic analysis will help determine the larger-scale allogenic controls on alluvial architecture and stratigraphy. Detailed analysis of the internal facies architecture will enable determination of the plan-view style of the rivers that build each channel belt. This will also allow a test of the classic idea that meandering systems form muddy alluvial successions while braided systems are form predominantly sandy successions.

Introduction

Locally within a fluvial system, the positioning of coarse versus fine sediments is largely controlled by avulsion. In ancient deposits, channelized sand bodies are especially difficult to predict due to uneven distribution (Hajek et al., 2010). Channelized sandstones encased in floodplain shales form an important hydrocarbon-reservoir class (Mesaverde Reservoirs in Colorado, Lorenz et al., 1991; Prudhoe bay, Adams and Bhattacharya, 2005; Travis Peak Formation, Tye 1991; Scalby formation, Eschard et al., 1991). Thus subsurface reservoir prediction requires improved models of channel-belt organization.

Channel-belt organization, as seen in ancient outcrops, is influenced by a mix of autogenic and allogenic controls. The large scale stratigraphy might be some combination of accommodation change because of the sequence stratigraphy as well as local controls such as vegetation, valley morphology and active tectonics (Schumm, 2005). Many studies try to infer allogenic and autogenic influence from alluvial basins (ex. Allen, 1978; Bridge and Leeder, 1978; Leeder 1978). However, the variables that create channel-belt organization are still vague. Is channel-belt organization random? Does it compensate to larger basin wide controls? Is it self-organized? And if so, are channel-belts self attractive or self evasive? These are the questions left to be answered through outcrop analysis of an ancient fluvial system of the Late Cretaceous.

Wright and Marriot (1993) and Shanley and McCabe (1994) apply the concept of sequence stratigraphy to continental strata (Figs. 1 and 2). Wright and Marriot (1993) recognize a fall in relative sea level that creates valley incision and the sequence boundary at the base of the low stand systems tract. As the valley begins to infill, accommodation is restricted by the margins of the valley and thus channel amalgamation is common (Fig. 3B). Increased gradients in the early lowstand, might cause low sinuosity (braided) deposits that are coarser grained. In the early stages of the transgressive systems tract, multistorey channel-belts form, as accommodation is still low. However, channels become more isolated once they are no longer confined within the valley walls and are able to avulse more freely (e.g. highstand). Accommodation decreases in the late high stand systems tract causing lower gradients in channels that coalesce and erode into the floodplain.

Shanley and McCabe (1994) propose a model where system tracts are classified according to changes in base level. However, a key difference lies in the location of tidally influenced facies and isolated channels (Fig. 2). A fall in base level creates valley incision and terrace formation. Channels amalgamate as base level rises and valleys infill. Towards the top of the valley, tidally influenced facies are deposited. As base level continues to rise and reaches a peak, channels avulse out of the valley and become isolated. In opposition to Wright and Marriot (1993), Shanley and McCabe (1994) claim that the greatest isolation of channels occurs within the highstand systems tract, versus the transgressive systems tract.

Bristow and Best (1993) present a schematic diagram illustrating the preservation of braided river deposits as a function of aggradation rate, channel migration and avulsion (Fig. 4). Hajek et al., (2010) use a more quantitative approach to classify the degree of channel avulsion. Through experiments and outcrop analysis they propose self-organization of fluvial systems into avulsion clusters. Hence, the architecture of the channel-belts in Sweetwater Wash could be an 'avulsion dominated stratigraphy' (Hajek et al., 2010), implying minimal influence from basin boundary conditions and more self-organization over long time periods. Thus tectonic tilt, subsidence, sediment supply and sea level may have a less prominent signature than implied by basin wide sequence stratigraphic models. This hypothesis could be tested by using the method outlined by Cressie (1993) in which a K constant is used to determine the degree and length scales of non-random clustering within the system.

Sweetwater Wash shows the traditional facies expected of meandering and braided systems. Although heavily criticized within the literature (e.g. Adams and Bhattacharya, 2005), preliminary observations of the deposits in Sweetwater wash show that meandering rivers are mostly muddy while braided rivers are coarse grained and sandy. The northern most extent of Sweetwater Wash contains an example of laterally accreting flood deposits (Fig. 5). The muddy lithology of these heterolithic deposits is a good example of the facies associated with a meandering river. Within the same wash, southernmost outcrops contain sandy bars that accrete in the direction of mean paleocurrents. These downstream accreting bars may represent a sandy braided succession (Fig. 6).

The Jones and Hajek (2007) approach to the study of avulsion styles can also be applied to the exposures in Sweetwater Wash. They classify avulsions as being stratigraphically abrupt or transitional; based on whether channels overlie distal fine grained floodplain sediments or proximal overbank and levee deposits respectfully. Overbank deposits encompass crevasse splays and crevasse splay channels. The significance of this classification is that it enables inferences to be made regarding avulsion styles, levee strength and substrate erodability. For example, a local avulsion occurs proximal to the alluvial ridge where crevasse splays are common. Superposition of coarse grained channel-fill on overbank deposits is likely since the channel rejoins its original path downstream (Fig. 7A). A regional avulsion occurs on a larger scale and would produce a channel that overlies fine grained floodplain sediments (Fig. 7B, Jones and Hajek, 2007). Hence, self attractive versus self evasive or local versus regional avulsion styles can be proven using stratigraphical styles (abrupt vs. transitional).

Regional Geology

In the late Cretaceous a north to south seaway (Western Interior Seaway) extended through North America (Fig. 8). Within this basin, fluvio-deltaic sediments were deposited as part of the Notom delta complex during the Sevier Orogeny. The Sevier Orogeny created a fold and thrust belt that developed into a foreland basin in the Middle Turronian to Late Santonian (DeCelles and Giles, 1996; Ryer and Anderson, 2004). As a result of this Orogeny, rivers flowed to the northeast and created complexes which consist of the Notom, the Last Chance to the west and the Vernal delta to the north (Ryer and Anderson, 2004). The Notom delta, being the oldest of the three, was deposited prior to a regional avulsion that led to the creation of the Last Chance and Vernal delta (Fig. 9; Gardner, 1995).

The Ferron Sandstone Member of the Mancos Shale Formation is the result of fluvial deltaic deposition. It is bounded by the Bluegate Shale Member at the top and the Tununk Shale Member at the bottom (Garrison and van den Bergh, 2004). The Bluegate-Ferron contact marks a transgressive surface of erosion and a deepening event in the geologic record. Peterson and Ryder (1975) classify the upper Ferron as fluvial dominated deposits as compared to the lower half which are shallow marine.

