Sequence Stratigraphy and Facies Architecture of the Cretaceous Ferron Notom Delta Complex, Central Utah, USA

By

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Abstract

The asymmetric model for wave-influenced deltas predicts sandier facies associated with updrift areas and river-borne muddier facies associated with downdrift areas. It is largely based on re-evaluation of several modern examples. However, there are few ancient examples. To test this model would require detailed facies architectural evaluation both in depositional dip and depositional strike directions. Its application to an ancient example will allow prediction of longshore drift patterns and the control on reservoir quality. The shoreline trajectory model provides a new perspective to predict and interpret facies stacking patterns, providing improved interpretation of system tracts and depositional cycles in deltaic systems. The shoreline trajectory model is also lacking in application to ancient examples. To examine the shoreline trajectory model needs a well-documented deltaic clastic wedge in a depositional dip view, and isochronous control, such as bentonites, for both local and regional correlation.

The Ferron Notom Delta was deposited in the Western Cordilleran foreland basin within the Cretaceous Western Interior Seaway during the Late Cretaceous. The superbly exposed 3D outcrops of the Notom Delta as well as the availability of chronostratigraphically significant bentonite datums provide the chance to test the asymmetric wave-influenced delta model and the shoreline trajectory model.

Preliminary work shows a wide variety of complex facies. Vertically, the facies generally show stacked upward-coarsening shallow marine facies successions passing into non-marine facies successions. Laterally, the facies change gradually from south to north with an increase in the proportion of marine versus non-marine facies. Facies show varying fluvial-, wave-influenced delta front and shoreface facies.

The major objective of this study is to apply sequence stratigraphic concepts in regional correlation and construction of the stratigraphic framework of the Notom Delta. The genetic

relationship between the fluvial channels and the shallow marine deposits are of special interest. The Notom Delta will be compared to the better-studied Last Chance Delta, in terms of facies stacking patterns, variability of fluvial-, tidal- and wave-processes. Evaluation of sequence boundaries in the Notom Delta will shed some light on sequence boundary controversies existing in the previous Last Chance Delta studies.

1. Introduction

1.1 Delta Facies Models

The most popular classification scheme of Deltas is that of Galloway (1975) who subdivided deltas into three major types—river-, wave- and tide-dominated—based on the dominant processes that control the delta morphology (Fig. 1). However, most deltas are mixed-influenced and may simultaneously show river, wave and tide influence. In previous studies of both modern and ancient systems, many deltas have been forced into one of the end-member categories (Bhattacharya and Walker, 1992; Dominguez, 1996). Therefore, it is necessary to distinguish "dominated" from "influenced" in terms of processes or facies properties.

Bhattacharya and Giosan (2003) emphasized variations of proportions of wave and river influence and the importance of interaction between fluvial discharge and sediment longshore drift in producing delta asymmetry. They proposed a process-based facies model for wave-influenced deltas. This model predicts that sandier facies are normally associated with the updrift areas whereas significant river-borne muds are associated with prodelta and downdrift areas (Fig. 2). As yet, there are few good ancient examples of such asymmetric wave-influenced deltas. The Notom Delta is superbly exposed in the Henry Mountains region. Preliminary work show a variety of shallow marine facies, such as fluvial-storm dominated delta fronts and wave- dominated shorefaces. This invites the possibility to test the asymmetric model, and may lead to the first well-described ancient example of an asymmetric wave-influenced delta.

1.2 Sequence Stratigraphy

By definition, a parasequence is “a relatively conformable succession of genetically related beds or bedsets bounded by flooding surfaces or their correlative surfaces” (Van Wagoner, 1990). Parasequences normally show progradational, retrogradational, or aggradational stacking patterns, all of which are basically upward stacked (Van Wagoner, 1990). However, where sediment supply is high during relative sea level fall, an accretionary forced regression with a gradual basinward and downward shift of the shoreline will occur, resulting in parasequences stacking in a down-stepping and basinward-stepping pattern (Posamentier et al., 1992; Van Wagoner, 1995). This pattern is presented by a basinward- and downward- oriented shoreline trajectory (Helland-Hansen and Martinsen, 1996; Fig. 3). The shoreline trajectory is determined by a combination of relative sea level change, sediment supply and basin physiography. The shoreline trajectory model shows variable scenarios of individual system tracts and provides a basis for describing shoreline migration patterns and depositional cycles (Helland-Hansen and Gjelberg, 1994). To test this shoreline trajectory model needs well-exposed deltaic clastic wedges and an isochronous control for local and regional correlation.

Bhattacharya and Willis (2001) discussed the application of shoreline trajectory model in an accretionary forced regression. They used the example of lowstand deltas in the Frontier Formation, central Wyoming, which is hundreds of kilometers basinward of highstand shoreline deposits. The non-marine facies are eroded away from the top of the interpreted deltaic successions.

Compared to the Frontier Formation example in Wyoming, the delta plain facies in the Notom Delta are well preserved. The Notom Delta has a well-exposed depositional dip cross section, and it has laterally continuous bentonites beds that form ideal time markers. So, the Notom Delta will be a good place to test the shoreline trajectory model.

Garrison and van den Bergh (2004) recognized two depositional sequences in the Notom Delta, separated by an erosional unconformity formed during a 4th-order relative sea level fall event. According to the shoreline trajectory model, this invites the questions as to how the delta plain was linked to the delta front when the shoreline trajectory model is applied. Is the forced regression in the Notom Delta non-accretionary or accretionary? If it is an accretionary forced regression, can we identify it from the rock record, given that the preservation potential for these coastal sediments is related to water depth, time of deposition and relative position of the associated incised valleys.

This research is dedicated to conducting a regional sequence stratigraphic analysis as well as detailed facies architectural studies of selected environments within the Ferron Notom Delta. The feeder systems for the delta fronts sands are of special interest. Olariu and Bhattacharya (2006) examined both modern and ancient fluvial dominated delta systems and concluded that multiple coeval terminal distributary channels exist in shallow basins, like the basins formed in the Cretaceous Western Interior Seaway. The terminal distributary channels link the marine facies and non-marine facies together. In the Notom Delta, some shallow and narrow channelized features have infilling showing a combination of fluvial and wave and tide processes. These characteristics make these channelized features candidate terminal distributary channels. In a terminal distributary channel, the channel-filled mouth bars are generically related to the delta fronts deposits. A further question is: Does each delta front parasequence have a delta-plain equivalent feeder system in the Notom Delta? Are these feeder systems trunk channels or distributary channels or terminal distributary channels, or even channels within incised valleys?

In this study, a sequence refers to a depositional sequence, representing “a relatively conformable succession of genetically related strata bounded by unconformities or their correlative conformities” (Mitchum, 1977; Van Wagoner et al., 1990). A genetic sequence, in contrast, represents a sedimentary package bounded by maximum flooding surfaces (Galloway, 1989).

2. Geological setting of study area

The Ferron Notom Delta was deposited in the Western Cordilleran foreland basin within the Cretaceous Western Interior Seaway during the Late Cretaceous. The seaway connected the Northern Boreal Sea with the Gulf of Mexico, and the western margin of the seaway extends from New Mexico to Alberta (Fig. 4). The foreland basin started to develop between the Cordilleran volcanic arc and cratonic North America in the Jurassic, due to thrusting from the west. Rapid subsidence of a foredeep east of the Sevier orogenic belt began in Early Cretaceous, and continued through Late Cretaceous (DeCelles and Giles, 1996; Ryer and Anderson, 2004). The sedimentary record along this margin shows a series of basinward-stepping sandy clastic wedges passing into marine muddy successions to the east (Fig. 5). The strike of the shoreline was oriented about north-northeast and the sediments came from the rising Sevier orogenic belt and volcanic highlands to the west (Van Wagoner, 1995, Fig. 6).

The Southern Utah Deltaic Complex (Garrison and van den Bergh, 2004), including the Notom, Last Chance and “A” Deltas, was deposited along the western margin of the seaway from the Middle Turonian to Late Santonian age during a widespread regression (Hale, 1972; Garrison and van den Bergh, 2004). The Notom Delta was the first developed deltaic system in this complex, and it started to develop in the Henry Mountains region around 90.7 Ma. A major river avulsion, at about 90.3Ma shifted the depocenter north-northwestward to the Castle Valley area forming the Last Chance Delta (Gardner, 1995a; Garrison and van den

Bergh, 2004).

