Facies Architectural Analysis of a River Dominated Deltaic System, Gallup Sandstone, New Mexico

Research Proposal By:

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Submitted: October 27th 2016

Earth Sci 4MT6

Abstract:

Multiple sequence stratigraphic research studies have been conducted on the Gallup Sandstone in the area surrounding Gallup, New Mexico. However, little to no studies have focused on the facies architecture of this complex formation. This study aims to analyze the facies architecture of a well exposed distributary channel in the area west of Gallup, New Mexico. Preliminary studies in this area have documented sandstone thicknesses which have demonstrated interdigitate sandstone geometries that are characteristic of a river-dominated delta. In this study, architectural elements will be analyzed using 3 detailed stratigraphic logs, paleocurrent measurements, bedding thicknesses and a high resolution photomosaic of the outcrop exposure. The Gallup Sandstone represents one of a few regressive facies within a succession of transgressive-regressive clastic wedges in northwestern New Mexico. This formation represents the northeast progradation of a deltaic sequence that was present during the late Turonian to earliest Coniacion (Late Cretaceous) along the southwestern margin of the Western Interior Seaway. Future work will involve the construction of bedding diagrams using a high-resolution photomosaic that will be used to identify architectural elements in order to calculate paleodischarge, river depth/slope and mean flow velocity. These variables will then be used to determine if the Gallup delta was a topset or foreset dominated deltaic environment. Detailed facies analysis of the stratigraphic sections will also be conducted to reconstruct the paleoenvironment at the time of deposition. This will help build upon previous research that has proposed a river-dominated deltaic environment in this area.

Introduction:

Deltas are found where a river carrying sediment enters a standing body of water that is then deposited and reworked by basinal processes. Deltas are a regressive landform that are classified based on their degree of wave, tide or fluvial influence (Bhattacharya 2006). They commonly pass through multiple cycles of progradation and abandonment, which is driven by episodes of trunk river avulsion that result in the growth of new delta lobes. These avulsions control the location and degree of sediment distribution within the basin. Trunk rivers entering a standing body of water are commonly associated with a network of branching distributary channels which split the trunk river discharge and sediment load among a variable number of smaller scale channels downstream (Li and Bhattacharya 2014; Olariu and Bhattacharya 2006). The scale and number of distributary channels depends on the type of delta such that wave dominated deltas tend to have fewer distributary channels due to wave reworking processes. Tide dominated deltas generally have more, longer-lived distributary channels than wave dominated deltas. River dominated deltas typically have significantly more distributary channels that are frequently abandoned due to river avulsions. Additionally, the substrates susceptibility to erosion and the trunk channel discharge affects the number of distributary channels that are formed (Olariu and Bhattacharya 2006). Basins that have a low accommodation and a shallow slope generally have a larger more laterally extensive network of distributary channels. These deltas are commonly referred to as topset-dominated deltas due to the fact that their topsets are thicker than their foresets (Edmonds, Shaw, and Mohrig 2011) (Figure 1). These two types of deltas are significantly different in the type of sub-environments that are associated with their formation and progradation. Topset-dominated deltas generally have a larger more laterally extensive network of distributary channels and associated interdistributary bays, floodplains and other associated deltaic environments. These distinct differences generate significant variations in the resulting stratigraphy of these deposits (Edmonds, Shaw, and Mohrig 2011). Therefore, distinguishing between these two types of deltas in ancient outcrop examples will benefit petroleum exploration projects that use outcrop analogues as models to locate potential oil and gas plays.

This study will evaluate the facies architectural elements of a distributary channel in order to determine if this deltaic system was topset or foreset dominated at the time of deposition. This type of analysis will benefit shallow marine deltaic facies models that are used to discover oil and gas plays within these complex depositional environments. This will also further the understanding of the evolutionary history of the Gallup delta in New Mexico, U.S.A.

Objective:

The primary focus of this project is to document and analyze the detailed facies architecture of shallow marine/fluvial deposits of the Gallup Sandstone. This analysis will be used to reconstruct the ancient river depth, width, paleodischarge and mean flow velocity. These calculations will be conducted with the use of crossbed thickness measurements, bar heights, and storey thickness. This will help establish if the Gallup delta was a topset or foreset dominated delta. An in-depth facies and stratigraphic analysis will also be conducted to determine the paleoenvironments at the time of deposition. Furthermore, crossbed and ripple paleocurrents will help determine the direction of sediment transport and flow mechanisms.

