3D Geometry and Facies Architecture of Fluvial-dominated Mouth-bar Deposits, Ferron Notom Delta, Utah, USA

By
Yangyang Li

Advisor: *Dr. Janok P. Bhattacharya*

Proposal submitted to the Faculty of the Geosciences Department, University of Houston, in partial fulfillment of the requirements for the degree of:
Doctor of Philosophy in Geosciences

November, 2009

Abstract

Distributary mouth-bar deposits have been widely recognized and studied in both modern and ancient deltaic systems. However, detailed facies architectural studies of bed-scale mouth-bar deposits in ancient deltaic systems in outcrop are sparse despite their significance in reservoir characterization and in understanding the internal hierarchy of deltaic system. Superb exposures of the Turonian Ferron Notom Delta in southern Utah allow reconstruction of the 3D geometry and facies architecture of fluvial-dominated, wave-influenced mouth-bar deposits within a recently developed high-resolution sequence stratigraphic framework.

Six sequences, 18 parasequence sets, and 42 parasequences have been identified. Mouth-bar deposits are well exposed in both parasequence 6a and the overlying parasequence 5. There are no distinct differences in size and internal sedimentary structures in these two sets of mouth-bar deposits. However, parasequence 6a is much sandier and more amalgamated suggesting a lobate delta whereas parasequence 5 is muddier and heterolithic indicating a bird-foot delta. The morphology of mouth bars in fluvial-dominated conditions is commonly interpreted to be controlled by the nature of the effluents. However, we hypothesize that the differences between parasequence 6a and 5 in Ferron are controlled by shoreline trajectory. Under a negative shoreline trajectory, during the progradation of parasequence 6a, an incised valley system was developed with most of the sediments bypassing the shoreline. Consequently, muddy facies were much less developed immediately behind the shoreline and in the delta front but were in fact being partitioned to the prodelta and further basinward on the shelf. A lobate shape sandy delta with multiple distributary channels was developed. In contrast, parasequence 5

progrades under a positive shoreline trajectory and a greater portion of mud is inferred to have been trapped behind the shoreline and the more proximal part of the delta as suggested by the well-developed heterolithic mouth-bar and inter-bar bay-fill facies within it. In this case a bird-foot delta with abundant lagoonal and bay-fill deposits was formed.

Few studies are focused on the hierarchy and growth mechanism of delta front deposits. It is proposed based on modern deltaic systems that mouth bars coalesce to form complex bar assemblages which in turn build delta lobes. A few ancient deltaic studies based on seismic data have recognized similar hierarchy. However, there is no support of this argument from ancient deltaic system based on outcrop studies. The bed-scale facies-architectural study of mouth bar deposit in Ferron Notom delta will test this modern case based hierarchy and help interpret the mechanisms by which deltas actually grow.

Introduction

Distributary mouth bars are one of the basic building blocks of deltaic systems (Gani and Bhattacharya 2007). They form at the river mouth where the fluvial outflow enters a permanent body of water and the coarse sediments are deposited (Bates 1953; Wright 1977). Detailed facies architectural studies of mouth-bar deposits are of scientific and economic importance because they can help understand the growth mechanism and internal hierarchy of deltas, as well as provide better geologic models for reservoir modeling.

The morphology of mouth bars is mainly controlled by the nature of the effluents in river-dominated conditions. Inertial dominated effluents favor lunate-shaped mouth bars; friction-dominated effluents develop lozenge-shaped mouth bars (also documented as middle ground bars) and buoyant effluents generate crescent-shaped mouth bars (Bates 1953; Wright 1977; Van Heerden and Roberts 1988) (**Figure 1**). However, the effluents will be modified in wave- and tide-dominated conditions, resulting in reworking of river mouth deposits and formation of beach ridges parallel to the shoreline where waves are operative, and linear tidal ridges perpendicular to the shoreline where tides are operative (Wright 1977; Coleman and Wright 1975; Galloway 1975; Bhattacharya and Walker 1992) (**Figure 2**). Most mouth bars in reality are not end members as described above, but are intermediate in nature due to the mixed influence of rivers, waves, and tides. The triangular-shaped, sharp-based mouth bars in Burdekin delta form a good intermediate example between lozenge-shaped mouth bars of river-dominated deltas and beach ridges of wave-dominated deltas reflecting of river-dominated and wave-influenced conditions (Fielding et al. 2005).

Mouth bars scale broadly to the width of the flow and can be up to several kilometers long in large deltaic systems like the modern Atchafalaya delta (Van Heerden and Roberts, 1988; Bhattacharya 2006). Statistical study of the mouth bar geometries shows that distributary mouth bars are about twice as long as they are wide on average, in both modern and ancient deltas, even though modern mouth bars are typically much smaller in size than ancient ones (Reynolds 1999; Tye 2004).

In river-dominated environments, most mouth bars have a general upward coarsening trend, probably due to the tendency of concentrating coarse-grained sediments at the apices of the mouth bars and the progradation of the delta (Wright 1977; Van Heerden and Roberts 1988; Tye and Coleman 1989; Willis et al. 1999; Wellner at al.

2005). However there are also examples of sharp based fining upward mouth bars, as well as those that show no distinct grain size change such as the mouth-bar deposits in the Burdekin delta, which are considered to be the consequence of short-duration, high-velocity flood events that deliver sediments into shallow water (Fielding et al. 1988, Fielding et al. 2005).

Mouth bars grow by vertical aggradation, and downstream, lateral, and upstream accretion (Van Heerden and Roberts 1988; Olariu and Bhattacharya 2006). The downstream and lateral accretion of the mouth bar sand bodies builds up the most distinctive feature of delta front deposits, clinoforms, which show a unidirectional seaward dipping pattern in dip direction and a bilateral dipping style in strike view (Tesson et al. 1993; Hart and long 1996; Willis et al. 1999; Olariu 2005). Clinoforms have been widely recognized from both modern and ancient deltaic systems, however there are far more dip-oriented examples than strike-view examples (Rich 1951; Bhattacharya 1993; Chidsey 2001; Hampson 2000; Roberts et al. 2004).

Mouth-bar deposits are widely documented in the literature on deltaic system studies (Van Heerden and Roberts 1988; Overeem et al. 2003; Reynolds 1999 and Tye 2004; Fielding et al. 2005; Bhattacharya 2006; Gani and Bhattacharya 2007); however few of them show detailed facies architectural characteristics and construction of 3-D mouth bar geometries, which will be the emphasis of this research.

