PS Evaluating Along-Strike Variation Using Thin-Bedded Facies, Upper Cretaceous Ferron Notom Delta, Utah*

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Abstract

The Upper Cretaceous Ferron Sandstone consists mainly of fluvial-deltaic deposits. Within deltaic environments, thin beds commonly occur, especially in delta front and prodelta. Primary initiation processes to form thin beds include ignitive turbidity currents, hyperpycnal flows and storm surges. Ignitive turbidites are characterized by the classical fining upward Bouma sequence. Hyperpycnites can show either inversely graded or normally graded bedding. Storm deposits (tempestite) are fining upward and are characterized by the hummocky cross stratification (HCS) and wave ripples. All these three processes are common in deltaic systems. Ignitive turbidity currents and hyperpycnal flows indicate fluvial-dominated depositional environments, whereas tempestites directly linked to wave/storm dominated environments. With the fully developed sequence stratigraphic framework across the study area, the relative amount of sedimentary structures generated by each depositional process can be calculated from a series of measured stratigraphic sections within a single parasequence (Parasequence 6) which is continuously exposed along depositional strike. For each measured section, important sedimentological data including grain size, lithology, bedding thickness, sedimentary structures and ichnological suites have been documented in a millimeter to centimeter scale. The thin-bedded prodelta and distal delta front facies within Parasequence 6 show a strong along-strike variation with completely wave-dominated facies in the north, passing into river-dominated facies southward, then to river-dominated, wave-influenced facies south to southeastward, and a wave/storm-dominated facies further to the southeast. Results show that it is practical to quantify the relative importance of formative processes and determine the along-strike variation within Parasequence 6 of the ancient Notom Delta system using thin-bedded facies analysis.

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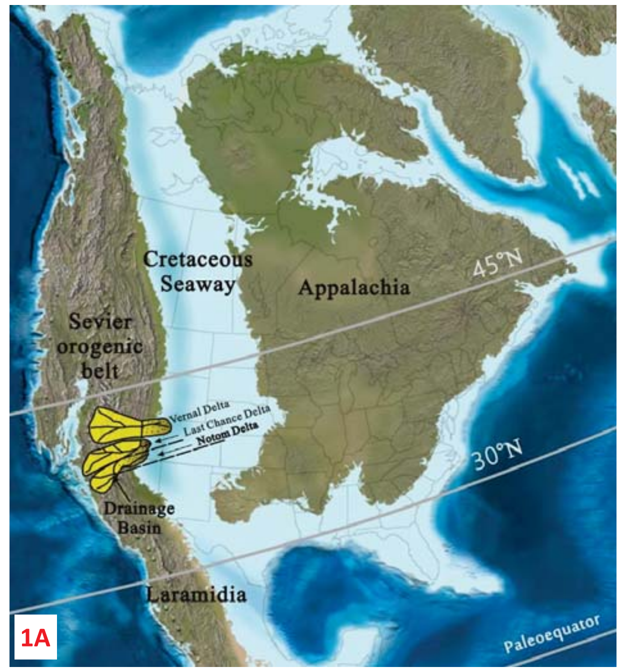
Abstract

The Upper Cretaceous Ferron Sandstone consists mainly of fluvial-deltaic deposits. Within deltaic environments, thin beds commonly occur, especially in delta front and prodelta facies. Primary initiation processes that form thin beds include ignitive turbidity currents, hyperpycnal flows, and storm surges. Ignitive turbidites are characterized by the classical fining upward Bouma sequence. Hyperpycnites can show either inversely graded or normally graded bedding. Storm deposits (tempestites) are fining upward and are characterized by hummocky cross stratification (HCS) and wave ripples. All three processes are common in deltaic systems. Ignitive turbidity currents and hyperpycnal flows indicate fluvial-dominated depositional environments, whereas tempestites are directly linked to storm-wave dominated environments. With the fully-developed sequence stratigraphic framework across the study area, the relative amount of sedimentary structures generated by each depositional process can be calculated from a series of measured stratigraphic sections within a single parasequence (parasequence 6), which is continuously exposed along depositional strike. For each measured section, important sedimentological data including grain size, lithology, bedding thickness, sedimentary structures and ichnological suites have been documented in millimeter to centimeter scale.

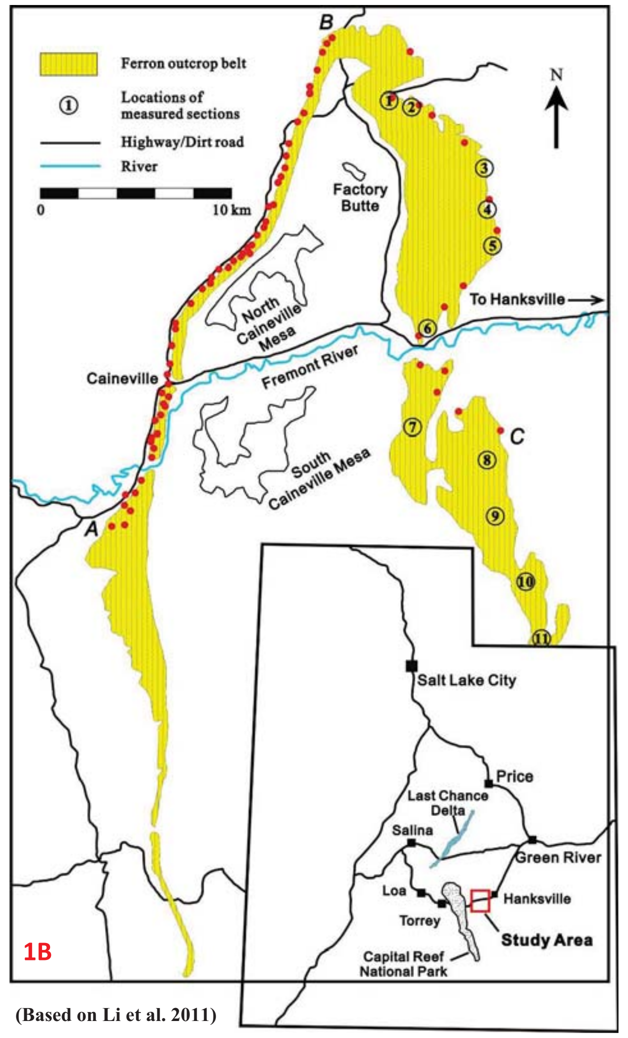
The thin-bedded prodelta and distal delta front facies within parasequence 6 show a strong along-strike variation with a completely wave-influenced environment in the north, passing abruptly into a fluvial-dominated area , then to an environment with varying degrees of fluvial and wave influence southward, and back to a wave-dominated environment further to the southeast . The depositional model of parasequence 6 is interpreted as a bayhead delta based on this along-strike variation. Results in this study indicate that it is practical to quantify the relative importance of depositional processes and determine the along-strike variation within an ancient delta system using thin-bedded facies analysis.