Literature Review:

Geologic and Stratigraphic Settings

Alternating regressions and transgressions of the Cretaceous Western Interior Seaway (Figure 2) and accompanying tectonism controlled the deposition of sediment of the Gallup Sandstone formation (McCubbin 1969; Kelley 1957). The Gallup delta was a northeastward prograding clastic wedge which experienced many minor regressions and transgressions within an overall transgressive period of deposition. This caused the formation of 6 sandstone tongues (named F-A with F being the oldest) that make up the Gallup Sandstone, which is a part of and interfingers with the Mancos Shale member (Figure 4) (Nummedal and Molenaar 1995). Fossil dating has revealed that this formation was deposited during the late Turonian to earliest Coniacian (Late Cretaceous) over the span of ~1.2 million years (Molenaar 1973). This study will analyze the Gallup formation outcrops in the area west of Gallup, New Mexico which represent the earliest regression (F tongue) of the Gallup delta.

Previous Studies

The outcrops west of Gallup, New Mexico, where this field study is being conducted have been relatively understudied compared to areas such as Noserock Point (east of Gallup town) and the northern Shiprock region of the Gallup Sandstone Formation (Nummedal and Molenaar 1995). However, Flores et al. (1991) created a detailed facies analysis of this region using 144 measured stratigraphic sections. These measured sections were then joined together to form a three-dimensional facies distribution diagram (herein referred to as fence diagrams). The constructed fence diagrams were then analyzed to determine the depositional environments associated with them. Figure 4 shows where their measured sections are located (black dots) and

Figure 5 has this same field diagram overlaying the field site of this research project. With careful examination, one is able to notice that at least one of their measured sections lines up with the field site where this project took place. Flores et al. (1991) obtained many sandstone thicknesses in this area in order to construct an isopach map of the geometry of the Gallup Sandstone Formation (Figure 6). The area where this project was conducted shows a digitate sandstone geometry, which is characteristic of a river-dominated deltaic environment (Olariu and Bhattacharya 2006). Using this isopach map and the fence diagrams Flores et al. were able to construct a three-dimensional depositional environmental model (Figure 7). The distributary channel shown in the northern section of Figure 7 is the distributary channel that will be analyzed in this study. Flores et al. also produced a stratigraphic cross-section which is approximately parallel to depositional strike and is divided into 3 units (Figure 8). This study will focus on the lower sandstone dominated section, specifically the northern area. This cross section is slightly landward of where this studies field area is, however, multiple channel and mouth bar sandstones are crudely mapped in this diagram. Therefore, this project will build upon the findings of this project by carrying out a detailed facies architectural analysis of this distributary channel. This will further the understanding of paleodischarge, ancient river depth/slope and mean flow velocity in this ancient deltaic environment.

Topset Dominated Deltas

First-order stratigraphy models assume that deltaic systems have thicker foresets than topsets and that they should be all classified as foreset-dominated in nature (Figure 1). This model has been applied to ancient as well as modern deltas. However, a recent study shows that this is not always the case, as it is possible for the topset beds to be thicker than its foresets and this has been found to be very common in modern deltas (Edmonds, Shaw, and Mohrig 2011). The model that was proposed by Edmonds et al. (2011) suggests that if the calculated channel to basin depth ratio is greater than or equal to one, the delta is topset-dominated. This model accounts for a number of variables such as channel depth/discharge at the delta apex (h_0), initial basin depth where the river switches from confined to unconfined flow (d_0), and slope (s). The results of this geometric model suggest that the stratigraphic relationships between foreset-dominated and topset-dominated deltas will vary in three ways. Firstly, the topset will thin basinwards as distributary channels bifurcate and become shallower and the foreset will thicken as the delta progrades into progressively deeper water. Secondly, topset dominated deltas will have a more variable stratigraphy. Edmonds et al. explain this variable stratigraphy by explaining how in topset-dominated deltas, zones of progradation will occur at channel mouths and these deposits will have a classic fining upward sequence with a well-defined set of foresets. Alternatively, the sheltered areas in between these zones of progradation will fill in passively with fine grained sediments. This creates a spatially discontinuous foreset deposit which differs from the generally continuous foreset deposits found in foreset-dominated deltas. Lastly, vertical stratigraphic columns taken from topset-dominated deltas may not follow the classic upward coarsening sequence that is commonly found in foreset-dominated deltas. This is due to the spatial heterogeneities of topset-dominated deltas which were mentioned previously. Keeping in mind these suggested stratigraphic relationships and knowing that foreset-dominated deltas commonly form in basins with steep slopes and large initial depths with the opposite being true for topset-dominated deltas, one is able to gain insight into the resulting stratigraphy given minimal data. Modern topset-dominated deltas have been identified in numerous low-slope, shallow water depth basins around the world. With this in mind, the Western Interior Cretaceous

Seaway where the Gallup delta was deposited has been identified as being a shallow, low-slope basin which leads to the assumption that this delta was indeed a topset-dominated delta. This study aims to test this hypothesis by evaluating channel dimensions using facies architectural analytical techniques from Miall (1985).