Geological setting of the study area

A series of progradational sandy wedges were developed at the western margin of the Cretaceous Western Interior Seaway during the late Cretaceous. These wedges formed along with the continued thrusting of the Sevier orogenic belt to the west and the associated subsidence of the Cordilleran foreland basin (DeCelles and Giles 1996; Ryer and Anderson 2004; Bhattacharya and Tye 2004) (**Figure 3**). The Ferron Notom delta was the first deltaic system deposited into the seaway during this period. It is bounded by the Blue Gate Shale Member above and the Tununk Shale Member below (Barton et al. 2004; Garrison and Van den Bergh 2004) (**Figure 4**).

A high resolution regional sequence stratigraphy of the Ferron Notom delta has recently been constructed by Yijie Zhu and Weiguo Li. Six sequences, 18 parasequence sets and 42 parasequences are identified (**Figure 5**). This study will focus on parasequence 6a and the overlying parasequence 5, both of which have well exposed mouth-bar deposits. According to their study, parasequence 6a developed in the late lowstand-systems tact, has a coeval incised valley system further landward, and is associated with a negative shoreline trajectory. Parasequence 5 developed in the highstand-systems tract, has a coeval muddier delta plain further upstream, and is associated with a positive shoreline trajectory. The study area is located along the Coalmine Wash close to Factory Butte in south central Utah (**Figure 6**). Outcrop exposures in both dip and strike provide a great opportunity to do detailed facies architectural and 3-D geometric studies of delta-front sand bodies.

Mouth-bar deposits in the Ferron sandstone

Mouth bars are well-developed and exposed in parasequence 6a and its overlying parasequence 5. In dip view these mouth bars show distinctive unidirectional clinoforms of 5°-8°; and in strike direction they have a mounded, bilateral dipping pattern. Field mapping shows that mouth bars from these two parasequences have no obvious difference in size and internal structures. Detailed field descriptions show planar stratification, current ripple cross-lamination and aggradational ripple cross-lamination, near bar tops, dune-scale cross stratification are common. Widespread graded beds, soft-sediment deformation, and low abundance and diversity of bioturbation within delta-front to prodelta facies indicates a fluvial-dominated setting. The occurrence of hummocky cross stratification, wave-ripple cross-lamination, and combined-flow ripple cross-lamination, however, suggests storm/wave reworking of the mouth bar and delta-front deposits in both parasequences.

However, despite those similarities, parasequence 6a is sandier and consists of thicker, far more amalgamated, lobate sand bodies (**Figure 7**). In contrast, parasequence 5 is muddier, more heterolithic, and mouth bars contain significant proportions of muddy interdistributary bay-fill facies (**Figure 8**). In addition, mouth bars in parasequence 6a show a general upward coarsening trend with a relatively smooth base, while in parasequence 5 mouth bars commonly show an erosional sharp base with no obvious grain size change vertically.

Hypothesis

Even though the 3-D geometry of the mouth bars still need to be worked out next summer, it can be concluded that outcrop exposures indicate a lobate-shape delta in parasequence 6a much like the Wax Lake in Atchafalaya Bay (Wellner el al. 2005), in contrast to parasequence 5a which suggests a bird-foot delta like the Mississippi. The hypothesis for this research is that the differences between delta types in parasequence 5 and 6a are controlled by ancient shoreline trajectory.

Shoreline trajectory is the shoreline path viewed along a cross-sectional depositional-dip section. It is a function of sediment supply and accommodation, which includes relative sea level and shelf bathymetry. The shoreline trajectory circle shows that 0^0 to -30^0 occurs in forced regression, 0^0 to 90^0 occurs in normal regression and 0^0 to 180^0 occurs in transgression (**Figure 9**). According to the contribution of the sediment supply to the building of shoreline trajectory, Hansen and Martinsen (1996) further divided the forced regression and transgression into accretionary and non-accretionary situations. In the rock record, the ancient shoreline is usually diagnosed by the lateral position of beach deposits.

Shoreline trajectory can be inferred from the trajectory of the shelf edge using seismic and well data. Three shelf-edge trajectories have been recognized based on high quality 3-D seismic study of Tertiary coastal delta deposited in offshore Norway: 1) positive shelf edge trajectory; 2) flat shelf edge trajectory; and 3) negative style (**Figure 10**). Bullimore et al. (2005) also proposed that shelf edge trajectory patterns can be used to predict lithology in prograding systems, as positive shelf edge trajectories tend to be associated with barrier islands and lagoonal facies in the coastal plain area, and negative shoreline trajectory are associated with bypass and erosion favoring incised valley systems landward, and basin floor fan deposits (Bullimore et al. 2005).

This approach can be used to interpret the Ferron. Under a negative shoreline trajectory, during the progradation of parasequence 6a, an incised valley system was developed with most of the sediments bypassing the shoreline. Consequently, muddy facies were much less developed immediately behind the shoreline and in the delta front but were in fact being partitioned to the prodelta and further basinward on the shelf. A lobate sandy delta with multiple distributary channels was developed. In contrast, parasequence 5 prograded under a positive shoreline trajectory, and a greater portion of mud is inferred to have been trapped behind the shoreline and the more proximal part of the delta as suggested by the well-developed heterolithic mouth-bar and inter-bar bay-fill facies within it. In this case, a bird-foot delta with abundant lagoonal and bay-fill deposits was formed.

More information will be gathered next summer to test this hypothesis, such as the regional sequence stratigraphic relationship of parasequence 5 and 6a, the detailed facies architecture and 3-D geometry of the mouth-bar deposits, and the lithofacies and ichnofacies of inter-bar deposits.

Objectives of this study

The primary objective of this study is to determine the detailed bed-scale facies architecture and 3-D geometry of mouth bars both in parasequence 5 and 6. The paleogeography will also be reconstructed.

Based on the study above and the previous studies on regional sequence stratigraphy and shoreline trajectory theory, the differences and the factors controlling the differences between mouth-bar deposits in parasequence 6a and its overlaying parasequence 5 will be determined. The comparison of mouth bars in Ferron with previously studied mouth bars in other deltaic systems will be also done.

Wellner et al. (2005) divided the Wax Lake delta into ten bar assemblages and each of the bar assemblages have been subdivided into a couple of individual bars. Bhattacharya (2006) proposed that mouth bars are a fundamental architectural element in building modern deltas. They can coalesce to form complex bar assemblages which in turn build delta lobes. Roberts et al. (2004) recognized the same hierarchy with seismic mapping of the Lagniappe delta in the northeast of the Gulf of Mexico. The question is whether this hierarchy is applicable in the ancient rock records. Discussion of internal hierarchy of deltas with outcrop studies are rare but important, in that this will test the concepts built up from modern deltaic systems and clarify the relationships with divisions in ancient systems. Based on variation of bedding geometry, grain size, sedimentary structures, bioturbation, and palaeo-flow orientation, Willis et al. 1999 characterized the internal architecture of the Frewens delta with three grades: 1) individual beds which record accumulation of short depositional events; 2) bedsets which are defined by progressive changes in facies, mean bed thickness and density of shales, record a period of delta front progradation and abandonment, and 3) large scale progradation and abandonment trends (Willis et al. 1999). The same method will be used to address the hierarchy question of the delta-front deposits in Ferron Notom delta.