1. Geological Setting and Study Areas



(Slingerland et al. 1996, Bhattacharya ad Tye 2004).

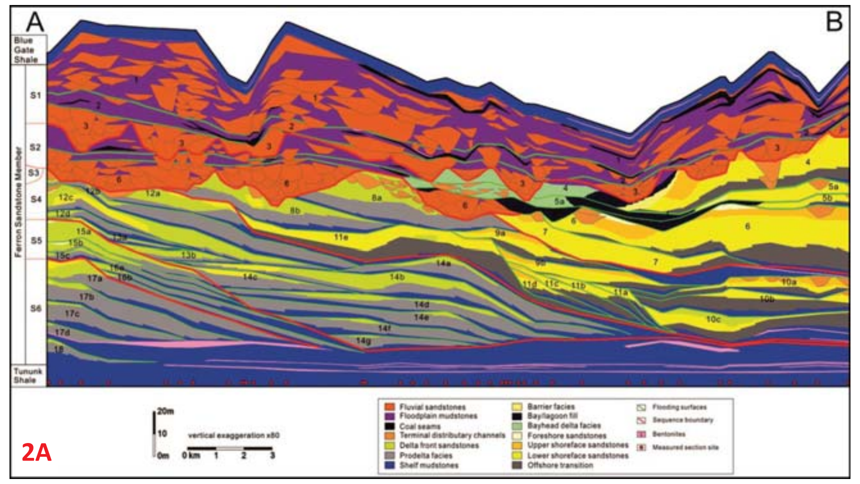
Fig 1A. Paleogeographic reconstruction of the Western Interior Seaway during late Cretaceous. Previous studies indicate that the western interior seaway is storm-dominated.



(Based on Li et al. 2011)

Fig 1B. Location of the Ferron Sandstone outcrop belt. Red dots indicate the locations of all regional sequence stratigraphic sections showing in Fig 2A and 2B. Black circles with numbers indicate the locations of all the sections measured in this study.

2. Regional Sequence Stratigraphy



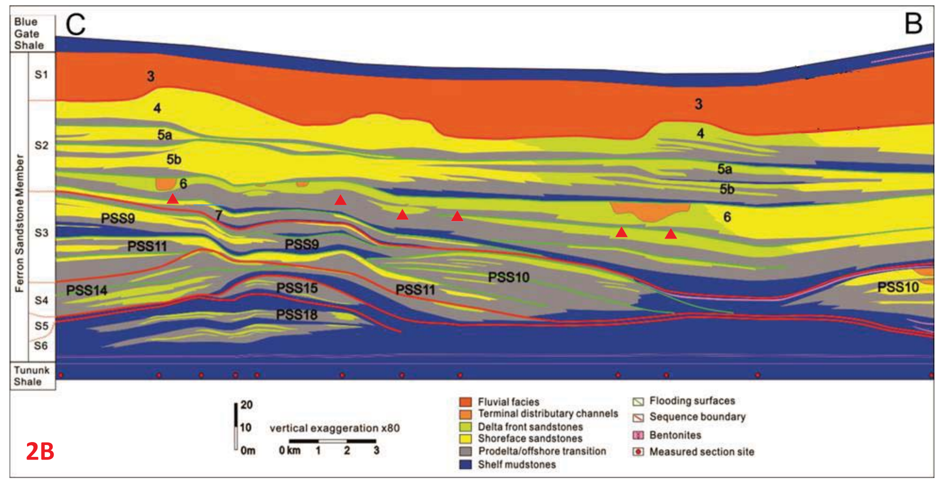
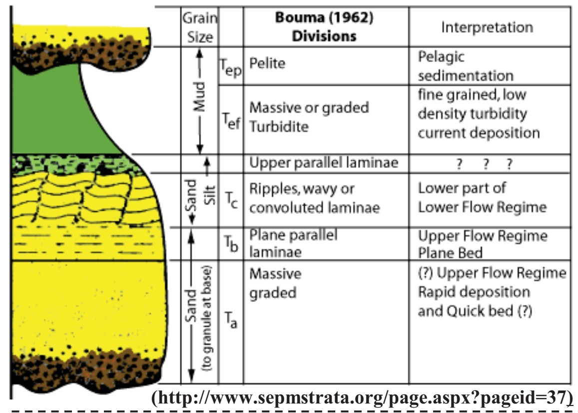


Fig 2A. Dip stratigraphy of the Ferron Notom Delta. Forty-three parasequences, 18 parasequence sets, and 6 sequences have been identified (Zhu et al. 2012). This study is focused on the thin-bedded muddy prodelta facies and heterolithic delta front facies in parasequence 6.
Fig 2B. Strike stratigraphy of the Ferron Notom Delta (Li 2009). Note the sandy facies in Parasequence 6 show strong along-strike variation from the wave-dominated shoreface deposits in the north into fluvial-dominated, wave-influenced facies towards the south. The red triangles indicate the locations of measured sections in this study. Only the first 6 sections are shown in this strike stratigraphy.