Facies Architectural Analysis Techniques

Facies architectural analysis is a technique used to determine the stratigraphic evolution of a given paleoenvironment by analyzing its bedding geometry. This technique breaks up the different depositional elements found in a fluvial environment into a hierarchy (A. D. Miall 1985a). This hierarchy is depicted in (Figure 9) with smaller elements at the top of the hierarchy which form “complexes” that make up the larger elements at the bottom of the hierarchy. Using high-resolution imagery of an outcrop one is able to trace out minor and major bedding contacts in order to visualize and interpret the bedding geometry of the fluvial system. These bedding contacts are ranked such that first-order contacts bound individual crossbed sets, second-order contacts bound cosets, third order contacts are marked by the basal scour surface of a major channel and fourth order contacts would define a group of channels such as a paleovalley (A. D. Miall 1985b). Once these contacts are traced out, the resulting geometry of these contacts provides insight into the fluvial processes that took place at the time of deposition, which helps to construct a more accurate paleoenvironmental interpretation. Identification of depositional elements such as lateral accretion surfaces can provide insight into the degree of paleochannel sinuosity. Basal scour surfaces would be used to determine paleochannel dimensions (depth and width) which can then be used for paleodischarge calculations. Facies observations can then be tied to this data to help distinguish if the paleochannel was distributary or fluvial by analyzing the presence or absence of marine sedimentary structures such as wave ripple laminations and tidal bundles along with marine ichnofossils. This technique has been used and slightly modified to analyze ancient distributary channels with much success (Li and Bhattacharya 2014; Olariu and Bhattacharya 2006). The high-resolution Gigapan imagery obtained from the field will be used to conduct this same type of analysis on the distributary channel being analyzed in this study.

Methodology and Analysis

Stratigraphic data was obtained from a well-exposed cliff face in the southwestern portion of the Gallup Formation west of Gallup, New Mexico. Three detailed vertical stratigraphic logs, which contain shallow marine and fluvial influenced sandstone and shale beds were measured on a centimeter to meter scale. As these were measured they were also analyzed using a hand lens and grain size card to determine their lithology and grain size. Furthermore, the presence or absence of sedimentary structures and ichnofauna were noted. A Silva compass was then utilized to determine paleocurrent direction from crossbed dip direction, lateral accretion surfaces and overall channel flow direction. High-resolution Gigapan imagery was obtained to eventually construct facies bedding architecture diagrams in order to analyze elements such as channels and potential bar features.

Timeline:

The timeline for this project is illustrated in *Table 1*. Field work, which included a great deal of location scouting, occurred over 3 months from May 2016 to July 2016. The research proposal and literature review were submitted near the end of October 2016. The digitization of the stratigraphic logs and the construction of facies architectural bedding diagrams will be completed in early December 2016. The rough draft of the thesis shall be completed by late February 2017. After this, reviews and edits will be made and a full revised copy of the thesis will be ready for final submission in April.

Table 1: Timeline for Thesis Process

Task	**Completion Date**
Field Work	May to July 2016
Research Proposal/Literature Review	Late October 2016
Digitize Measured Sections and Construct Bedding Diagrams	Early December 2016
First Draft of Thesis	Late February 2017
Final Draft of Thesis	Early April 2017
Research Presentation	April 7th 2017

