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Depositional elements associated with a basin floor channel-levee system: case study from the Gulf of Mexico

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Abstract

The seismic geomorphology and seismic stratigraphy of a deep-marine channel-levee system is described. A moderate to high-sinuosity channel trending southeastward across the northeastern Gulf of Mexico basin floor, and associated depositional elements are well imaged using conventional 3D multi-channel seismic reflection data. Depositional elements described include channels, associated levees, a channel belt, avulsion channels, levee crevasses, frontal splays, sediment waves, and mass transport complexes. Distinguishing morphologic and stratigraphic characteristics of each depositional element are discussed. These deposits are presumed to be associated with repeated deep-marine turbidity flows and other mass transport processes.

Keywords: Turbidity; Seismic data; Deep-water deposits

1. Introduction

3D seismic data have revolutionized the study of deep-water deposits and has resulted in quantum advances in the understanding of the spatial and temporal distribution of such deposits and how they form (Beauboeuf & Friedmann, 2000; Beaubouef, Friedmann, & Mohrig, 2000; Booth, Dunvernay, Pfeiffer, & Styzen, 2000; Bourges, Urruty, & Safa, 2001; Mayall & Stewart, 2000; Pirmez, Archie, Heeralal, & Holman, 2000; Posamentier, 2001, 2002; Posamentier & Kolla, 2003; Posamentier, Meizarwin, Wisman, & Plawman, 2000). In particular, shallow-buried deposits can be imaged with remarkable clarity, with vertical resolution down to 2–4 m in some instances. Plan view images yield insights as to external form (i.e. geomorphology) as well as to spatial configuration. Complementary cross-section images yield insights as to temporal relationships as well as stratigraphic architecture.

With recent advances in 3D seismic acquisition and processing, the cost of these data has decreased substantially and as a result the availability has increased. Moreover, with recent vast improvements in computer software and hardware, such data can now be manipulated far more quickly and efficiently, opening up such data to greatly increased scrutiny. Data quality also has improved dramatically over the past decade.

A variety of depositional elements is shown in a seascape from the DeSoto Canyon area of the northeastern Gulf of Mexico (Fig. 1). They include a leveed channel, an avulsion channel, a debris flow leveed channel, and several debris flow lobes, including those characterized by steep margins and those characterized by gentle margins. This study will address the seismic stratigraphy and seismic geomorphology of the leveed channel and associated depositional elements. Whereas seismic stratigraphy can be defined as the study of stratigraphic geometries observed in profile view, seismic geomorphology can be defined as the study of landforms, and, by extension, depositional systems, using 3D-seismic derived plan view images (Posamentier, 2000). When used in conjunction seismic stratigraphy and seismic geomorphology can provide significant improvement to the understanding of basin fill evolution and prediction of lithofacies distribution.

The subject of this study is the leveed channel system, henceforth referred to as the *Joshua* channel system, and associated depositional elements shown in Fig. 1. These deposits are situated on the basin plain southeast of Mississippi canyon and just west of the Florida escarpment. The sediments that comprise these deposits were transported through the Mississippi River and canyon

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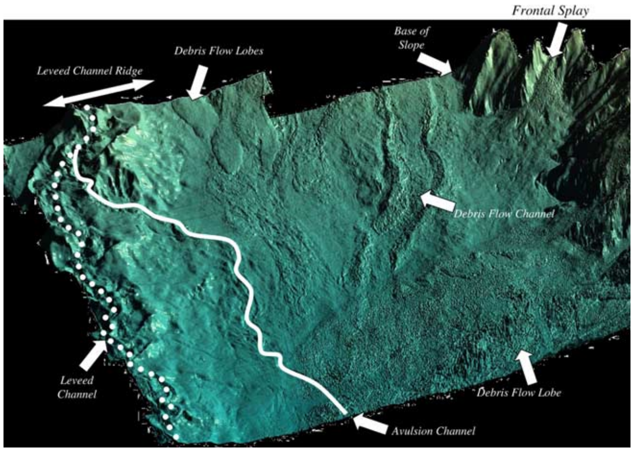

Fig. 1. Seascape of the DeSoto Canyon area showing the base of the continental slope and the basin floor. The slope of the slope is approximately 1.7° whereas the slope of the basin floor is approximately 0.3°. Depositional elements shown include a leveed channel ridge (i.e. the Joshua channel-levee system), several mass transport complexes, a debris flow leveed channel, an avulsion channel, and a frontal splay.

system, probably during the mid to late Pleistocene and currently lie at water depths in excess of 2500 m. These deposits are buried by a nearly uniform blanket of sediments approximately 30 m thick. The blanket consists of acoustically transparent seismic facies that is inferred to constitute a mud drape across the region.