3. Methodology

Parasequence 6 is exposed to both strong fluvial influence and storm influence. In a fluvial-dominated deltaic system, the delta front and prodelta facies are prone to form thin beds. Under strong storm influence, thin beds commonly occur in the lower and distal lower shoreface facies. Three primary formative processes of thin beds include 1) ignitive turbidity currents, 2) hyperpycnal flows, and 3) storm surges.

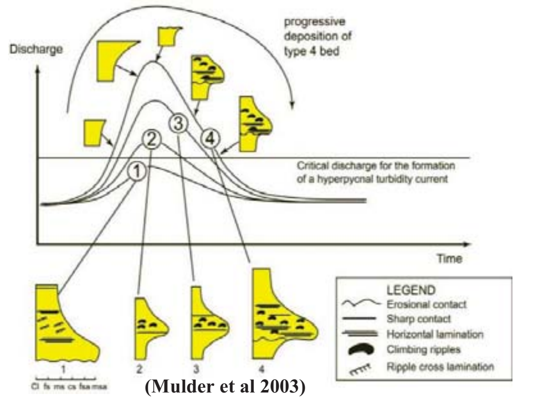


Grain Size		Bouma (1962) Divisions	Interpretation
Mud	T_{ep}	Pelite	Pelagic sedimentation
	T_{ef}	Massive or graded Turbidite	fine grained, low density turbidity current deposition
Silt		Upper parallel laminae	? ? ?
Sand	T_c	Ripples, wavy or convoluted laminae	Lower part of Lower Flow Regime
	T_b	Plane parallel laminae	Upper Flow Regime Plane Bed
Sand (to granule at base)	T_a	Massive graded	(?) Upper Flow Regime Rapid deposition and Quick bed (?)

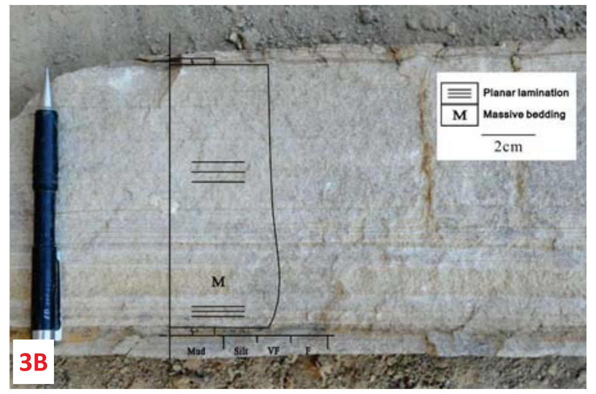
(http://www.sepmstrata.org/page.aspx?pageid=37)

Ignitive turbidite are characterized by classic Bouma sequence. Typical sedimentary structures include massive, planar bedding, ripple cross lamination, and normal grading. Sequences of sedimentary structures are overall fining upwards, indicating waning flow condition.

Fig 3A. Typical Bouma T_a-T_c units.

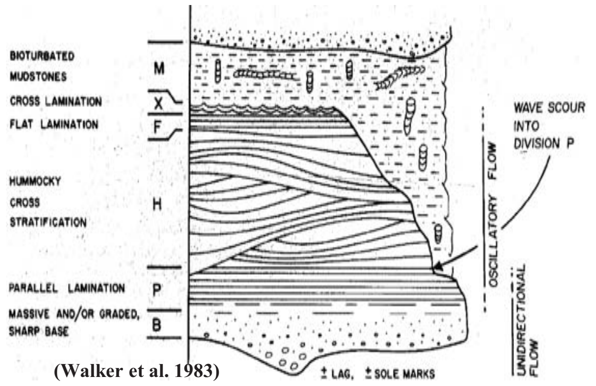


(Mulder et al 2003)

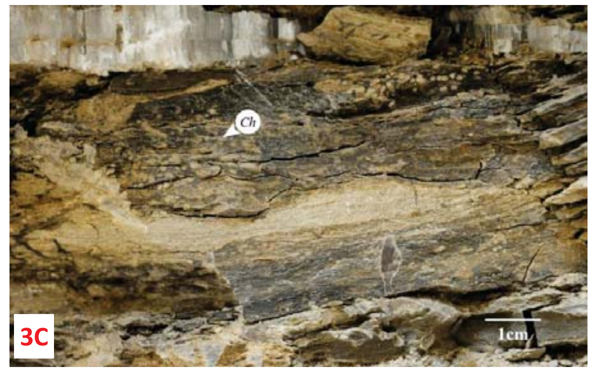


Hyperpycnite can be recognized based on inverse-to-normal grading and any sequences of sedimentary structures that indicate deposition from waxing to waning flows.

Fig 3B. Sedimentary structures grade from the planar lamination at the bottom, up to massive bedding, then overlain by planar lamination again.



(Walker et al. 1983)



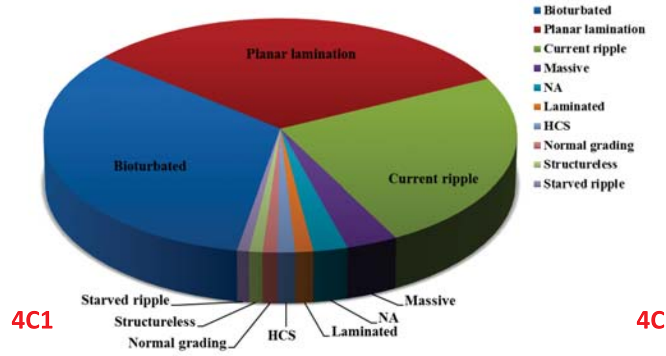
Tempestite are formed under the combined effects of oscillatory flows and unidirectional flows. Typical sedimentary structures include hummocky cross stratification which grades upwards into small wave ripples, and is eventually capped by a mud drape.