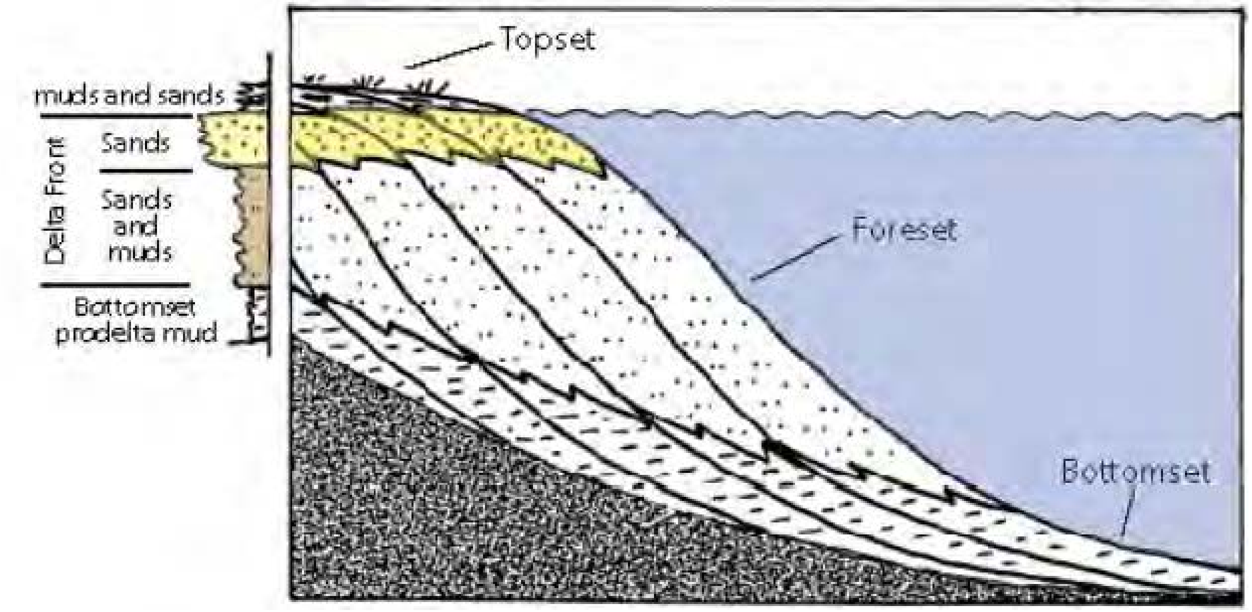

Figure 1: Stratigraphic body classification of various beds in a delta (Scruton 1960).

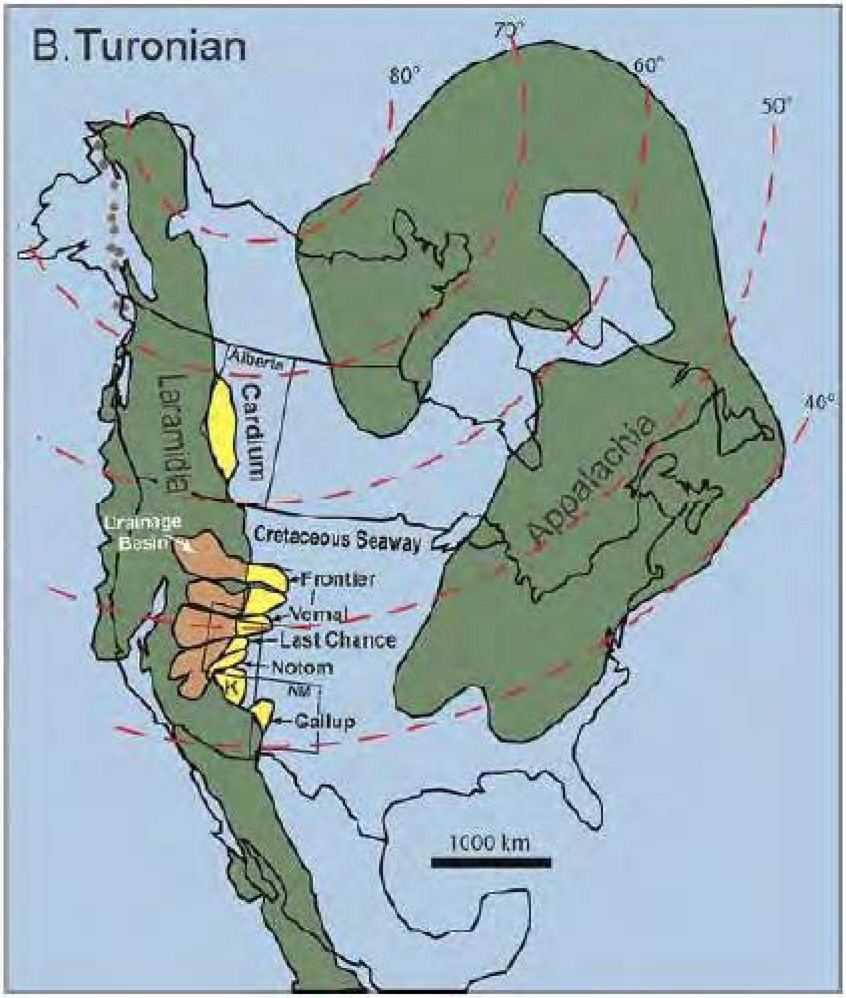

Figure 2: Map of the late Cretaceous (Turonian) Western Interior Seaway depicting the location of the Gallup Delta (Bhattacharya and MacEachern 2009).