The idea that the Ferron Sandstone is a fluvial-deltaic depositional system was firmly established by many publications in the late 1970s (Ryer, 2004). The Notom fluvial-deltaic system consists of both non-marine fluvial-dominated delta plain facies association and genetically related shallow-marine facies association (Peterson and Ryder, 1975, Garrison and van den Bergh, 2004).

3. Previous studies

The Ferron Sandstone was described as a Member of the Mancos Shale formation by Charles T. Lupton (1916) (Ryer, 2004). It is bounded by the Blue Gate Shale Member on its top and the Tununk Shale Member at its bottom.

Previous study on the Ferron Last Chance Delta

The Last Chance delta of the Ferron Sandstone is one of the most well studied ancient deltas. Katich (1951) and Davis (1954) divided the Ferron Sandstone in the Last Chance Delta into two distinct units: the Lower Ferron consists of gray, fine-grained, calcareous marine sandstone and siltstone, which has a northwest and western sediment source; the Upper Ferron consists of shallow-marine sandstone, coal, carbonaceous shale and fluvial sandstone, which has a southwest sediment source (Ryer, 2004). Hale (1972) recognized these two distinct units in the Ferron and named these two features as a west-southwestward extending “Vernal” Delta (Lower Ferron) and a northeastward extending “Last Chance” delta (Upper Ferron). Cotter’s work during the 1970s considerably improved the interpretation of Ferron Stratigraphy and depositional history (Ryer, 2004).

Ryer and his colleagues’ contribution to the Ferron is their work from the early 1980s on recognition and mapping the packages of strata showing the major sedimentation cycles in the Ferron, represented by 7 delta-front or shoreface units from Kf-1 through Kf-7 (Ryer, 1981; Ryer, 1991; Anderson and Ryer, 2004; Fig. 7).

Gardner brought the Ferron studies into a more comprehensive level (Gardner 1995a, 1995b). A hierarchy of cycles interpreted to be related to base-level fall and rise turnarounds were defined: the whole Ferron was interpreted to represent a long-term (2nd order) cycle which can be subdivided into four intermediate-term (3rd order) cycles. The short-term (4th order) cycles are compatible with the delta-front sandstones units identified by Ryer (Ryer, 1991). These 4th order cycled units were regarded as genetic sequences—— from GS1 to GS7 (Ryer, 2004, after Gardner, 1994; Fig. 8).

According to Ryer and Gardner’s interpretations, rates of lowering eustatic sea level had always been exceeded by rates of basin subsidence. However, based on parasequence relationships within the seaward-stepping part of Lower Ferron, Barton and Tyler (1995) suggested relative sea level fall in the Ferron led to the incision of channel systems to form incised valleys. Therefore, many deposits previously interpreted as simple channel belts overlying delta plain or alluvial plain should be re-examined for the possibility of being valley fills.

Garrison and van den Bergh (2004) represented the most detailed stratigraphic framework of the Ferron Sandstone based on substantial outcrop studies and is a milestone in Ferron studies. In this study, 42 parasequences were recognized which can be grouped into 14 parasequence sets (Fig. 9). Four unconformity-bounded depositional sequences were identified based on erosional features at the bottom of deeply incised channel belts (Garrison and van den Bergh, 2004).

Much debate still exists in Ferron studies, despite the fact that it has been extensively examined in the past 25 years. A primary controversy focuses on the question of where are the sequence boundaries. Seven sequence boundaries have been identified by various workers but apparently they don’t agree with each other (Ryer, 2004). Gardner (1995a) thinks there are no unconformities within the Ferron, although he recognized channel and macroform scour bases. Gardner does not think these channels extend beyond their delta and they do not generally incise into the associated delta-front deposits below. However, more and more people recognized multistory channels belts that lie within incised valleys in the Ferron (Bhattacharya and Tye, 2004, Barton et al., 2004, Garrison and van den Bergh, 2004, Garrison and van den Bergh, 2006). Three fluvially eroded unconformities with up to 25-32 m of incision were recognized by Garrison and van den Bergh (2006). These unconformities separate four fourth order depositional sequences denoted FS1-FS4 and represent records of forced regression.

Previous study on the Ferron Notom Delta

Compared to the Last Chance Delta, the Ferron Notom Delta has received much less attention. The Ferron Notom Delta crops out in the Henry Mountain region.

Hunt (1946) did the first mapping of the Ferron Sandstone in the Henry Mountain area, and he distinguished the sandier upper part of the Ferron with coal from the muddier lower part. Peterson and Ryder (1975) divided the Ferron Sandstone in the Henry Mountain area into two subunits: the lower unit of Ferron is conformable with the Tununk Shale Member and consists of prodelta to delta front deposits, and the upper unit of Ferron is separated from Blue Gate Shale Member of the Mancos by an unconformity and consists of non-marine delta plain facies. Cotter (1976) and Uresk (1978) realized that the Ferron Sandstone in the Notom area represents a delta separate from the Last Chance and Vernal Deltas to the north. Uresk (1978) made a detailed sedimentological study of the upper delta plain facies association near Caineville and interpreted the Ferron as a prodelta to distributary mouth bar “sequence” overlain by point-bar and channel fill deposits. Hill (1981) attempted to describe the depositional history of the Notom Delta.

According to Gardner (1995a), the Ferronensis Sequence in the Henry Mountain region is represented by the Ferron Sandstone which shows seaward-stepping to vertically stacked cycles of coal-bearing fluvial-deltaic sandstone (Fig. 10). However, Garrison and van den Bergh (2004) identified additional genetic sequences and elevated Gardner's genetic sequences to composite depositional sequences. Garrison (submitted) re-interpreted the data from Peterson and Ryer (1975) and identified a type-1 sequence boundary and 7 shallow-marine parasequences in the Ferron Notom Delta (Fig. 11). Compared to the 42 parasequences he identified in the Last Chance Delta, the 7 parasequences identified in the Notom Delta suggest that facies architectural studies on the Notom Delta is still at the level of studies of the Last Chance Delta back in the early 1980s when Ryer identified 7 delta-front or shoreface units in the Last Chance Delta (Ryer, 1981). With more detailed examination of the outcrops, many of these 7 parasequences in the Notom Delta may be elevated to parasequence sets.

Garrison and van den Bergh (2004) presented a composite section through the Southern Utah Deltaic Complex, the Notom Delta, Last Chance Delta and "A" Delta are projected into the cross section plain that shows their general age relationships (Fig. 12). Based on biostratigraphic studies, the Notom Delta is time equivalent to the Vernal Deltaic Complex to the north (Garrison and van den Bergh, 2004).

4. Methodology

Data for this study will be mainly derived from measuring sedimentological sections. The lithofacies, trace fossils, body fossils, sedimentary structures and orientations of paleoflow indicators are carefully described for each section. Photomosaic mapping on selected outcrop will delineate the facies architecture of especially well-exposed delta front environments. The locations for measured sections, photomosaics and observation sites are tracked by GPS. The field equipment includes 1 Aluminum precision Jacob's Staff with a Sokkia Abney level, 1 Nikon D70 Digital SRL camera, 1 Brunton Classic Geo Transit 5008 compass, 1 Garmin eTrex Vistas hand-held GPS system, and technical climbing equipment. The coverage of the photomosaics will be considerably improved by a proposed helicopter survey in the summer of 2007. The continuity of units between the measured sections will also be evaluated by walking out beds. Some selected bentonites will use $^{40}Ar/^{39}Ar$ isotopic dating to determine their absolute ages.

5. Proposed research

Our initial study area is a triangular outcrop belt north of Notom (Fig. 13). In the summer of 2005, Bhattacharya (2006) collected 6 vertical measured sections over a 460 square kilometer area, spaced 5km to 15km apart (Fig. 14). This preliminary work shows a wide variety of complex facies and sedimentary features, including strong storm-fluvial influenced delta front, wave-dominated shorefaces, and some possible incised valley features. The measured sections show 7 marine coarsening-upward parasequences overlain by interbedded non-marine floodplain mudstone and fluvial channel deposits. The delta front facies show fluvial-, wave- and storm-dominated varieties and little tidal influence. Generally, the facies change gradually from south to north with an increasing proportion of marine to non-marine deposits. The observed facies change showed greatest variation between the “Caineville 1” and the “Factory Butte” sections measured in 2005. In 2006, ten sections were measured along the Caineville reef (Fig. 15), with 6 sections between “Caineville 1” and “Factory Butte”. The other 4 sections went a little farther to the south and north. The next step is to correlate these measured sections and identify areas for infill sections to be done next summer.

