Papers
Start
Author
Search
Help

A Linked Shelf-Edge Delta and Slope-Channel Turbidite System: 3D Seismic Case Study from the Eastern Gulf of Mexico

Posamentier, Henry W.
Anadarko Canada Corporation
425 1st Street SW
Calgary, Alberta T2P 4V4
Canada
e-mail: henry_posamentier@anadarko.com

Abstract

Linked shelf edge deltas and slope channel systems are observed in the eastern Gulf of Mexico. The slope channels are characterized by deep incision into the substrate and moderate sinuosity nearly to the shelf-slope break. Channelized flows were not fully confined as evidenced by well-developed levees up to 90 m thick. This sinuosity suggests that turbulent flow within the channel was likely nearly from the uppermost slope. With apparent turbulence characterizing these channels nearly to the shelf-slope break, the dominant mode of sediment delivery to the slope and basin beyond probably was in the form of density underflow (*i.e.*, hyperpycnal flow) rather than shelf edge slump and/or slide progressively transformed into turbidity flow.

The stages of evolution of these slope channels are (**1**) clustering of small slope gullies on the slope at the initiation of lowstand deposition, (**2**) dominance of one of these slope gullies and formation of one significant channel, formation of a frontal splay fed by the dominant channel, (**3**) abandonment of frontal splay deposition in favor of leveed channel deposition across the entire slope, and (**4**) entrenchment of the leveed channel into the earlier deposited leveed channel and frontal splay.

Introduction

Several slope channels are observed on the continental slope of the northeastern Gulf of Mexico (Fig. 1). All are incised 100-250 m into the slope substrate and all are associated with levee development to a

Papers
Start
Author
Search
Help

greater or lesser degree. All are overlain by predominantly drape facies and although no chronologic data are available, it is inferred that these channels likely are late Pleistocene in age. The focus of this study is two roughly parallel channel systems that originate at the upper slope and can be followed across the slope and onto the basin floor. These channel systems lie just below the sea floor, covered by 100-150 m of drape deposits. Systems such as these have alternatively been referred to as *canyons* or *slope channels*. This paper will refer to these features as *slope channels* reserving the term *canyon* for conduits so deeply cut into the substrate that gravity flows would have been completely confined by the walls bounding the system. In this instance, the association of levees with the channels studied suggests that bank spillover was occurring.

The slope channels are associated with updip shelf-edge deltaic wedges, which suggests a genetic linkage between depocenters in the staging area of the outer shelf, and conduits for sediments derived from there to be delivered to the basin floor down system. This genetic linkage raises questions regarding the mode of sediment delivery from the river systems to the ultimate location of deposition. The primary modes of delivery include (**1**) delivery from river systems directly into the slope channels without pause via density underflow (*i.e.*, hyperpycnal flow), and (**2**) deposition of river-borne sediments deposited at the shelf edge and then subsequently remobilized by slump or slide, ultimately transforming into turbidity flow. Both mechanisms can yield similar turbidite deposits though in the former instance deposition would occur over a period of days or even weeks, corresponding to periods of high river discharge, whereas the latter would occur episodically with deposition occurring over much shorter time periods of hours rather than days. This has implications with regard to understanding how specific depositional elements such as meander loops and apparent "point bars" form.

Evidence is presented here that suggests that hyperpycnal flow may be a dominant contributing mechanism towards the process of delivery of sediments to the slope and basin. The presence of channels with moderate sinuosity originating almost at the shelf-slope break suggests that turbulent flow must have been occurring this close to the shelf edge and river mouths. This tends to run counter to the suggestions by Milliman and Sivitski (1992) and Mulder and Sivitski (1995) that most rivers even when they are in flood are not capable of producing significant hyperpycnal flow events. Resolution of these conflicting views lies beyond the scope of the present study and warrants additional work.

The seismic volume used in this study is migrated full stack data acquired and processed by VeritasDGS. The interpretation software used is Stratimagic™ and VoxelGeo® by Paradigm Geophysical. The study area is shown in Figure 1.

Papers
Start
Author
Search
Help

Slope Channel Morphology

The slope channels are approximately 1.8 km wide and vary from 175 m deep on the slope to 275 m deep at the shelf edge. They are characterized by the presence of a moderate sinuosity channel (sinuosity of 1.55) in the thalweg of the system. The channel slope is approximately 1.8 degrees and the thalweg slope is 1.1 degrees (Fig. 2). At the head of one of the slope channels (*i.e.*, Channel "**W**") a small shelf edge delta can be observed (Figs. 3 and 4). This small delta is restricted areally and confined laterally by the margins of the channel. The clinoforms of this smll delta are characterized by high amplitude reflections dipping at approximately 4 degrees.

Numerous small slope gullies can be observed on the surface that is characterized by clinoform downlap related to an overlying prograding shelf-edge delta, which later is associated with slope channel development (Figs. 5 and 6). It is likely that this shelf edge delta marked the depocenter during the time of active channel formation and was associated with delivery of sediments to the upper slope. The slope channels seem to cluster and increase their density in the part of the slope where ultimately the dominant slope channel forms (Fig. 7).

Subsequent to formation of the surface characterized by multiple slope gullies, a single slope channel appears to form at the expense of most of the slope gullies. As a result, a single slope channel forms within the prograding section overlying the gullied downlap surface (Fig. 6). The leveed slope channels initially appear to feed elongate frontal splays (Figs. 8 and 9). The transition from leveed channel to frontal splay lies approximately 10 km from the shelf edge. Based on amplitude extractions, the frontal splays appear to be sand prone. These images also suggest a pattern of distributary to braided channels within these deposits consistent with similar patterns within frontal splays observed by Posamentier and Kolla (2003).

The leveed channel to frontal splay complex is in turn overlain by a single sinuous leveed channel that traverses the entire slope study area (Figs. 8B and C). This leveed channel is deeply entrenched into the earlier-formed deposits. This late-formed channel is characterized by higher sinuosity than the earlier formed channel; the earlier channel sinuosity is 1.10, whereas the entrenched channel sinuosity is 1.55. The well developed levees seem to have formed early and are later eroded by the entrenched channel, leaving the levees only partially preserved (Fig. 10). The remaining levee "thicks" correspond to outer bends of an earlier-formed channel system having lower sinuosity and do not correspond to outer bends of the last-formed entrenched system.

Papers
Start
Author
Search
Help

Slope System Evolution

The slope system evolves in a series of stages. These stages occur predominantly when the depocenter is at or near the shelf margin, a situation, which, in turn, characterizes lowstands of sea level. During the course of a sea-level fall, shorelines commonly migrate seaward rapidly in response to the process of forced regression (Posamentier *et al.*, 1992). The shelf edge and outer shelf can be referred to as the *staging area* (Posamentier and Kolla, 2003) for sediments that ultimately will be carried onward onto the slope and basin beyond. These sediments are brought to the outer shelf/upper slope by shelf or coastal plain processes and are subsequently available for transport and ultimate deposition in deeper water farther seaward. An active staging area commonly is characterized by a protuberance of the shoreline corresponding to a shelf-edge delta. Four stages of slope and shelf edge evolution are observed:

Stage 1: Early Lowstand—Development of Multiple Slope Gullies (Fig. 11A)

When the mouths of rivers first reach the shelf margin, sediments apparently are delivered to the upper slope in a relatively disorganized manner so that there exist several active delta distributaries. In association with these multiple distributaries, multiple small slope channels or gullies form. These gullies have characteristically low sinuosity, almost being straight channels. Significantly, these gullies tend to cluster into a more tightly-spaced series of slope sediment conduits immediately down-system of the deltaic coastline bulge (Fig. 7).