Fig 3C. Symmetrical wave rippled very fine sandstone overlain by highly bioturbated mudstone

4. Facies Description and Interpretation

4.1 Fluvial-Dominated Environment
Measured Section 1

Thirty-three percent of the deposits are bioturbated, thus showing no distinct sedimentary structures. About 60% of the deposits show sedimentary structures such as massive bedding, planar lamination, and current ripple lamination. Less than 5% of this section is composed of laminated mudstone, normally graded mudstone, and structureless mudstone. Only 1% of the deposits contain hummocky cross stratification (Fig 4A and 4C).



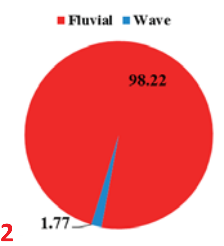


Fig 4C1. Relative amounts of different sedimentary structures
Fig 4C2. Relative influence of fluvial- and wave-dominated processes.

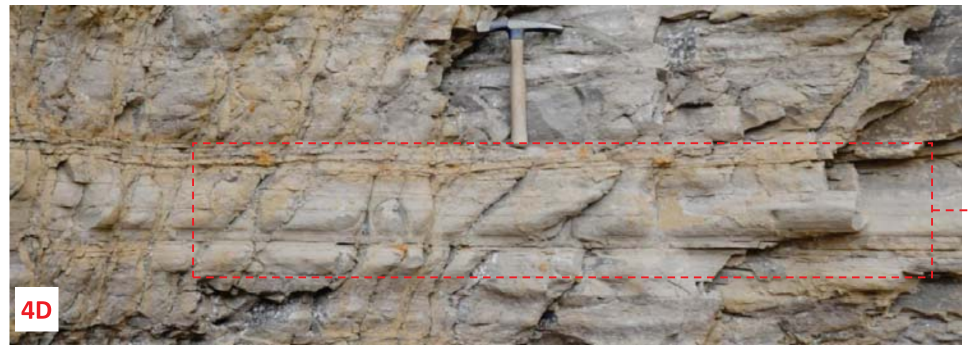
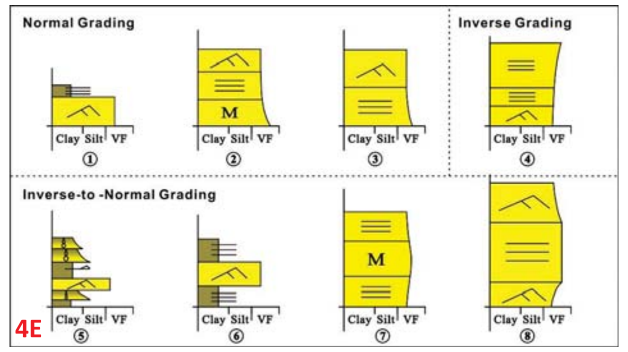


Fig 4D. Planar lamination and well-preserved HCS, inversely grade upward to planar lamination, massive bedding, then overlain by normally graded beds with planar lamination and current ripple lamination.

Fig 4E. Schematic drawings of the common grading sequences among event beds presented in section 1. Total thicknesses range from several millimeters to decimeters.



Process interpretation: More than 98% sedimentary structures indicate deposition under unidirectional-current-dominated flows (Fig 4C). Typical features of turbidites include normally graded bedding and Bouma sequences (Fig 4E1-3). Hyperpycnites are characterized by inverse-to-normal grading and wax-wane stratification sequences (Fig 4E 5-8). The particular grading pattern and sequence of sedimentary structures presented in Fig 4D indicate deposition from combined effects of storm surges and hyperpycnal flows. However, HCS only accounts for 1% of the whole section, suggesting that storm event are rare.

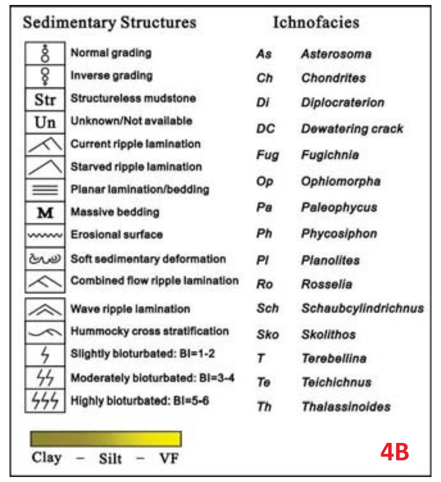
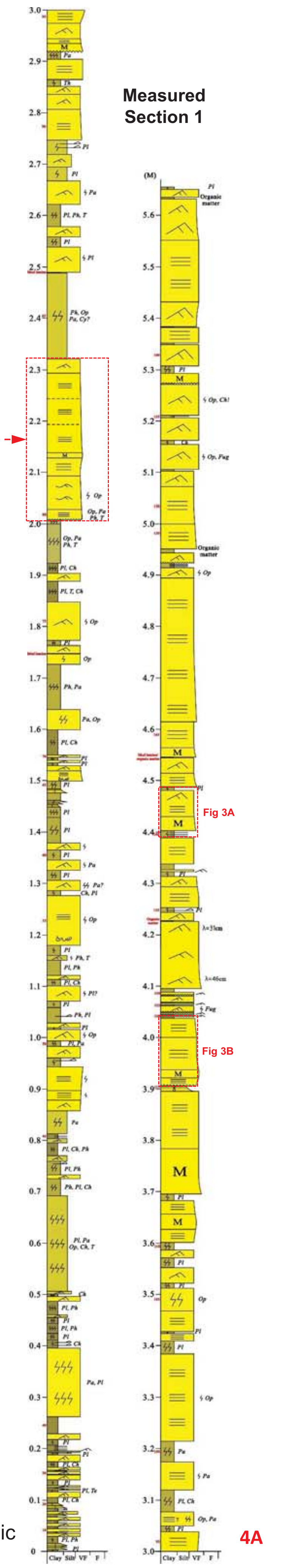


Fig 4B. Facies key for the stratigraphic sections presented in this study.