Volcanic ash layers (bentonites), if laterally extensive, make good datums for regional correlations because of their chronostratigraphic significance (Van Wagoner, 1995; Gardner, 1995a; Garrison and van den Bergh, 2004). In the Notom Delta, most of the bentonites were found in the prodelta mudstone. The bentonites are laterally extensive and most can be traced all the way along the Caineville reef. These bentonites make excellent isochronous lower datums. The coaly flood plain muds and coal seams in the Notom Delta are also laterally continuous along the Caineville reef. They are candidate datums for the correlation within the non-marine section.

In the Notom Delta, the measured paleocurrent directions indicate a northeast depositional-dip. The cross-sectional direction of the outcrop along the Caineville Reef approximates the depositional dip direction. Using the bentonites as chronostratigraphic datums, the facies architecture of the Notom Delta should show the shoreline migration pattern and provide a good chance to test the shoreline trajectory model which in most published examples was delineated only by cartoons.

Since the Last Chance and Notom Deltas were fed by the same river system (Gardner, 1995a, Garrison and van den Bergh, 2004), it would be meaningful to compare the Notom Delta with the Last Chance Delta in terms of fluvial, tidal and wave influence. Also, although the Last Chance and the Notom Deltas are not time-equivalent, the controversies in positioning sequence boundaries in the Last Chance Delta might be solved if similar depositional sequence boundaries could be found in the Notom Delta and then the same criteria could be applied to the Last Chance Delta.

Compared to the 2D outcrop belt of the Last Chance Delta, which is generally parallel to the depositional dip, the outcrop belt of the Notom Delta is 3D and it has both depositional dip and strike views (Fig. 12). The strike view is ideal for studies on the distributary channels on their number, spacing and avulsion events. The strike variability also enables comparison of the updrift and downdrift differences predicted in an asymmetric wave-influenced delta. Based on detailed 3D facies architecture, the relationship between the storm-fluvial dominated delta front facies and adjacent wave-dominated shorefaces facies observed in the Notom Delta can be tested using the new asymmetric facies model for wave-influenced deltas (Bhattacharya and Giosan, 2003).

In the Notom Delta, the incised channelized features overlying the delta fronts and shorefaces facies were observed, but it is not yet known if these fluvial channels are genetically related to the delta fronts. In the Notom Delta, some infilling of shallow and narrow channelized features show a combination of fluvial and wave and tide processes. These characteristics make these channelized features candidate terminal distributary channels which link the shallow marine and non-marine environments (Fig. 16; Bhattacharya, 2006; Olariu and Bhattacharya, 2006). It is crucial to understand if the channels fills are mouth bars that fill the terminal distributaries and are associated with delta front deposits, or transgressive facies associated with abandoned distributary channels. Some multistoried channelized features in the Notom Delta might be candidate incised valleys. A detailed facies architectural analysis will be able to illustrate the relationships between the fluvial channels and delta fronts in the Notom Delta.

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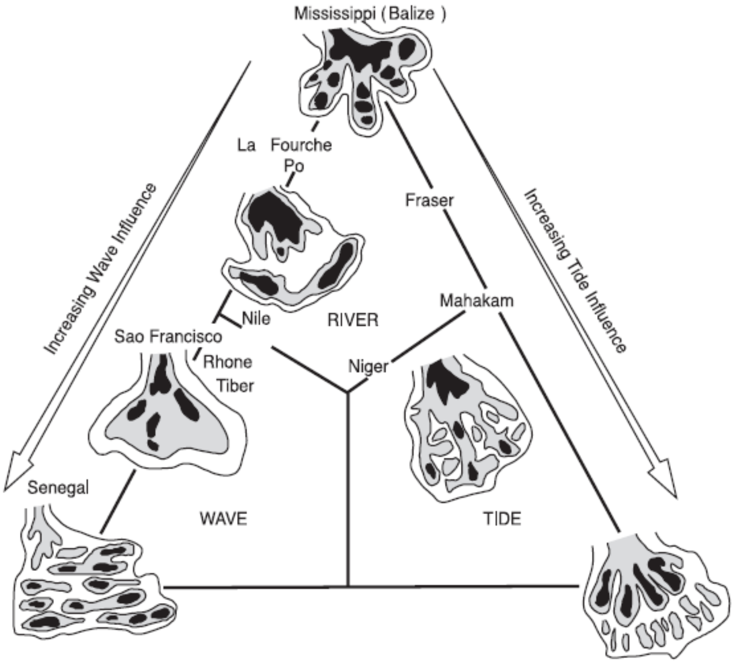

Fig. 1. Sandbody geometries of the six delta types defined by Coleman and Wright (1975) plotted on the tripartite classification of deltas by Galloway (1975). (from Bhattacharya and Walker, 1992).

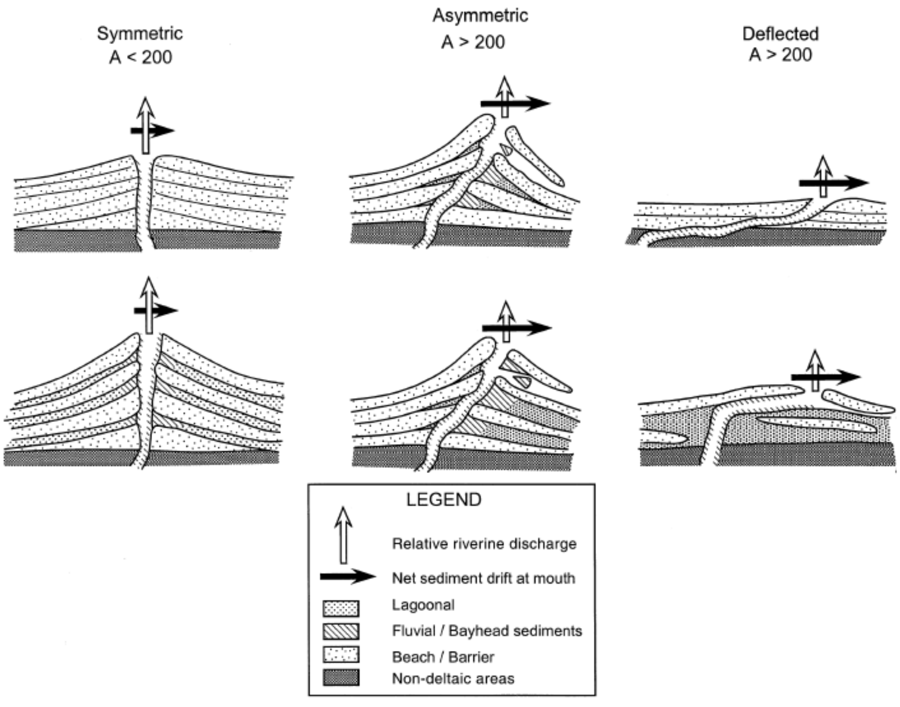

Fig. 2. Wave-influenced Delta Morphology. The upper row has lower fluvial discharge than the corresponding lower ones. “A” represents Asymmetry Index which is the ratio of fluvial discharge to longshore sediment transport rate. (from Bhattacharya and Giosan, 2003)