Stage 2: Middle Lowstand—Shelf Edge Progradation and Development of a Single Large Slope Channel (Fig. 11B)

Subsequent to slope gully formation, and when sea level is at its lowest position, shelf edge progradation occurs (Fig. 4C and D). These deposits lap down on the Stage 1 surface of multiple gullies (Fig. 6). During this lowstand stage, a single slope channel develops, presumably as a result of drainage capture by one of the centrally-located gullies. Although no genetically linked delta distributary-channel can be observed, it is inferred that this linkage nonetheless existed. During this time the moderate sinuosity thalweg within the slope channel is connected to and feeds a frontal splay whose apex is approximately 10 km from the shelf margin (Figs. 8 and 9). At the transition from leveed channel to frontal splay, the morphology of the transport fairway changes from confined leveed channel to multiple small channels, probably associated with low sand-prone levees, and arranged in a distributive to braided pattern. During this time the shelf edge deltaic deposits continue to pro-

Papers
Start
Author
Search
Help

grade, possibly under the influence of continue sea-level fall as evidenced by downstepping delta plain architecture (Figs. 4C and D) indicative of forced regression (Posamentier *et al.*, 1992).

Stage 3: Late Lowstand I—Shelf edge Progradation and Aggradation; Evolution of Slope Channel into a Single Moderate Sinuosity Channel across the Slope (Fig. 11C)

During the late lowstand, when sea level has resumed its rise, the rate of shelf edge progadation decreases and is accompanied by significant shelf aggradation (Figs. 4C and D). These systems are still shelf-edge restricted; at this time the process of aggradation likely results in sequestering of a significant portion of the sand delivered to across the shelf. As a result, the sand made available for sediment gravity flows into associated slope channels is diminished resulting in a decreased sand-to-mud ratio in the resulting flows. Consistent with suggestions by Posamentier and Kolla (2003), this results in significant extension of the channel-levee complex across the earlier-deposited frontal splay (Fig. 12).

The thalweg of the slope channel is characterized by moderate sinuosity nearly to the toes of the small delta observed within the confines of the uppermost reaches of the slope channel (Fig. 13). Such sinuosity strongly suggests turbulent rather than laminar flow. No evidence of slumping or sliding is seen in the upper slope channel setting. Turbulent flow this high up the slope and this close to the associated shelf-edge delta raises the possibility that the mode of delivery of sediment to the slope is by flow directly from river or distributary channels into associated slope channels by the process of density underflow or hyperpycnal flow. By extension, this would suggest that flows responsible for transport of sediment across the slope and onto the basin floor might occur over prolonged periods of days or weeks, or as long as associated rivers and distributaries remain in flood. This is in contrast with the notion that flows in slope channels are of short duration (*i.e.*, lasting hours rather than days), associated with catastrophic and short-lived retrogressive slumping and sliding of slope channel headwalls.

Stage 4: Late Lowstand II—Minor Shelf-edge Progradation; Entrenchment of Slope Channel (Fig. 11D)

During the last part of the lowstand, the slope channel entrenches deeply into the slope (Fig. 8). The channel sinuosity increases relative to the early lowstand channel pattern as evidenced by the apparent disconnect between levee thicks and thalweg pattern (Fig. 10). Whereas levees commonly are thickest at outer channel bends, those related to Channel “**W**” seem to bear little

Papers

Start

Author

Search

Help

relationship to thalweg outer bends, suggesting that these levees formed at an earlier time (Fig. 10).

Presumably at this time, sand-to-mud ratio within gravity flows is diminished further, because of preferential sequestering of sand within the shelf environment (*e.g.*, within incised valleys, estuaries, and canyon heads). This leads to a condition of undercharged (with respect to sand) flows. With less sand available to fall out of suspension as the flows proceed downslope, flows are more capable of eroding and entraining sediments derived from the substrate. This increased erosion due to undercharge by sand occurs synchronously over the entire system, resulting in entrenchment of the channel across the slope.

Also at this time, a short period of resumed sea-level fall seems to have occurred as marked by the deposition of a small shelf-edge delta fully confined within the upper reaches of the slope channel (Figs. 3, 4, and 13). The presence of this small delta confirms the linkage of shelf-edge delta and channel-levee system. These deltaic deposits are characterized by high-amplitude seismic reflections suggesting the presence of sand in the system at that time. The sinuous channel marking the thalweg of the slope channel system can be tracked almost to the clinoforms of this small delta (Fig. 13), further supporting the inference of hyperpycnal flow into the head of the slope channel. Supporting this interpretation is the absence of any evidence for slumping or sliding down the delta clinoforms.

Notable by their absence is any seismic evidence of incised valleys on the shelf just inboard of the shelf edge delta. This absence of incised valleys during these relatively recent lowstands of sea level confirms the suggestion by Posamentier and Allen (1999) and Posamentier (2001) that relative sea-level falls do not necessarily result in the formation of significant incised valleys from the shelf edge landward.

Conclusions

An area along the northeast margin of the Gulf of Mexico characterized by numerous shallow-buried slope gullies and slope channels has been examined. Slope gullies are common features in this upper-slope setting. These slope gullies seem to cluster in the area of coastline bulges and form on surfaces that later are buried by prograding lowstand shelf-edge deltas and comprise downlap surfaces. Commonly, during a single lowstand period, one slope gully tends to dominate and evolves into a slope channel that exceeds the other gullies in size by at least an order of magnitude. The slope channels are characterized by moderate sinuosity and the presence of flanking levees. Channel sinuosity is observed nearly to the shelf slope break suggesting that turbulent flow begins very high up the slope, possibly right to shelf-edge river mouths. This raises the possibility that these rivers generate hyperpycnal flows that result in the delivery of river-borne sediment directly onto the slope and basin beyond. In the early stage of development the slope channels are observed to feed elongate frontal splays in the middle slope. These frontal splays are later overridden by sinuous leveed channels. During the final stages of development, the slope channels are characterized by apparent entrenchment. This entrenchment is attributed to the imbalance between sediments falling out of suspension and sediments entrained by erosion late in a sea-level cycle when flows are characterized by a progressively decreasing sand content.

Acknowledgments

Thanks are due to the many colleagues who have shared their ideas with me through the years. In particular I wish to thank V. Kolla for the many stimulating conversations we have shared. This paper benefited from reviews by P. Bart as well as an anonymous reviewer. I thank VeritasDGC for permission to reproduce the seismic images presented here. Finally, I thank Anadarko Canada Corporation for permission to publish this paper.

References

Milliman, J.D., and J.P.M. Sivitski, 1992, Geomorphic/Tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers: Jour. Geology, v. 100, p. 525-544.

Mulder, T., and J.P.M. Sivitski, 1995, Turbidity currents generated at river mouths during exceptional discharge to the world's oceans: Jour. Geology v. 103, p. 285-298.

Posamentier, H.W., 2001, Lowstand alluvial bypass systems: incised vs. unincised: AAPG Bull., v. 85, p. 1771-1793.

Posamentier, H.W., and G.P. Allen, 1999, Siliciclastic sequence stratigraphy – concepts and applications: SEPM Concepts in Sedimentology and Paleontology no. 7, 210 p.

Posamentier, H.W., G.P. Allen, D.P. James, and M. Tesson, 1992, Forced regressions in a sequence stratigraphic framework: concepts, examples, and exploration significance: AAPG Bull., v. 76, p. 1687-1709.

Posamentier, H.W., and V. Kolla, 2003, Seismic Geomorphology and stratigraphy of depositional elements in deep-water settings: Jour. Sedimentary Research, v. 73, p. 367-388.