The 3D seismic data set used in this study is a Western Geophysical speculative survey with 25 m bin spacing. The dominant frequency of these data across the shallow-buried interval of interest is approximately 125 Hz with a maximum vertical resolution of 2–4 m. For the purpose of this study a migrated, stacked 3D volume was used.

The approach used in this study follows the concept of depositional elements outlined by Mutti and Normark (1991). The following section summarizes observations and interpretations of several depositional elements genetically associated with the leveed channel system. Fig. 2 illustrates the regional geomorphology, with the leveed channel system shown on the southern half of the image.

2. Depositional elements

Several depositional elements have been observed in association with the Joshua channel system within the study area. The Joshua channel comprises a channel within a larger channel belt. Locally, the channel is characterized by high sinuosity and cutoff meander loops, or oxbows. The channel itself is bounded by levees similar to the inner levees described by Deptuck et al. (this volume) and the channel belt also is bounded by master levees similar to outer levees described by Deptuck et al. (this volume). In the late stages of channel activity, numerous avulsion events occurred. These avulsion events are associated with levee crevasses and avulsion channels, which in some instances feed frontal splays. In places, flow stripping and flow

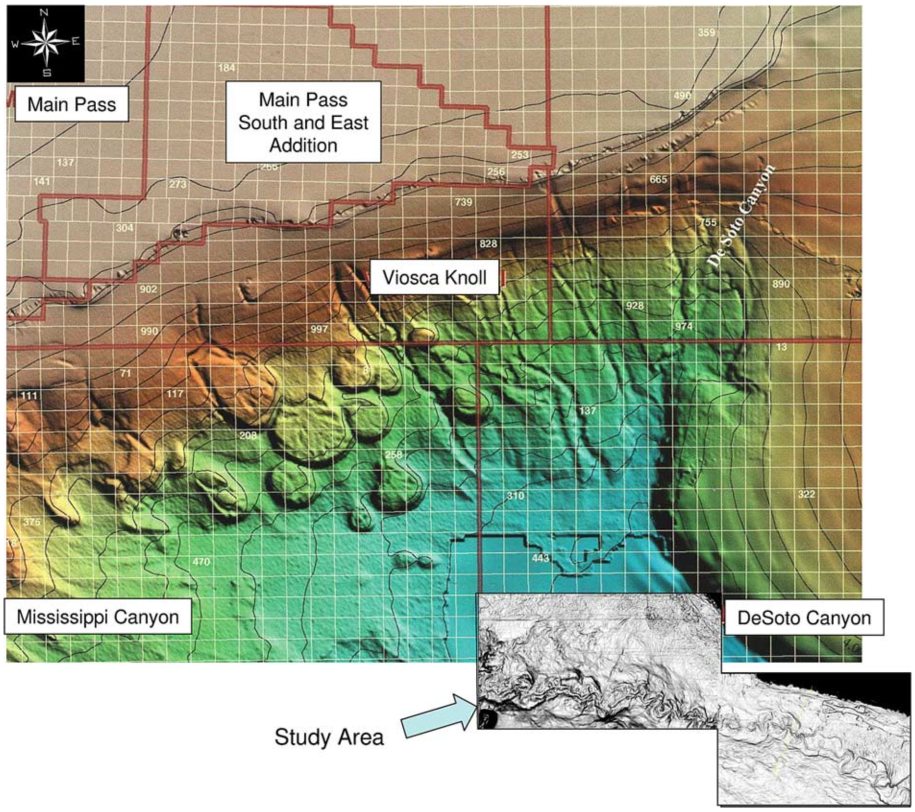

Fig. 2. Location of the Joshua channel in the DeSoto Canyon area of the northeastern Gulf of Mexico (base map courtesy of TGS NOPEC).