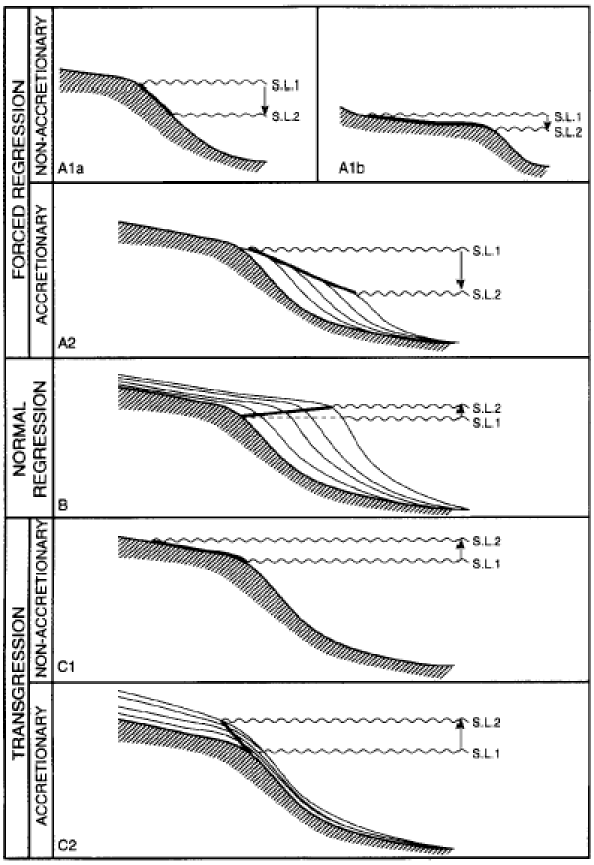

Fig. 3. Shoreline trajectory model. (from Helland-Hansen and Martinsen, 1996)

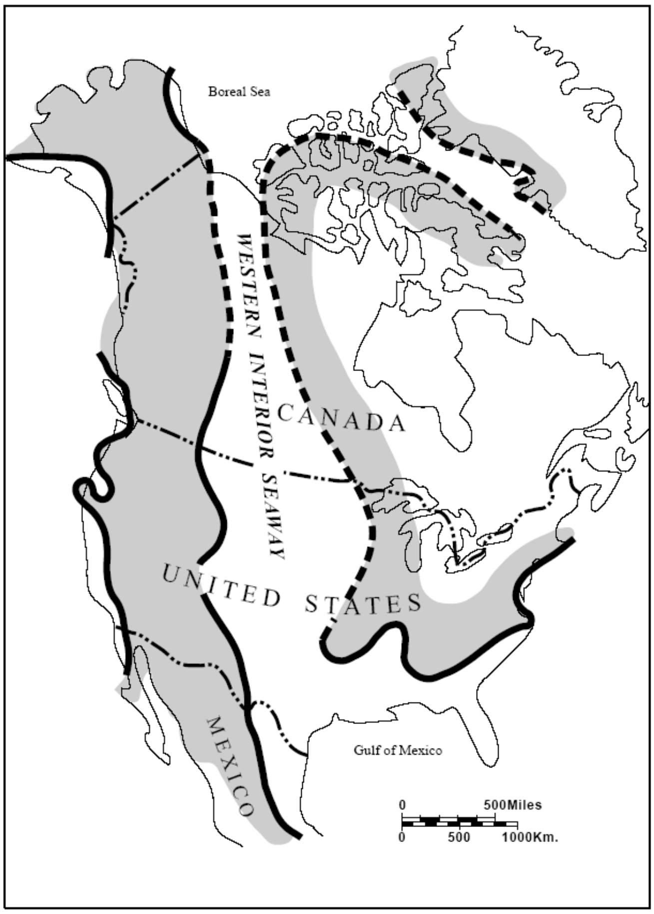

Fig. 4. Outline of the Cretaceous Western Interior Seaway, North America. (from Krystinik and DeJarnett, 1995, after Gill and Cobban, 1973)

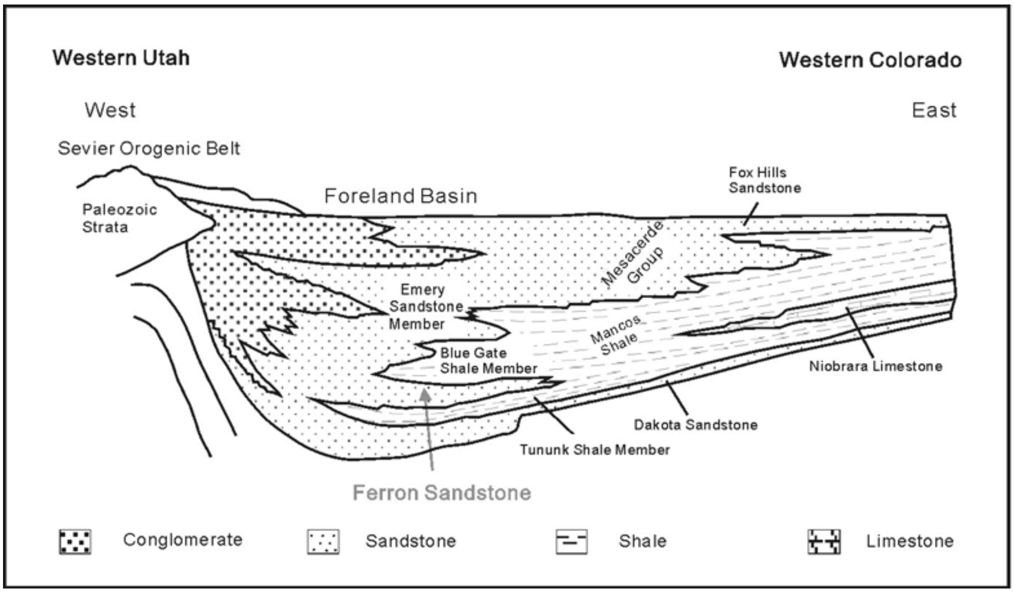

Fig. 5. Cross section of Cretaceous foreland basin across Utah modified from Armstrong, 1968. (from Barton et al., 2004)

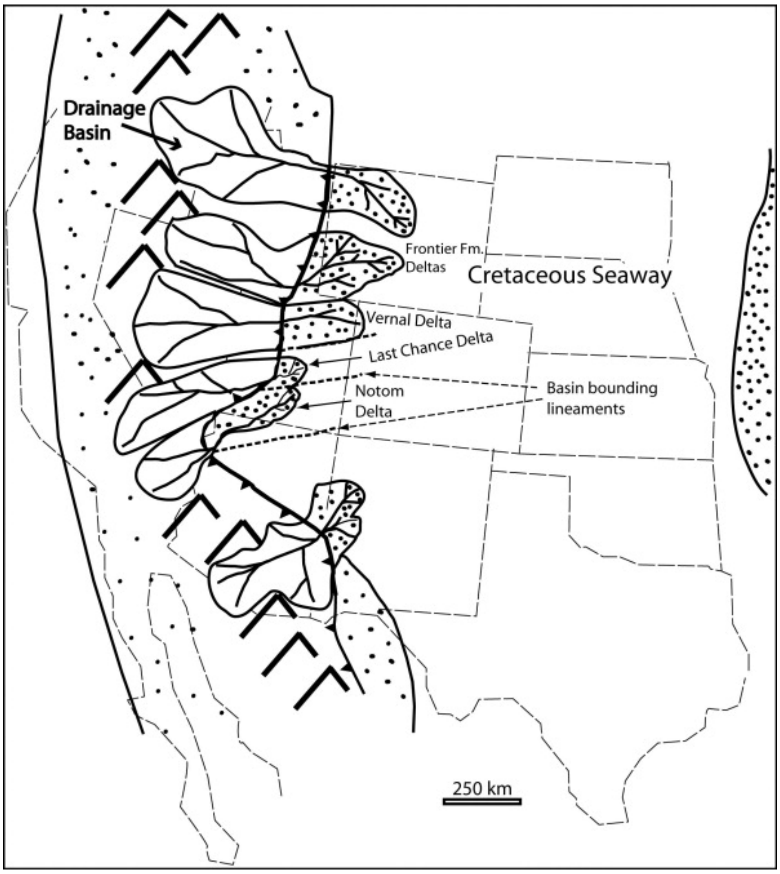

Fig. 6. Paleogeographic reconstruction map of mid-Cretaceous clastic wedges mainly based on Gardner (1995a) and Williams and Stelck, 1975. (from Bhattacharya and Tye, 2004)