The Ferron member is classified into 6 sequences, 18 parasequence sets, and 42 parasequences (Fig. 10; Zhu et al., 2010). Bentonite age dating revealed that the Notom delta complex was deposited in 620,000 years, suggesting sequences of 100,000 years (Zhu et al., 2010). This study focuses on the fluvial deposits within sequence 1, exposed between Caineville and Hanksville, Utah (Fig. 11). Sweetwater Wash has exposures of fluvial channel-belts in a low net to gross environment. They extend to the north, where fluvial bodies were studied by Li et al., (2010). This project aims to pick up where Li et al., (2010) stopped and add more detail to the cross section created by Zhu et al., (2010). Li et al., (2010) showed that sequence 1 forms a compound valley fill overlain by a low net to gross transgressive to highstand package (Figs. 12 and 13). Multiple cut and fill episodes occur with V1 cutting into V2 which cuts into V3 (Fig. 13). These compound valleys are equivalent to parasequence sets and are part of the lowstand systems tract (Li et al., 2010). The second cross section (B-B’) is relatively close to Sweetwater Wash and shows a lack of preservation of V2 and V3, thus making the base of V1 the starting point of this study. Nevertheless, V2 as noted by Li et al., (2010) shows more meandering systems with marine and tidal influence while V1 shows a vertical succession from braided to meandering attributed to a decrease in slope and discharge as the valley filled. However, the detailed analysis of the clustering of channels in the upper part of sequence 1, integrated with paleosols, hasn't yet been elucidated. Nor has any work been done in terms of looking at the fluvial style within these low net to gross packages.

Research techniques

South of US-24 and the Freemont River there are continuous exposures of isolated fluvial channel-belts encased in floodplain shales. Research methods included trenching, taking measured sections, capturing photomosaics, and interpreting bedding diagrams. In addition, nine measured sections were collected and placed into a cross section (Fig. 14).

Equipment that was used included grain size cards, Brunton 10X lenses, Jacobs staff, Stanley tape measure, Brunton compasses and 2 DSLR cameras. Trenching was undertaken with a pair of shovels and a pick axe. A Gigapan and telephoto lens were also used to capture detailed facies architecture of particular cliff faces. Gigapan software, Adobe Illustrator and Adobe Photoshop were used to stitch and edit photos. In terms of interpreting bedding diagrams the Miall (1992) classification scheme will be followed distinguishing up to eighth order surfaces.

Initial research results

A cross section was constructed in conjunction with the regional stratigraphic work by PhD candidate Oyebode Famubode as well as MS candidate Omar Montes. A correlation of the measured sections shows the overall channel stacking in Sweetwater Wash. Figure 15 shows an oblique view cross section of 3 major groups of channel-belts, within an interpreted transgressive to early highstand systems tract. The valley floor and lowstand systems tract is below the range of the measured sections in the south but is more clearly seen in North Sweetwater. The 3 groups within the cross section include a lower section that is relatively amalgamated (CHB. B), a middle section that is highly isolated (IS CHB.), and an upper section that is more amalgamated (CHB. A). The isolated channel-belts are encased in gleyed paleosols and floodplain shales. It is immediately apparent that the middle channelbelt, although low net to gross, clearly clusters suggesting nonrandom cut and fill. My project is particularly focused on the stratigraphic organization of channel-belt B. Photomosaics and paleocurrents suggest an overall downstream and lateral accreting. Work by Montes (in prep.) shows the facies architecture of Channel-belt A and the muddy isolated channel-belts while Famubode 2011 (in prep.) focuses on the cyclicity of floodplain deposits and their associated paleosols within a fluvial sequence-stratigraphic framework.

The datum for this study is the transgressive marine surface of the Bluegate Shale. Hanging on the Bluegate-Ferron contact doesn't seem to disrupt the geometry of the channel-belts, and it is more regionally significant compared to the isolated coal seams within the sequence. Panels that were measured were mostly medium to coarse grained, trough cross-bedded sandstones draped by fine grained ripple-laminated sandstones. In the northernmost extent of Sweetwater Wash, at least three different stories are evident, with mud chips and pebble lags at the base followed by fining upward sequences. Paleocurrents showed a progressive change from northwest to the northeast and ultimately, southeast. Some trough cross beds were lined with mud indicating tidal influence. A trace fossil called *Teredolites* was evident at the base of channel-belts suggesting marine influence (Bromley et al., 1984). The presence of isolated coal seams implies a relatively wet environment where rapid burial of organic rich sediments was possible. Floodplain deposits were also measured and included purple to green colored paleosols and mudstones with abundant rooting and slickensides.

Proposed future research

The proposed future research involves calculating channel dimensions, in terms of width and depth, from the data collected. Dimensions can be extracted by looking at detailed facies architecture of the outcrop. Interpretive bedding diagrams are one way to outline significant surfaces, bedform geometry and grain size trends. They also allow channel dimensions to be easily recognized through thalweg deposits and fining upward trends. These patterns should help constrain the depth of the channels, since the uppermost channel of a channel-belt usually preserves its true depth. Paleocurrents, along with mapping of channel-belt margins, will help reconstruct channel-belt geometry.

The degree of channel clustering (influence of autogenic controls) can be calculated through a K function (Cressie, 1993)

$$K(h) = \lambda^{-1} E(N(h))) \text{ for } h > 0$$

where λ is the number of points in the study area, N is the area of the region and E(N(h)) is the average number of points within distance h of each element. Thus, autogenic controls will be constrained by the type of deposits located in Sweetwater Wash. Allogenic influences can be interpreted by creating a cross section and comparing the architecture to sequence stratigraphic models. Consequently, inferences could be made about discharge, climate, base level, sediment supply and tectonic trends.

