PS Role of Relative Sea Level Change on Geometric Characteristics of Submarine Fans (Onlapping versus Non-Onlapping)*

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Abstract

Deepwater sediments hold a significant amount of hydrocarbon reserves and have always been the most challenging reservoirs to explore and produce. Conventional sequence stratigraphic model for deepwater clastic system consider that deposition and growth of submarine-fan mostly occurs during relative sea-level fall or lowstand. However, recent studies by various workers have shown that sediments can be supplied to deep water even during rising sea level if the sediment supply is high enough to prograde the entire shelf-edge. In order to apply the concepts of sequence stratigraphy for deep-water clastic systems, it is important to understand the various factors other than relative sea-level change, which controls the deep-water clastic sedimentation. Various outcrop, subsurface and modern examples have been reviewed to show how factors like rate of sediment supply, shelf-edge width, and gradient along the relative sea level change are significant for developing the sequence stratigraphic model of a deep-water system. Deepwater sediments can either onlap to underlying unconformable surfaces or form a linked shelf-slope-basin system. Brushy Canyon Formation in the Permian Basin is a classic example, which has deposition of carbonates during highstand and deposition of deepwater clastic submarine fans and slope channels onlapping against the underlying sequence boundary during lowstand. A linked lowstand shelf-slope-basin system is found in the Kuitei Basin (East Kalimantan) during Pleistocene. This study also concludes that deepwater submarine fans are not uniquely related to relative sea-level fall/lowstand. Examples were found in Lewis Shale Formation in the Washakie Basin, Oceanside and Carlsbad canyon-channel system in the California Boarderland Basin, and Upper Sobrarbe Formation in the Ainsa Basin (Northern Spain). Results show that submarine fans and channel-levee systems can develop at any relative sea level, lowstand, highstand or standstill. Shelf-edge delta acts as the sediment source and progradation of these deltas are able to transport coarse sediments to deep water during highstand. The development of highstand submarine fans requires a strong fluvial drive on the deltas. Lowstand submarine fans tend to be bigger thicker and laterally extensive while the highstand submarine fans tend to be smaller and less laterally extensive. Therefore, lowstand deepwater fans are expected to hold more hydrocarbon reserves than highstand fans.

Role of Relative Sea Level Change on Geometric Characteristics of Submarine Fans (Onlapping versus Non-Onlapping)

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BACKGROUND

Deepwater sediments hold a significant amount of hydrocarbon reserves and have always been the most challenging reservoirs to explore and produce. Conventional sequence stratigraphic model for deepwater clastic system considers that deposition and growth of submarine-fan mostly occur during relative sea-level fall or lowstand. However, recent studies by various workers have shown that sediments can be supplied to deep water even during rising sea level if the sediment supply is high enough to prograde the entire shelf-edge. In order to apply the concepts of sequence stratigraphy for deep water clastic systems, it is important to understand the various factors other than relative sea-level change, which controls the deep water clastic sedimentation.

'SLUG' MODEL

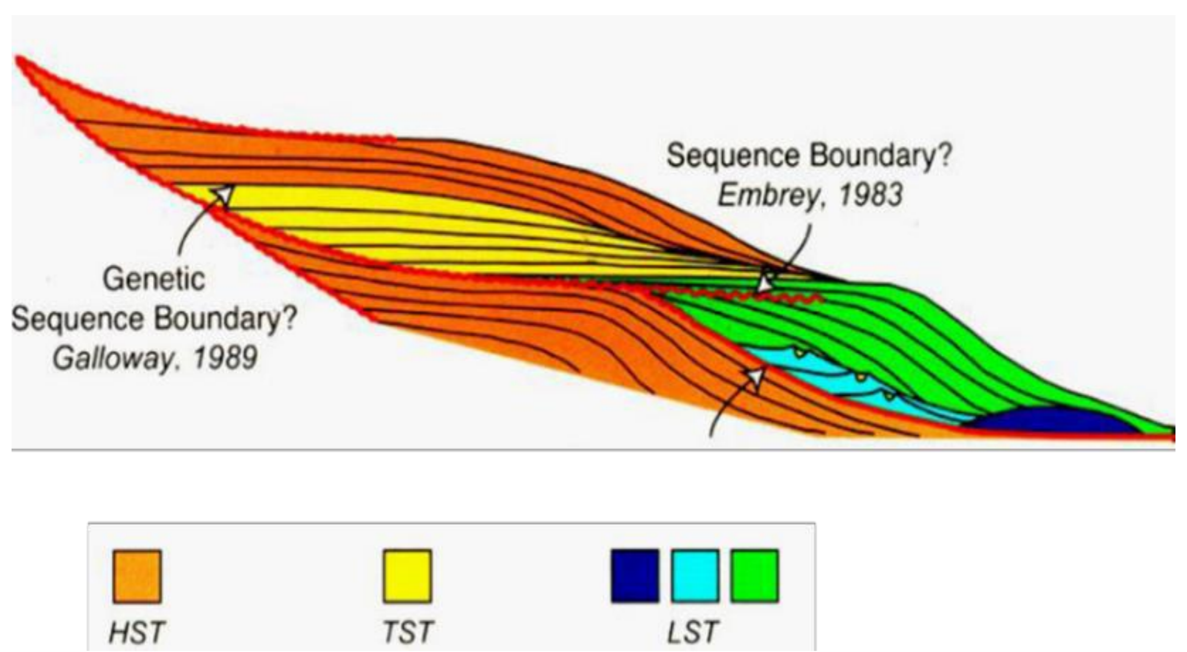

Figure.1 Exxon "Slug model" showing lowstand deep-water submarine-fan in a classical sequence stratigraphic model.