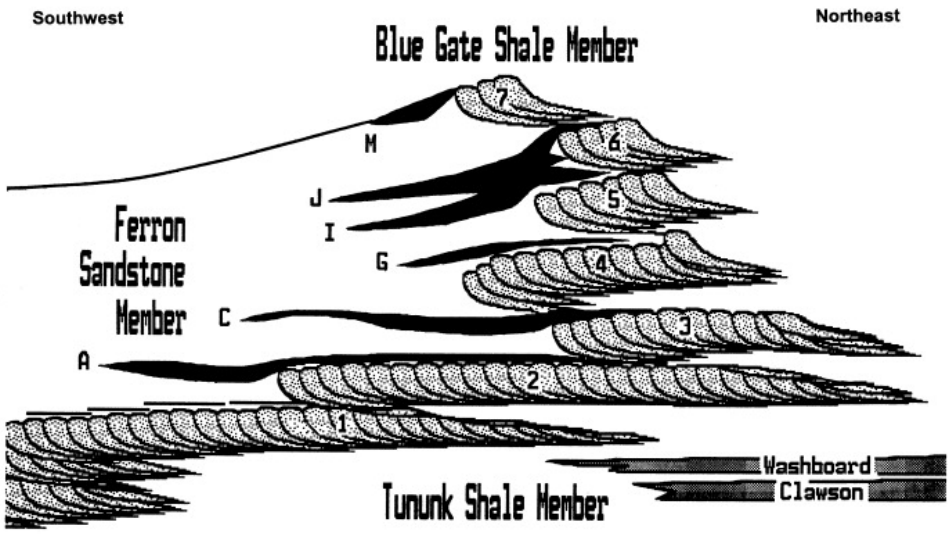

Fig. 7. Southwest to Northeast Cross section of the Ferron, showing no.1 to no.7 delta-front units. (from Ryer, 2004, after Ryer, 1991)

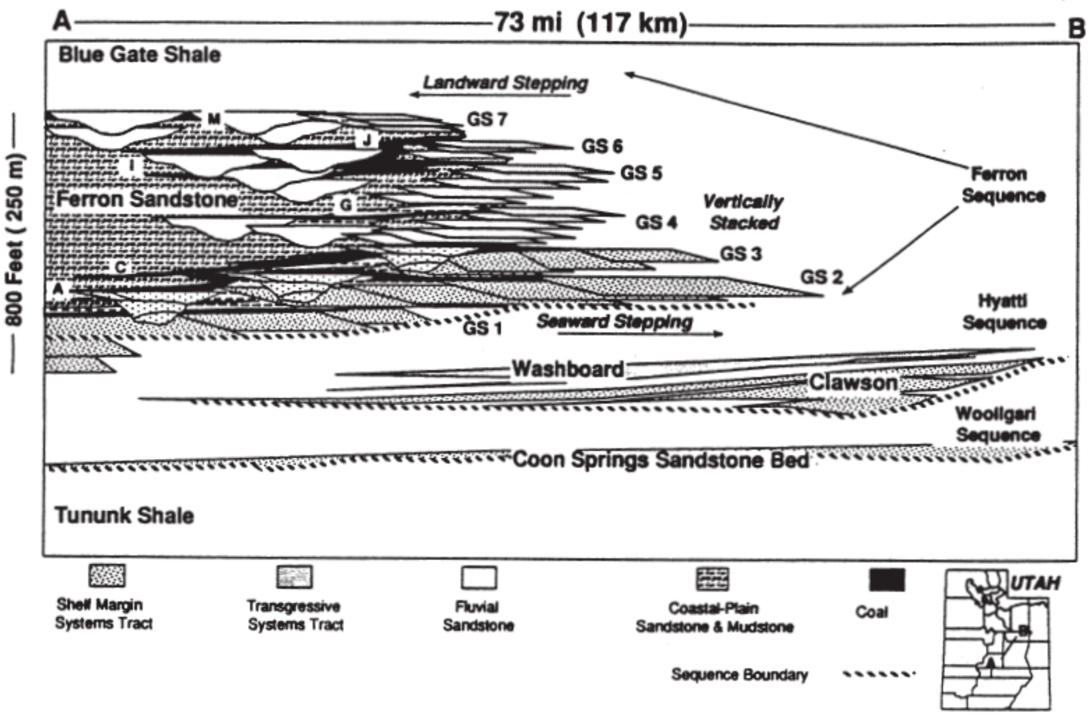

Fig. 8. Cross section of the Ferron at the Last Chance Delta showing 7 genetic sequences. (from Ryer, 2004, after Gardner, 1994)

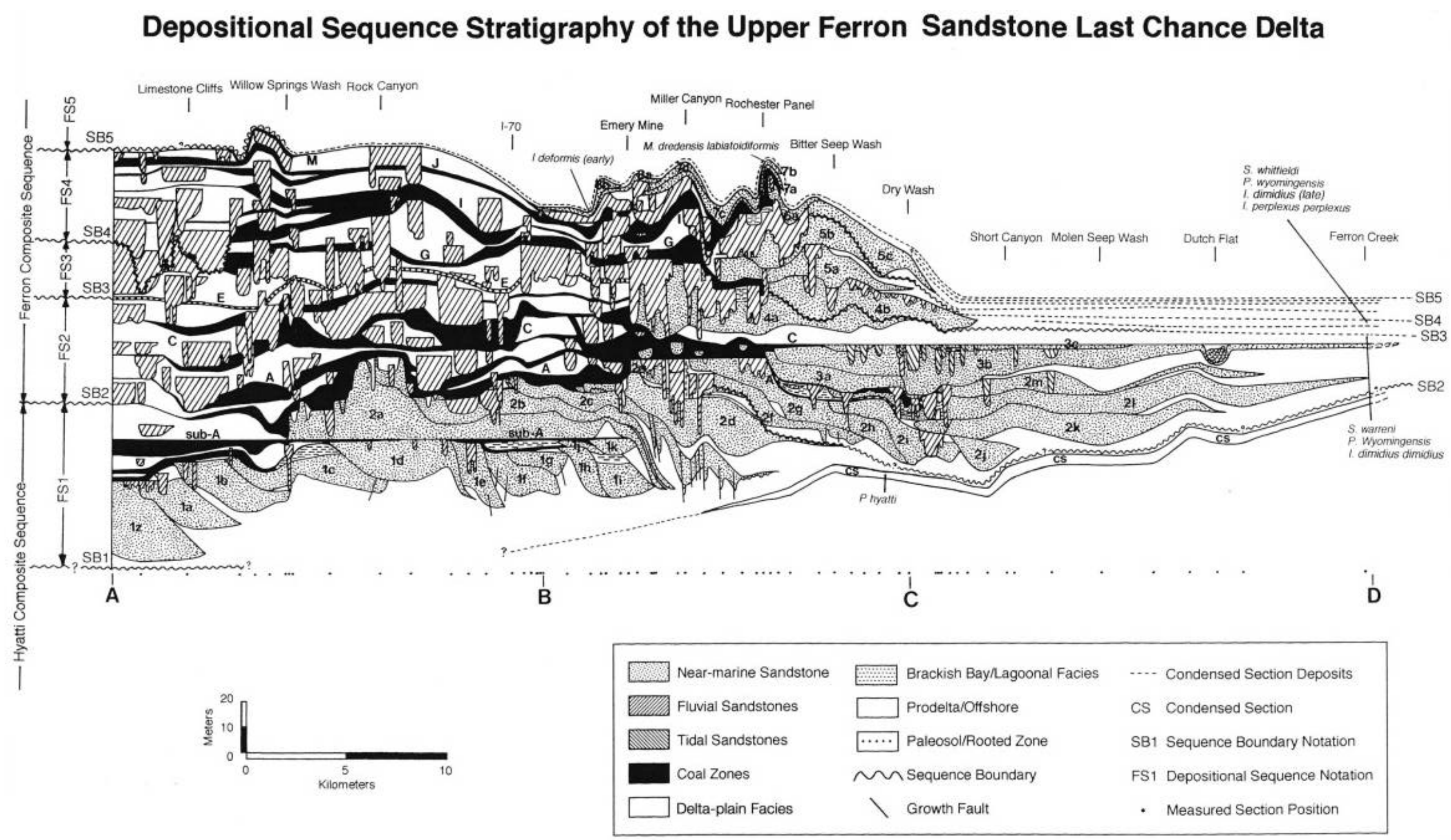

Fig. 9. Cross section the Ferron Last Chance Delta clastic wedge. (from Garrison and van den Bergh, 2004)

