SHOREFACE-DELTA FRONT TRANSITION IN AN ASYMMETRIC, WAVE-INFLUENCED DELTA, CRETACEOUS FERRON NOTOM DELTA, UTAH

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ABSTRACT

Research of asymmetry in the wave-influenced modern Danube and Brazos deltas suggests that the asymmetry resulted from the interaction of net longshore drift, fluvial sediment discharge and storm events. These processes result in a distinct facies change between the updrift and downdrift side of the delta. Despite the recent proposal of an asymmetric facies model, the bed-scale facies architecture of this transition in ancient settings is not well understood.

The Ferron Notom Delta is an asymmetric wave-influenced delta that consists of two facies associations, updrift wave/storm-dominated shoreface successions and downdrift river-dominated active delta fronts and mouth bars. The shoreface is located in the updrift side of the delta and is characterized by uniform sandy, coarsening upward successions. The river-dominated mouth bar deposits are present in the central part of the delta and are characterized by heterolithic, muddier, coarsening upward facies successions with soft sediment deformation and growth faults. These observed facies indicate the presence of shoreface and river-dominated architectural elements. Other architectural elements that are present include storm sheets and terminal distributary channels. The goal of the study is to map the bed-scale facies architecture of the transition between downdrift delta front and updrift shorefaces. By documenting the onlap/offlap/truncated geometry of the transition between the facies I aim to understand the chronological order of deposition and the processes operating in an ancient asymmetric delta using photomosaics and measured sections.

INTRODUCTION

Deltaic studies have been primarily quantified in the early literature based on external deltaic morphology, vertical facies analysis, observed depositional environments, and computer modeling of the several variables shaping specific modern, Holocene deltas (Galloway 1975, Coleman and Wright 1975, Komar 1973). This led to the establishment of the well-known Galloway tripartite classification (Fig. 1), which categorized several modern deltas based on the ratio of the types of energy that controlled the deltaic morphology and its accumulations (i.e. wave energy, tidal range, or river discharge) (Fisher 1969, Coleman and Wright 1975, Galloway 1975). Recent studies have shown that the Galloway tripartite classification led scientists to classify deltas according to these end members (Dominguez et al. 1996, Rodriguez et al. 2000, Giosan and Bhattacharya 2003, Kulp et al. 2005).

It was understood in early deltaic studies that deltaic depositional facies resulted from the complex interaction of dynamic processes (e.g. nearshore wave power, water discharge, sediment yield, tidal action), but the focus was primarily on modern systems, which proved to be inadequate in analyzing bed-scale facies architecture (Coleman and Wright 1975). In recent decades, the focus on understanding how these dynamic processes, or allogenic and autogenic controls, influence deltaic development has redirected attention to understanding the internal organization of deltas, i.e. the bed-scale facies architecture (Giosan and Bhattacharya 2005).

This was driven by the expansion in subsurface reservoir modeling capabilities and caused a renewed interest in outcrop studies (Tye et al. 1999, Rodriguez et al. 2000, Bhattacharya and Tye 2004). Extensive work has been conducted in understanding the facies architecture of fluvial (Miall 1996) and deep water (Bouma and Stone 2000) systems, but the lack of a detail oriented, comprehensive approach to understanding the internal structure of deltas resulted in an oversimplification of deltaic facies models that inhibited the ability for more efficient recovery in deltaic reservoirs (Tye et al. 1999).

Problems resulted when scientists began predicting deltaic internal facies on the basis of external morphology using the Galloway tripartite classification (Giosan and Bhattacharya 2003). Studies suggested that the ambiguity between the external morphology, observed lithologies and deltaic formative processes was because of the overemphasis on the tripartite classification (Rodriguez et al. 2000, Giosan and Bhattacharya 2003). For example, Dominguez (1996) questioned whether the classic wave-dominated end member delta, the São Francisco, qualified as a delta or if it was a strandplain, Rodriguez et al. (2000) discussed the misclassification of the Brazos Delta as a wave-dominated delta, and Kulp et al. (2005) emphasized the role of waves and longshore drift in shaping the traditionally interpreted river-dominated Mississippi delta. The misclassification of modern deltas was directly addressed by Giosan and Bhattacharya (2003), who re-examined several deltaic systems (e.g. the modern Danube) based on surface geomorphology, and agreed with the idea that most of these deltas are mixed influence and would fall within the Galloway tripartite classification (Galloway and Hobday 1996). The potential for misclassification of deltaic systems by relying solely on external geometry suggests that these systems are much more complex than previously thought, and different approaches to understanding deltaic facies models are required.

The Asymmetric Delta

The principal hypothetical asymmetric delta model was introduced by Giosan and Bhattacharya (2003). Previous studies had touched on mechanisms that caused deltaic asymmetry, but few studies explicitly compiled these ideas within a process-based model of an asymmetric delta (Dominguez 1996, Giosan and Bhattacharya 2003).

Several modern deltas classified as wave-dominated were called into question. The modern Sf. Gheorghe lobe of the Danube, was found to exhibit an apparent difference in lithologies when comparing the updrift side of the delta as opposed to the downdrift side (Giosan and Bhattacharya 2003). It was observed that the updrift area of the Sf. Gheorghe was composed of a succession of amalgamated beach ridges, while the downdrift area was composed of sandy ‘shoestring’ ridges encased in lowlands, interpreted to be muddy (Fig. 2). Giosan and Bhattacharya (2003) explain this variability using the asymmetrical delta model.