Generally, these classical models are based on passive continental margin setting, where the deepwater clastic environment corresponds to the continental slope and the abyssal (basin floor) settings. The shelf edge acts as the boundary between the shallow and deep water environment. The slope acts as the route for sediment bypass.

During relative sea level fall or lowstand, the river and delta are forced to prograde to the shelf edge and become entrenched and if the sea level falls below the shelf break, sediment bypasses directly onto the slope and basin floor. The prograding shelf-edge delta or incised valleys acts as the feeder for deepwater submarine-fans.

During periods of sea-level rise and highstand, these models postulate that the sediment budget is mainly stored on the shelf with little sand reaching the slope or basin floor and the deep-water fans (low-stand) become draped by muds and condensed sections develops. The famous Exxon "slug model" in figure 1 shows the position and geometric onlapping relationship of the lowstand submarine-fans with the underlying sequence boundary and other system tracts.

OBJECTIVES

- Summarize different types of deep water depositional models, particularly focus on geometric relationship and relative sea level change.
- Understand the combined role of relative sea-level change, sediment supply and shelf-width in each type of the deep-water system classified before.

METHODOLOGY

Detailed literature review was done to compile outcrop, sub-surface and modern-day example for deep water clastic systems. Examples include:

- Brushy Canyon Formation in the Permian Basin
- Pleistocene deposits in the Kuitei Basin
- Lewis Shale Formation in the Washakie Basin
- Oceanside and Carlsbad canyon-channel system in the California Borderland Basin
- Upper Sobrarbe Formation in the Ainsa Basin

Example from each type of deep-water clastic system will be discussed along with the factors which controlled its formation. This will be followed with discussion on conceptual and industrial significance of this study.

APPROACH

- Deep water submarine fans and channel-levee systems can develop both during sea level fall or lowstand, and sea level rise or highstand. So only lowstand system tract cannot be ubiquitously assigned to deep-water clastic sediments.
- Onlapping relationship of deep water clastic sediments against the sequence boundary is not a unique geometric feature, but there are systems which forms a continuous linked geometric relationship between shelf-slope- basin i.e. deep water clastic sediments are non-onlapping.

A classification scheme of deep sea clastic sediments, based on geometric relationship and relative sea level change has been proposed as shown in figure 2.

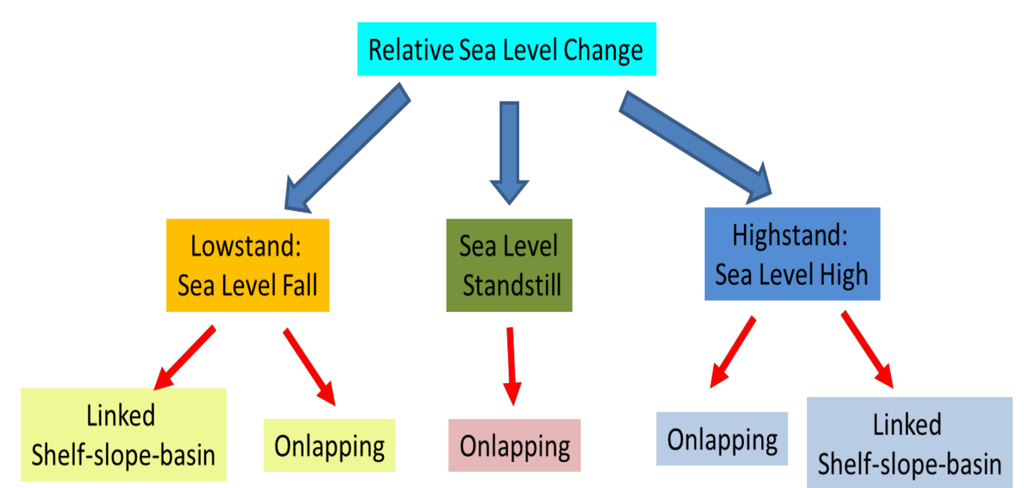

Figure.2 Classification of deepwater clastic sediments (submarine fans and channel-levee system) based on relative sea level change and geometric relationship

SIGNIFICANCE

Onlapping submarine fan and channel levee systems form a closed system which traps the hydrocarbon. While in a linked shelf-slope-basin system, the continuous-connected sand-body can act as a conduit for hydrocarbon migration from the basinal fans to shelf-edge delta.

Lowstand submarine fans also tends to be bigger thicker and laterally extensive while the highstand submarine fans tends to be smaller and less laterally extensive. So, lowstand deepwater fans have higher potential to hold more hydrocarbon reserves than highstand fans.