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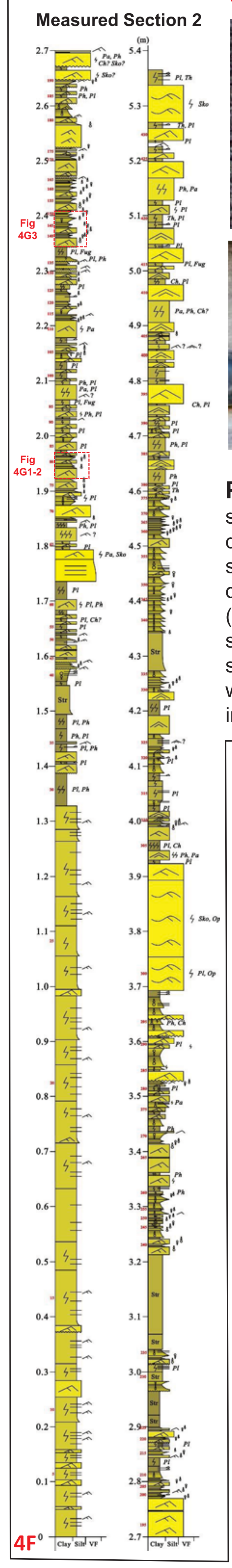
4. Facies Description and Interpretation

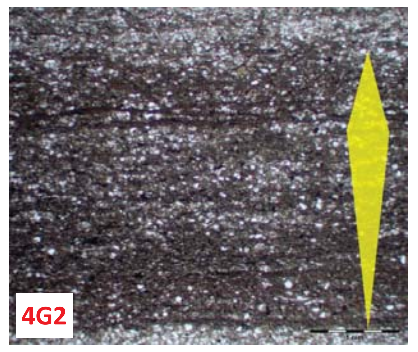
Measured Section 2

Measured Section 2



4F

4G1

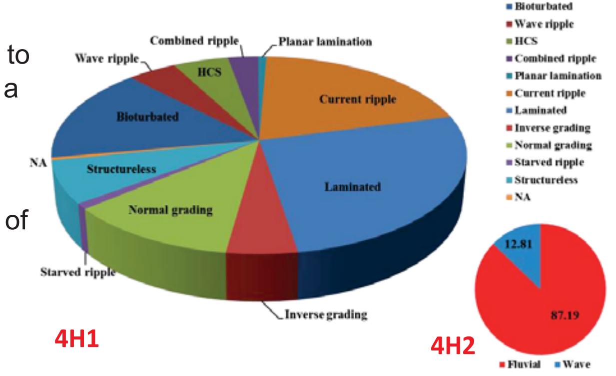


4G2

4G3

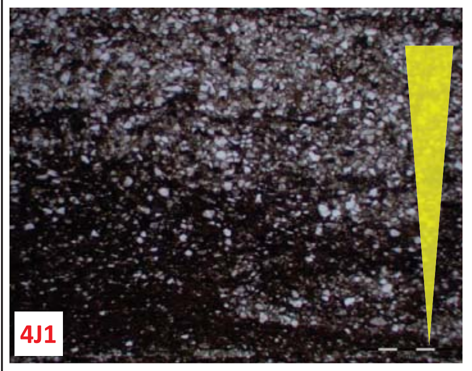
Fig 4G. Common sedimentary structures occurring in this section. *1,* current ripple laminations (foresets highlighted by dashed lines) in thin section, plain light; *2,* inverse-to-normal grading in thin section, plain light; *3,* amalgamated inverse-to-normal grading in outcrop.

Process interpretation: Similar to section 1, this section also contains a dominant proportion (87%) of sedimentary structures typical of deposition from unidirectional flows (*Fig 4H1 and 2*). Higher percentage of storm-generated sedimentary structures indicate that this locality was exposed to stronger storm influence compared to section 1.