The asymmetric delta model has been defined as depending on the angle of wave approach and the influence of net longshore transport with respect to river input (Giosan and Bhattacharya 2003). The model is based on the idea that a high riverine discharge exerts a groyne effect (Komar 1973), which buffers the strong net longshore sediment transport oriented obliquely to the shoreline (Fig. 2). This is hypothesized to result in an updrift shoreface and strandplain consisting of homogenous, mature, and potentially sharp-based sands, and a downdrift facies that consists of narrow barrier-lagoon sandstones alternating with low areas of mostly fine-gained sediment (Fig. 2) (Giosan and Bhattacharya 2003; Li et al. in preparation). Bhattacharya (2006) hypothesized a different arrangement of the transition in facies between the updrift and downdrift side as opposed to the Giosan and Bhattacharya model (2003) (Fig. 2). The documentation of the processes in an ancient asymmetric delta and the facies that make up the updrift and downdrift side remains largely unknown. Asymmetric deltas are found in microtidal settings where it is common to have significant sediment input, due to extreme flooding events (Giosan and Bhattacharya 2003).

Outcrops of the “Notom Delta” within the Cretaceous Ferron Sandstone Member in Central Utah provide a unique opportunity to understand how wave and fluvial processes affect sedimentation by documenting the facies architecture and geometry of an ancient asymmetrical delta along strike (Bhattacharya et al. 2008). The goal will be to specifically map out the transition between the facies observed, i.e. wave/storm-dominated shoreface facies and river-dominated active delta front facies, by tracking these facies northeast from the study area (Fig. 4). It is hypothesized the transition between shoreface and delta front would support the asymmetrical delta model, and by examining the geometry of the transition between the facies a better idea of the degree of asymmetry in the Ferron will be understood.

GEOLOGICAL SETTING

The Ferron Notom Delta crops out in south central Utah, between Hanksville and Caineville, UT north of Highway 24. The outcrops in this study are located in Coalmine Wash, next to Factory Butte (Fig. 3) (Bhattacharya et al. 2008). The Ferron Sandstone Member is part of the Mancos Shale Formation and is situated above the Tununk Shale Member and below the Blue Gate Shale Member (Ryer and Anderson 2004) (Fig. 5).

The Ferron Sandstone Member was deposited around the Middle Turonian to Late Santonian, 90.7 Ma – 90.3 Ma, during a highstand of the Cretaceous Western Interior Seaway (Fig. 6) (Garrison and van den Bergh 2004). The seaway stretched roughly north-south across central North America (Fig. 7) (Gani and Bhattacharya 2007). Paleoceanographic models and facies relationships suggest that the Ferron was deposited during the Cenomanian-Turonian Greenhorn transgression and highstand, and was wave dominated with a longshore drift oriented SSW along the western margin due to a counterclockwise gyre created by coastal jets (Slingerland et al. 1996, Li et al. in preparation). Central Utah was subjected to winter and summer storms, where storm currents were observed to run parallel to the shoreline and many parts of the seaway were microtidal (Slingerland et al. 1996).

The Ferron is deposited in a foreland basin that was subjected to two major orogenic events that influenced the stratigraphy and structural setting. These were the Sevier orogeny, which lasted from 140 Ma – 50 Ma, and the Maestrichtian-Tertiary Laramide orogeny, lasting from 80 Ma– 35 Ma, accounting for two thrusting episodes (Gardner 1995). Structural segmentation resulted in three drainage basins situated in a migrating, asymmetric retroarc foreland basin, which fed three major fluvial-deltaic wedges of the Ferron Sandstone Member (Gardner 1993).

During the widespread transgression and highstand there was a joining of an epeiric seaway with the Tethyan Sea towards the south (Slingerland et al. 1996). The area was characterized by the southward migration of mid-Cretaceous depocenters and northward-directed transgressions which combined to produce high-accommodation and high sediment-supply conditions during a time of slow sea level rise (Gardner 1993).The Ferron Sandstone was subjected to a series of high-frequency transgressions and regressions, which account for the multiple sandstone units that show both seaward and landward stepping stacking patterns(Garrison and van den Bergh 2004), (Gardner 1993).

The Ferron Notom Delta consists of six sequences bounded by unconformities and their correlative conformities, and nine parasequence sets where eight are deltaic to marine shoreface and on is fluvial (PSS9 – PSS1) (Fig. 4) (Li et al. in preparation). Four sequence boundaries have been identified (Bhattacharya et al 2008). Stratigraphically the study area is located in parasequence 7a, which contains both fluvial and wave dominated facies (Fig. 4) (Bhattacharya et al. 2008). Parasequence 7 is characterized by a downward and basinward stepping geometry, suggesting a negative shoreline trajectory during a strong progradation (Fig. 4) (Li et al. in preparation).

The Ferron member contains a spectrum of depositional environments, ranging from wave-dominated to strongly fluvial-dominated facies, yet the facies architecture is relatively poorly studied compared to the Last Chance Delta (Ryer and Anderson 2004). This provides an opportunity to study a deltaic system along strike orientation.

EXPECTED FACIES

The study will be approached using facies architectural analysis by analyzing the sedimentary structures and documenting stacking patterns of the facies in response to depositional processes and the migration and growth of the delta (Gani and Bhattacharya 2007). Preliminary observations of the parasequence indicates that the Ferron Notom Delta is a wave influenced system with three major facies types, wave/storm-dominated shorefaces, river-dominated active delta fronts, and wave/storm-reworked delta fronts (Li et al. in preparation). The architectural elements of interest fall in two main categories of study, a shoreface/strandplain environment located hypothetically on the updrift side of the Ferron

Notom Delta, and a river dominated delta front environment located on the downdrift side (Fig. 8) (Li et al. in preparation).

ARCHITECTURAL ELEMENTS

Shoreface/ Strandplain

The shape and extent of wave influenced coastlines is determined by the interaction of sediment supply and wave energy expended on the coast (McCubbin 1982). The wave approach in the Ferron Notom Delta was found to be uniformly SSW, as suggested by the strike directions of wave ripple crests found in shoreface successions (Li et al. in preparation).