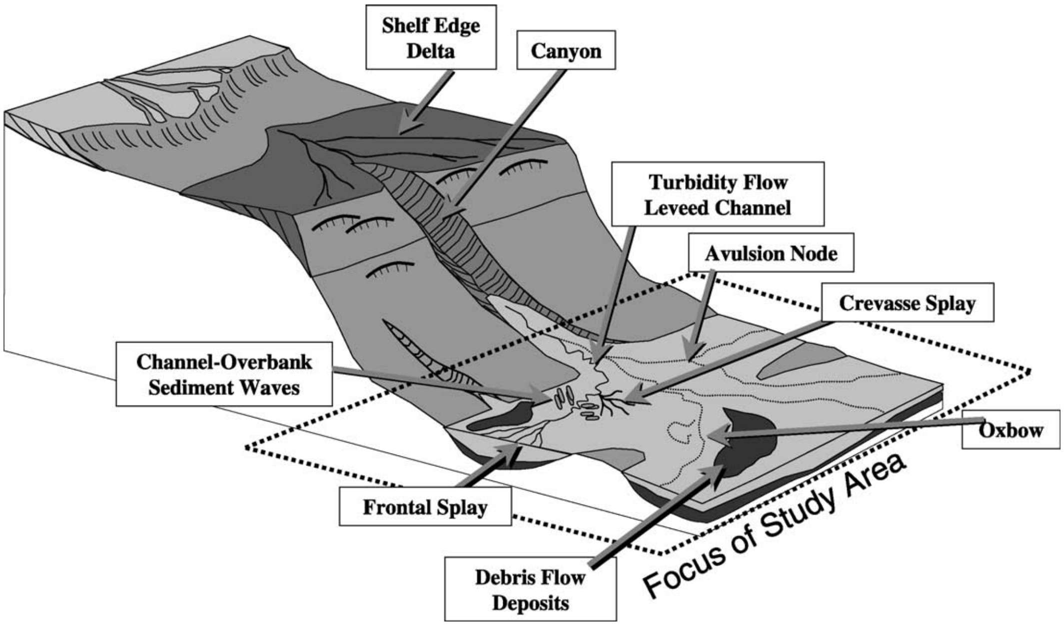

Fig. 3. Schematic illustration of principal depositional elements from shelf edge staging area to basin plain. Focus of study area is shown.

overspill has resulted in formation of sediment waves on the levees. The elements are well expressed on 3D seismic data, and on the basis of those data, geomorphologic and stratigraphic aspects such as external form and stratigraphic architecture are described. Fig. 3 schematically illustrates the physiographic setting of these various elements.

2.1. Channel

Fig. 4 illustrates the high-sinuosity Joshua leveed channel system on the basin floor of the northern Gulf of Mexico. The channel is 600–700 m wide and characterized by average sinuosity of 2.21, though for some stretches sinuosity is as high as 4.88. The channel is characterized seismically by high-amplitude continuous to discontinuous reflections (Fig. 5) suggestive of a sand prone fill. Fig. 6 illustrates several seismic attributes of the upper bounding surface of this channel-levee system, including dip magnitude, curvature and roughness. These surface attributes are based on analysis of 75 m^2 areas. Dip magnitude is a measure of the dip angle of each three by three area; roughness is a measure of the variability of z-values within this area; curvature is a measure of the deviation from a plane of a best fit curved surface across the 75 m square area. Channel fill, a channel belt, levees, and sediment waves can be observed to varying degrees on these images.

The upper bounding surface of the Joshua channel lies above the adjacent basin floor as illustrated in Figs. 6 and 7. The relief of this channel fill itself is 6–7 m (Fig. 6d). Differential compaction probably accounts for the super-elevated or inverted aspect of the channel fill, suggesting that this fill was substantially less compactable and therefore more sand-prone than the adjacent flood plain. It is striking that differential compaction has had such a striking effect after only minimal burial and presumably a relatively short period of time.

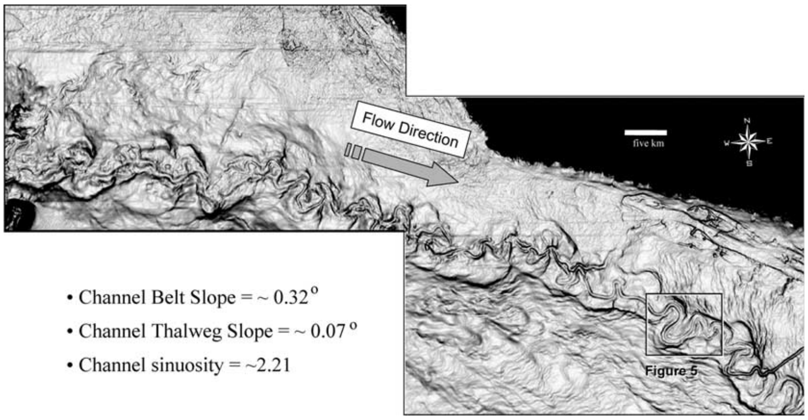

Fig. 4. Dip magnitude map of the upper bounding surface of the Joshua channel-levee system (see Fig. 5 for seismic reflection profile with this surface identified).