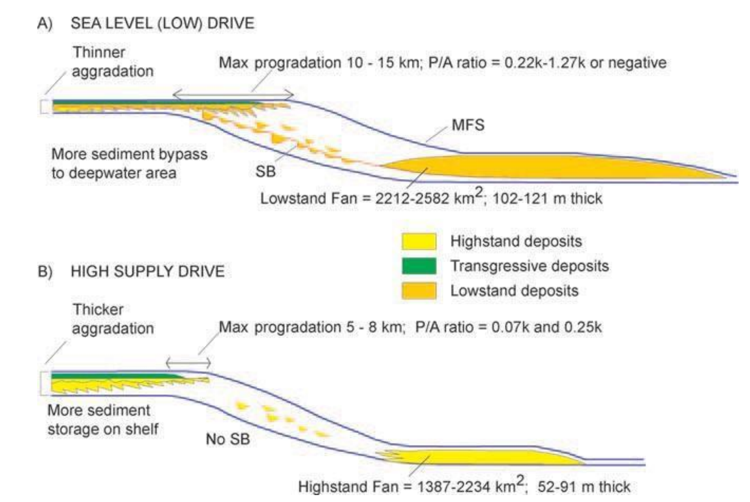

Figure 3 Diagram explains the differences between highstand vs. lowstand submarine fans. From Carvajal and Steel, (2006)

ONLAPPING (Lowstand)

Brushy Canyon Formation in the Permian Basin is a classic example, which has deposition of carbonates during highstand and deposition of deepwater clastic submarine fans and slope channels onlapping against the underlying sequence boundary during lowstand.

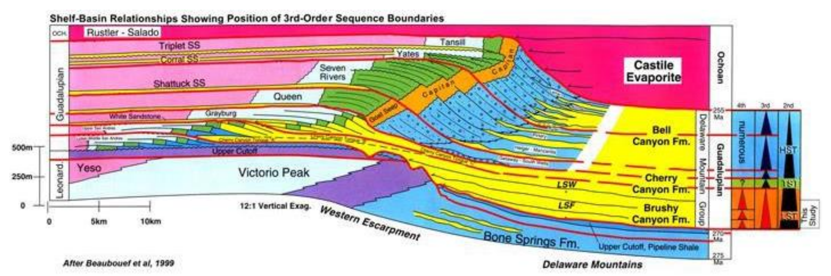

Figure.4 Schematic figure showing the Upper Permian stratigraphy in a cross-section of north- west shelf of Delaware Basin and the third-order sequence stratigraphy of the Guadalupian formations. Deepwater clastic deposits of Brushy Canyon Formation is in the lowstand system tract. (sempstrat.org)

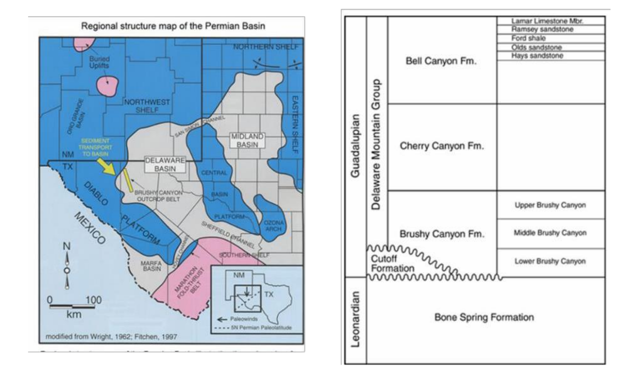

Figure. 5(Left) Map showing location of Permian Basin. (Right) Upper Permian stratigraphy of Permian Basin (sempstrat.org)

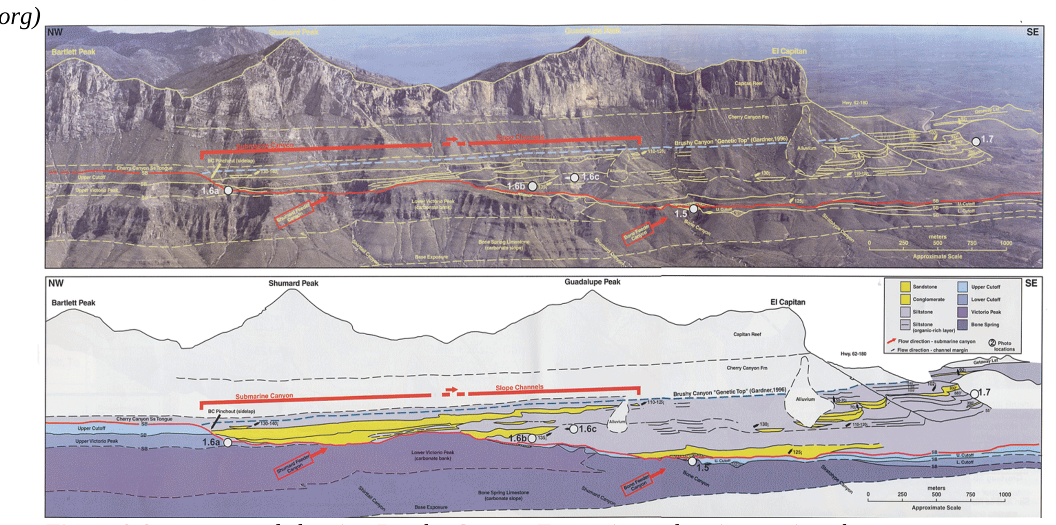

Figure.6 Outcrop panel showing Brushy Canyon Formation onlapping against the sequence boundary between the Leonardian and Guadalupian strata.(Sempstrat.org)

NON-ONLAPPING (Lowstand)

- During Pleistocene, Kuitei Basin in East Kalimantan (fig. 7) has been subjected to three sea-level lowstand cycles.
- Seismic reflectors which corresponds to the first sea-level lowstand can be traced downslope from a prograding lowstand delta at shelf edge continuously to basin floor fan in the central part of the Indonesian shelf (Saller et al., 2004).
- Oxygen isotope data collected from these sediments matches the Pleistocene sea level curve and it indicates falling sea level during the deposition of such a linked lowstand delta and submarine fan.
- During the first sea-level lowstand that ended at about 240 ka, a shelf-edge delta prograded over the previous shelf edge, and sand-rich sediments spilled onto the slope. Amalgamated and unconfined channel levee system developed along the slope and coeval deepwater submarine fans developed in the basin floor (fig. 8).
- It has been interpreted that high sediment influx from the paleo-Mahakam delta which prograded along the shelf edge resulted in the formation of this linked system (fig. 9).