Methodology

Data used for this study are basically collected on the field by measuring sedimentological sections, in which lithology, sedimentary structures, and trace fossils are carefully recorded. Photos of well-exposed outcrops are also taken to help illustrating the geometry and facies architecture of delta front mouth-bar deposits. Devices used for the field work include a rock hammer, a measuring tape, a compass, a Jacob's Staff, a

Nikon D70 camera, and a Garmin GPS for locating the measured sections. Technical climbing gear is also used in vertical cliff faces where outcrops are difficult to walk up. For the next summer in 2010, the RTK and Ground Penetrating Radar equipment will be used to collect GPR data of the mouth-bar deposits.

References:

Barton M. D. and Tyer, N. 1995, Sequence stratigraphy, facies architecture, and permeability structure of fluvial-deltaic reservoir analogs — Cretaceous Ferron Sandstone, central Utah: University of Texas, Bureau of Economic Geology, Field Trip Guidebook, August 21–23, 1995, 80 p.

Bates, C.D., 1953, Rational theory of delta formation: American Association of Petroleum Geologists Bulletin, v. 37, p. 2119–2162.

Bhattacharya, J.P., 1993, The expression and interpretation of marine flooding surfaces and erosional surfaces in core: examples from the Upper Cretaceous Dunvegan Formation in the Alberta foreland basin: in Summerhayes, C.P., and Posamentier, H.W., eds., Sequence Stratigraphy and Facies Associations: International Association of Sedimentologists, Special Publication 18, p. 125–160.

Bhattacharya, J. P., 2006 Deltas: in Facies models revisited, Society for Sedimentary Geology (SEPM): Tulsa, OK, United States, Special Publication - Society for Sedimentary Geology, September 2006, Vol. 84, pp. 237-292.

Bhattacharya, J., and Giosan, L., 2003, Wave-influenced deltas: geomorphological implications for facies reconstruction: Sedimentology, v. 50, p. 187–210.

Bhattacharya, J.P., and Tye, R.S., 2004, Searching for modern Ferron analogs and applications to subsurface interpretation: in Chidsey, T.C., Adams, R.D., and Morris, T.H., eds., Regional to Wellbore Analog for Fluvial–Deltaic Reservoir Modeling: The Ferron Sandstone of Utah: American Association of Petroleum Geologists, Studies in Geology, v. 50, p. 39-57.

Bhattacharya, J. P., and Walker, R. G., 1992, Deltas., In Walker, R. G., and James, N. P., eds., Facies Models: Response to Sea Level Change: Geological Association of Canada, p. 157–177.

Bullimore S., Henriksen s., Liestol F., and Helland-Hansen W., 2005, Clinoform stacking patterns, shelf-edge trajectories and facies associations in Tertiary coastal deltas, offshore Norway: Implications for the prediction of lithology in prograding systems, v. 85, p, 169-187.

Chidsey, T.C., JR., 2001, Geological and petrophysical characterization of the Ferron Sandstone for 3-D simulation of a fluvial–deltaic reservoir: Salt Lake City, Utah, Utah Geological Survey, Report, 490 p.

Coleman, J.M. and Wright, L.D., 1975, Modern river deltas: variability of processes and sand bodies: in Broussard, M.L., ed., Deltas, Models for Exploration: Houston, TX., Houston Geological Society, p. 99-149

DeCelles, P.G., and Giles, K.A., 1996, Foreland basin systems: Basin Research, v. 8, p. 105-123.

Fielding, C.R., Al-Ruball, M., and Walton, E.K., 1988, Deltaic sedimentation in an unstable tectonic environment: the Lower Limestone Group (Lower Carboniferous) of East Fife, Scotland: Geological Magazine, v. 125, p. 241–255.

Fielding, C. R., Truman, J., and Alexander J., 2005b, Sharp-based mouth bar sands from the Burdekin River Delta of northeastern Australia: extending the spectrum of mouth bar facies, geometry, and stacking patterns: Journal of Sedimentary Research. v. 75. p. 55–66.

Galloway, W.E., 1975, Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems: in Broussard, M.L., ed., Deltas, Models for Exploration: Houston, TX., Houston Geological Society, p. 87-98.

Gani, M.R., and Bhattacharya, J.P., 2005a, Lithostratigraphy versus chronostratigraphy in facies correlations of Quaternary deltas: application of bedding correlation: in Giosan, L., and Bhattacharya, J.P., eds., River Deltas: Concepts, Models, and Examples: SEPM, Special Publication 83, p. 31–48.

Gani, M. and Bhattacharya, J. P., 2007, Basic building blocks and process variability of a Cretaceous Delta: internal facies architecture reveals more dynamic interactions of river, wave, and tidal processes than is indicated by external shape: Journal of Sedimentary Research, v. 77, p. 284- 302.

Garrison, J.R., and Van Den Bergh, T.C.V., 2004, The high-resolution depositional sequence stratigraphy of the Upper Ferron Sandstone Last Chance Delta: an application of coal zone stratigraphy: in Chidsey, T.C., Adams, R.D., and Morris, T.H., eds., Regional to Wellbore Analog for Fluvial–Deltaic Reservoir Modeling: The Ferron Sandstone of Utah: American Association of Petroleum Geologists, Studies in Geology, v. 50, p. 125-192.

Hampson, G.J, 2000, Discontinuity surfaces, clinoforms, and facies architecture in a wave-dominated, shoreface–shelf parasequence: Journal of Sedimentary Research, v. 70, p. 325–340.

Hart, B.S., and Long, B.F., 1996, Forced regressions and lowstand deltas: Holocene Canadian example: Journal of Sedimentary Research, v. 66,p. 820–829.

Heerden, I.L., Van, and Roberts, H.H., 1988, Facies development of Atchafalaya Delta, Louisiana: a modern bayhead delta: American Association of Petroleum Geologists, Bulletin, v.72, p. 439–453.

Helland-Hansen and Martinse O.J., 1996, Shoreline trajectories and sequences: Description of variable depositional-dip scenarios: Journal of Sedimentary Research. v. 66, p. 670-688.

Overeem, I., Kroonenberg, S.B., Veldkamp, A., Groenesteijn, K., Rusakov, G.V., AND Svitoch,A.A., 2003, Small-scale stratigraphy in a large ramp delta: recent and Holocene sedimentation in the Volga delta, Caspian Sea: Sedimentary Geology, v. 159, p. 133–157.