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Figures

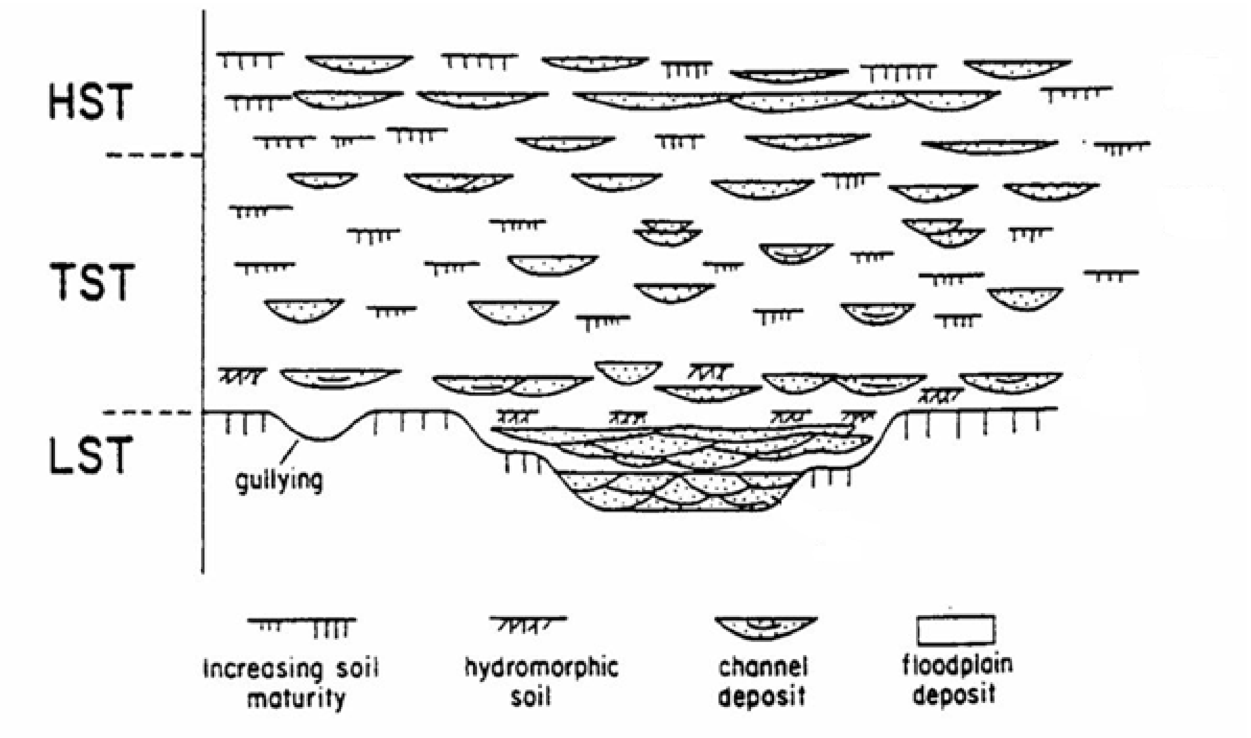

Figure 1. A conceptual sequence stratigraphic framework that shows channel geometry in non marine systems. The lowstand and highstand systems tract emphasizes channel amalgamation while the transgressive systems tract shows isolated channels encased in floodplains (Wright and Marriot, 1993).

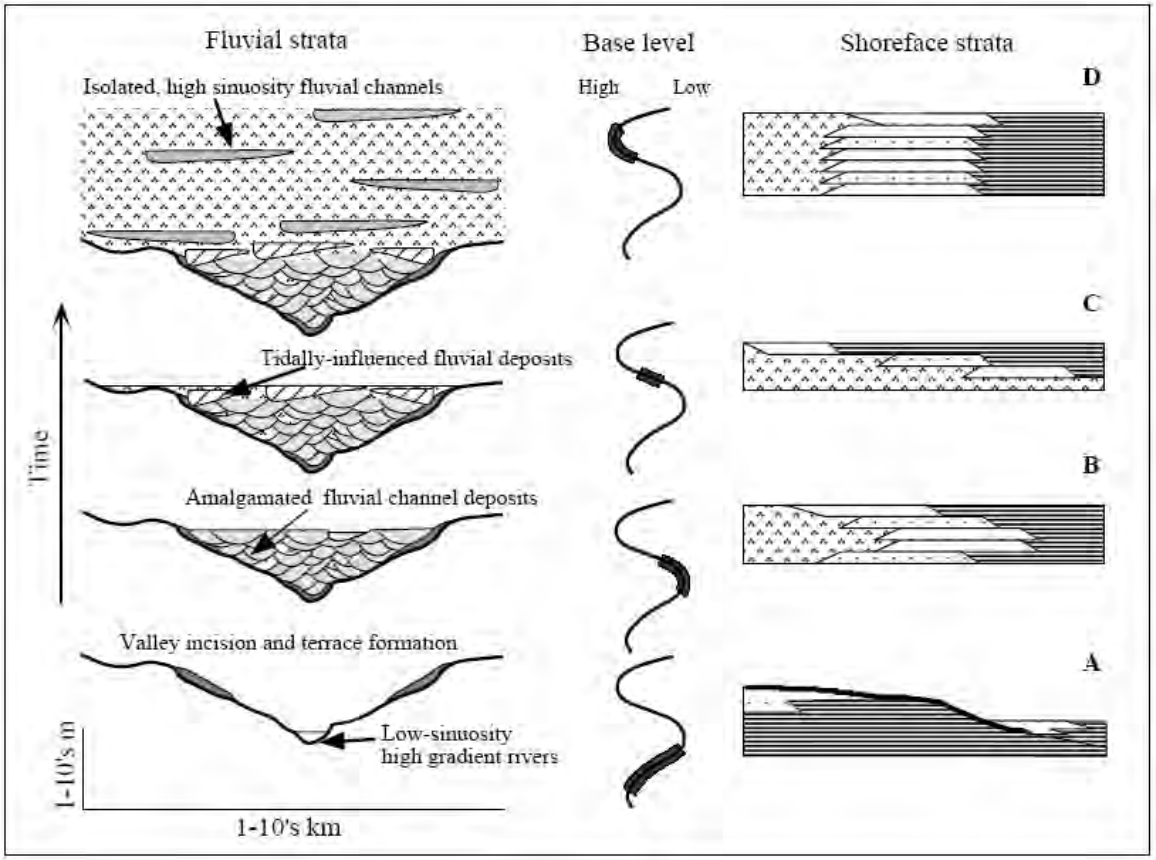

Figure 2. A conceptual sequence stratigraphic framework for continental strata with base level as a main control. Fall in base level creates valley incision. Lowstand and transgressive systems tract result in valley infill and deposition of tidally influenced facies. Isolated channels encased in floodplain are prominent within the high stand systems tract (Shanley and McCabe, 1994).