Papers
Start
Author
Search
Help

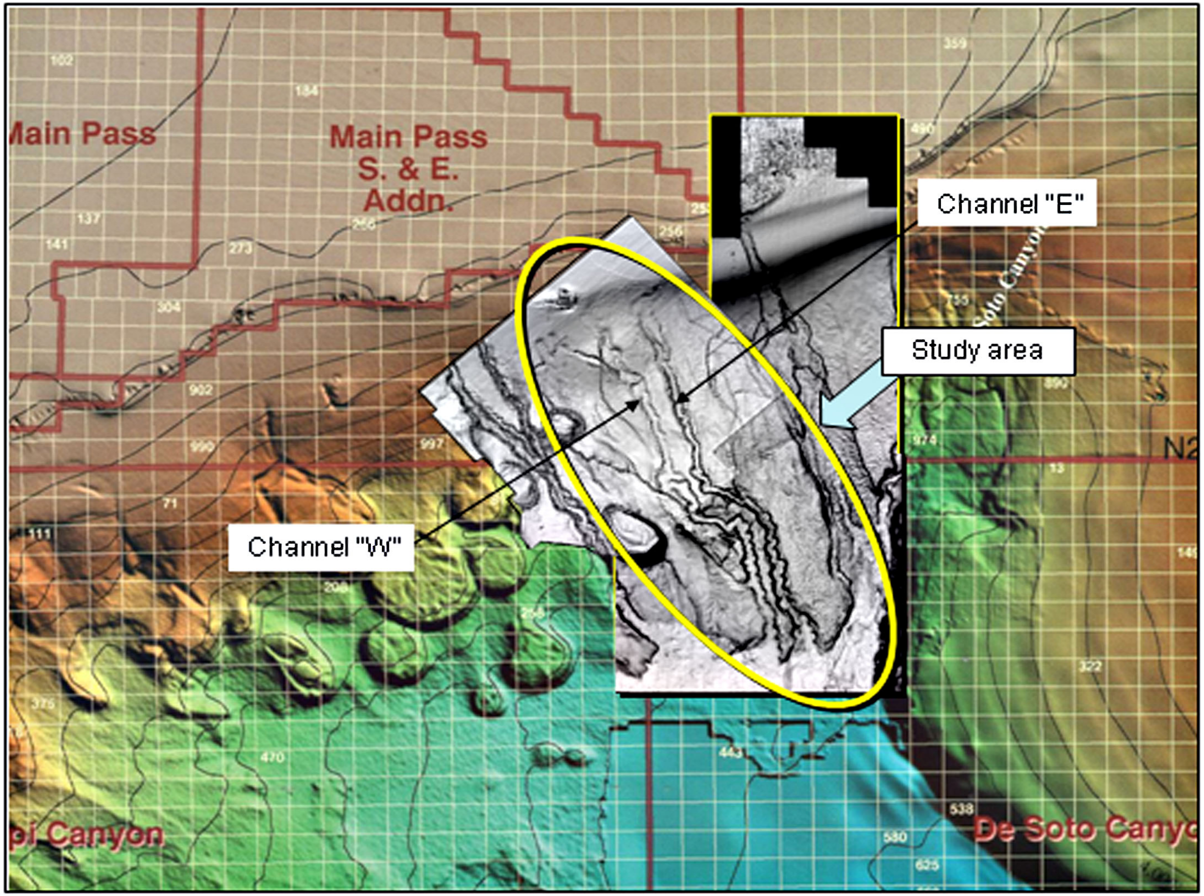

Figure 1. Location of study area in the eastern Gulf of Mexico (base map courtesy of TGS Nopec; seismic overlay courtesy of Veritas DGC).

Papers
Start
Author
Search
Help

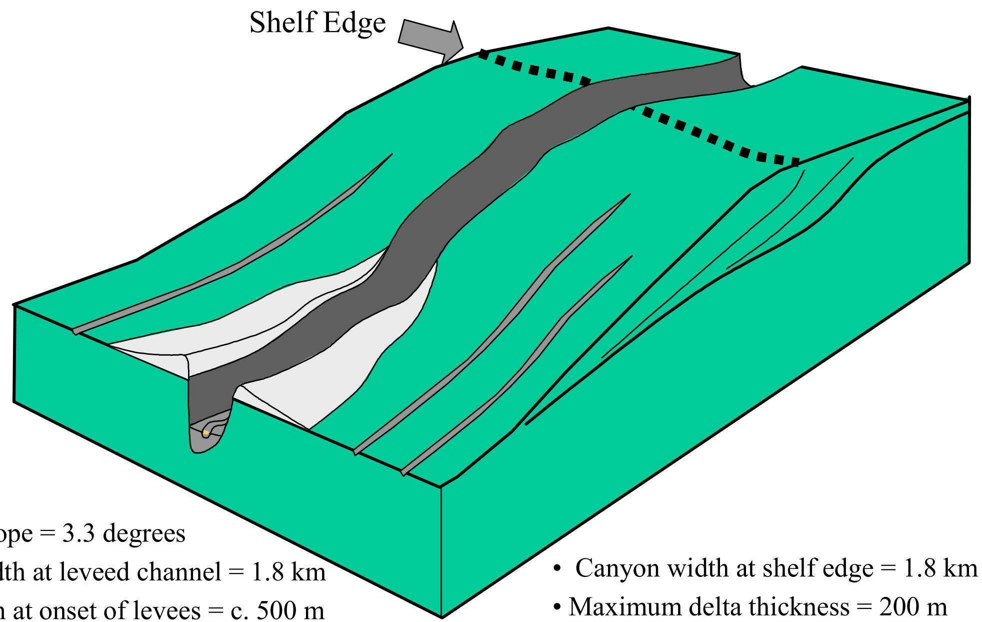

Figure 2. Schematic depiction of outer shelf to upper slope environment with key metrics indicated.