The shoreface succession (Fig. 8) generally coarsens upward and is sandier and less heterolithic compared to river dominated deltaic facies (Li et al. in preparation). Moving from the offshore to the foreshore there is a transition from interbedded mudstone and sandstone with wave and current ripple cross-laminations to a coarser grained hummocky and swaley cross-bedding (HCS and SCS) with minor wavy laminations to trough/planar cross-beds (Fig. 9) (Hampson and Storms 2003). The presence of HCS and SCS, coarsening upward successions, and prominent *Cruziana* and *Skolithos* in the Ferron Notom Delta has indicated that there is a wave-/storm shoreface environment (Fig. 8) (Li et al, in preparation).

River dominated delta front

Bifurcation is inhibited in strongly wave-influenced deltas, resulting in relatively few terminal distributary channels and mouth bars, unlike fluvial dominated deltas where there is no external influence preventing mouthbar deposition and accretion (Bhattacharya 2006). Despite this, previous and current research on the Ferron Notom Delta has indicated that mouth bars (Fig. 10) and terminal distributary channels are abundant. They are hypothesized to occur in the center or downdrift side of an asymmetrical delta (Li et al. in preparation, Olariu and Bhattacharya 2006).

The mouth bars observed in the study area have been documented to consist of a river-dominated delta front facies (Fig. 10). The river-dominated delta front facies is constructed due to the high fluvial discharge rate compared to longshore drift (Li et al in preparation). Mouth bars broadly scale to the width of flow, have a pinch and swell geometry, and show bidirectional downlap (Bhattacharya 2006). The delta front facies is observed to be muddier, more heterolithic, contains unidirectional current ripples and crossbedding, and has a lower rate of bioturbation compared to the observed shorefaces (Fig. 8) (Li et al. in preparation). Discharge variation is thought to produce an irregular coarsening-upward succession with interbedded mudstones and sandstones, indicating a waxing and waning of hyperpycnal flows and an increase in water turbidity at the mouth (Mulder and Syvitsky 1995, Bhattacharya in press). Periods of rapid loading of increased sedimentation rates accounts for observed soft-sediment deformation and growth faulting (Bhattacharya in press). Assuming that the Ferron Notom Delta was subjected to both fluvial and wave influence, the mouth bar geometry should reflect the strength of longshore drift, storm event frequency, sediment supply, and flow conditions (i.e. spreading angle of river effluence, width, frictional forces), and accommodation (Fielding et al. 2006; Tye and Bhattacharya 2004; Bhattacharya, 2006).

Purpose

Despite the observation of these “end member” facies in the Ferron and previous studies, the transition between them is not well understood (Fig. 11) (e.g. Gani and Bhattacharya 2007). This project will map the bed-scale facies architecture of the transition between mouth bar facies and updrift shorefaces and storm sheets. By documenting the onlap/offlap/truncated geometry and the trajectory of the facies transition zone, or “shazam”, of shoreface in relation to the delta front (Fig. 2). This will aid in understanding the order of deposition, whether the delta was deposited first and then the updrift shoreface later onlapped the delta, or if the mouth-bars and shoreface elements were deposited simultaneously. The trajectory of the facies transition may also relate to the degree of asymmetry exhibited between the delta front and shoreface (Fig. 12).

FLUID FLOW ANALYSIS

Much of the interest of the Ferron Sandstone Member originated when significant accumulation of natural gas was found on Wasatch Plateau around 1951, making it a world-class outcrop analogue to ancient subsurface studies (Ryer 2004, Chidsey et al. 2004). As current research begins to elucidate details on facies architecture, much attention has been focused on understanding how architectural elements scale to different aspects of flow conditions, proving useful in conducting hydrodynamic analysis (Reynolds 1999, Tye 2004).

To make reliable volumetric estimates of recoverable hydrocarbons it is critical to be able to predict the dimensions (i.e. scale, geometry and orientation) of reservoir sandbodies (Reynolds, 1999). LeClair and Bridge (2001) established that dune-scale cross set thickness and grain size can aid in deriving flow depth and velocities of paleochannels. Reynolds (1999) attempted to develop a predictive relationship between sand-body thickness to width and length. His study revealed that when paralic sand bodies were differentiated by sand-body type, such as distributary channel or mouth bar, they produced tighter subgroups, meaning calculated dimensions from multiple outcrops yielded similar results (Reynolds 1999). The relationship suggested that on average, mouth bars were found to be twice as long as they were wide.

By conducting a bed-scale facies architectural analysis on the fluvially dominated mouthbars in the Ferron sandstone and deriving a detailed analysis of the flow conditions that occurred in the distal sandbodies, a more accurate understanding of flow behavior and thin bedded reservoir dimensions can be derived (Gani and Bhattacharya, 2007).

METHODOLOGY AND WORK PLAN

The proposed study area is situated in an arid environment in south-central Utah and readily accessible through Coalmine Wash. This will allow for detailed mapping of facies architecture and lateral facies variability on superbly exposed cliffs (Fig. 10).

Primary data will chiefly come from field sedimentological and stratigraphic observations. Fieldwork will consist of ten to twenty detailed sedimentological profiles done by rappelling down cliff faces. Paleocurrents, lithofacies, ichnology, sedimentary structures, and grain size data will be collected for each profile.

Photomosaics will also be constructed to aid in construction of the detailed bedding geometry. The photomosaics will be integrated with the measured profiles and paleocurrent data to construct a quantitative stratigraphic correlation panel of multiple cliff faces. The correlation panel would aid in understanding the geometry of the bedding patterns and reconstructing the paleogeography of the Ferron Notom Delta.

CONCLUSIONS

The key research goals that that must be approached when studying the distal, transitional end of the Ferron Notom Delta along strike include conducting a bed-scale and bar-scale facies architectural analysis of the Ferron Notom Delta and mapping out the transition between the facies observed, i.e. wave/storm-dominated shoreface and river-dominated active delta front. I hope to:

- Distinguish the architectural elements making up the Ferron Notom Delta.
- Understand the flow conditions that occur in parasequence 7a.

- Test Reynolds conclusion on mouthbar dimensions.

- Document the lateral change between mouth bars and updrift shorefacies.