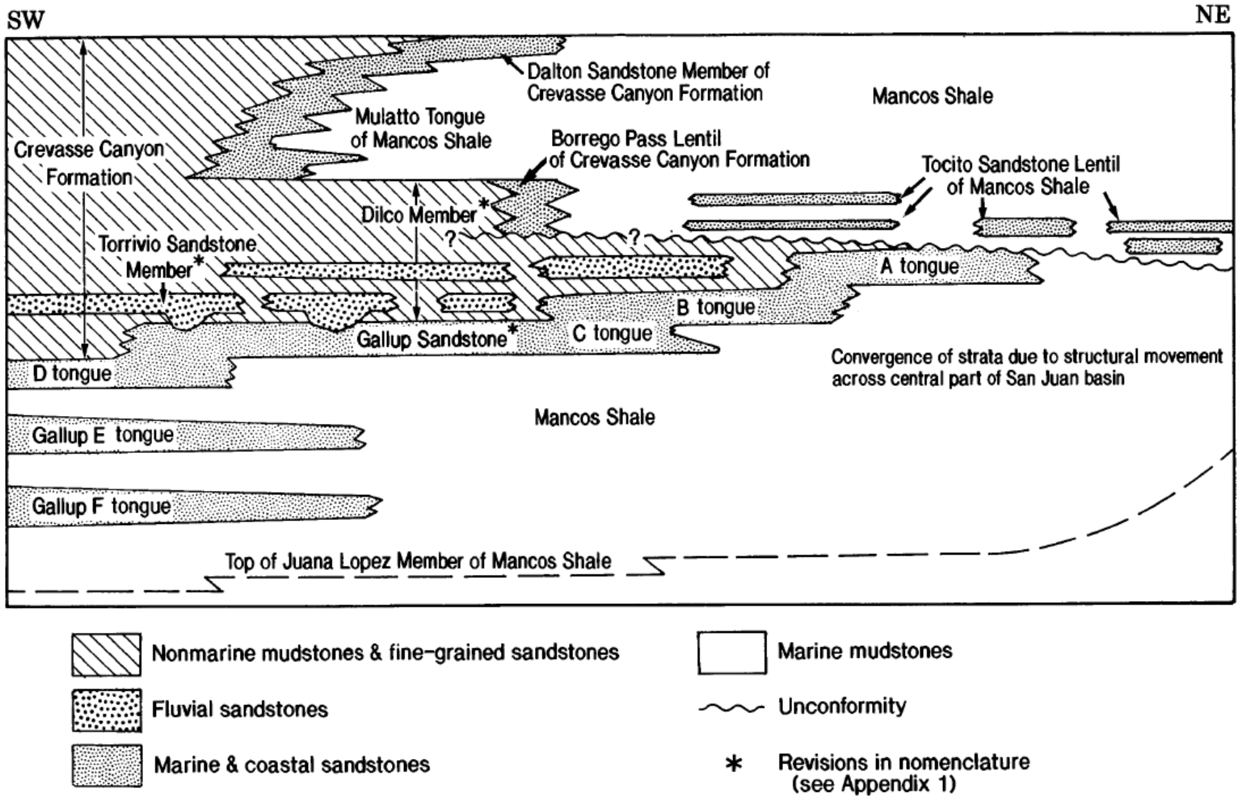

Figure 3: Schematic lithostratigraphic cross section of the Gallup Sandstone and its interfingering with the Mancos Shale Member (Nummedal and Molenaar 1995).