Reynolds, A.D., 1999, Dimensions of paralic sandstone bodies: American Association of Petroleum Geologists Bulletin, v. 83, p.211-229.

Rich, J.L., 1951, Three critical environments of deposition and criteria for recognition of rocks deposited in each of them: Geological Society of America Bulletin, v. 62, p. 1–20.

Ryer., T.A., and Anderson, P.B., 2004, Facies of the Ferron Sandstone, East-Central Utah, in Chidsey, T.C., Adams, R.D., and Morris, T.H., eds., Regional to Wellbore Analog for Fluvial–Deltaic Reservoir Modeling: The Ferron Sandstone of Utah: American Association of Petroleum Geologists, Studies in Geology, v. 50, p. 59-78.

Roberts, H.H., and Sydow, J., 2003, Late Quaternary stratigraphy and sedimentology of the offshore Mahakam delta, east Kalimantan (Indonesia): in Sidi, F.H., Nummedal, D., Imbert, P., Darman, H., and Posamentier, H.W., eds., Tropical Deltas of Southeast Asia—Sedimentology, Stratigraphy, and Petroleum Geology: SEPM, Special Publication 76, p. 125–145.

Roberts, H.H, Fillon, R.H., Kohl, B., Robalin, J.M., and Sydow, J.C., 2004, Depositional architecture of the Lagniappe Delta; sediment characteristics, timing of depositional events, and temporal relationship with adjacent shelf-edge deltas: in Anderson, J.B., and Fillon, R.H., eds., Late Quaternary Stratigraphic Evolution of the Northern Gulf of Mexico Margin: SEPM, Special Publication 79, p. 143–188

Tesson, M., Allen, G.P., and Ravenne, C., 1993, Late Pleistocene shelf perched lowstand wedges on the Rhone continental shelf: in Posamentier, H.W., Summerhayes, C.P., Haq, B.U., and Allen, G.P., eds., Sequence Stratigraphy and Facies Associations: International Association of Sedimentologists, Special Publication 18, p. 183–196.

Tye, R.S., 2004, Geomorphology: An approach to determining subsurface reservoir dimensions: American Association of Petroleum Geologists Bulletin, v. 88, p. 1123–1147.

Tye, R.S., and Coleman, J.M., 1989, Depositional processes and stratigraphy of fluvial dominated lacustrine deltas: Mississippi Delta Plain: Journal of Sedimentary Petrology, v. 59, p.973–996.

Wellner, R., Beaubouef, R., Van Wagoner, J., Roberts, H. H., and Sun, T., 2005, Jet-plume depositional bodies; the primary building blocks of Wax Lake Delta: Gulf Coast Association of Geological Societies, Vol. 55, pp. 867-909

Willis, B.J., Bhattacharya, J.B., Gabel, S.L., and White, C.D., 1999, Architecture of a tide-influenced river delta in the Frontier Formation of central Wyoming, USA: Sedimentology, v. 46, p. 667–688.

Wright, L.D., 1977, Sediment transport and deposition at river mouths: a synthesis: Geological Society of America Bulletin, v. 88, p. 857–868.

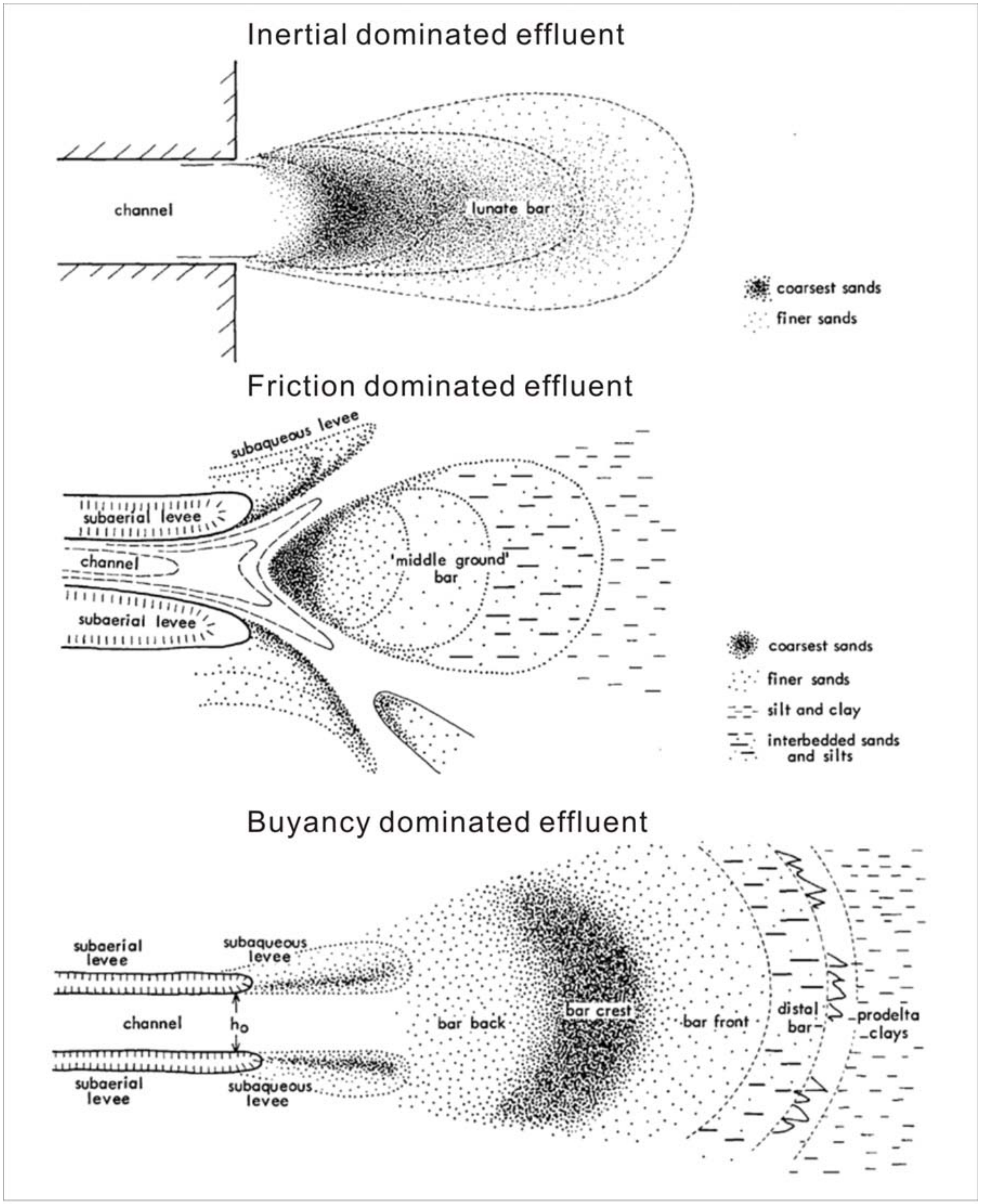

Figure 1 Three river-mouth depositional patterns in three different effluent conditions (From Wright, 1977)