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FIGURES

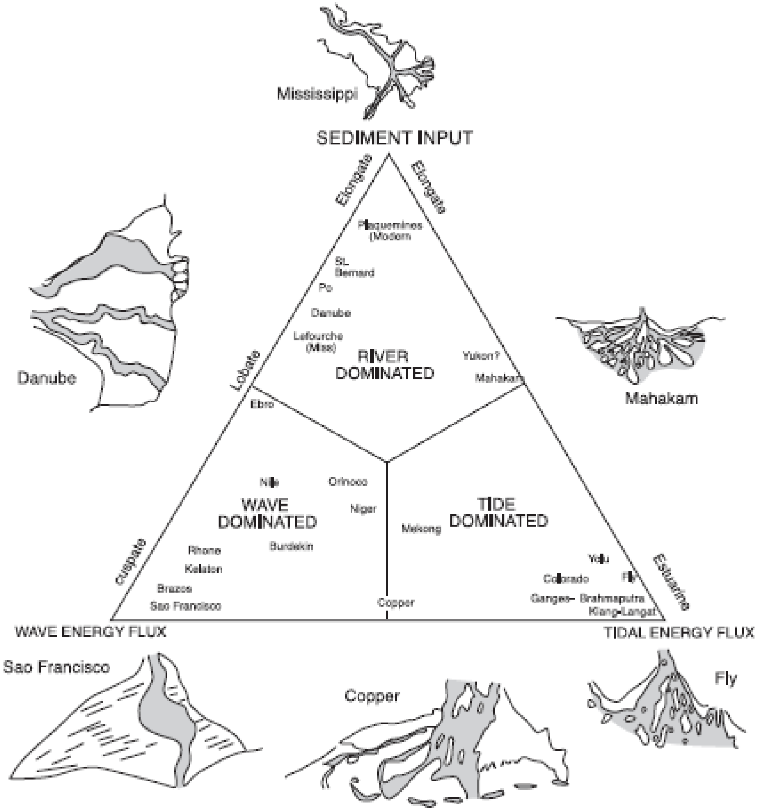

Figure 1. The Galloway tripartite classification of deltas (From Galloway, 1975).

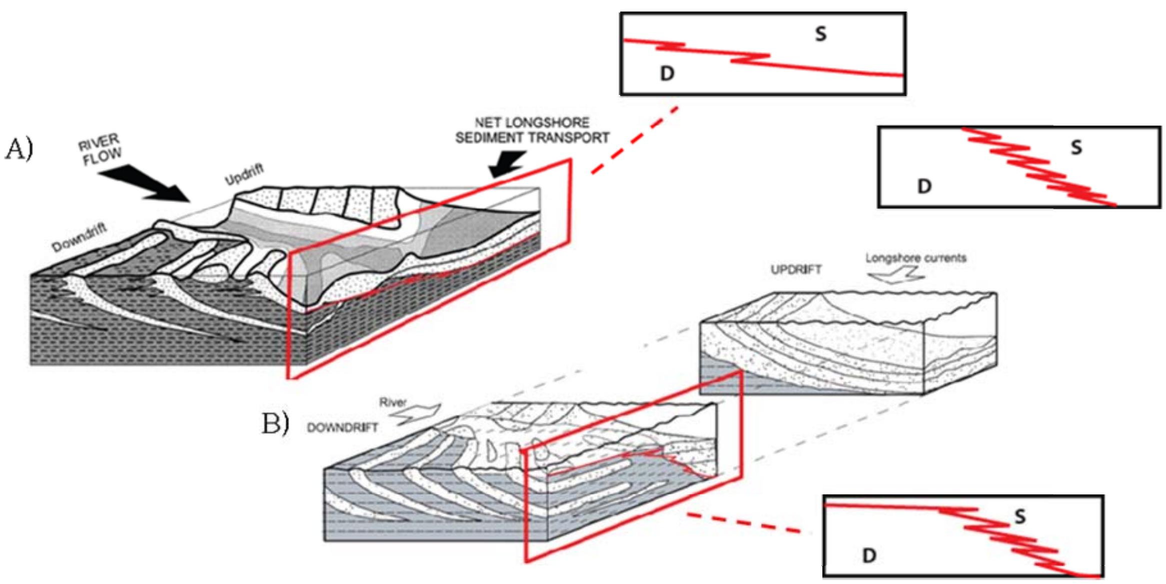

Figure 2. A) A hypothetical model of the processes working forming an asymmetric delta proposed by Giosan and Bhattacharya (2003). **B)** The asymmetric model with a differing facies hypothesized by Bhattacharya (2006). The study area is located along strike, where the transition or “shazam” will be documented at a bed-scale level between delta front (D) and shoreface (S) (modified from Giosan and Bhattacharya 2003, Bhattacharya 2006).