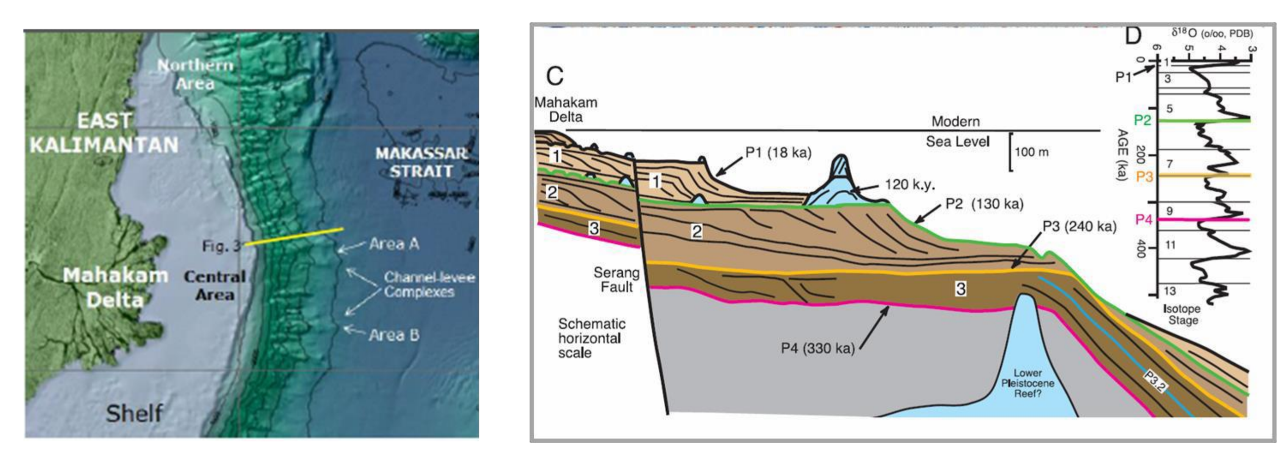

Figure.7 (Left) Map showing location of Kuitei Basin East Kalimatan, Indonesia.(Right) Schematic diagram showing three sea level lowstand cycles in Plesotecene and the corresponding deepwater clastic sediment deposited in offshore Kalimatan. (Modified from Saller et al., 2004)

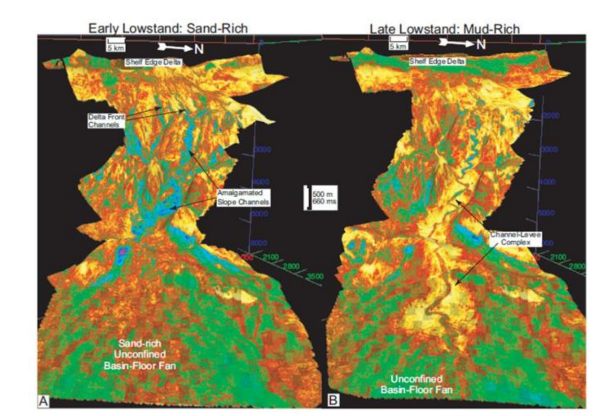

Figure. 8 (Left) Amplitude extraction 3-D map showing linked shelf edge delta-amalgamated slope channels complex-sand-rich unconfined basin floor fan, in Kuitei Basin. (Right) Amplitude extraction map showing, non-linked slope channels and basin floor fans in a mud-rich system. High sand-rich sediment influx results in deposition of linked system, while mud-rich, low sediment influx results in deposition of non-linked system. (Modified from Saller et al., 2004)

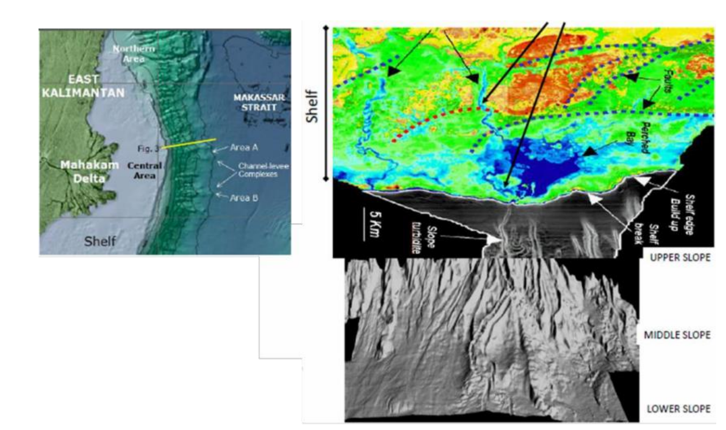

Figure. 9 Combined seismic amplitude maps showing the paleo-Mahakam delta can be linked to slope channels and submarine fans in the central part of Kuitei Basin. Paleo-Mahakam delta was the source of high sediment supply during the first cycle of Pleistocene lowstand. (Seller et al., 2013)