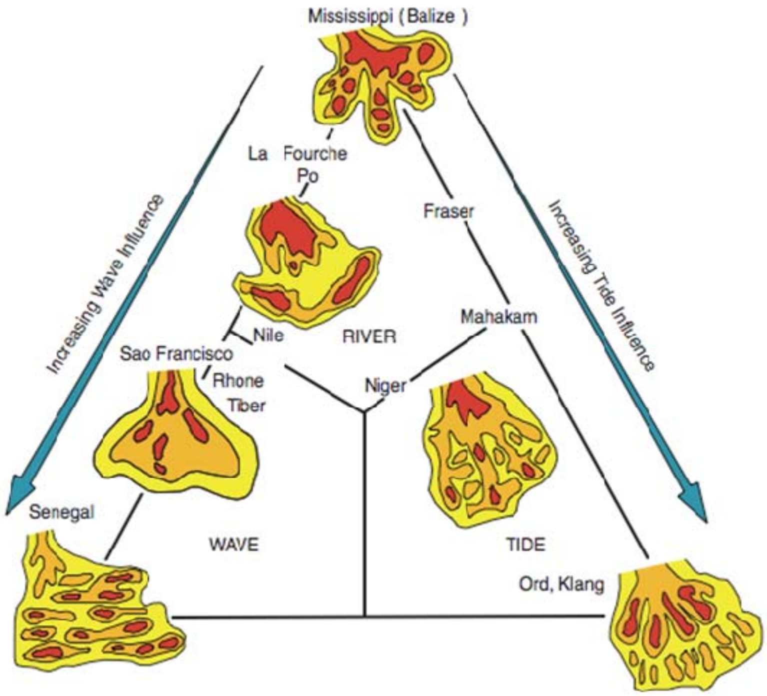

Figure 2 Depositional patterns under the interaction of river, wave and tide (From Bhattacharya and Walker, 1992 modified after Coleman and Wright, 1975)

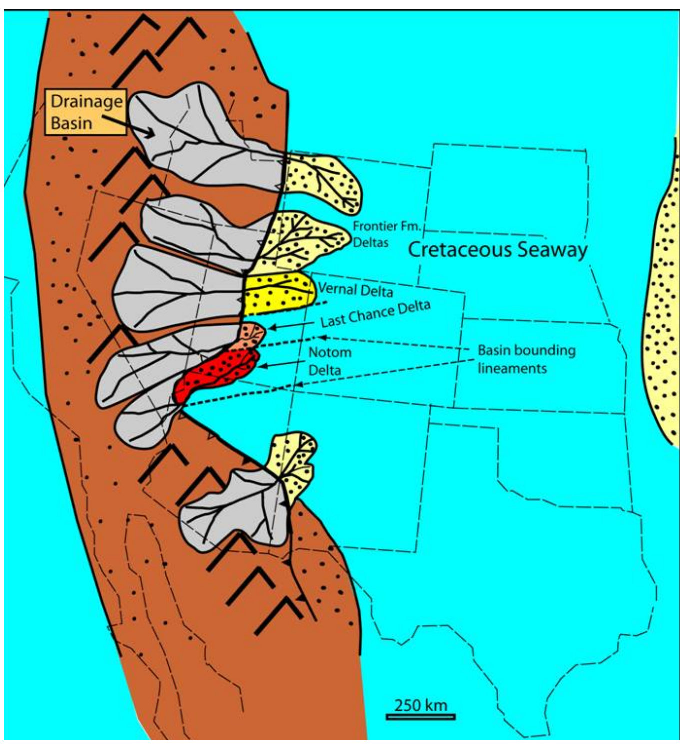

Figure 3 Paleogeography reconstruction showing the Cretaceous Seaway and relative positions of deltas developed in upper Cretaceous (From Bhattacharya and Tye, 2004)