Papers
Start
Author
Search
Help

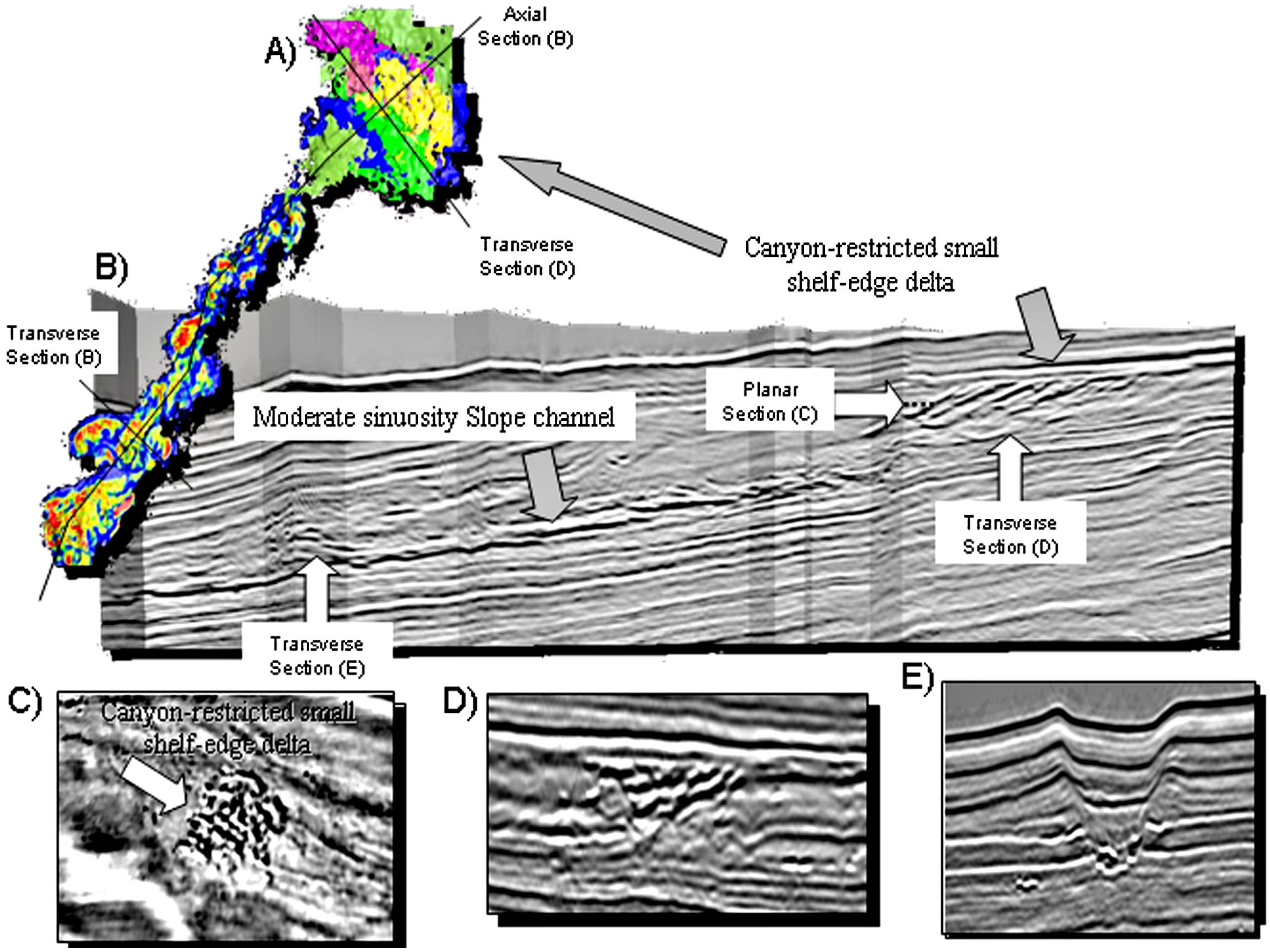

Figure 3. Seismic expression of slope Channel "W" (see Fig. 1 for location). (A) Amplitude extraction of sand-prone channel thalweg as well as successive delta shingles (each marked by a different color) located in the uppermost reaches of the slope channel. (B) Axial seismic traverse through slope channel. The high amplitudes at the base indicate the presence of a sand-prone meandering thalweg. (C) Seismic time slice through the uppermost part of the slope channel indicating the presence of a small sand-prone shelf-edge delta restricted to the confines of the upper slope channel. (D) Transverse seismic section through a small slope-channel confined shelf-edge delta. The high amplitude reflections suggest the presence of sand-prone sediments there. (E) Transverse seismic section across the slope channel. The high amplitude reflections at the base of the channel indicate the presence of a sand-prone meandering channel thalweg. Most of the fill of the slope channel, however, is characterized by low-amplitude seismic reflections suggesting that the bulk of the slope channel is mud filled. Note the presence of levees flanking the slope channel on either side.

Papers
Start
Author
Search
Help

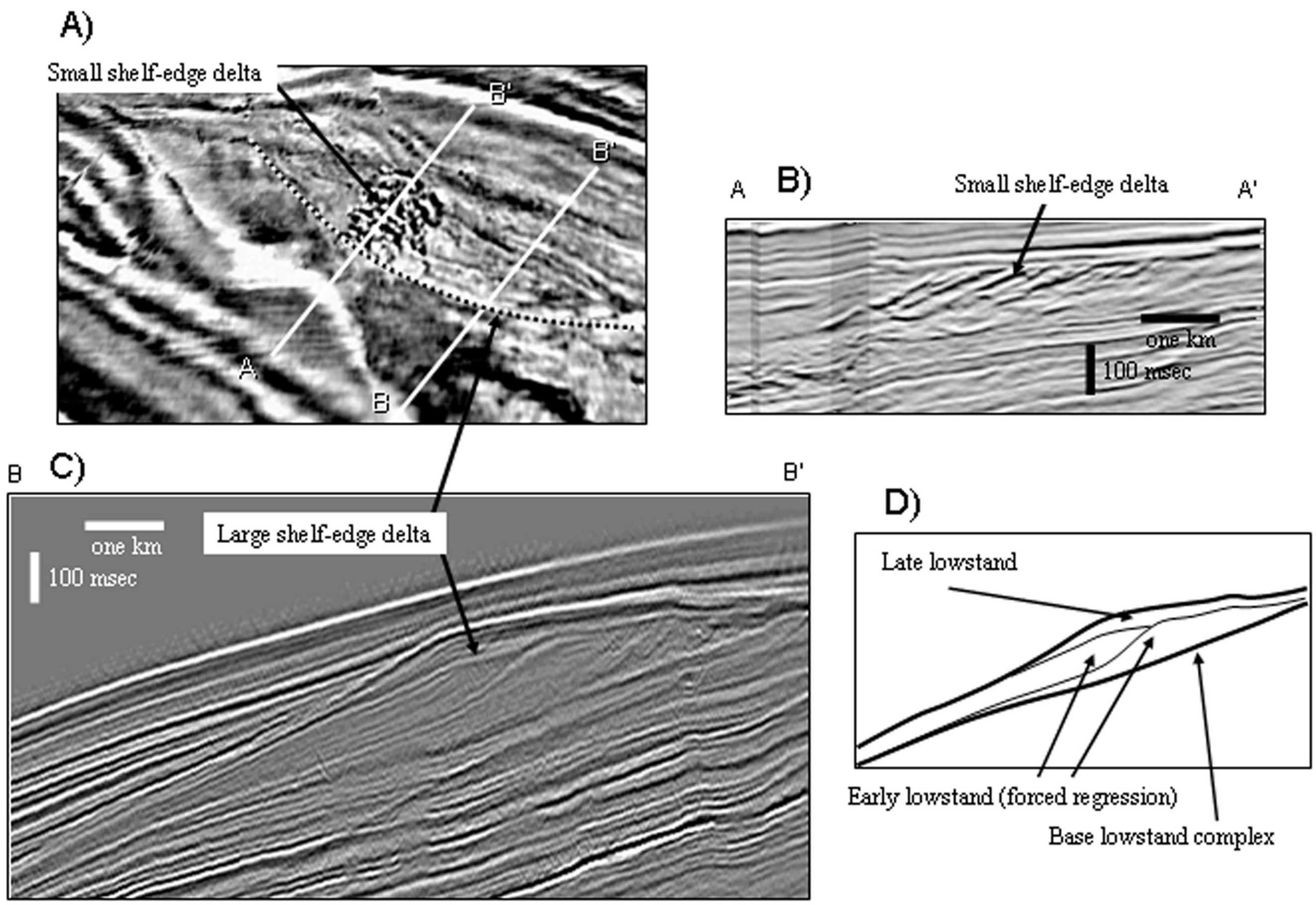

Figure 4. Seismic expression of a shelf edge deltaic complex (Channel "W"; see Fig. 1 for location). (A) Seismic time slice through shelf edge area showing the presence of a shoreline protuberance (dotted line) indicative of a shelf edge delta, as well as a small upper slope-channel restricted shelf-edge delta. (B) Axial section through the small upper slope-channel restricted shelf-edge delta shown in (A). The high-amplitude reflections suggest the presence of sand in this clinoform package. (C) Axial seismic section through the shoreline protuberance shown in (A) with an accompanying interpretation (D). This shelf edge delta is characterized by an early forced regressive component as indicated by the downstepping architecture of the delta top, and a later normal regressive component as indicated by the aggradational architecture of the delta top. Note the downlap surface formed at the base of the clinoform package.