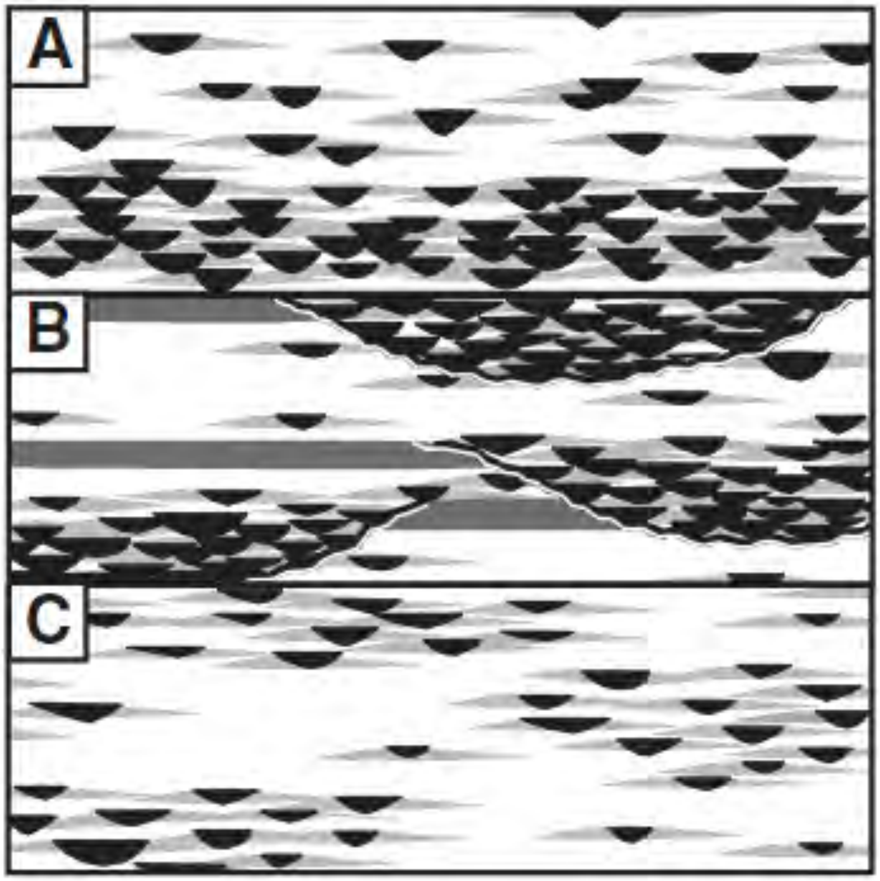

Figure 3. A strike view cross section emphasizing channel geometry according to different controls A) Geometry attributed to changes in basin wide controls B) Channel geometry due to fall in sea level followed by valley infill C) Channel clustering produced by non random avulsion. Black is coarse-grained channelbelts, light gray is overbank deposits like levees and crevasse splays and dark gray are regions of intense paleosol development (Hajek et al., 2010).

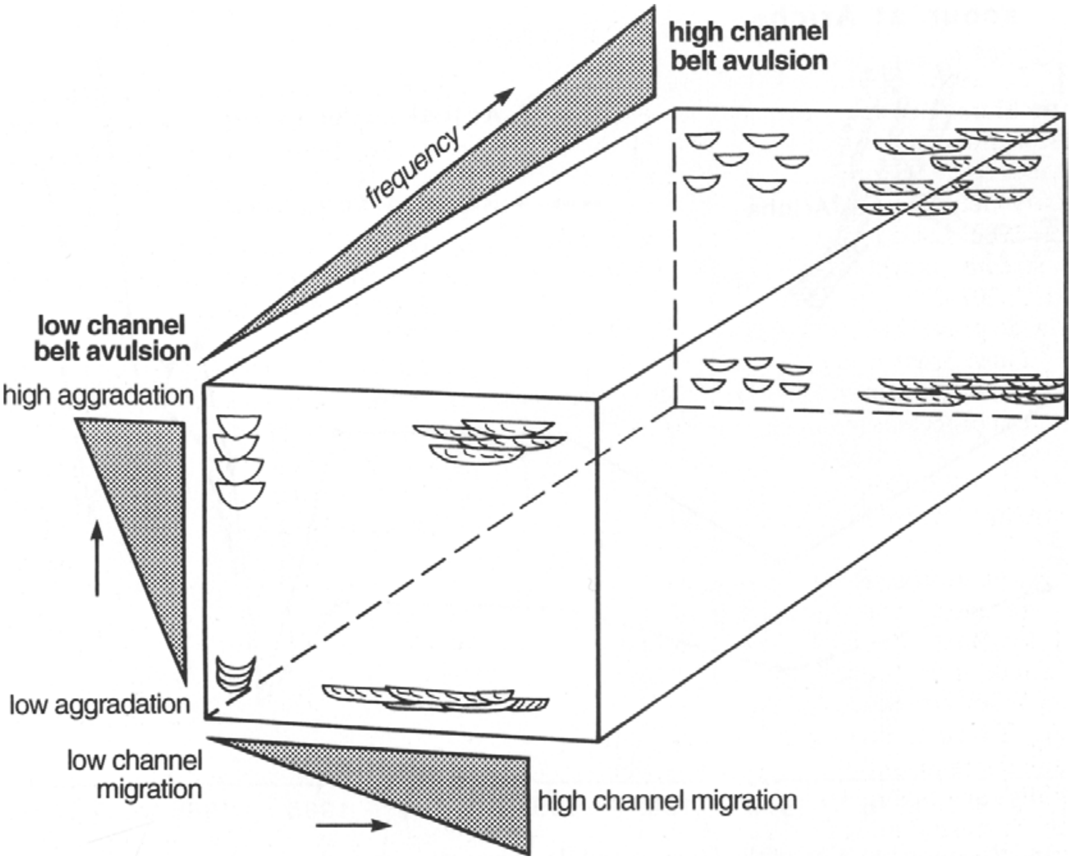

Figure 4. A schematic diagram showing preservation of a braided river with morphology based on channel migration, aggradation rate and avulsion (Bristow and Best 1993).

Figure 5. Laterally accreting flood deposits within a muddy, meandering stream in Sweetwater Wash.

Figure 6. Sandy braid bars dip in the direction of paleocurrents. Paleocurrent is from right to left.