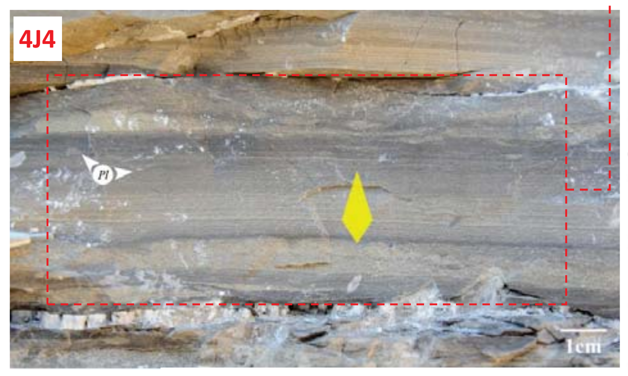


4H1 4H2

Measured Section 3: Mixed fluvial- and storm-influenced

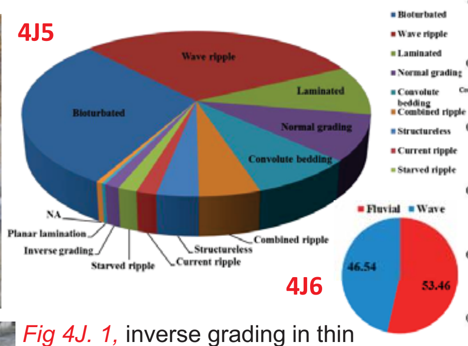


4J1

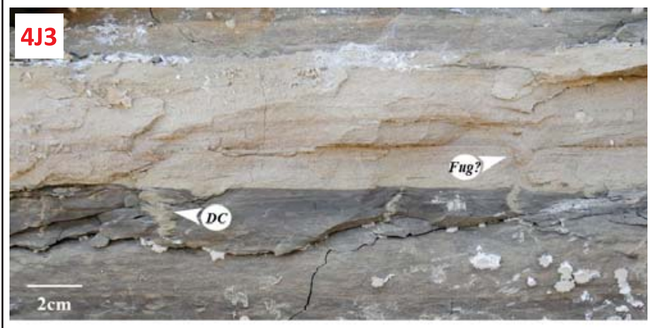


4J4

4J2



4J5 4J6



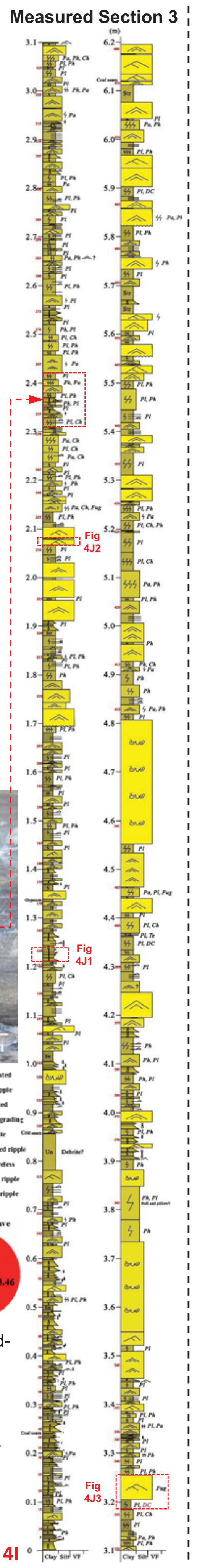
4J3

Fig 4J. 1, inverse grading in thin section (scale bar is 1mm); *2,* combined-flow ripple laminations characterized by both symmetrical outline and foresets only dipping in one direction; *3,* dewatering cracks and trace-fossil escape structure; *4,* mudstone with silty laminations, wave ripple laminations, and inverse-to normal grading; *5,* pie chart showing sedimentary structures present in section 3; *6,* fluvial vs. storm influence.

4. Facies Description and Interpretation

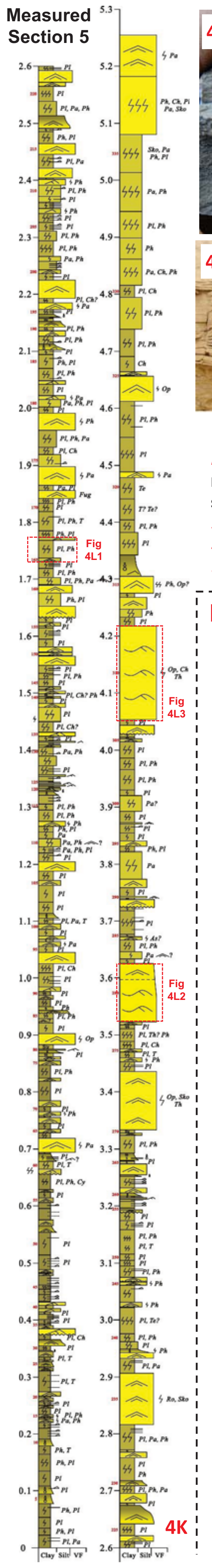
4.2 Mixed Fluvial- and Storm-influenced Environment