Papers
Start
Author
Search
Help

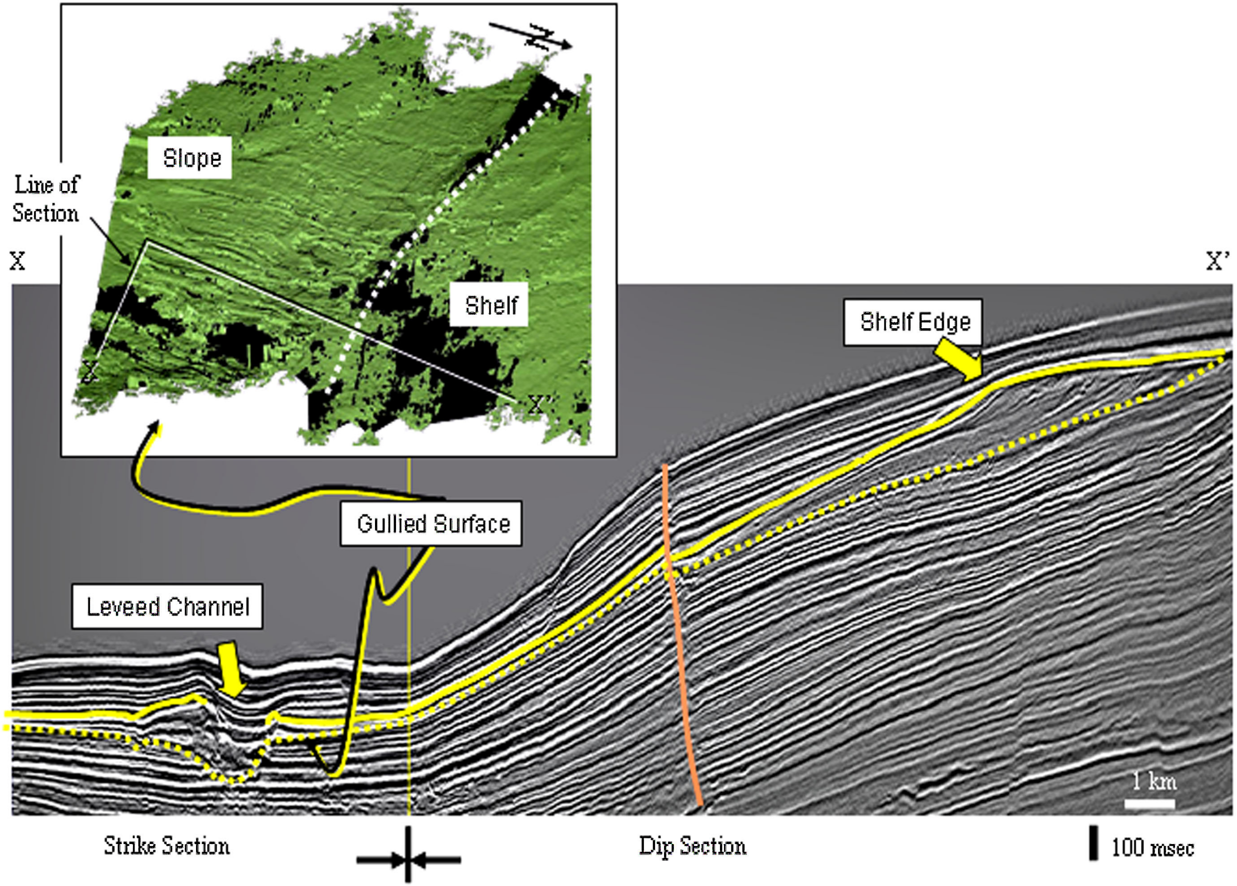

Figure 5. Dip and strike seismic reflection profile from shelf to upper slope illustrating shelf edge delta and coeval leveed channel. (Channel "W"; see Fig. 1 for location.) Inset illustrates the geomorphology of the downlap surface associated with the shelf edge delta. This image constitutes an illuminated seismic horizon shown in perspective view.

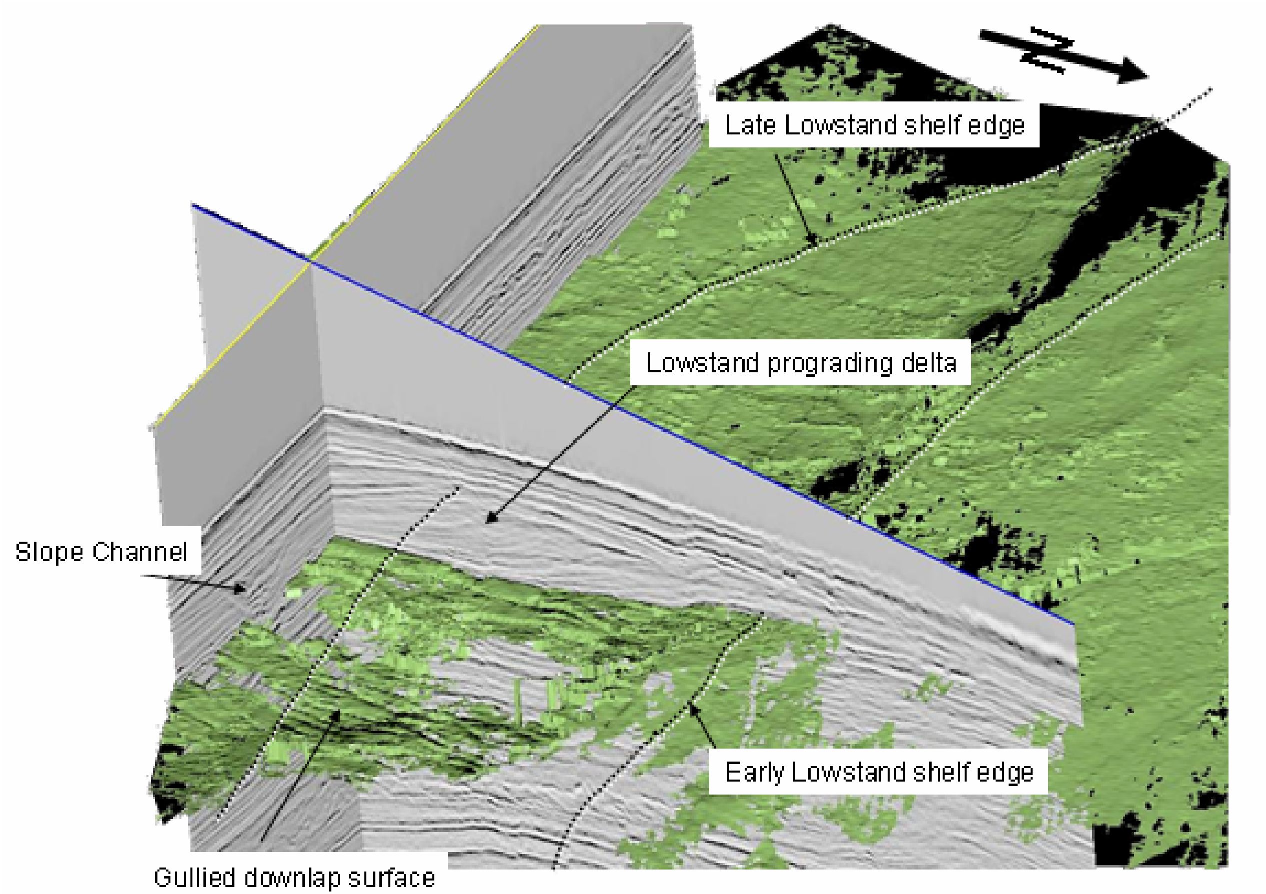

Figure 6. Dip and strike seismic reflection profile across the shelf edge (dip view) and upper slope (strike view). Also shown is the gullied downlap surface at the base of the shelf edge delta (compare with Fig. 5).