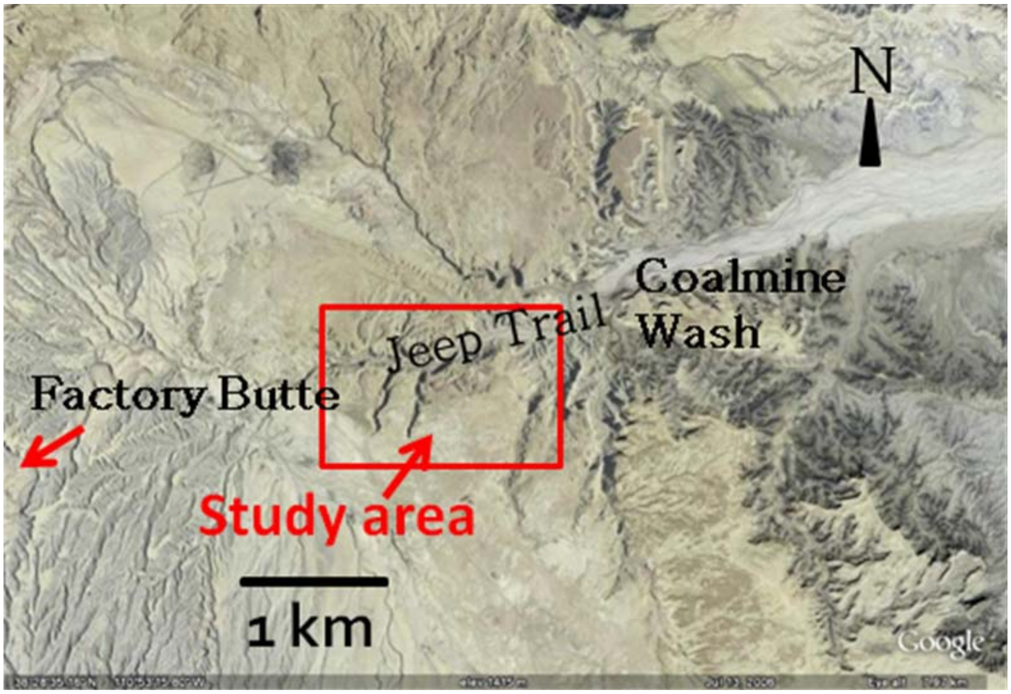

Figure 3. The area of study (Google 2009).

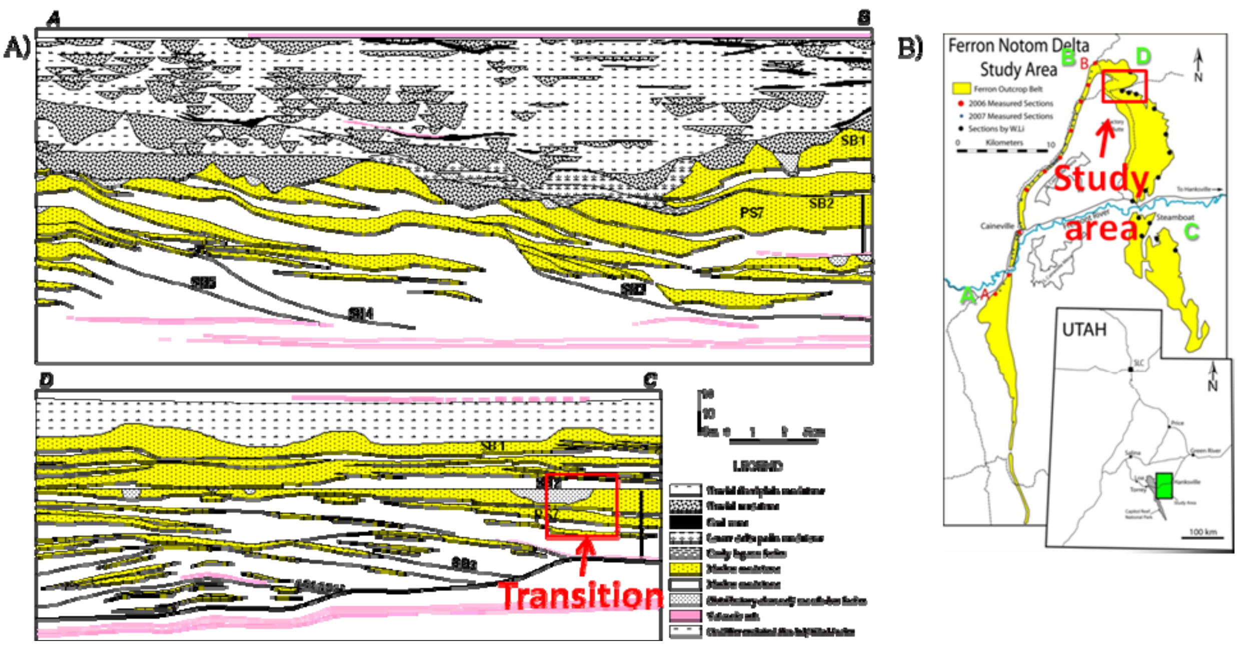

Figure 4. A) The study area in dip and strike orientation. The transition in the boxed parasequence (PS7) represents a late highstand systems with strong progradation. Cross section A-B is in overall depositional dip direction and C-D is in strike view. **B)** Base map of the study area. (Li et al. in preparation).

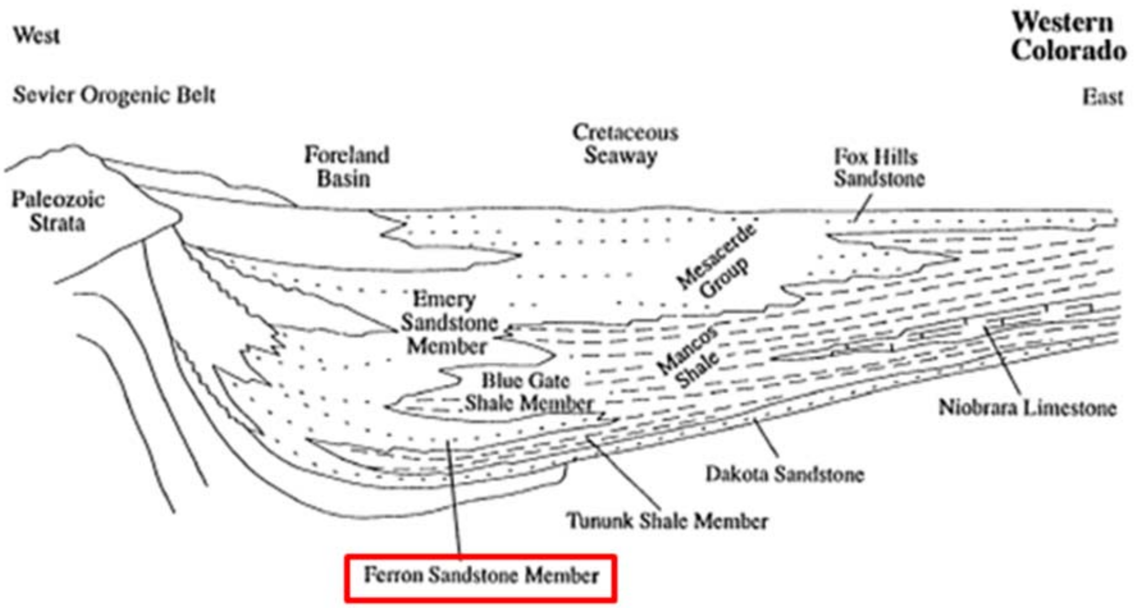

Figure 5. General stratigraphy of the Mancos Shale in east-central Utah (Modified from Barton 1994).