Measured Section 3



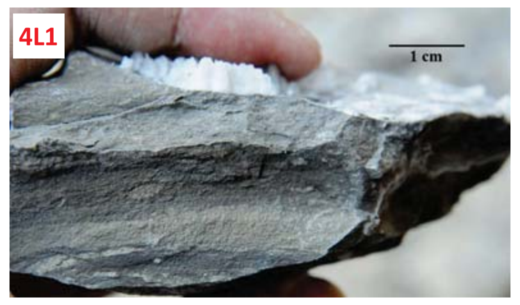
4I

Measured Section 5

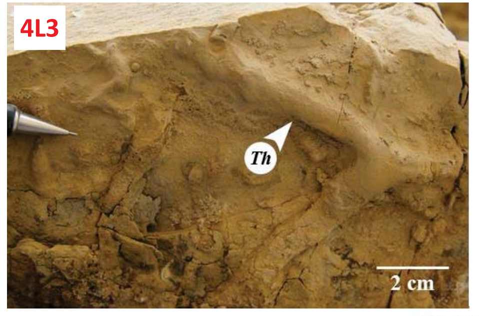


4K

Measured Section 5: Storm-dominated, fluvial-influenced

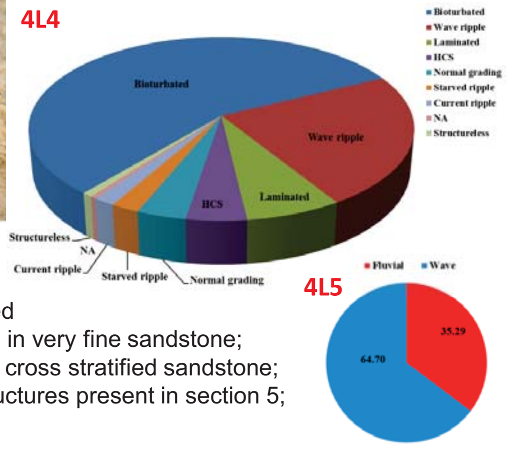


4L1



4L3

4L2

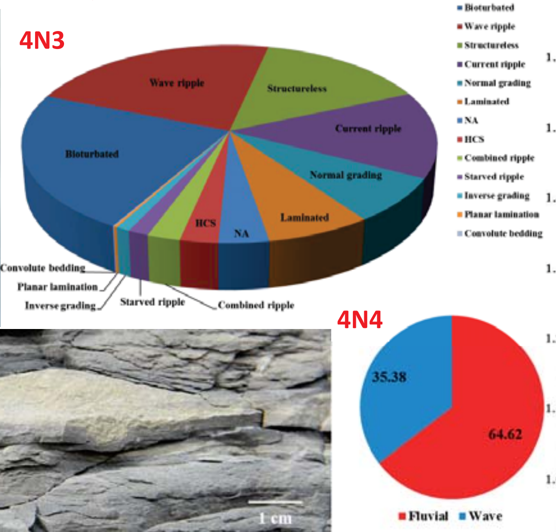


4L4 4L5

Fig 4L. 1, muddy siltstone contain small wave ripple laminations, overlain by slightly bioturbated silty mudstone; *2,* hummocky cross stratification in very fine sandstone; *3,* *Thallassinoides* at the base of the hummocky cross stratified sandstone; *4,* relative amounts of different sedimentary structures present in section 5; *5,* fluvial vs. storm influence.

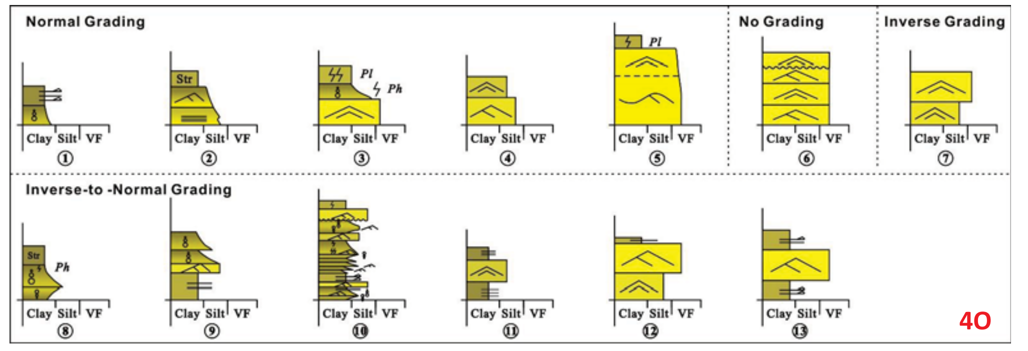
Measured Section 6: Fluvial-dominated, storm-influenced

4N1



4N3 4N4

4N2

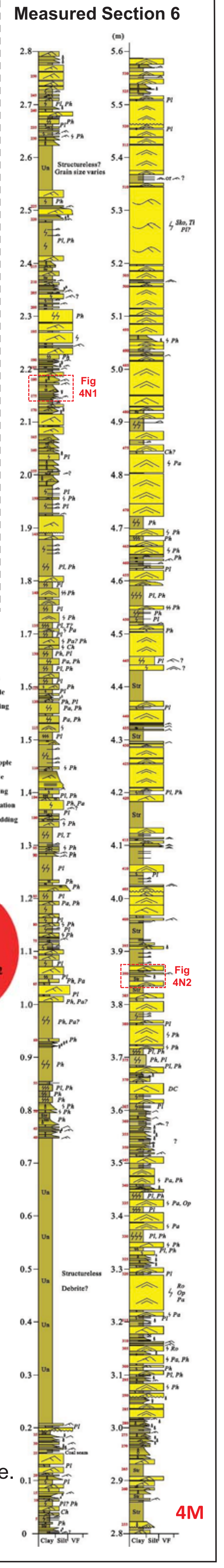


4O

Fig 4N. 1, amalgamated normal grading and inverse-to-normal grading; *2,* wave ripple laminations (bottom) and combined flow ripple laminations (top); *3,* relative amount of sedimentary structures; *4,* fluvial vs.. storm influences

Process interpretation: Sections 3 to 6 show strong fluvial and storm influence. The presence of combined flow ripple laminations, particular stratification, and grading sequences (Fig *4O 4,6,7, 11, 12 and 13*) all indicate deposition from the combined effects of unidirectional flows and oscillatory flows.