Papers
Start
Author
Search
Help

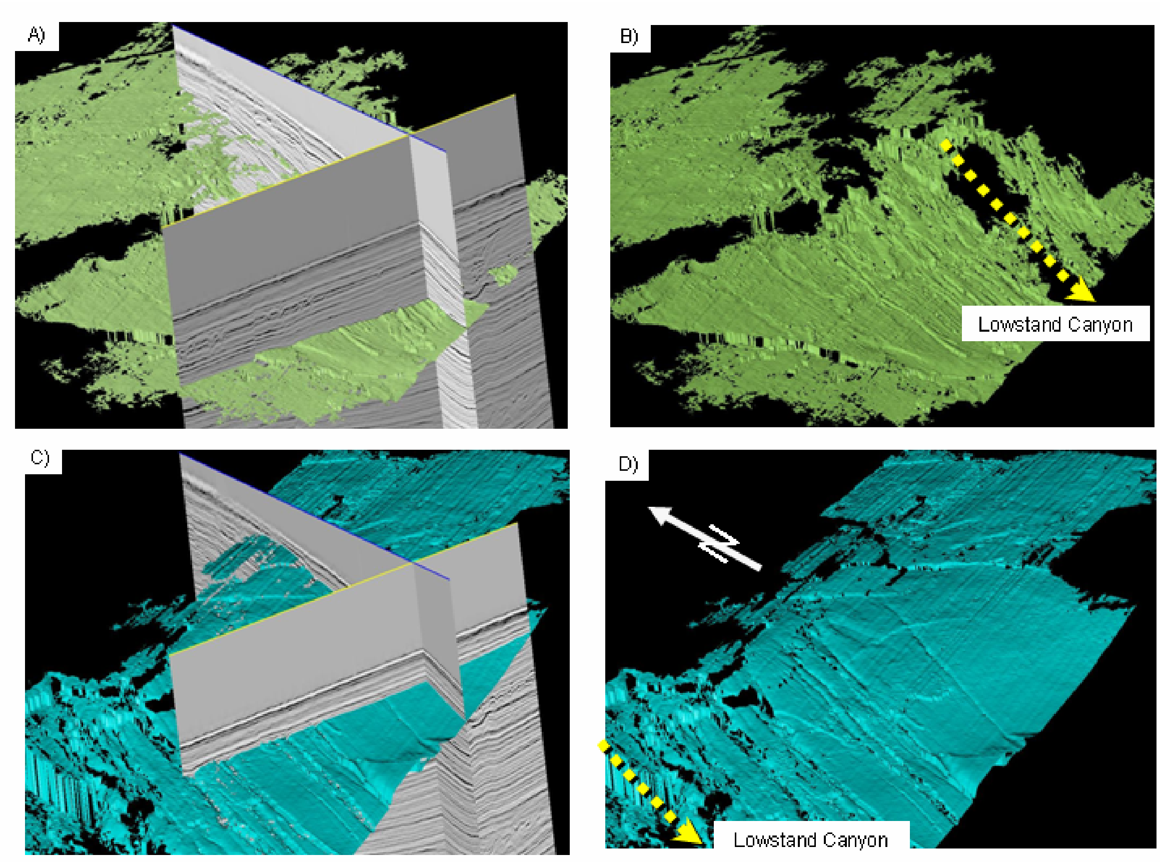

Figure 7. Illuminated seismic horizons at two levels characterized by extensive gullying. Both show an increased density and clustering in close proximity to the location of a single large slope channel. These two slope channels are shown in Figure 1.

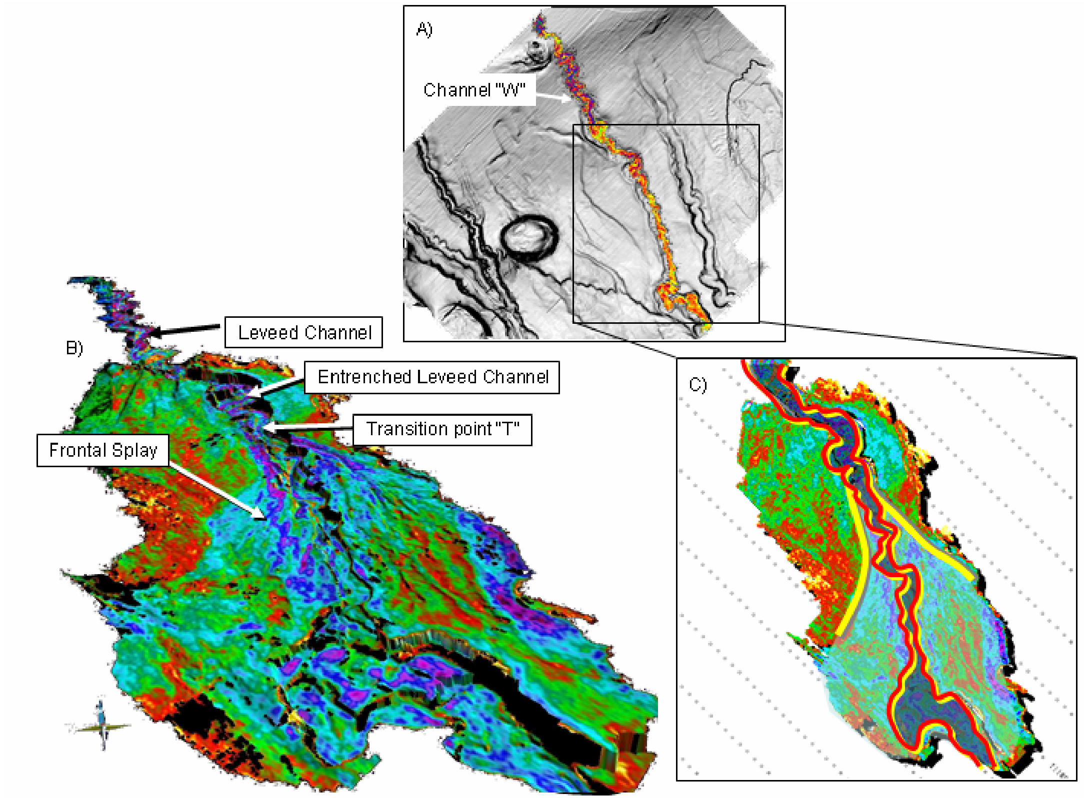

Figure 8. (A) Dip magnitude map of eastern Gulf of Mexico slope with overlay of thalweg reflection amplitude associated with slope channel "W." (See Fig. 1 for location.) (B) Perspective view of reflection amplitude map near the lower boundary of the slope channel system shown in (A). A single leveed channel is observed to be attached to a frontal splay as suggested by the fan-shaped spread of high amplitude reflections down system from the transition point (T). The reflection pattern within the frontal splay suggests the presence of a distributive channel network. The entire system is ultimately traversed by an entrenched channel (C).

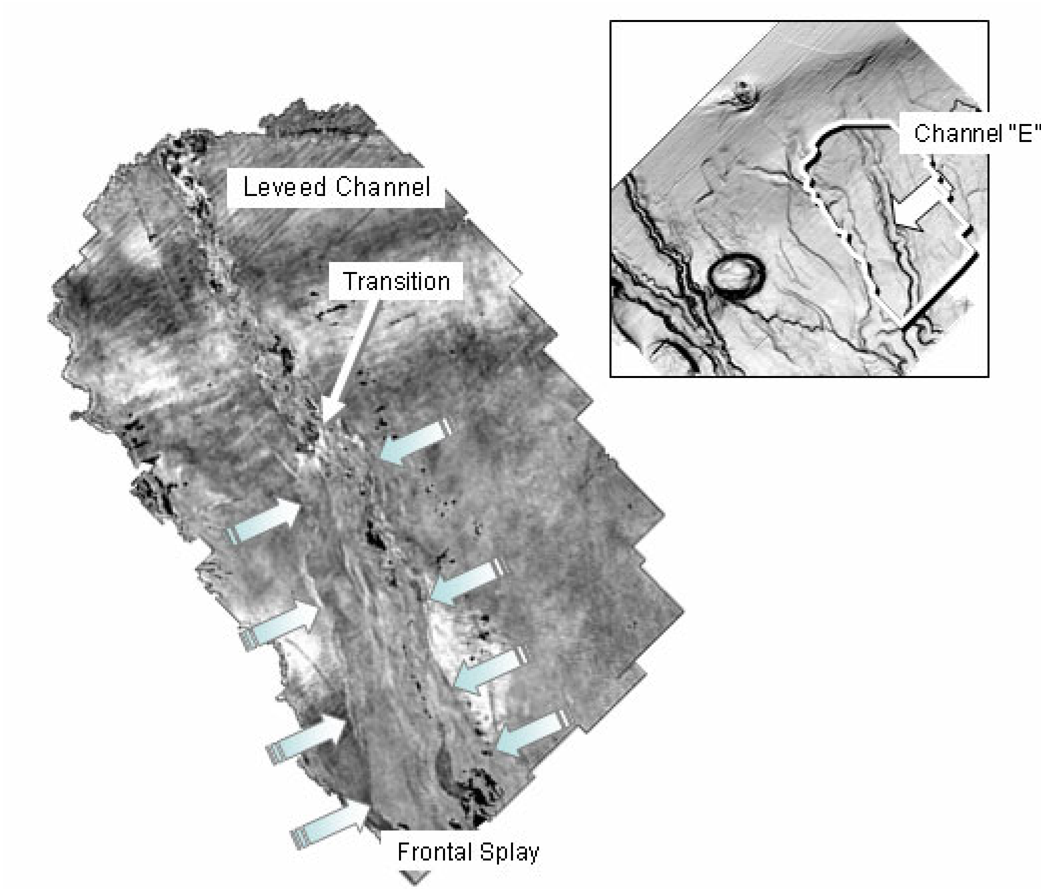

Figure 9. Seismic reflection amplitude map near lower boundary of slope channel “E” (shown in the inset illustration; see Fig. 1 for location). Note the elongate map view of the frontal splay in contrast with the more fan shaped frontal splay shown in Figure 8.