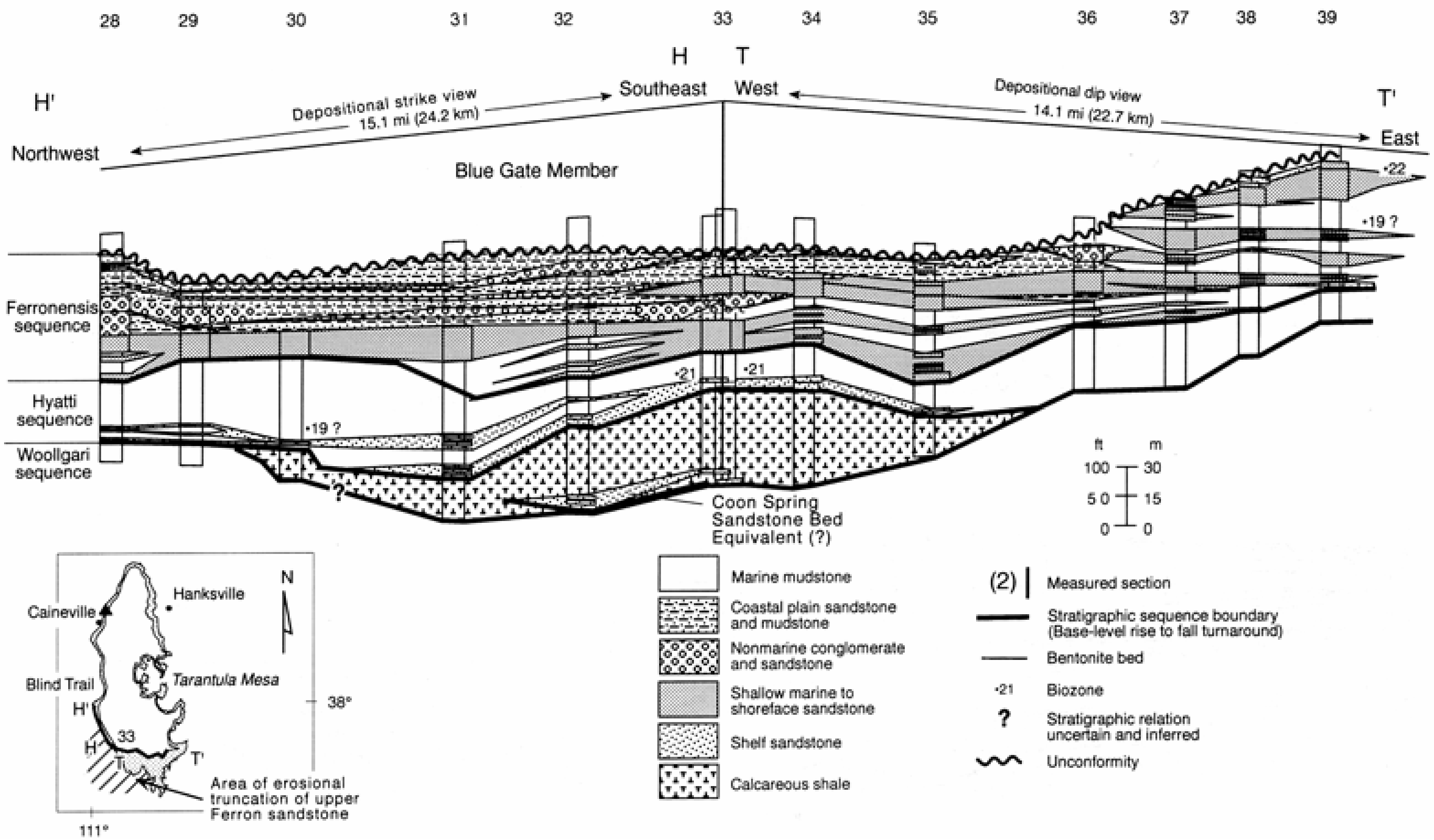

Fig. 10. Cross sections along depositional strike and dip of the Ferron Sandstone at the Henry Mountains region, modified from Peterson and Ryder, 1975. (from Gardner , 1995a)

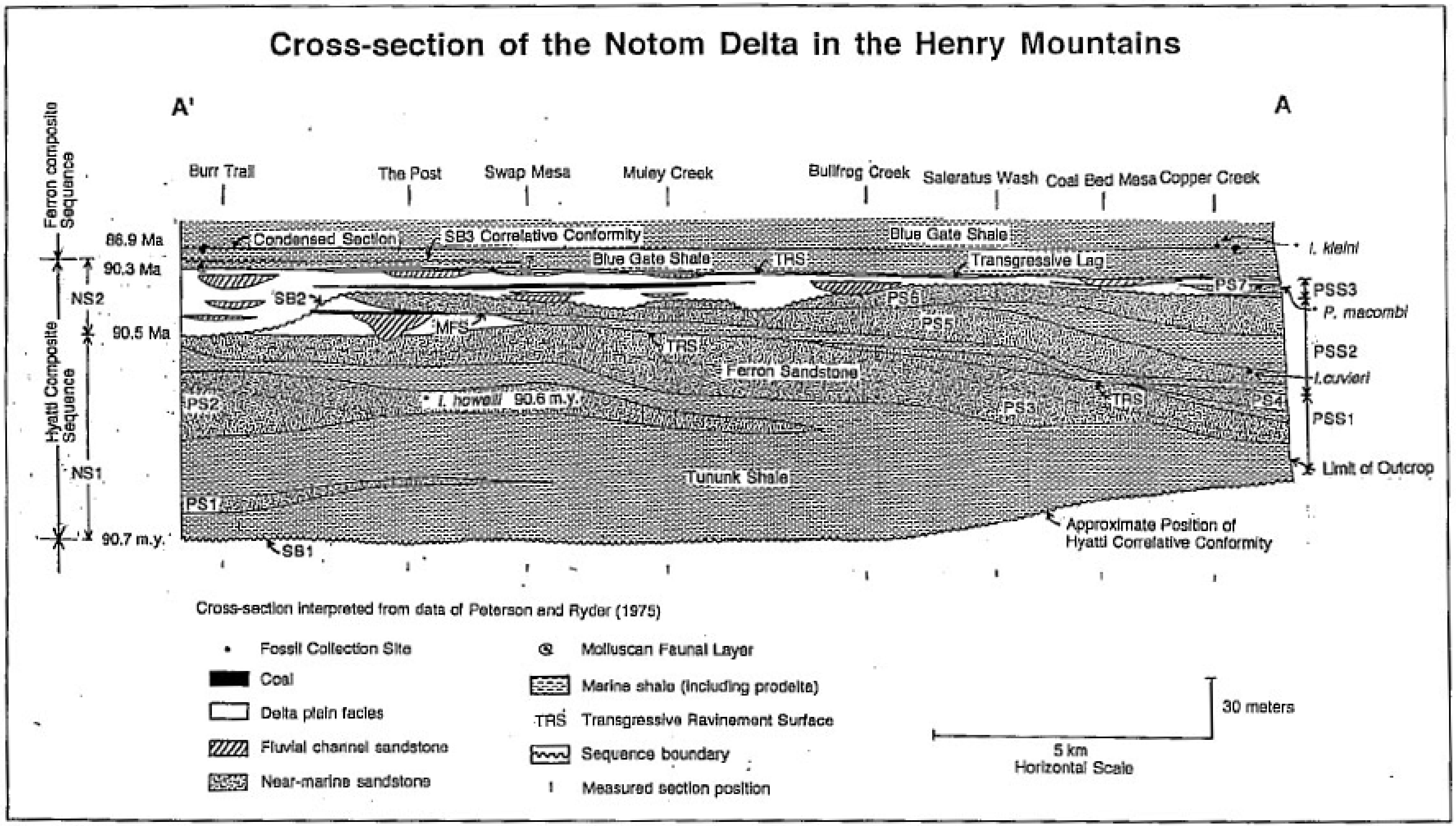

Fig. 11. Cross-section of the Notom Delta in the Henry Mountains region, reinterpreted the cross sections of Peterson and Ryder, 1975. (from Garrison, submitted)