Measured Section 6

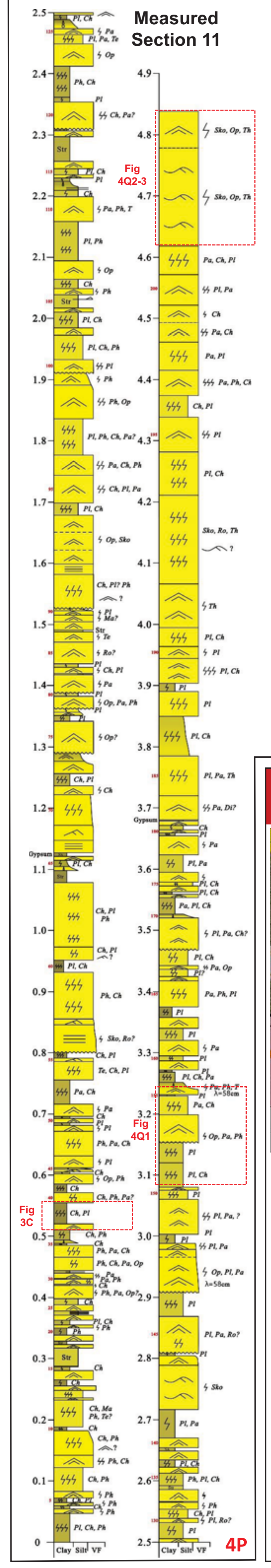


4M

4. Facies Description and Interpretation

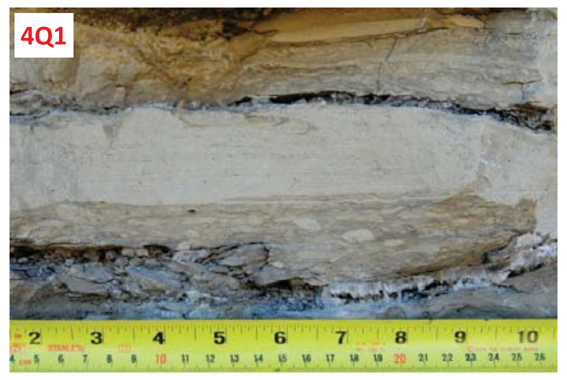
4.3 Storm-dominated environment

Measured Section 11

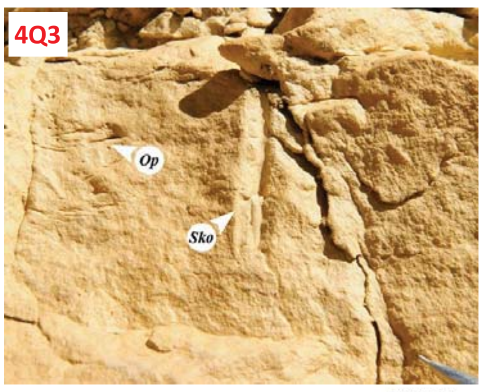


4P

Measured Section 11_Storm-dominated

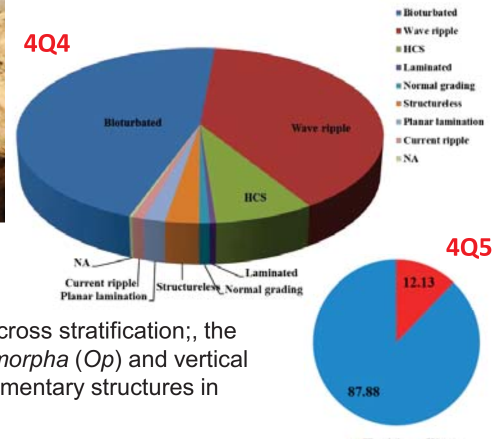


4Q1



4Q3

4Q2

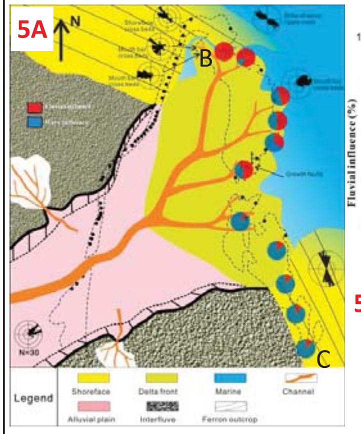


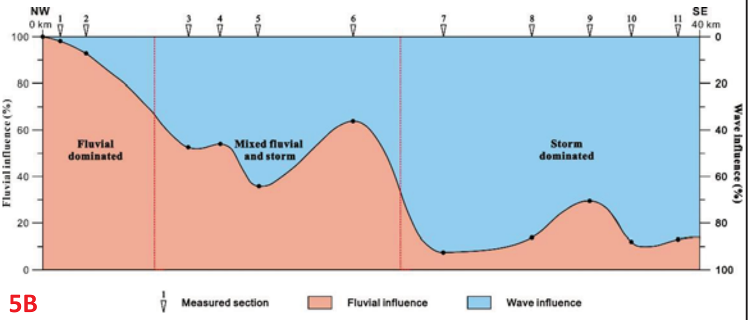
4Q4 4Q5

Fig 4Q. 1, slightly bioturbated very fine sandstone Contains wave ripple laminations, overlain by highly Bioturbated silty mudstone, the so-called lam-scram bedding; *2,* very fine sandstone showing hummocky cross stratification;, the length of the pencil is about 13cm; *3,* inclined *Ophiomorpha* (*Op*) and vertical *Skolithos* (*Sko*) in Fig 4Q2; *4,* relative amount of sedimentary structures in section 11; *5,* fluvial vs. storm influence.

Process interpretation: Sections 7 to 11 all contain significantly higher amounts of sedimentary structures, such as wave ripple laminations and HCS, typical of deposition of strong oscillatory flows. The relatively high bioturbation intensity also suggests that those localities are exposed to dominant storm influences.

5. Conclusions





5B

Fig 5A. bay-head delta model based on the results in this study (edited based on Li et al., 2014); *Fig 5B.* Along-strike variations between fluvial- and storm-dominated processes.

1) It is practical to quantify the relative importance of formative processes within each sedimentologic section and determine the lateral variation between fluvial and wave influences within an ancient delta system through thin-bedded facies analysis.
2) The thin-bedded facies with Parasequence 6 indicate a strong along-strike variation with a completely wave-influenced environment in the north, passing abruptly into a fluvial-dominated area (sections 1-2), then to an environment with varying degrees of fluvial and wave influence southward (sections 3-6), and back to a wave-dominated environment further to the southeast (sections 7-11). The depositional model of parasequence 6 is interpreted as a river-dominated bayhead delta which is partially protected from marine-influence by wave-formed shoreface deposits on both sides.
3) The thin-bedded prodelta and distal delta front units within Parasequence 6 were deposited from the combined influence of turbidity currents and storm surges. By examining the vertical stratification and grading sequences within these thin beds in great detail, conceptual models of deposition from turbidity currents, storm surges, and the interaction between these flows can be constructed.