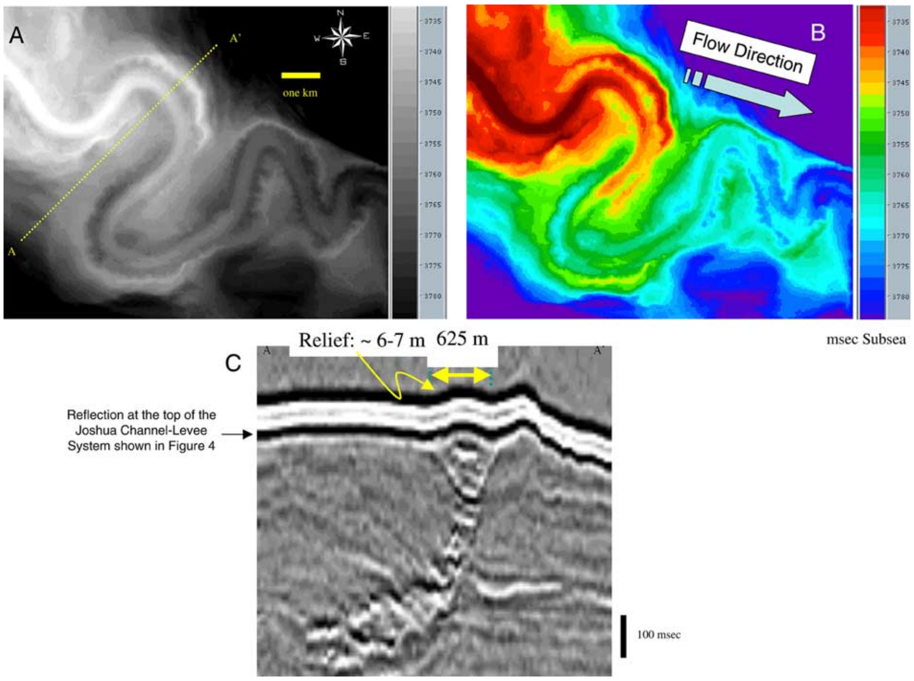

Fig. 5. Black and white (A) and color (B) time structure maps of the upper bounding surface of the Joshua channel-levee system (location shown in Fig. 4). (C) Transverse seismic reflection profile across the leveed channel illustrating 6–7 m of relief associated with the channel fill and similar relief associated with the levee. The high amplitude reflections that characterize the channel fill suggest a sand prone amalgamated aggradational fill architecture.

The Joshua channel is characterized by both swing (i.e. meander loop expansion) and sweep (i.e. down system meander loop migration) as it evolved through time. Fig. 8 illustrates an axial section through the channel belt. Note that the Joshua channel is crossed 22 times by this section and that all but six of these crossings indicate down-system meander loop migration. This down-system meander loop migration is counter to the suggestion by Peakall, McCaffrey, and Kneller (2000) that most channels are characterized by meander loop expansion but not by down-system meander loop migration. Detailed examination of meander loops illustrates both swing and sweep (Fig. 9). Horizon slices at two different levels through the channel system illustrate