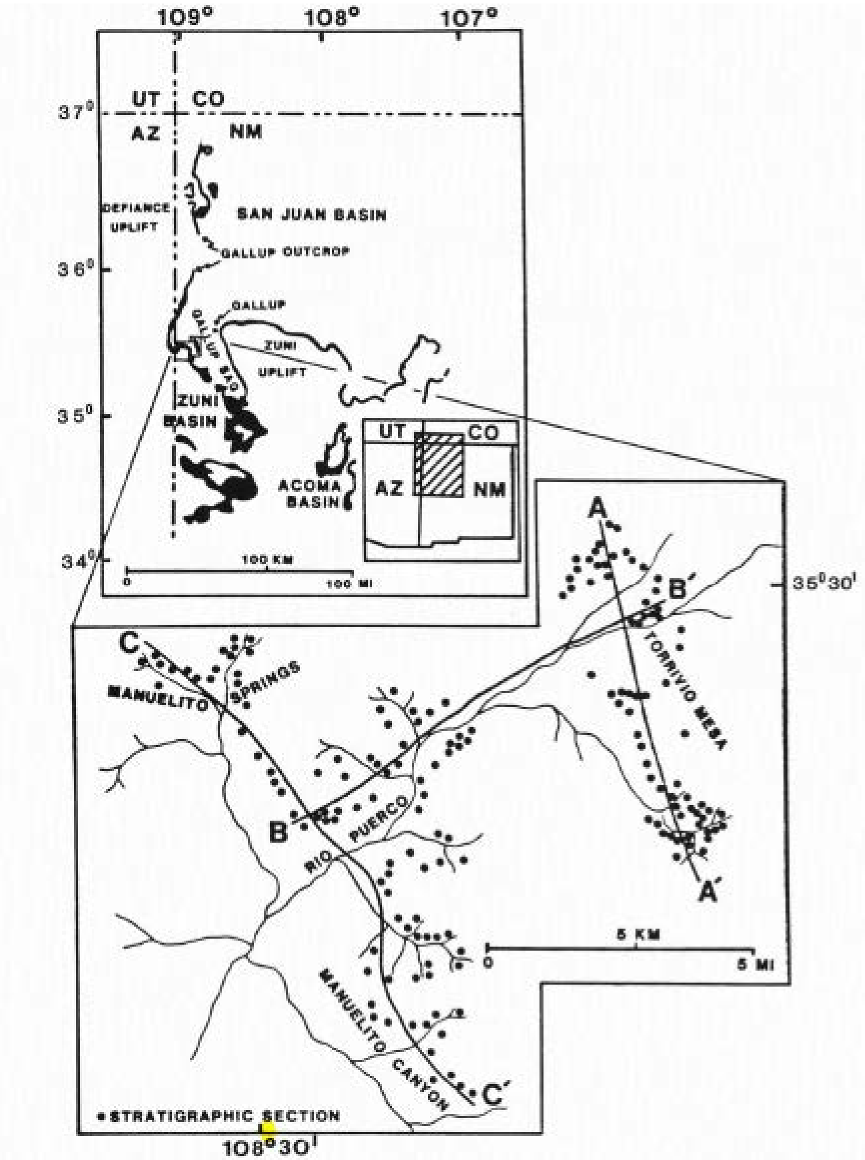

Figure 4: Map showing outcrop belts of the Gallup Sandstone in New Mexico and a close up view of the study area with the locations of measured sections in the 1991 Flores et al. study (Flores, Hohman, and Ethridge 1991).

Figure 5: Location of this research studies field site with an overlain diagram of the measured sections from the Flores et al. study.

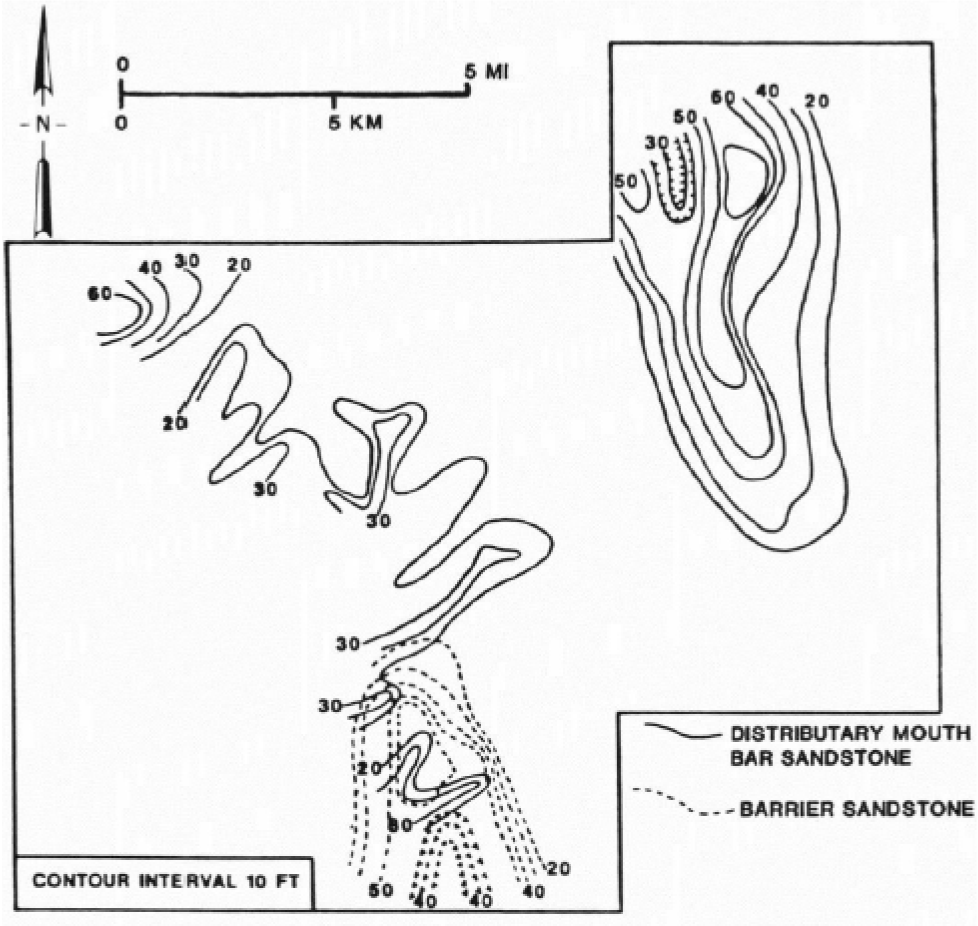

Figure 6: Isopach map of sandstone thicknesses and the resulting geometry of these measurements (Flores, Hohman, and Ethridge 1991).