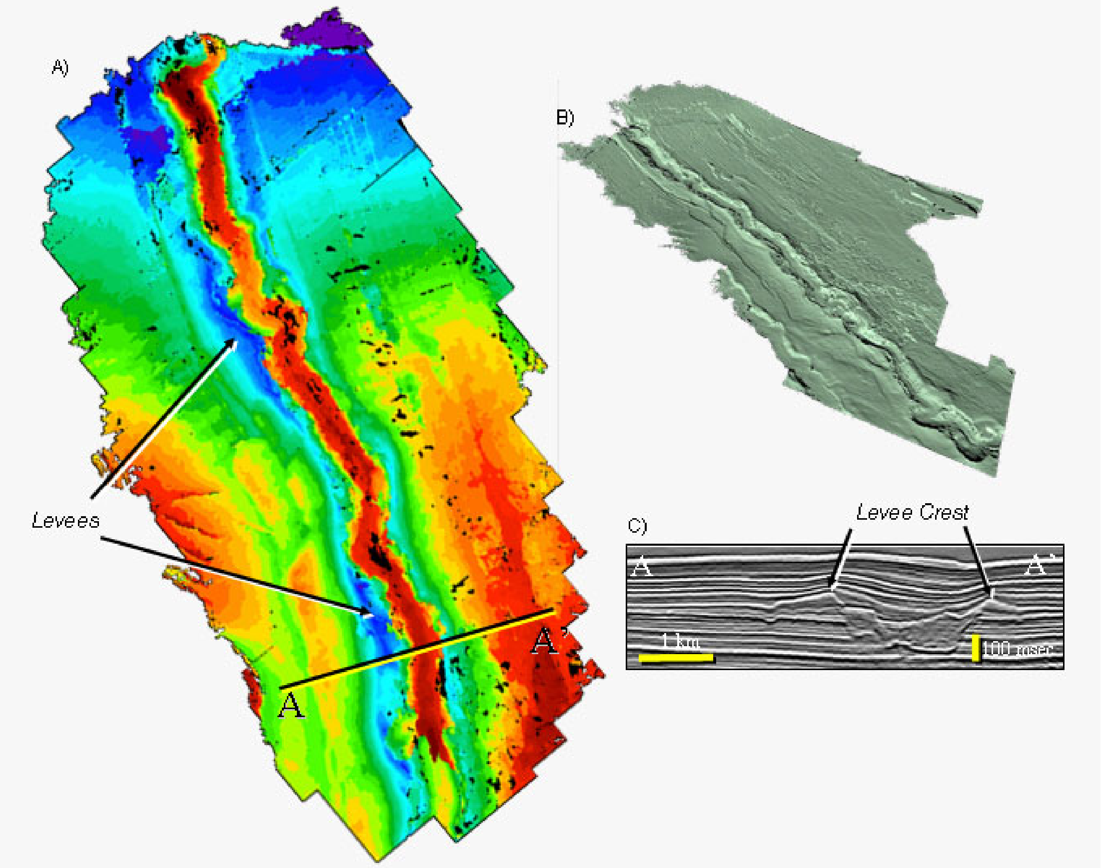

Figure 10. Isochron map of the levees associated with slope channel "E." (See Fig. 1 for location.) Note the lower sinuosity of the precursor channel that likely was associated with the formation of these levees. The maximum thickness of these levees reaches 80 m. (B) illustrates a perspective view of the levee tops and (C) illustrates a transverse seismic reflection profile.

Papers
Start
Author
Search
Help

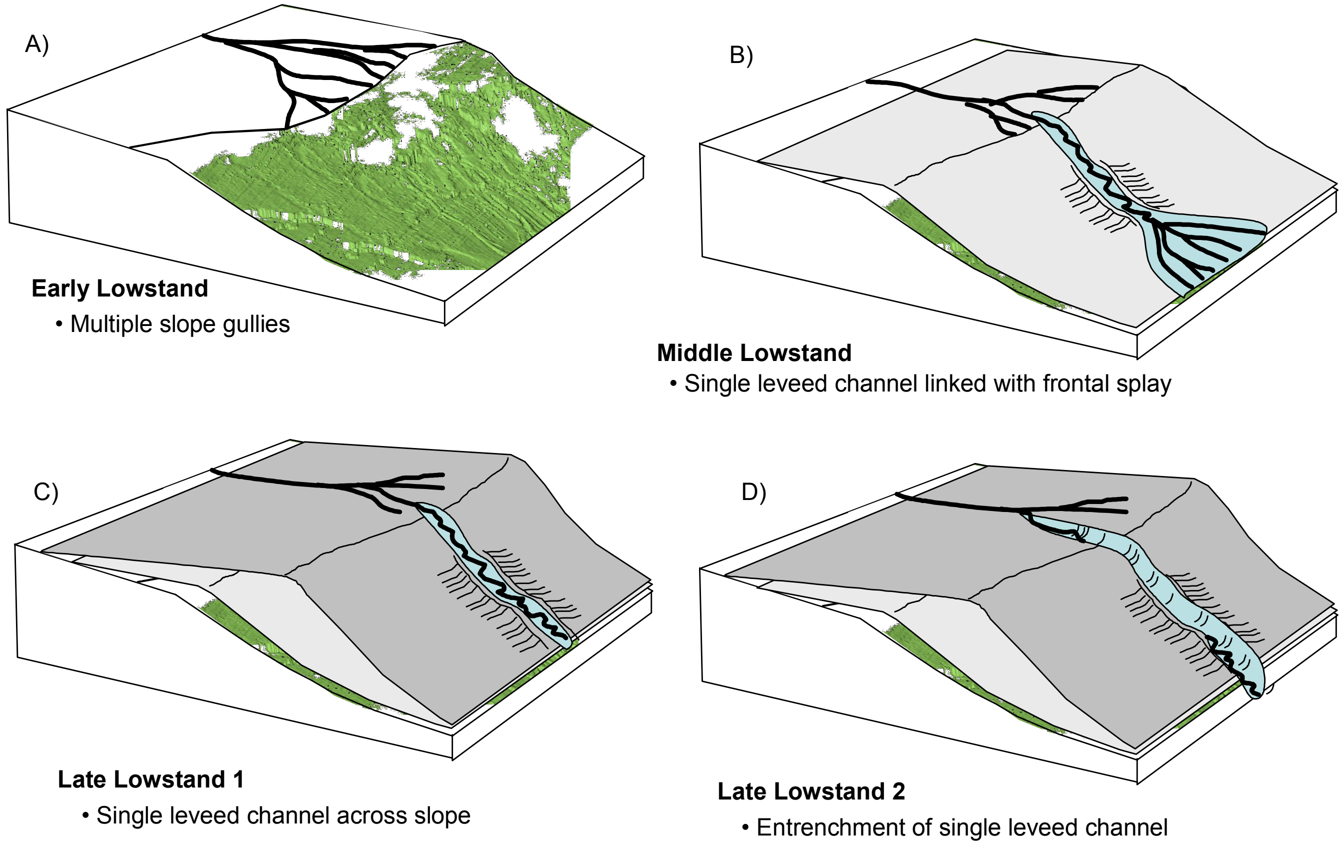

Figure 11. Schematic depiction of shelf edge and associated slope evolution. (A) Early lowstand—characterized by the first arrival of the depocenter at the shelf edge. Multiple distributaries debouche directly onto the upper slope. In response to these multiple point sources of sediment to the upper slope, numerous gullies form. These gullies are most densely spaced close to the center of the shoreline protuberance. The gullied surface ultimately forms the downlap surface for later lowstand shelf edge deltaic deposition. (B) Middle lowstand—at this time a single gully tends to capture the flow from the principal distributary channel, leading to the abandonment of the other slope gullies and the evolution of a single slope gully into a significantly larger slope channel. This slope channel feeds a frontal splay in the mid-slope environment. (C) Late lowstand 1—in response to a likely decrease in sand content within turbidity flows, the channel-to-splay system evolves into a single leveed channel across the slope. (D) Late lowstand 2—continued decrease in sand content within turbidity flows results in entrenchment of the entire leveed channel across the slope.