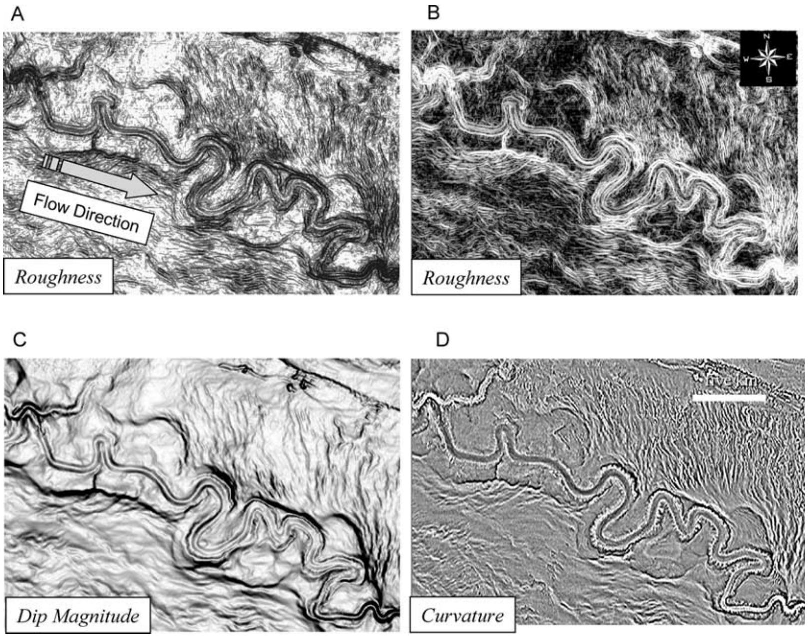

Fig. 6. Detail of the Joshua channel. Roughness (A and B), dip magnitude (C), and curvature (D), maps are based on analysis of 75 m^2 areas. The roughness maps are reverse polarity images of each other. Sediment waves, the convex-up aspect of the channel, and scoop-shaped slump scars can be observed to varying degree on these images.

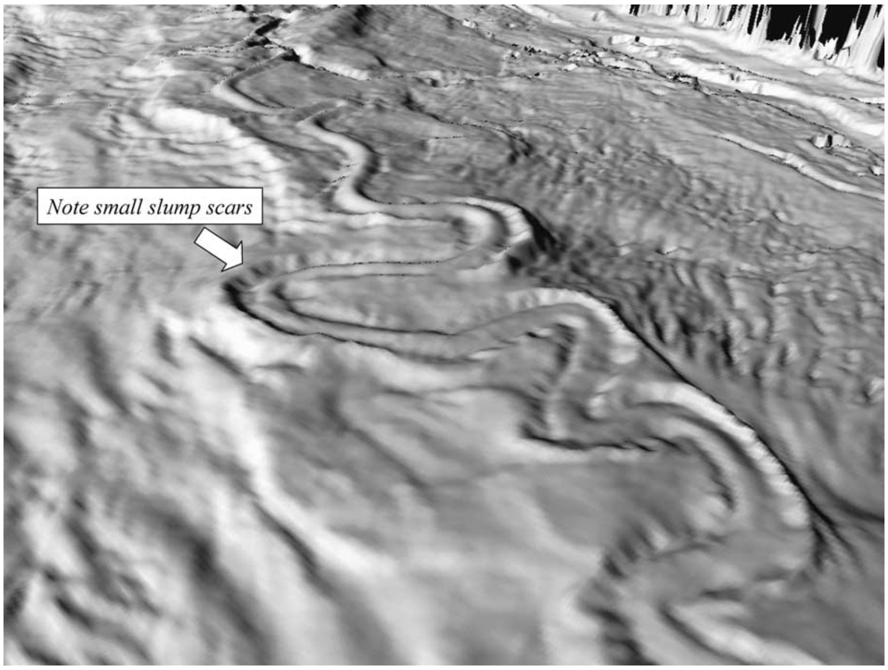

Fig. 7. Three-dimensional perspective view of the Joshua channel belt. Note the ridge-like form of the Joshua channel. Note, also, the levees associated with the channel. Small scoop-shaped slump scars characterize the inner margin of the levees. The levees are consistently higher and better developed along the outer channel bends. For scale, note that the convex up Joshua channel fill is approximately 625 m wide.

the significant spatial shift of the channel through time (Fig. 10).

2.2. Oxbows

Tight meander loops in some instances are characterized by neck cutoffs. These loop cutoffs, very similar to oxbows in fluvial settings, are illustrated in plan view (Fig. 11) and in section view (Fig. 8). The presence of loop cutoffs is evidence of the erosive power of turbidity flows and the dynamic nature of these channel systems. Such features were relatively uncommon in the area studied, with fewer than five meander loop cutoffs observed.