ONLAPPING (Highstand & Sealevel standstill)

This study also concludes that deepwater submarine fans are not uniquely related to relative sea-level fall/lowstand. Examples were found in Lewis Shale Formation in the Washakie Basin, Oceanside and Carlsbad canyon-channel system in the California Boarderland Basin, and Upper Sobrarbe Formation in the Ainsa Basin (Nothern Spain). Shelf-edge delta acts as the sediment source and progradation of these deltas are able to transport coarse sediments to deep water during highstand. The development of highstand submarine fans requires a strong fluvial drive on the deltas.

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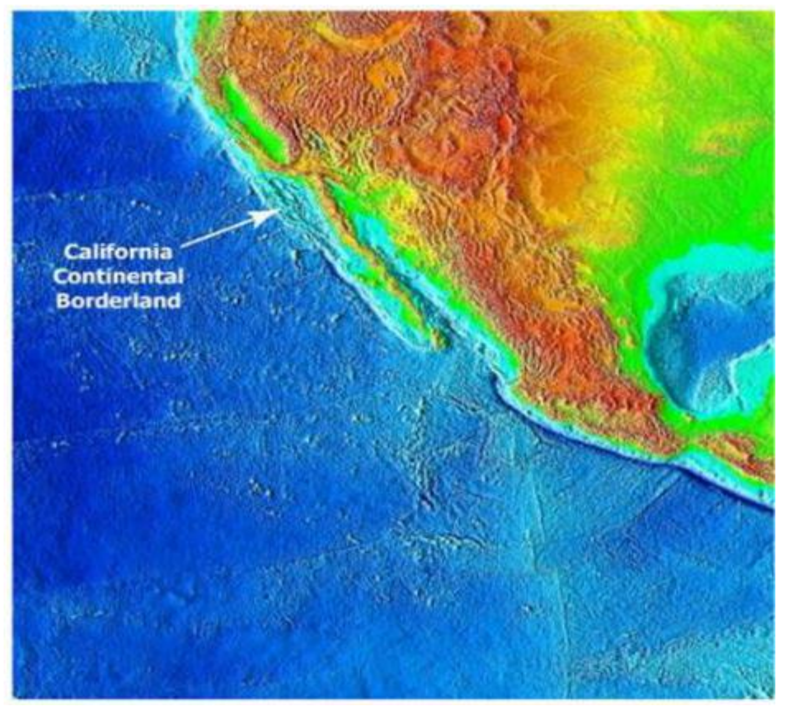
California Borderland

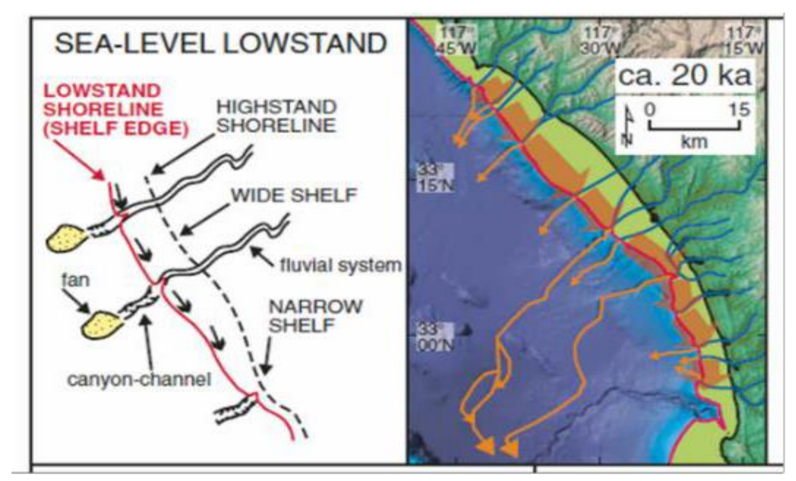
Background

- The California borderland basins has been fed by submarine canyons since the Late Quaternary till Recent.
- Sediment has been supplied to the southeastern Santa Catalina and San Diego Trough in the borderland area mainly by three submarine canyon-channel system since at least oxygen isotope stage (OIS) 3 (younger than 58 ka).
- From north to south, these canyon-channel systems are the Oceanside, Carlsbad, and La Jolla systems (fig. 10).

Highstand fans

- At present sea level highstand condition, deposition of thick submarine fan at La Jolla canyon system has been reported from interpretation of two-dimensional seismic reflection profiles (WesternGeco and USGS).