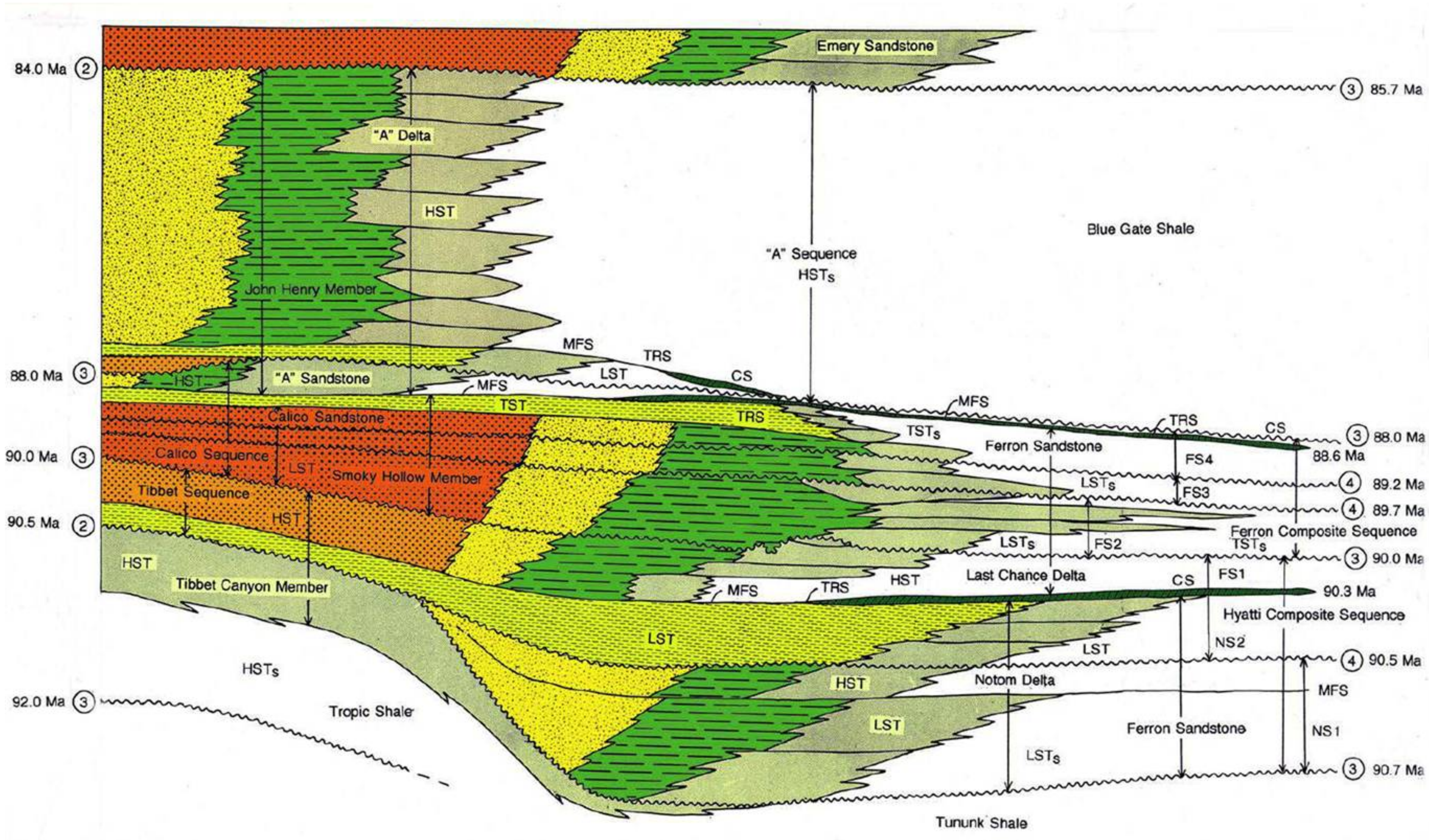

Figure 4 General stratigraphy of Cretaceous strata central Utah and the position of Ferron Notom delta (From Garrison and van den Bergh, 2004)

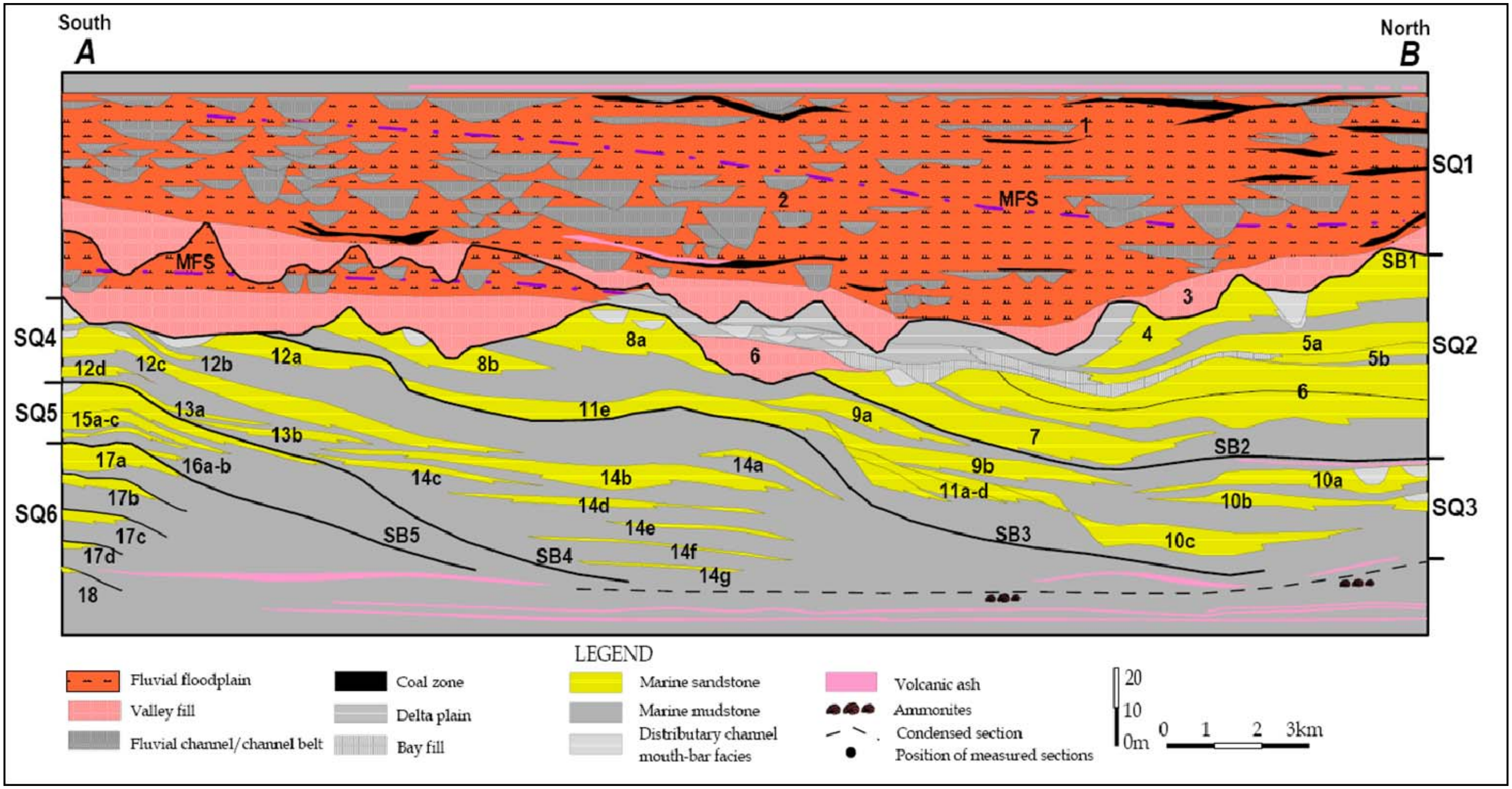

Figure 5 Regional sequence stratigraphy of Ferron Notom delta in dip view (From Yijie Zhu and Weiguo Li)