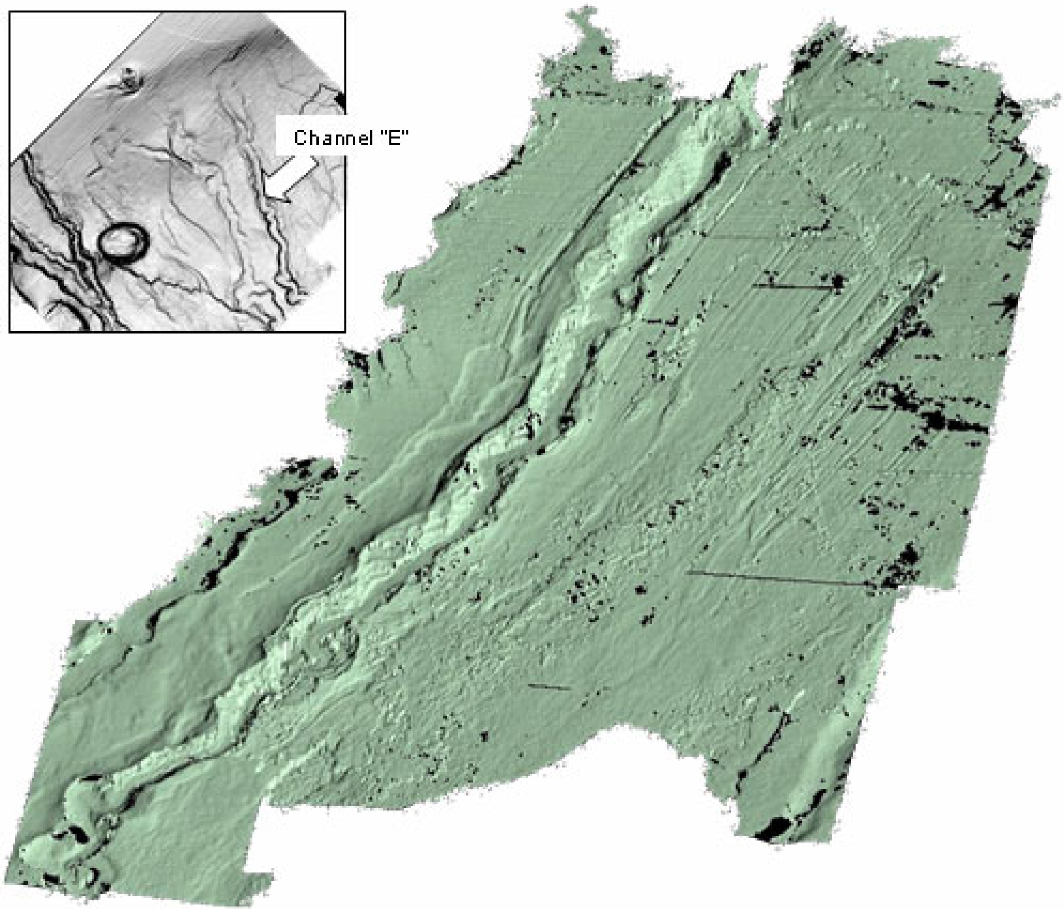

Figure 12. Illuminated perspective view of the upper surface of slope channel "E." (See Fig. 1 for location.)

Papers
Start
Author
Search
Help

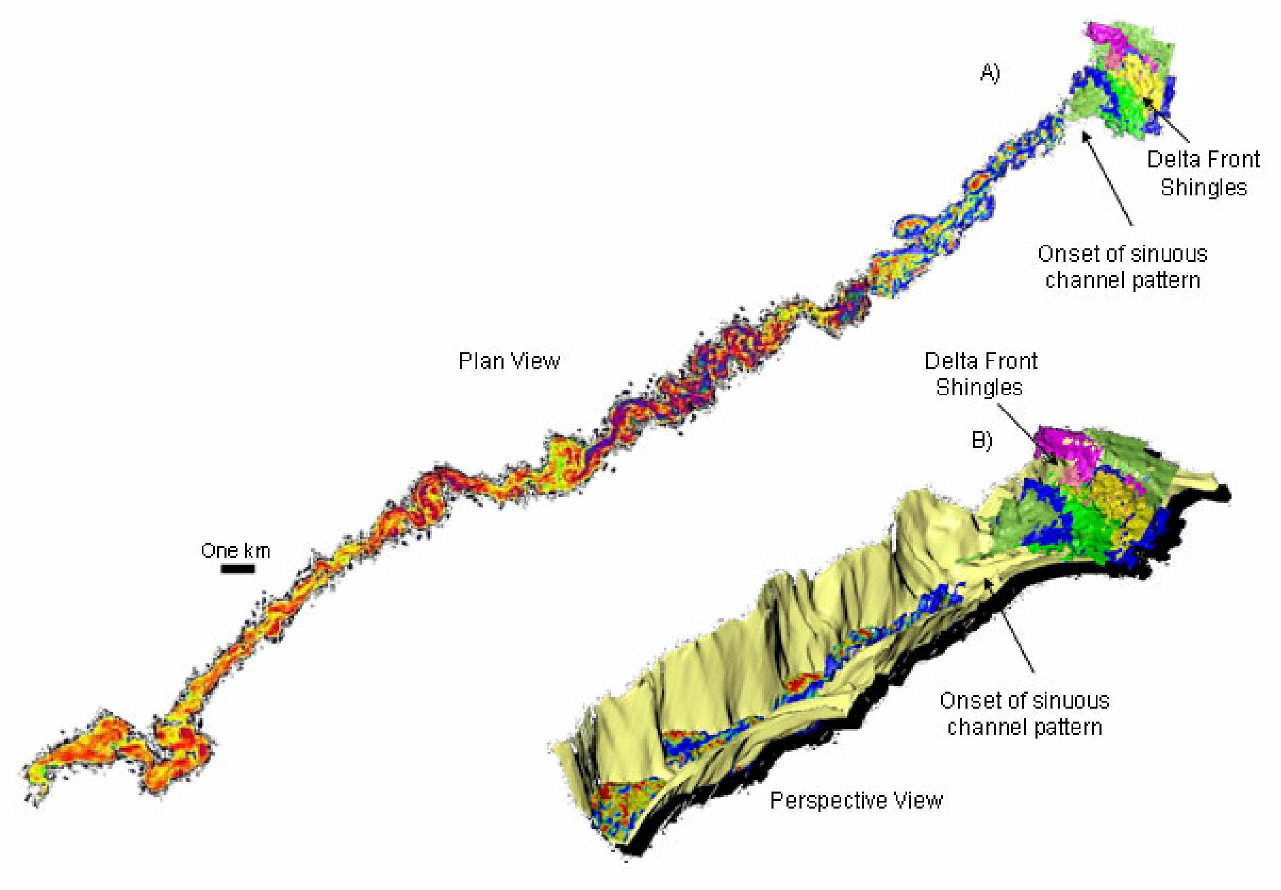

Figure 13. (A) Seismic reflection map of the thalweg of slope channel "W" linked to the head-of-channel confined shelf-edge delta. (See Fig. 1 for location.) Note that moderate sinuosity characterizes this thalweg almost to the toesets of the shelf edge delta. (B) Illustrates a perspective view of the thalweg and shelf edge delta within the slope channel walls.