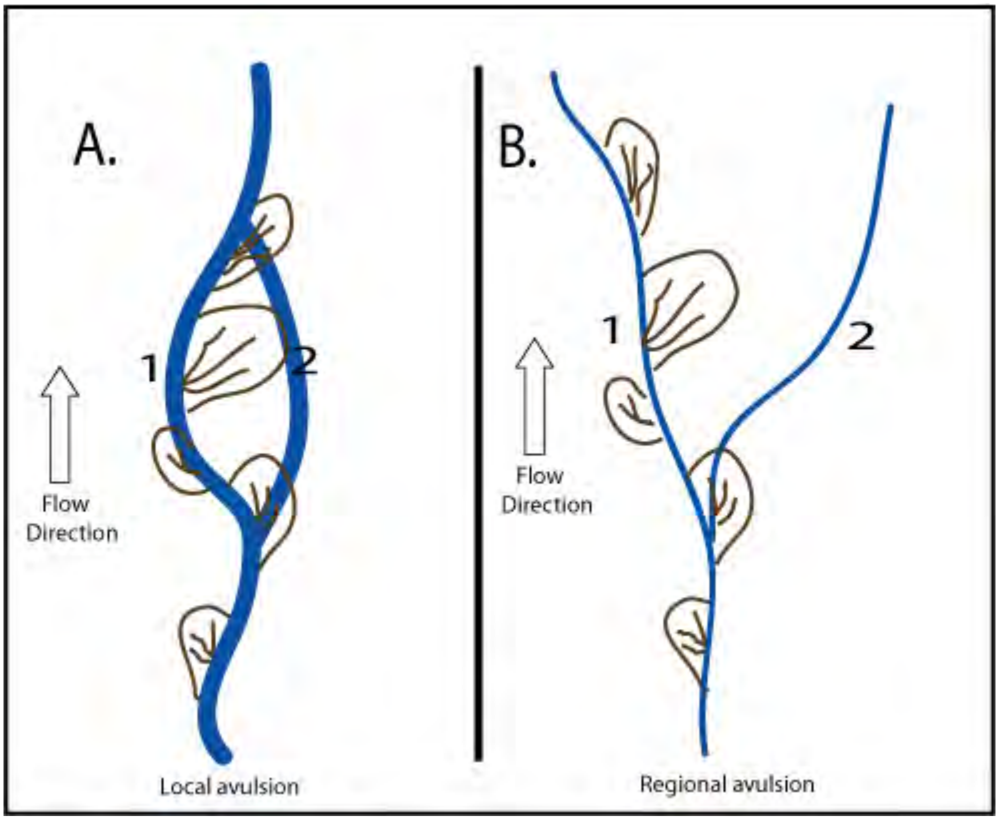

Figure 7. Cartoon shows different styles of avulsion in rivers with flow direction to the north. A. Local avulsion (from 1 to 2) where the river rejoins its path downstream; it overlies crevasse splays of the original system. B. Regional avulsion (from 1 to 2) where river jumps from its original path and overlies fine grained floodplain sediments.

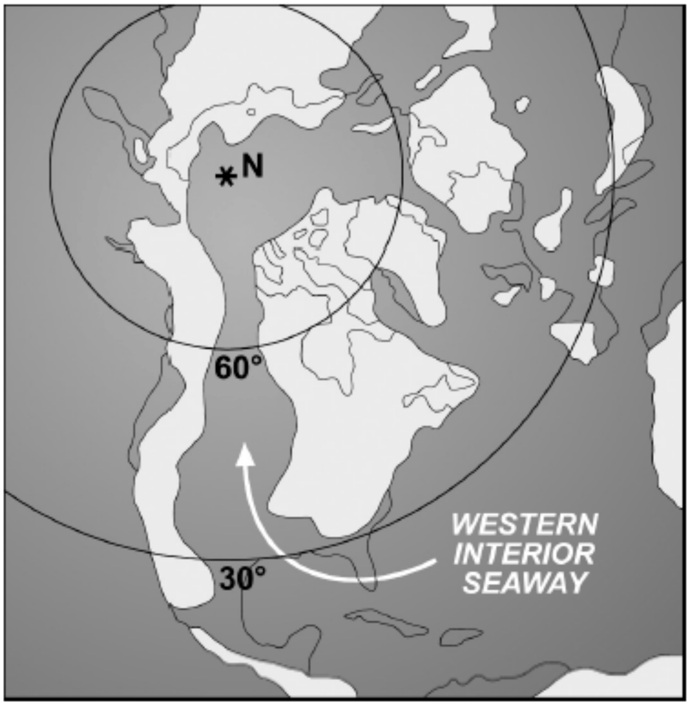

Figure 8. Reconstructed cartoon of the Western Interior Seaway (Ryer and Anderson, 2004).

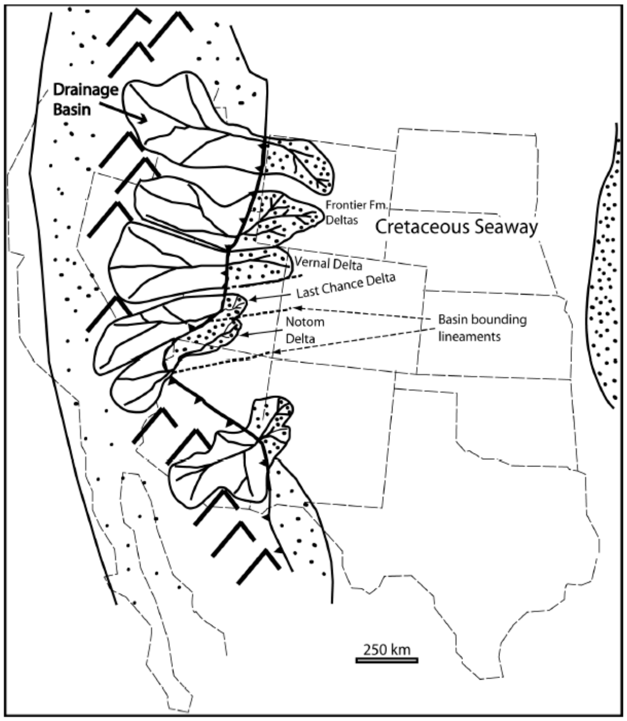

Figure 9. Paleogeographic reconstruction of the Western Interior Seaway with deltaic complexes being deposited in the Late Cretaceous (Gardner, 1995).