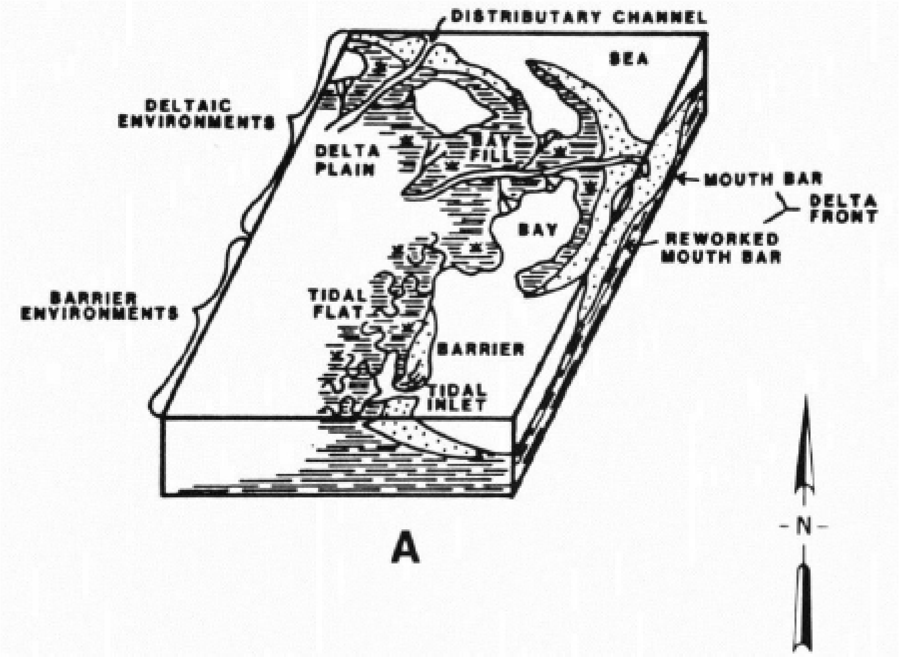

Figure 7: Reconstructed depostional models of interpreted paleoenvironments (Flores, Hohman, and Ethridge 1991).