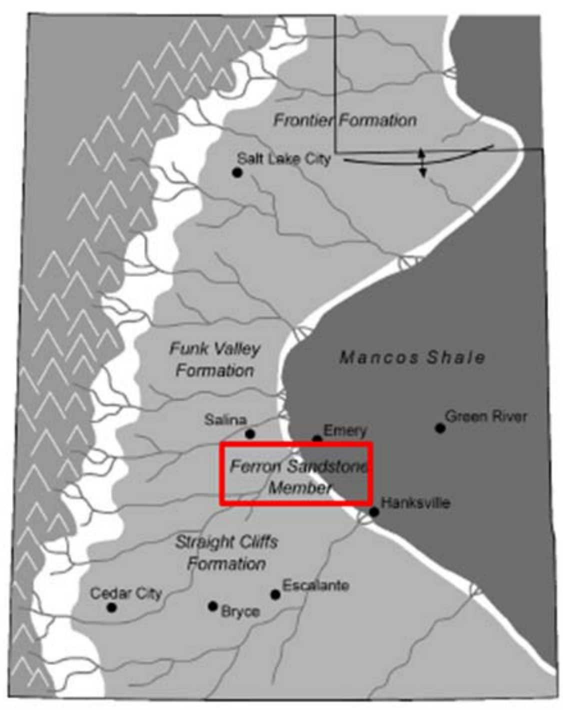

Figure 6. Paleogeographic reconstruction of the Ferron Sandstone Member during the Turonian Greenhorn transgression (Modified from Ryer and Anderson 2004, Slingerland et al. 1996).

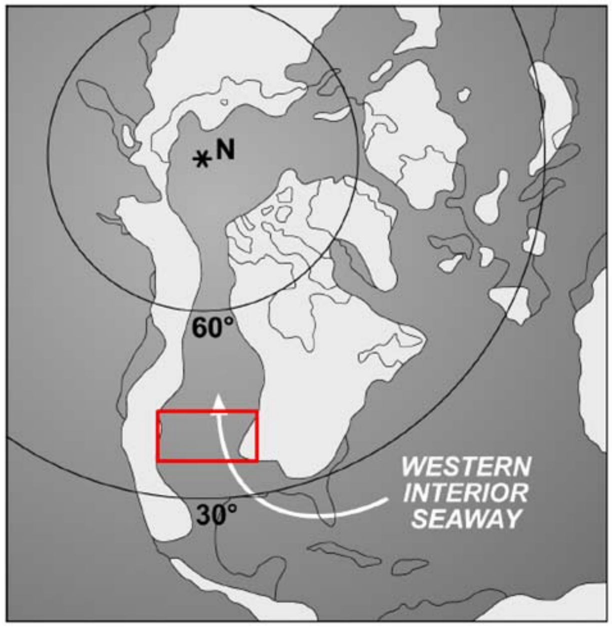

Figure 7. Paleogeographic reconstruction of the Ferron Sandstone Member during the transgression during the early Turonian. Study area is boxed (Modified from Ryer and Anderson, 2004).

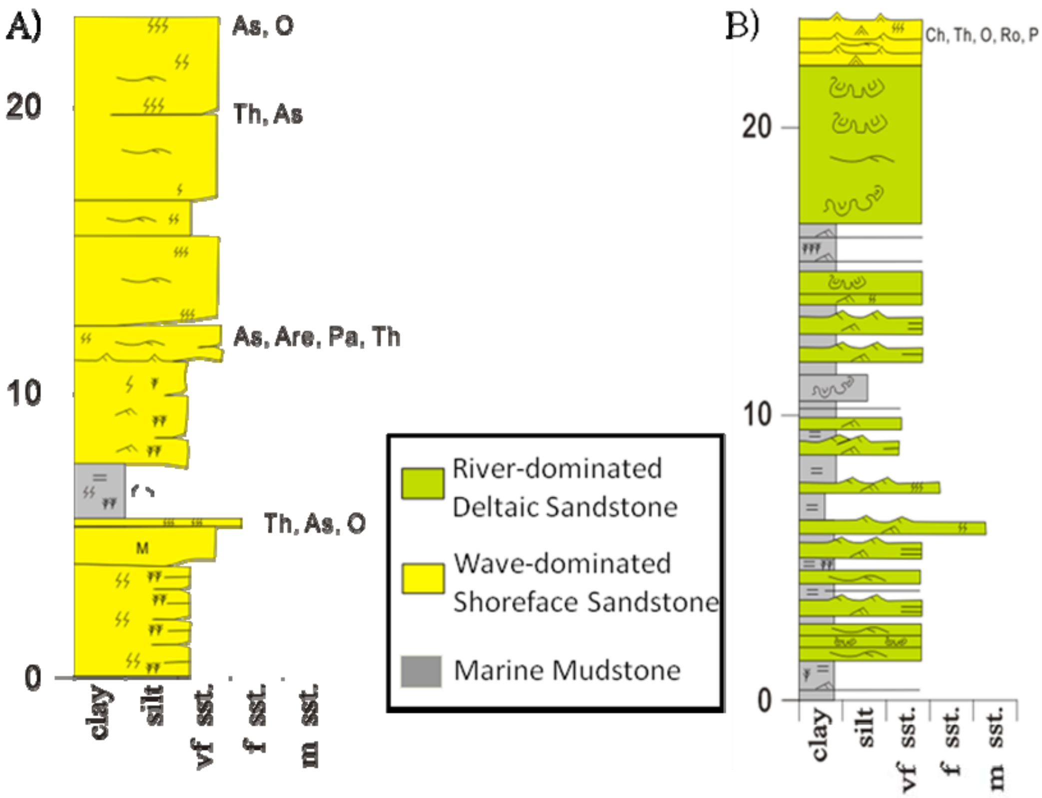

Figure 8. A) Vertical section of wave-dominated shoreface in the Ferron Notom Delta. This section is hypothesized to occur updrift according to the asymmetric delta model. This section is hypothesized to occur downdrift according to the asymmetric delta model. **B)** Where shoreface has been documented (Zhu et al. in preparation, Giosan and Bhattacharya (2003)).