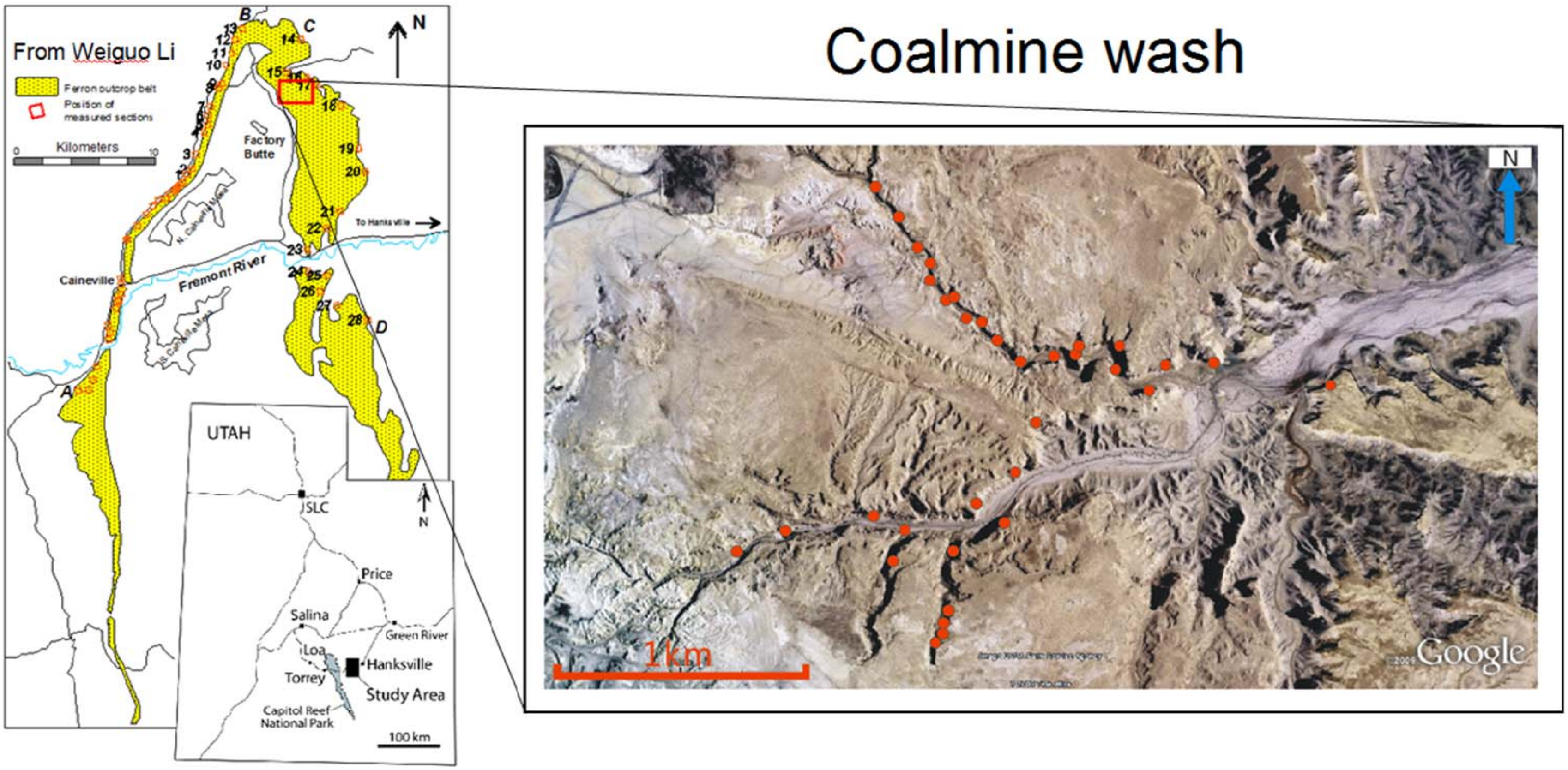

Figure 6 Location of the study area “Coalmine Wash” and the position of measured sections

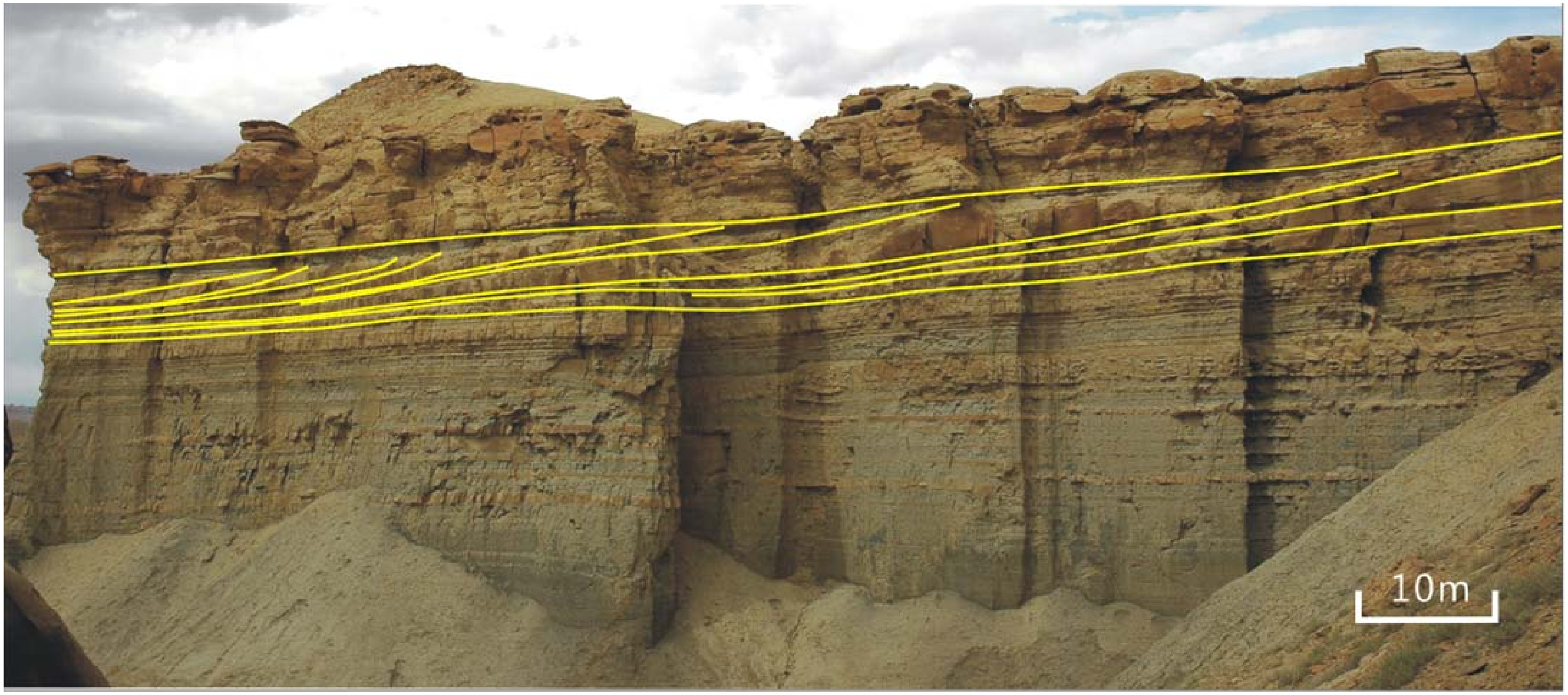

Figure 7 Mouth-bar deposits in Parasequence 6a showing distinct unidirectional dipping clinoforms

Figure 8 Mouth-bar deposits in Parasequence 5 showing bilateral pinching out pattern