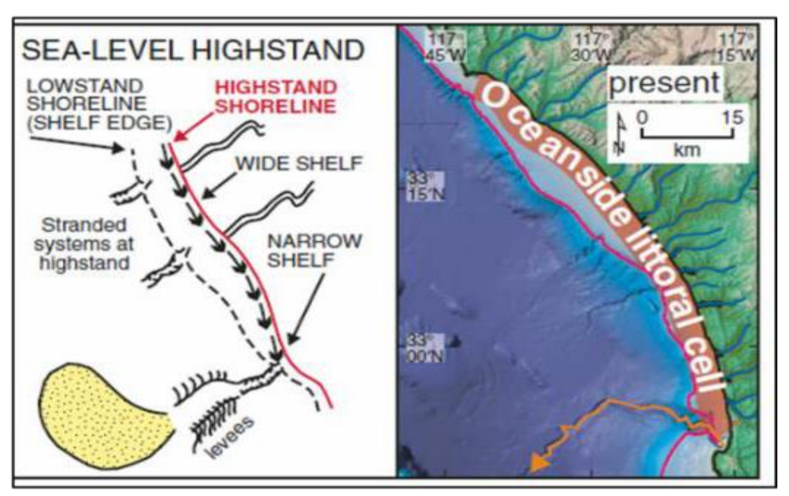


Figure 10 (upper) Map showing location of California borderland area. (lower two)Schematic figure showing deposition of submarine fans in Oceanside and Carlsbad canyon-channel system during sea level lowstand and La Jolla submarine fan during sea level highstand. From Covault et al., (2007)

Shelf width control (between the canyon head and the shelf-slope break)

During the latest Pleistocene interval of low sea level (ca. 20 ka)

- Oceanside and Carlsbad canyons: received sediment from fluvial systems
- La Jolla canyon: no sediments were finally deposited at during sea level lowstand due to absence of any fluvial source and sediment-laden longshore drift currents.

At recent sea-level highstand

- Oceanside and Carlsbad canyons: canyon heads cannot capture the sediments being supplied by their respective fluvial sources as the sea level rises and the shoreline moves further landward. So, the bulk of the sediments get transported by the longshore drift currents
- La Jolla canyon: get sediments captured from longshore drifts and deposited as submarine fans (fig. 10).

Lewis Shale, Washakie Basin, WY

Background

- The Lance-Fox Hills-Lewis depositional system (fig. 1) was deposited on continental crust during the third-order shoreline regression of the Cretaceous Western Interior Seaway.
- High sediment supply essentially led to the generation of large, sand-rich submarine fans during relative sea level rising, as well as falling (Carvajal and Steel, 2006; Pyles et al., 2010).

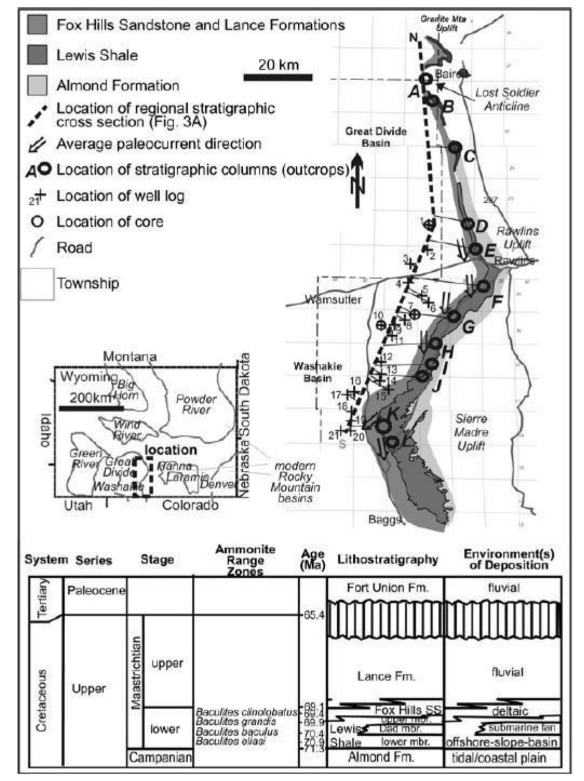


Figure.11 Location of Lewis Shale Formation and stratigraphy of basin (Carvajal and Steel, 2006)

Characteristics of highstand fans

- Highstand fans are relatively thinner, and smaller in dimensions. It lacks of the onlapping relationship with the underlying sequence boundary as lowstand fan does. More aggradation signature than progradation is revealed in highstand shelf edge deltas, therefore, it is defined as high sediment supply drive, rather than sea level drive.

Quantitative data:

- Well log correlation and outcrop data help tracing and quantifying shoreline trajectory across the profile (Fig. 12 and 13).
- 14 clinothems documented
- shelf-edge trajectory
- fan thickness and area
- the character and/or geometry of the sand accumulated on the slope