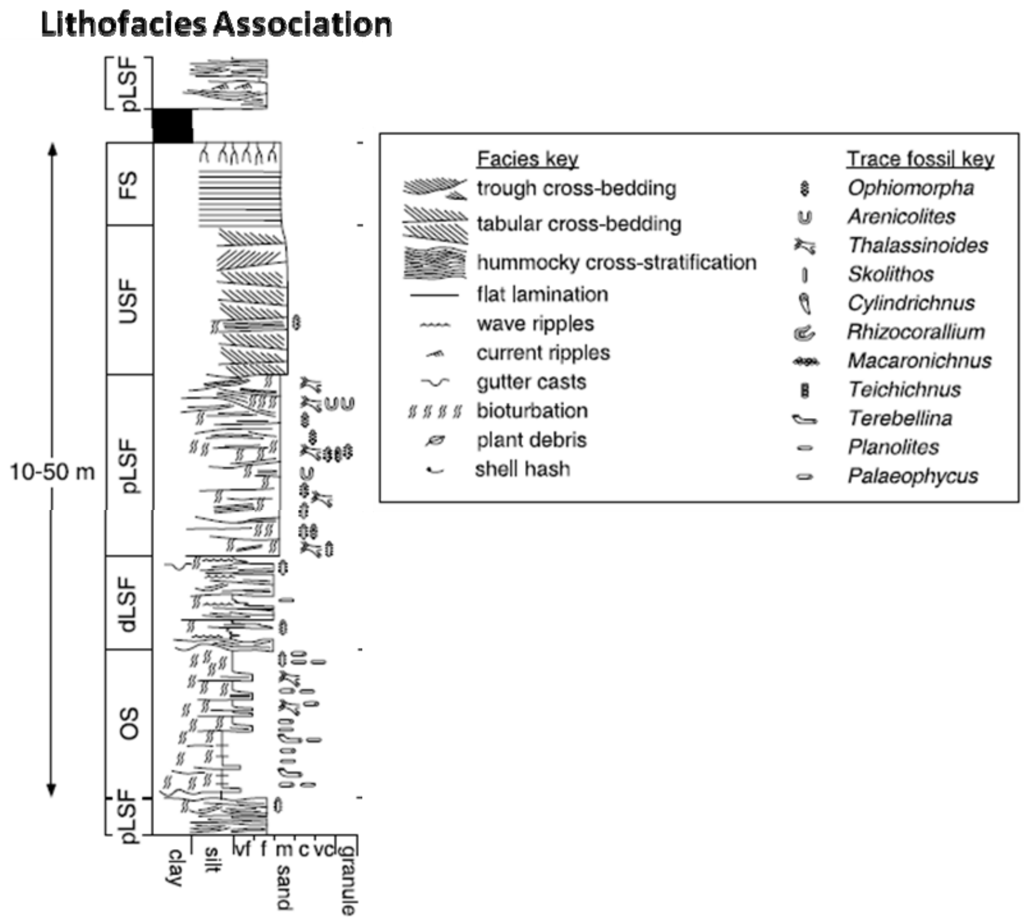

Figure 9. Vertical section showing typical lithofacies associations found in a shoreface coastline (modified from Hampson and Storms, 2003).