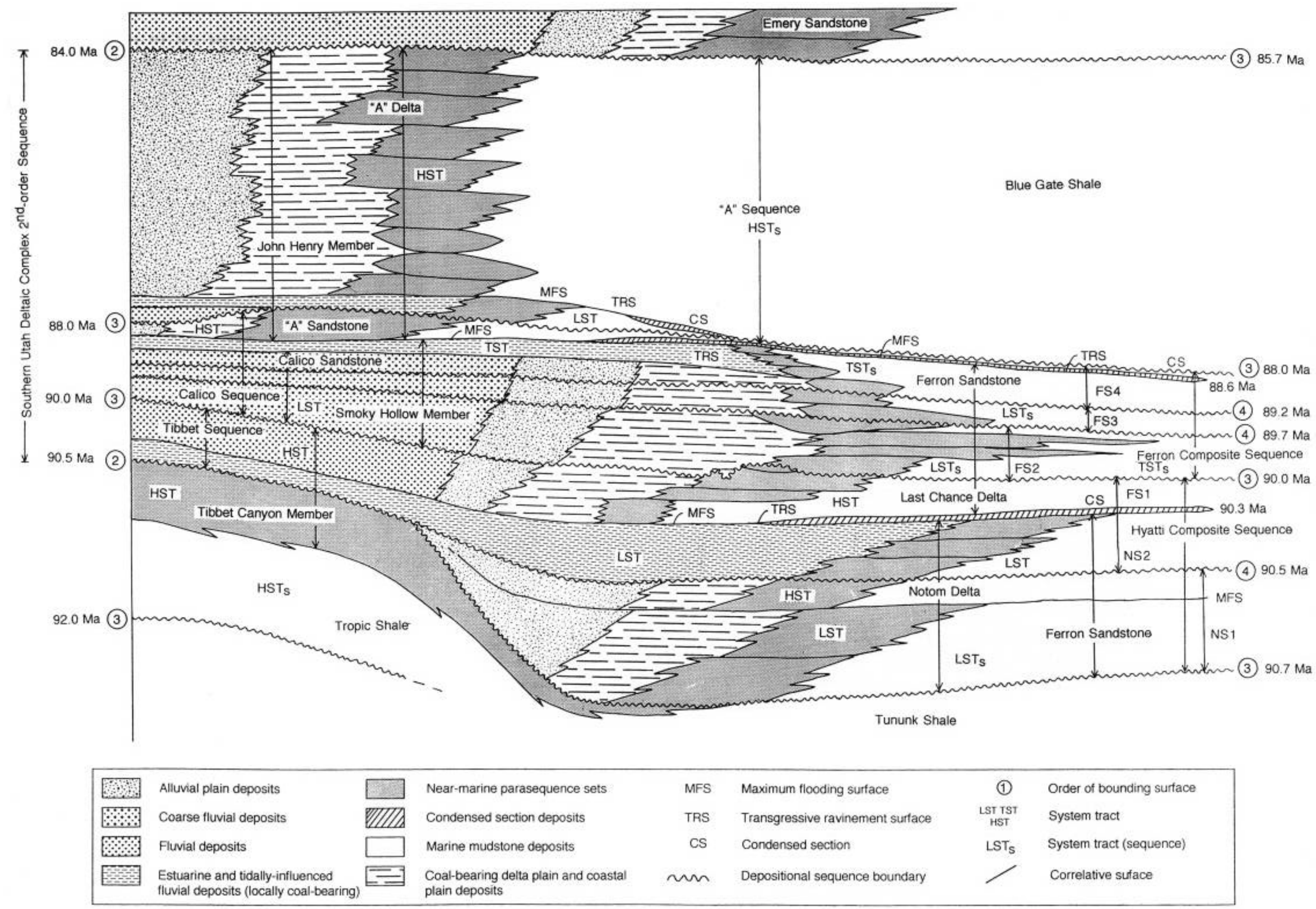

Fig. 12. Composite cross sections and sequence stratigraphic interpretation through the Southern Utah Deltaic Complex, showing the deltas age relationships of the Last Chance, Notom and "A" Deltas. (Garrison and van den Bergh, 2004)

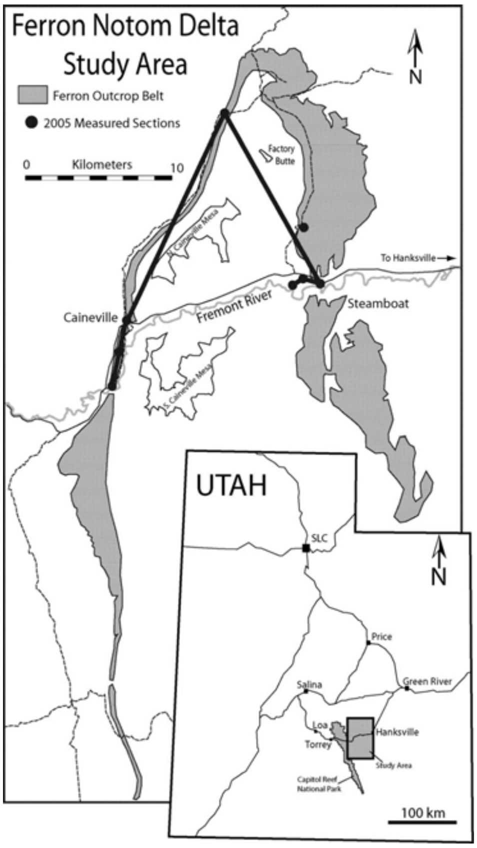

Fig. 13. Base map of Ferron outcrops and location of measured cross sections in summer, 2005. (from Bhattacharya, 2006b)

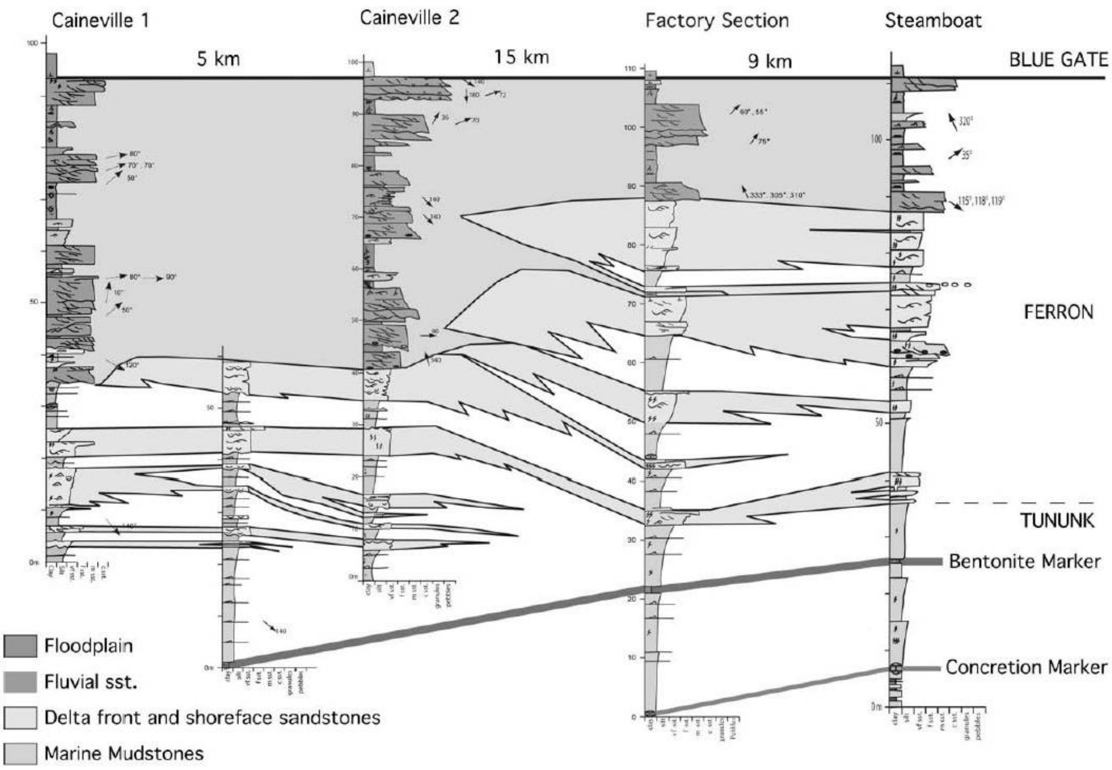

Fig. 14. Preliminary regional cross section through the Notom Delta (from Bhatttacharya, 2006b)