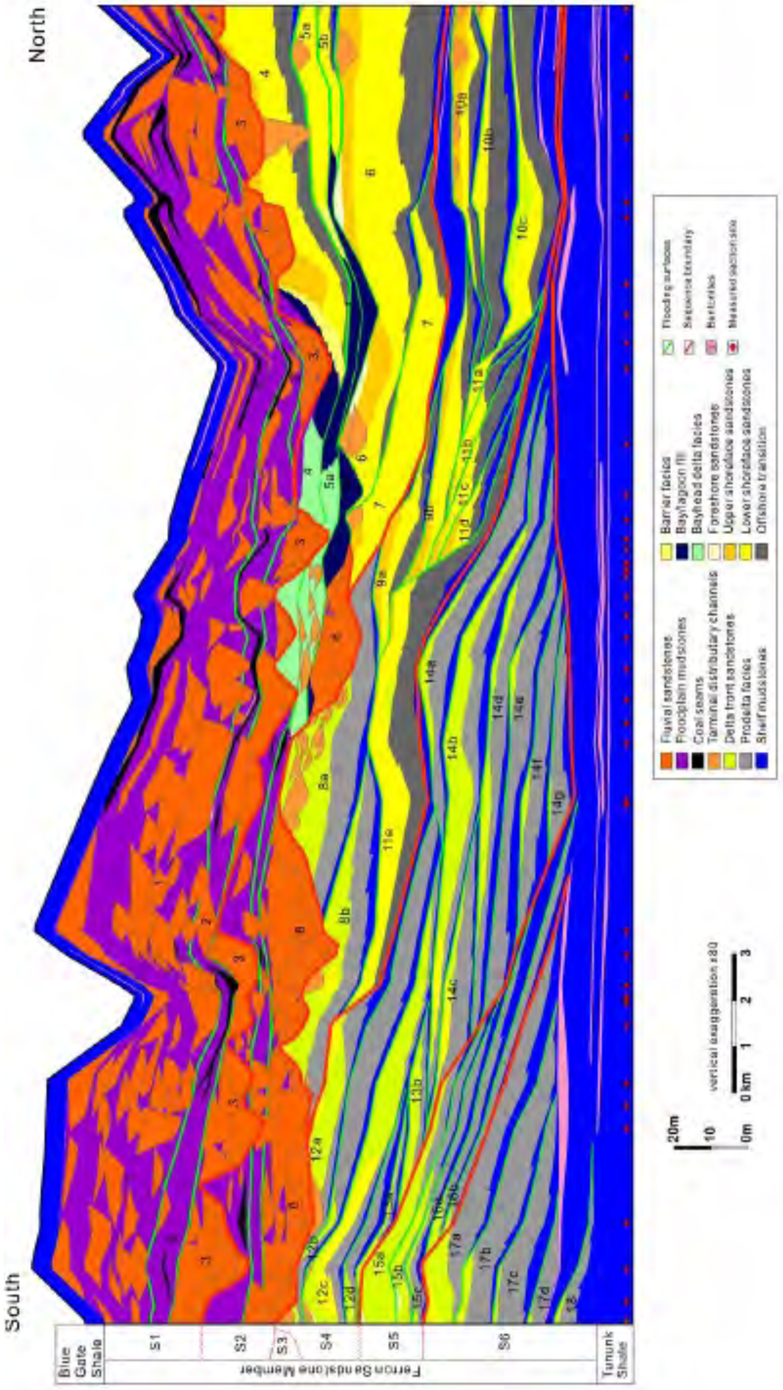

Figure 10. Dip section of the Ferron Notom showing 6 sequences, 18 parasequence sets, and 42 parasequences. The sequence stratigraphic framework as created by Zhu et al., (2010).

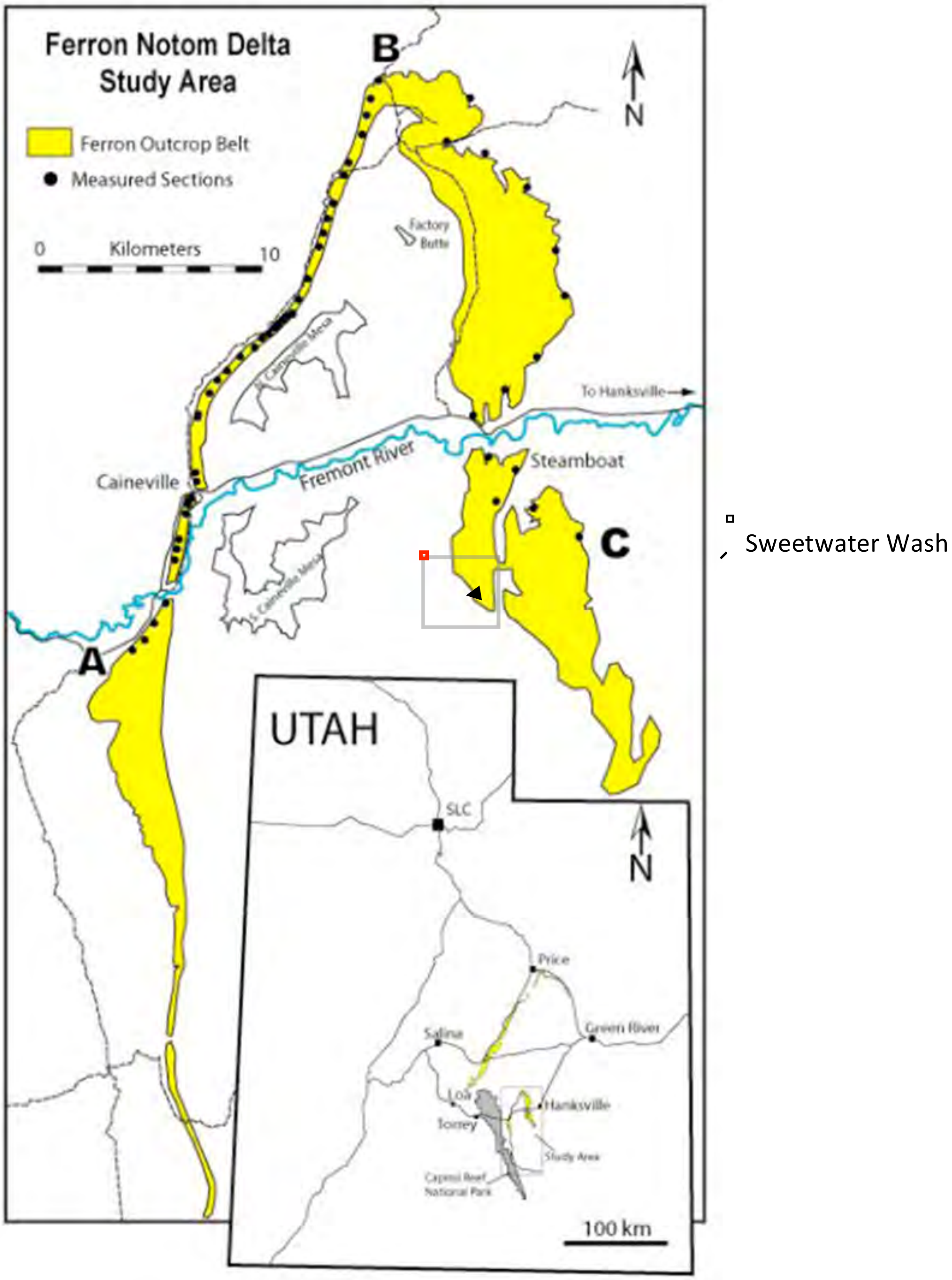

Figure 11. Location of study area (Zhu et al., 2010).