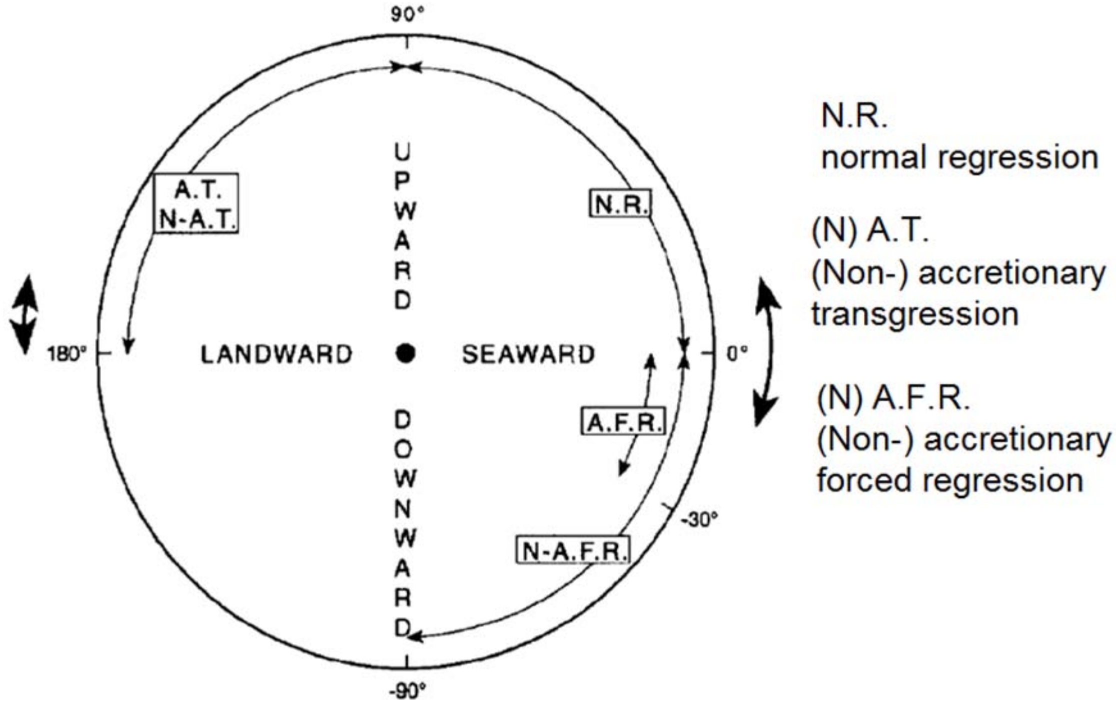

Figure 9 Shoreline trajectory circle (From Helland-Hansen and Martinsen, 1996)

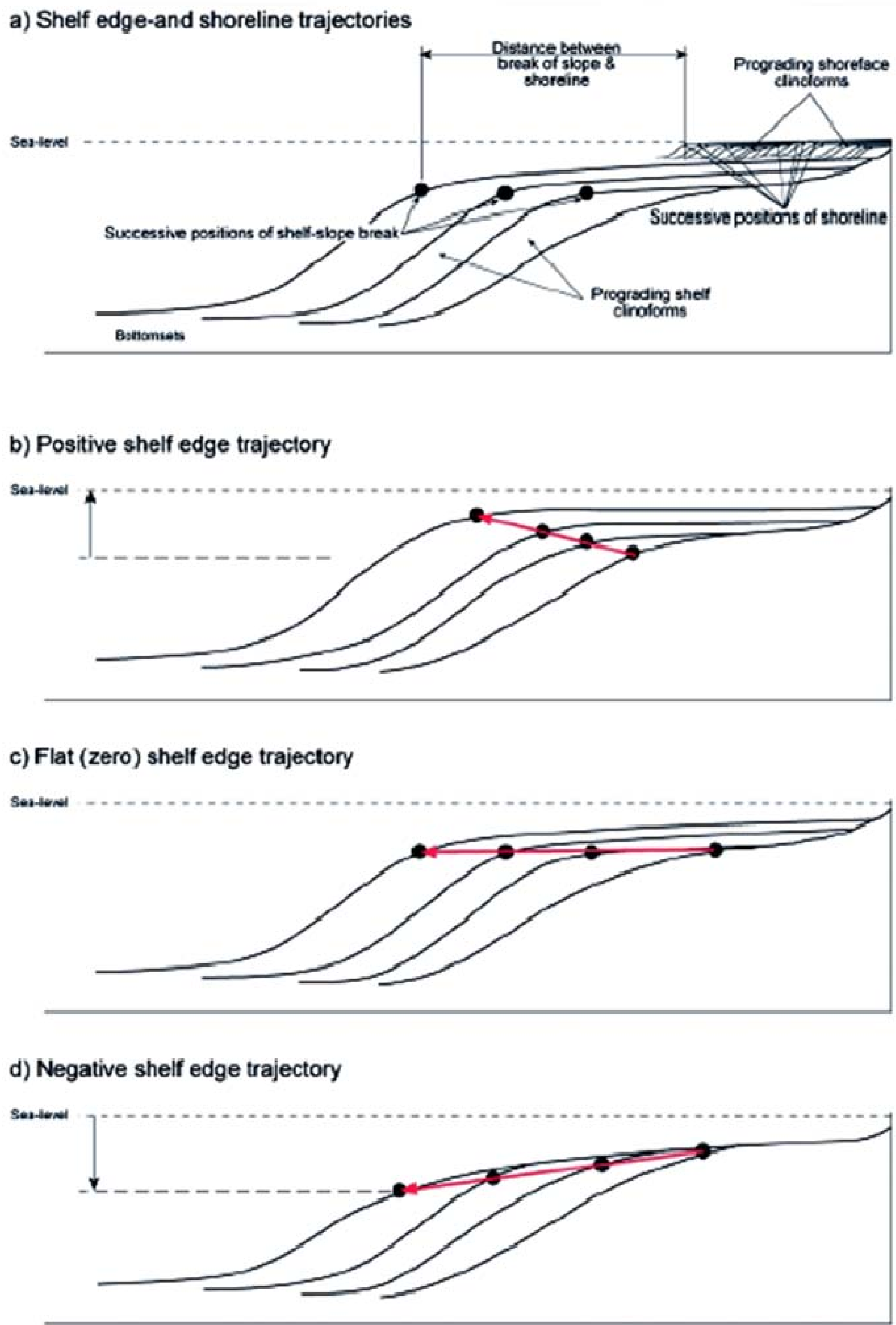

Figure 10 different shelf edge trajectory patterns (From Bullimore et al. 2005)