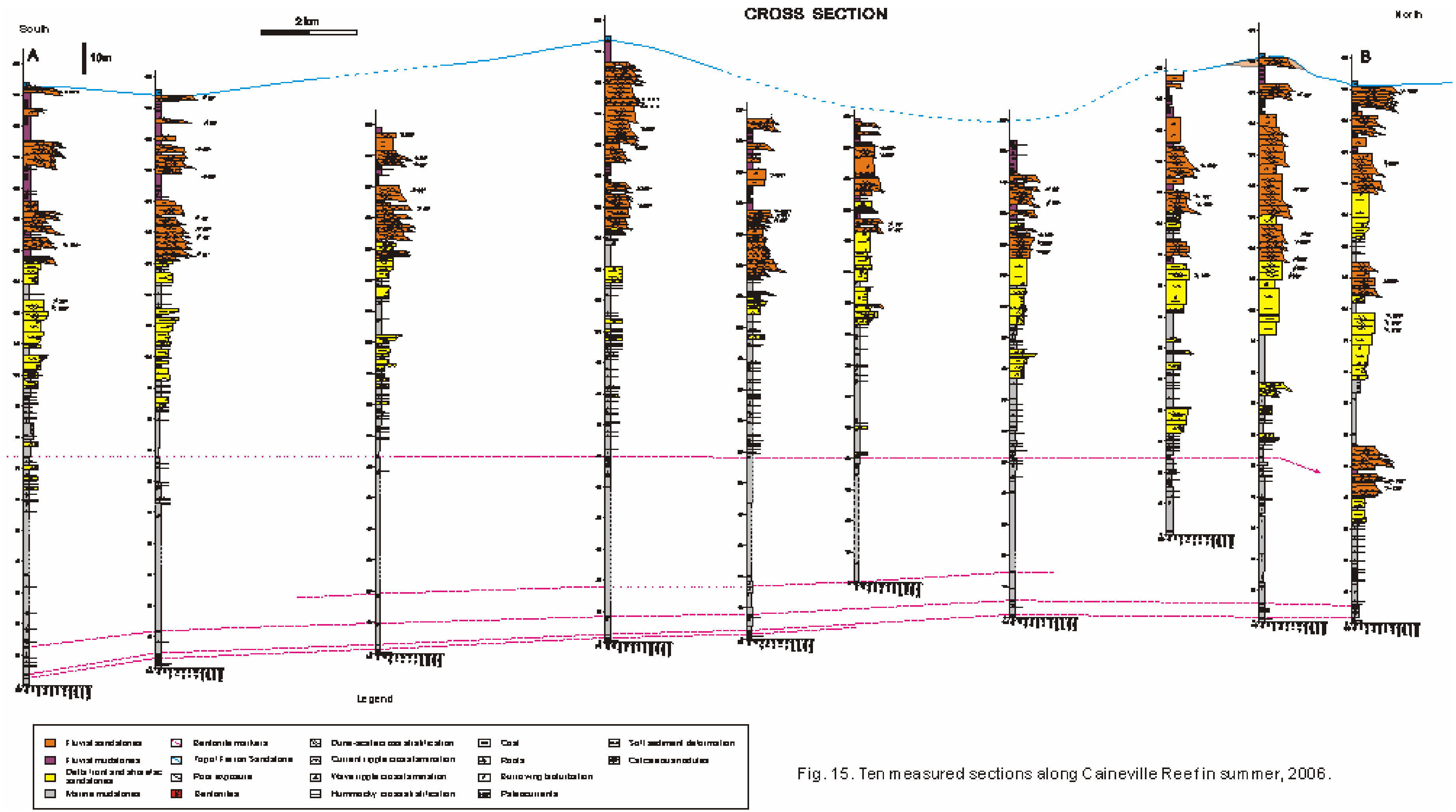

Fig. 15. Ten measured sections along Caineville Reef in summer, 2006.

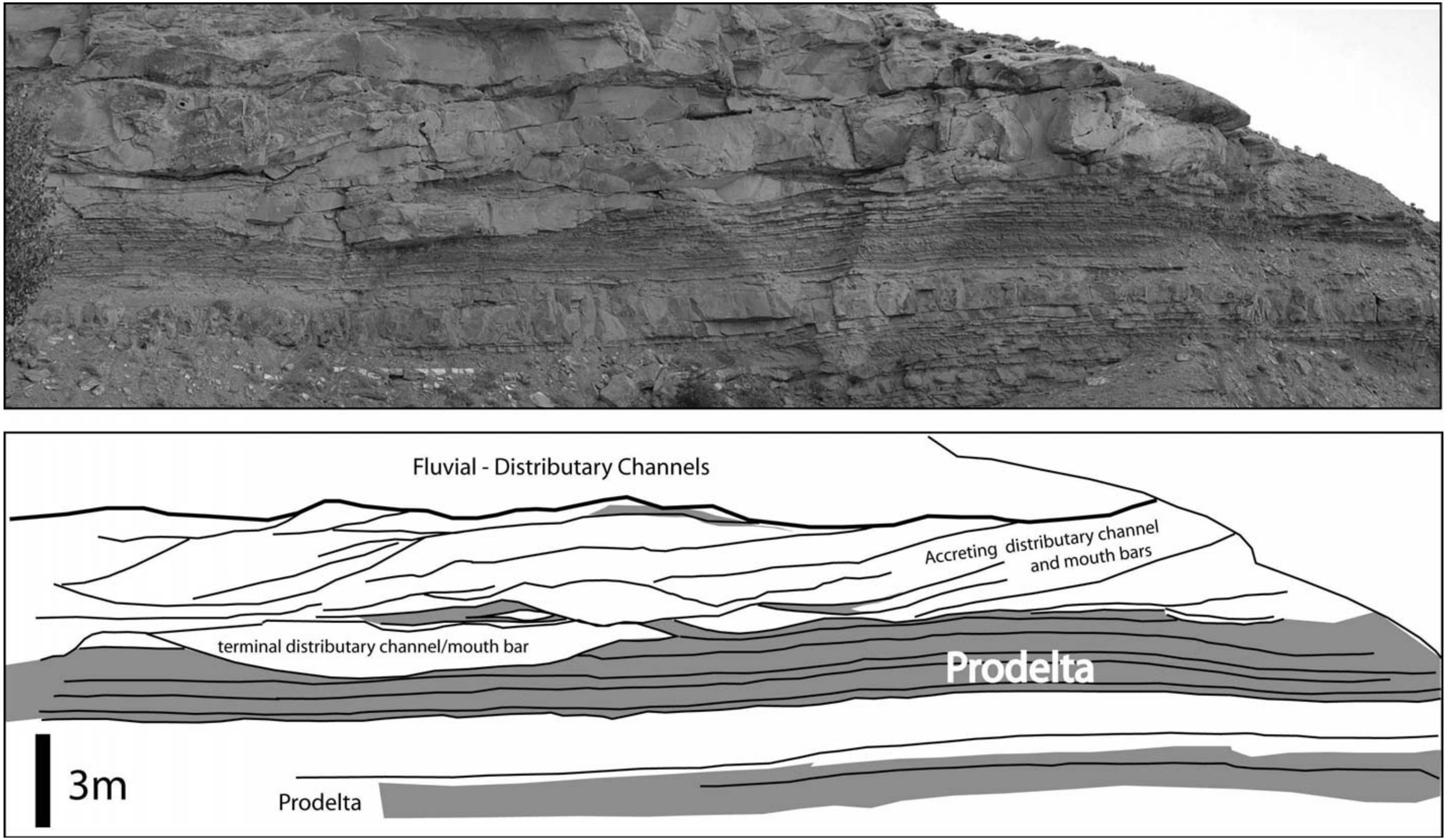

Fig. 16. Bedding diagram of marine to non-marine transition at Caineville. Channelized features overlying delta fronts and shorefaces show complex internal geometry (Bhattacharya, 2006b)