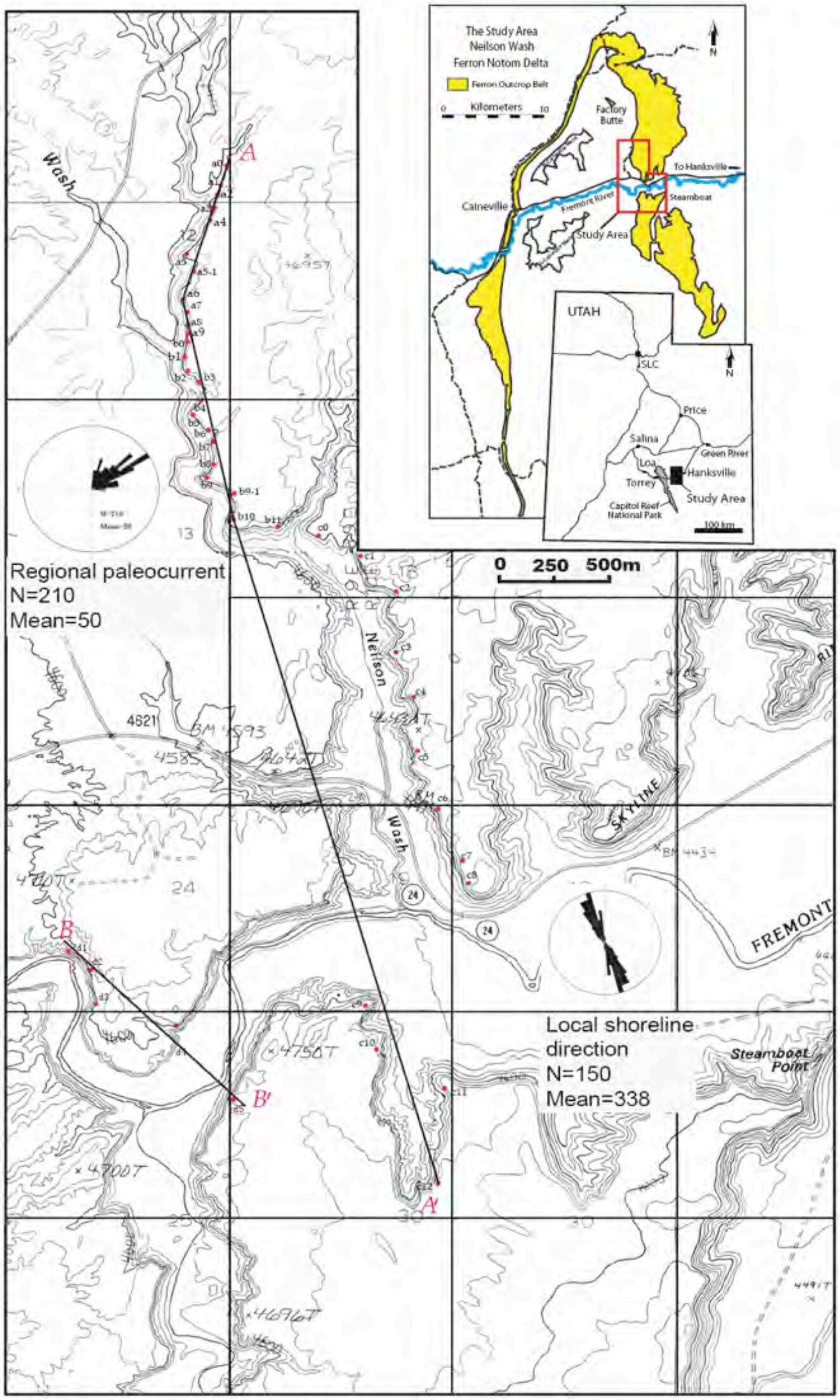

Figure 12. Location of 2 measured sections taken relatively close to the study area- north of Sweetwater (Li et al., 2010).