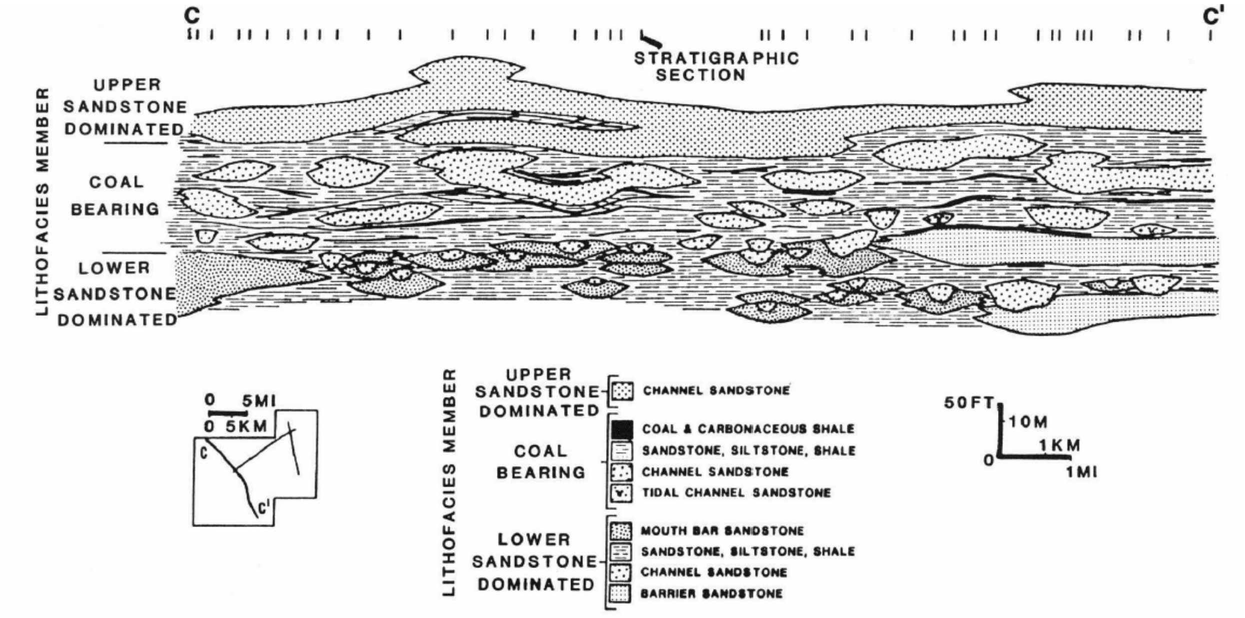

Figure 8: Cross-section parallel to depositional strike constructed using stratigraphic logs by Flores et al. (1991).

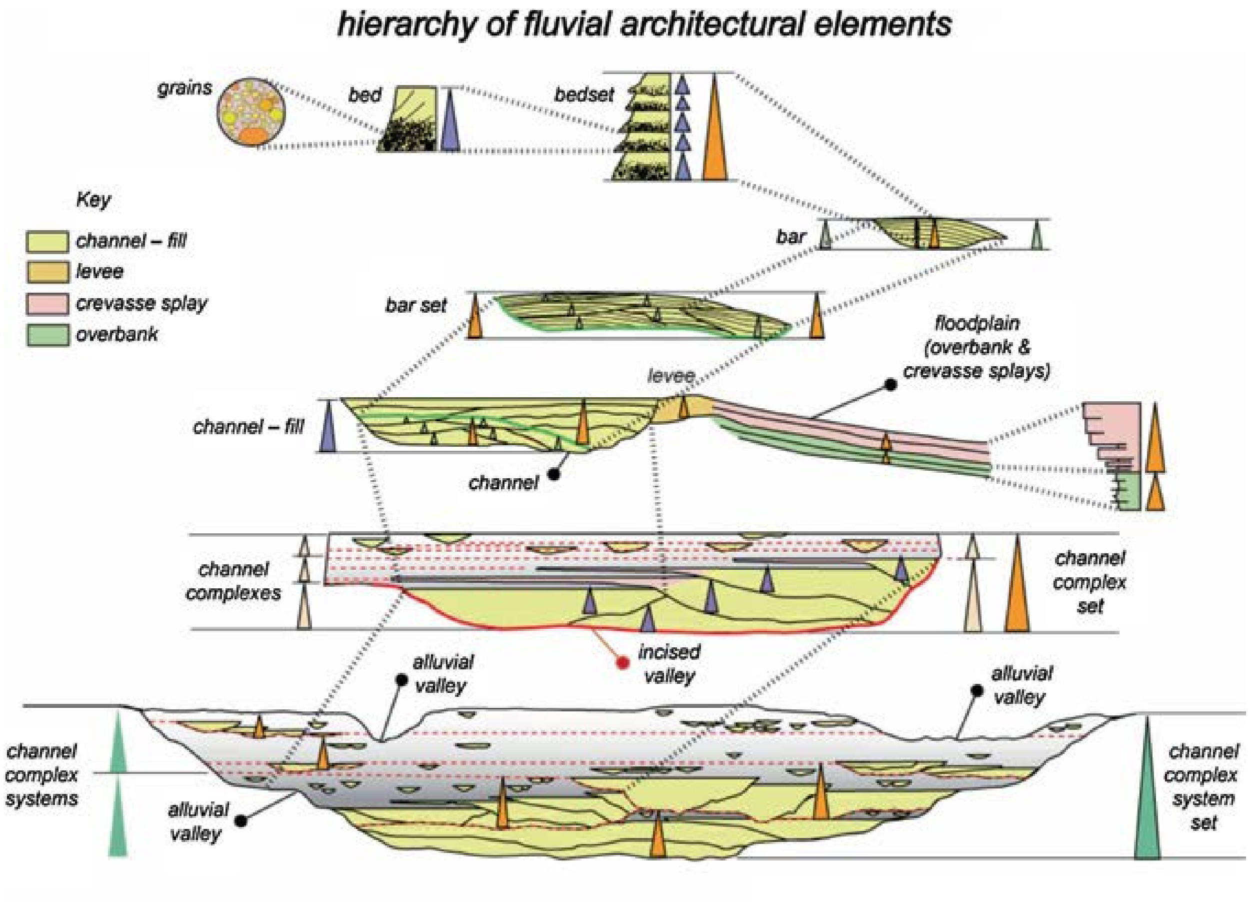

Figure 9: Diagram portraying the hierarchy of depositional elements within a fluvial system (A. Miall 2014).

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