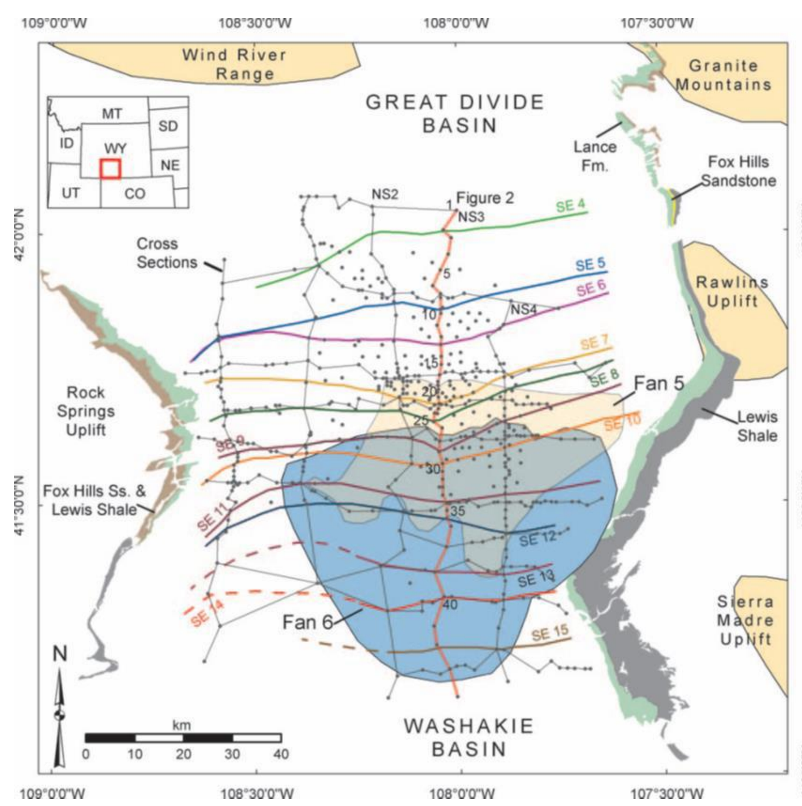


Figure 12 Base map showing the location of the cross section of Lewis shale, where it connects all well log data from No.1 to No.44. From Carvajal and Steel (2006)

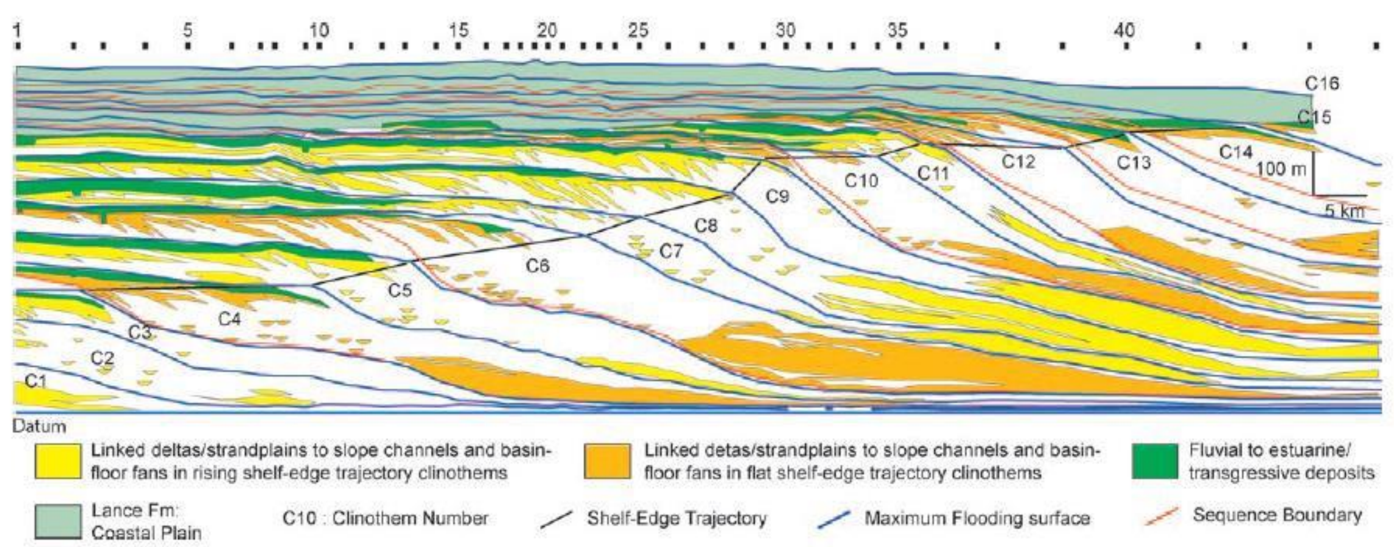


Figure 13 Cross section of Lewis Shale, clearly implying linked deltas to slope channels and basin floor fans in rising shoreline trajectory, as well as in flat shoreline trajectory. From Carvajal and Steel (2006)

Sobrarbe Deltaic Complex, Ainsa Basin, Northern Spain

- The youngest marine outcrop (the syn-tectonic Eocene Sobrarbe Formation) records the progradation of a linked shelf-slope-basin system across the basin (Fig.14).
- Shelf edge is located where transgressive surface starts dipping ca 2 degree northward.
- Local erosional surfaces (Fig.15) are correlated landward to delta plain.
- The topsets of the three erosional surface-bounded units are at almost the same elevation. It indicates sea level did not change measurably during deposition.
- This example suggests that deep marine fan deposits are not uniquely related to relative sea level rise or fall (Kim et al., 2013).

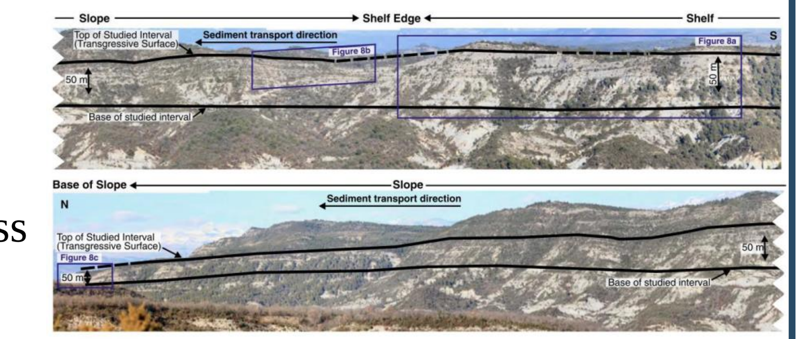


Figure 14 Photopanel of the shelf-to-basin complex profile exposed in the Upper Sobrarbe Formation.From Kim et al., (2013)