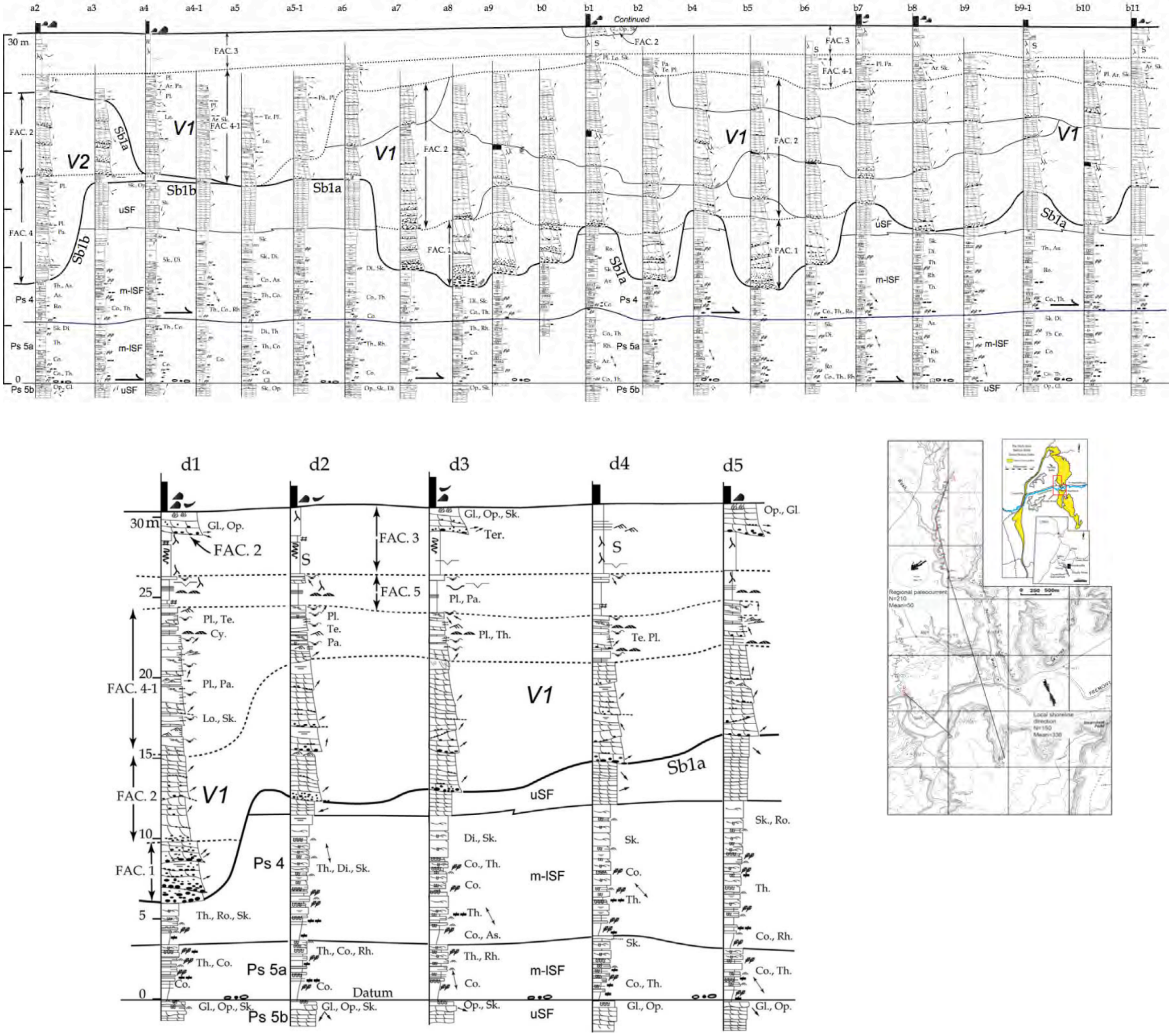

Figure 13. 2 cross sections that show stacked amalgamated valleys representing compound valley fills that are equivalent to parasequence sets. V1 cuts into V2 which cuts into V3. V1 being the oldest. The base of V3 marks the SB1 which separates is from the marine parasequence below, PS4 which is a marine parasequence (Li et al., 2010).

Figure 14. Google earth map showing the location of measured sections within Sweetwater Wash that were used to make the cross section. Extra measured sections were supplemented by PhD candidate Famubode.

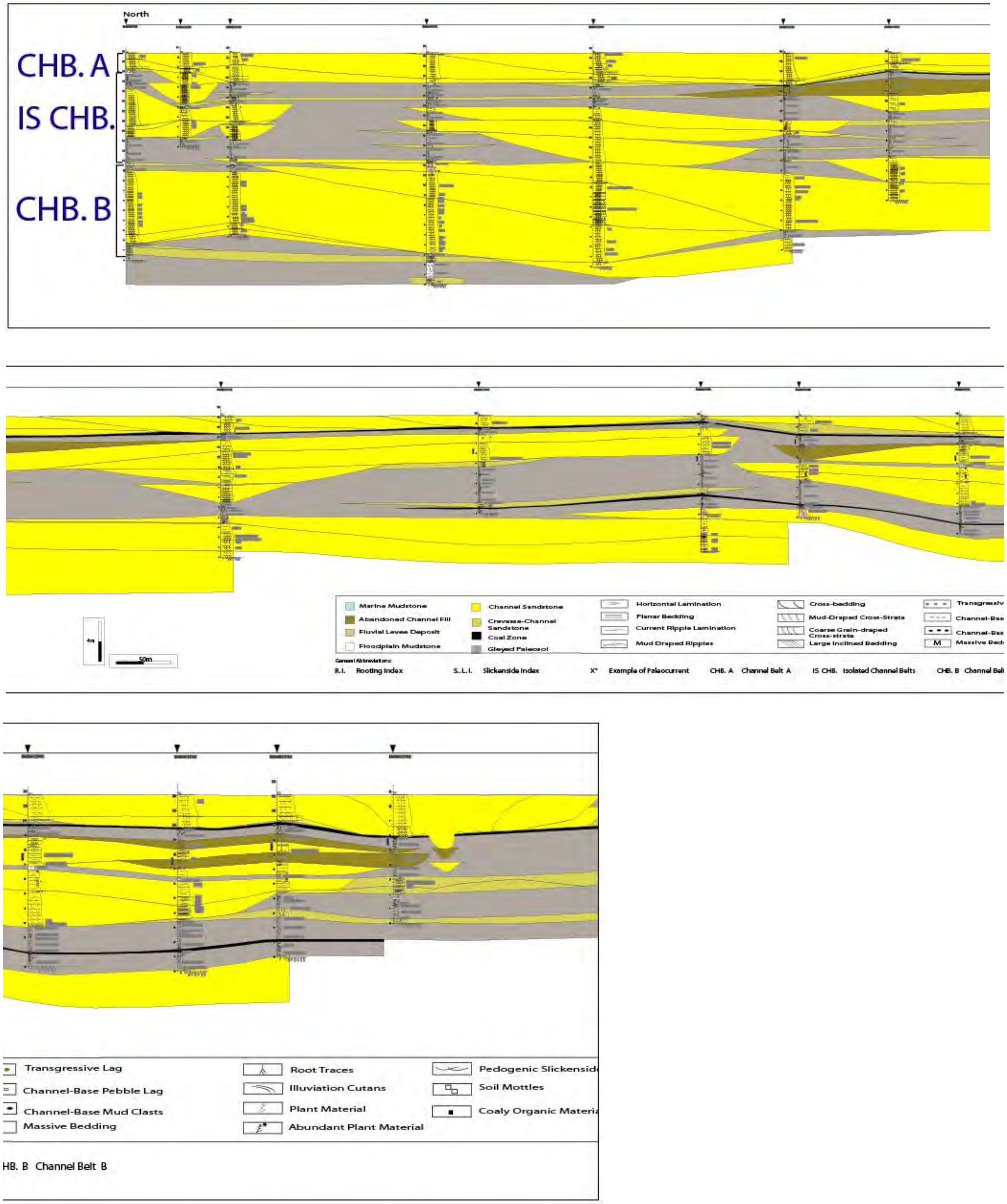

Figure 15. Correlation of measured sections taken in Sweetwater Wash. The 3 parts connect together to form a north to south cross section.