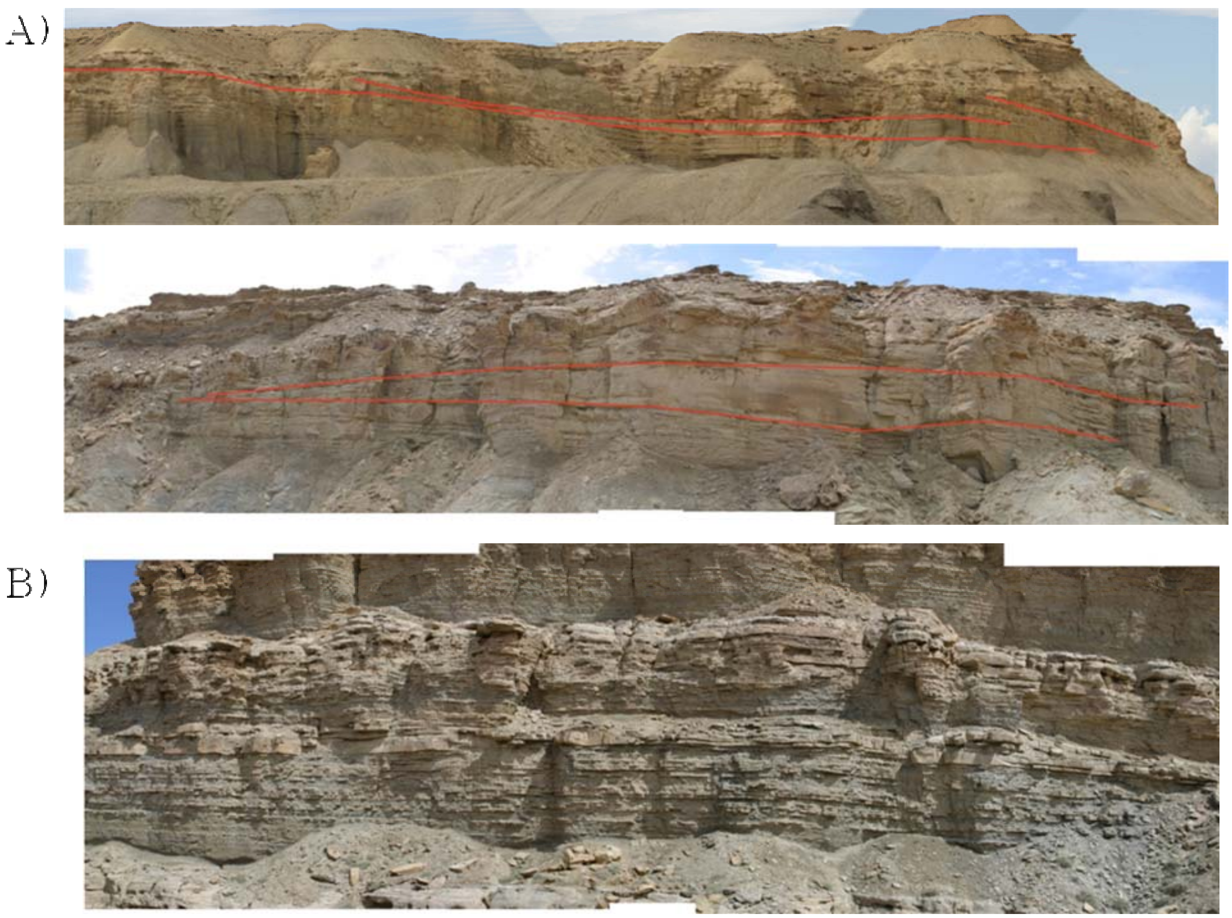

Figure 10. A) Photomosaic and interpretation of study area. Interpretation outlined in red shows possible distributary mouth bar packages **B)** Northwest of photomosaic A, the tabular bedding can be interpreted to represent shoreface (Courtesy of Janok P. Bhattacharya, modified by Sumiyyah Ahmed).

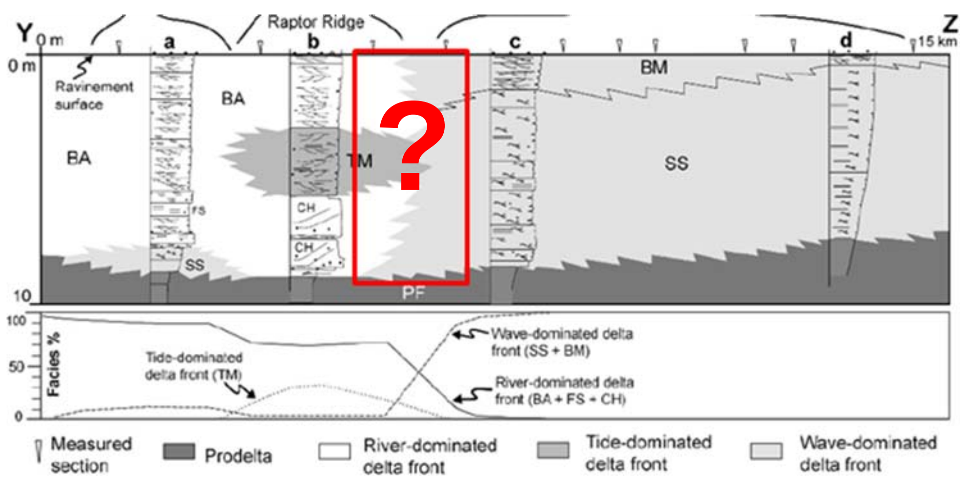

Fig 11. Correlation between a river-dominated mouth bar section and wave-dominated delta front (interpreted as storm sheet architectural element) in the Wall Creek Delta. The study will focus on

collecting data to understand the facies transition , or “shazam” geometry, between two “end-member” facies (Gani and Bhattacharya 2007).

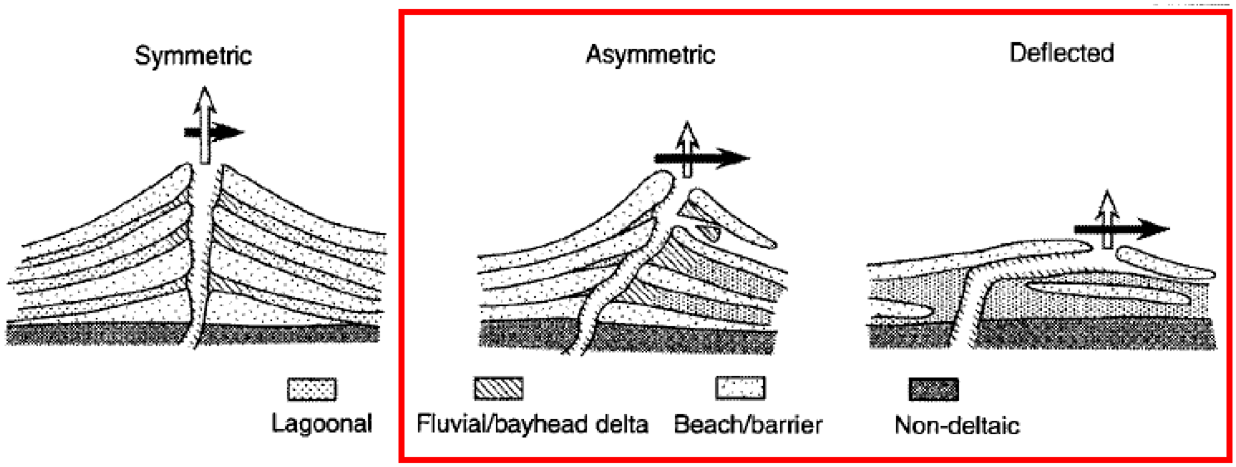

Fig 12. Deltaic asymmetry is dictated by the strength of river discharge as opposed to net longshore drift. The degree of asymmetry versus deflection can be better understood in the Ferron by studying the transition between the shoreface and delta front along strike orientation (Giosan and Bhattacharya, 2003).