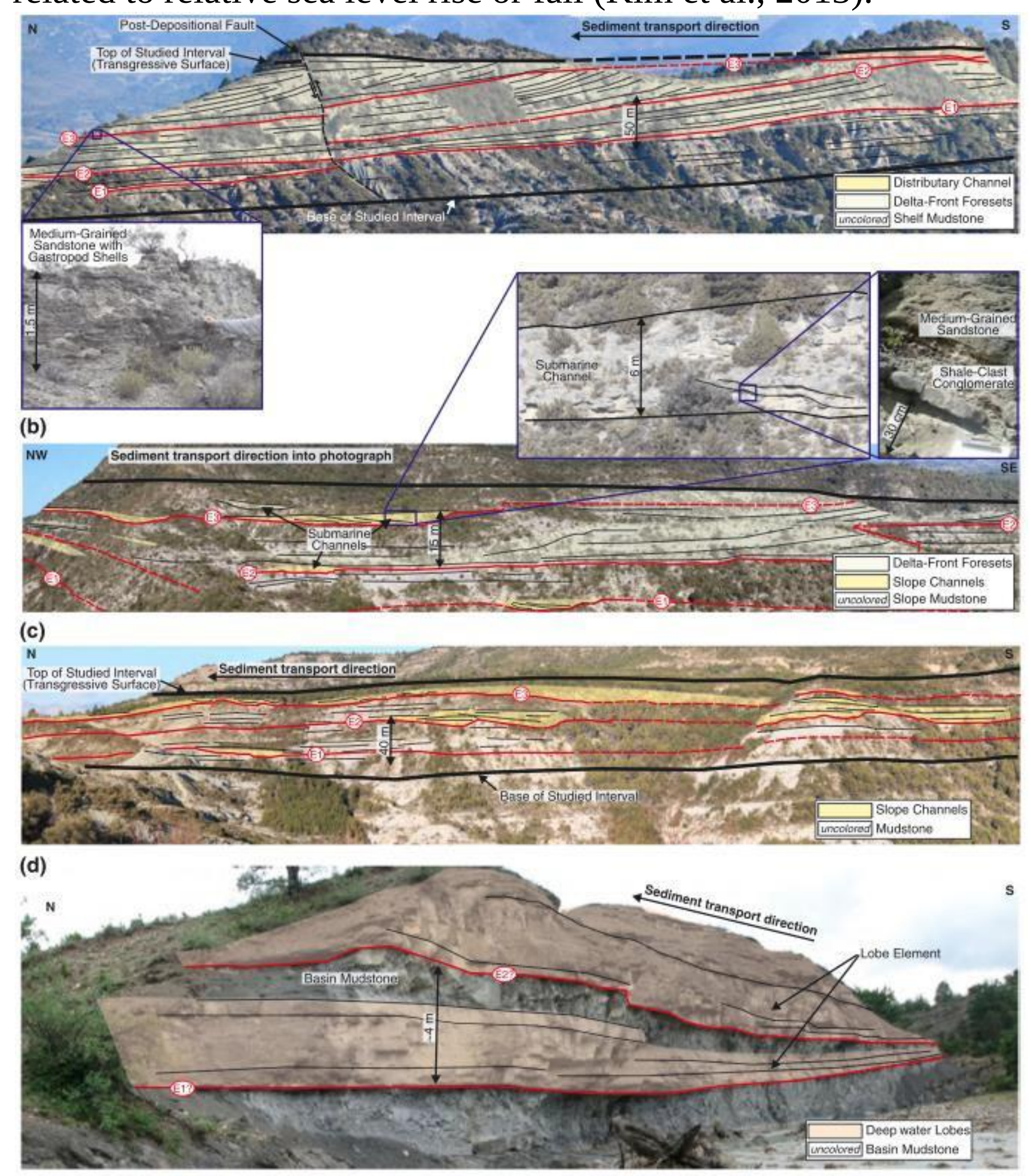


Figure 15 Photopanel of the shelf-edge delta highlighting delta front foresets and erosional surfaces. (b) Photopanel of strata located in the proximal slope representing submarine channels, slope mudstone, and the erosional surfaces. (c) Photopanel of the strata located in the medial part of the slope highlighting submarine channels, slope mudstone, and the ero- sional surfaces. (d) Photopanel of strata deposited on the basin floor highlighting lobe elements, basin mudstone, and plausible locations for the erosional surfaces.From Kim et al., (2013)

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CONCLUSION

- Deepwater submarine fans are not uniquely related to relative sea-level fall/lowstand.
- Submarine fans and channel-levee systems can develop at any relative sea level change, lowstand, highstand or standstill.
- Factors like sediment supply and shelf-edge width and gradient along with realative sea level change in combination controls the formation of deeepwater deposits.
- Progradation of shelf-edge delta plays a major role in formation of highstand-deepwater deposits.
- Deltas that prograde to the shelf edge are able to transport coarse sediment to deep water either with or without sea level changes.
- The development of highstand fans requires a strong fluvial drive on the deltas.
- Deepwater sediments can either onlap or form a linked shelf-slope-basin system.

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