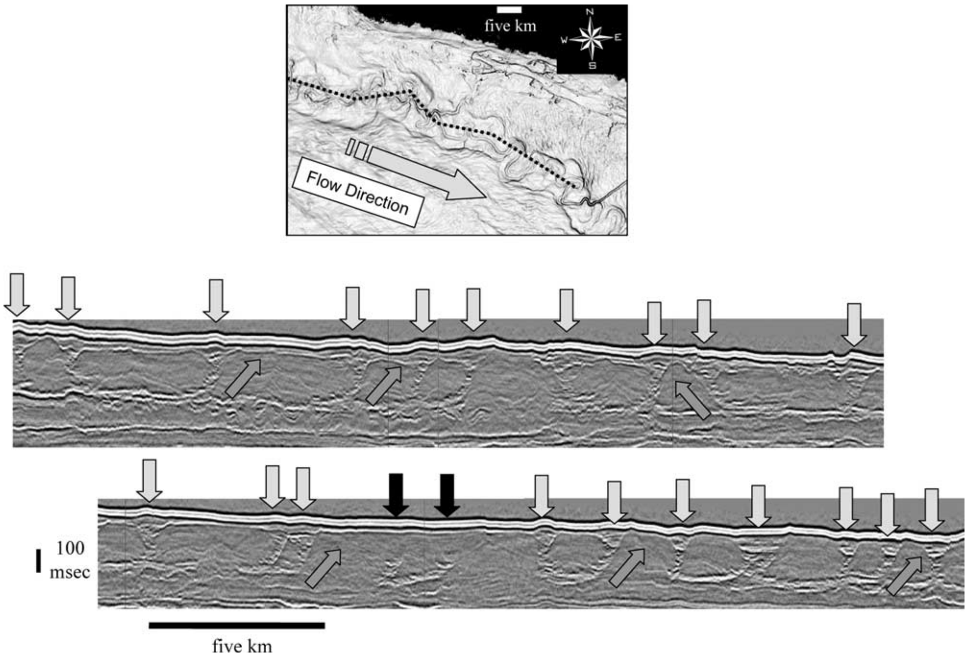

Fig. 8. Axial seismic reflection profile through the channel belt. Arrows indicate channel crossings. The black arrows indicate an abandoned meander loop. Sixteen of the channel crossings are characterized by down-system meander loop migration. One abandoned channel segment is shown.

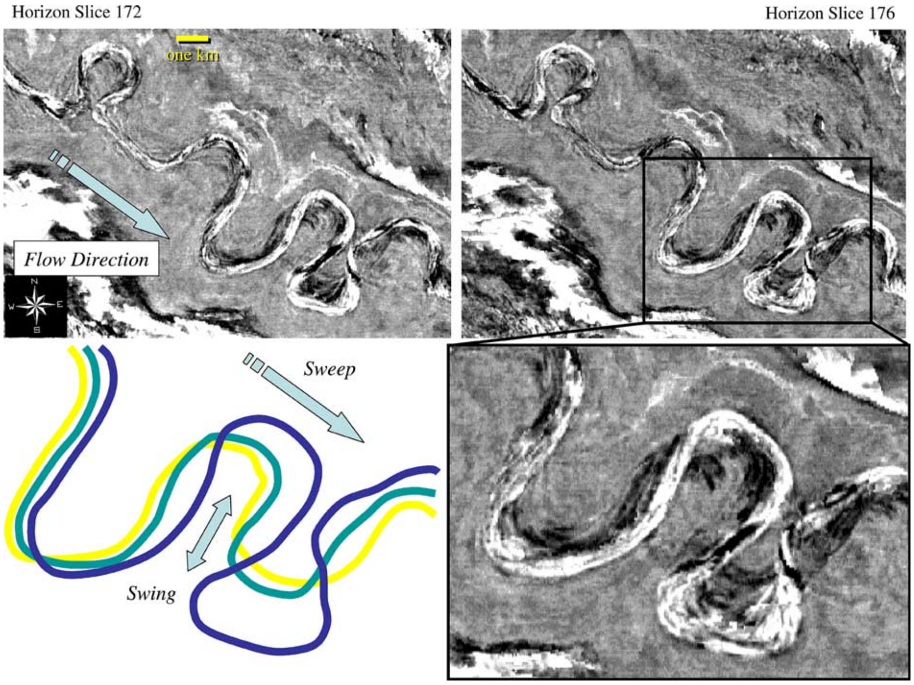

Fig. 9. Detail of the Joshua channel illustrating meander loop expansion (swing) and meander loop down-system migration (sweep). The line drawing of the channel locations illustrates the order of channel formation with yellow being the oldest position and purple being the youngest.

2.3. Levees

The Joshua channel is bounded by levees of variable height. The levees are significantly higher along the outer bends than along the inner bends ranging from up to 8 m along outer meander bends to less than 2 m along inner meander bends (Fig. 7). This suggests that the flow overspill from the channel to the overbank is significantly more active along outer banks, consistent with observations by Piper and Normark (1983). The maximum levee height is approximately 7 m (Fig. 5). Small scale scoop-shaped indentations along the levees of the channel are illustrated in Fig. 6d. Similar indentations can be observed in the three-dimensional display of this same surface (Fig. 7). These features are interpreted as small slump scars associated with mass wasting of levee walls.

This leveed channel lies within a larger channel fairway also bounded by levees (Fig. 12). These outer levees are referred to as master-bounding levees, which formed as

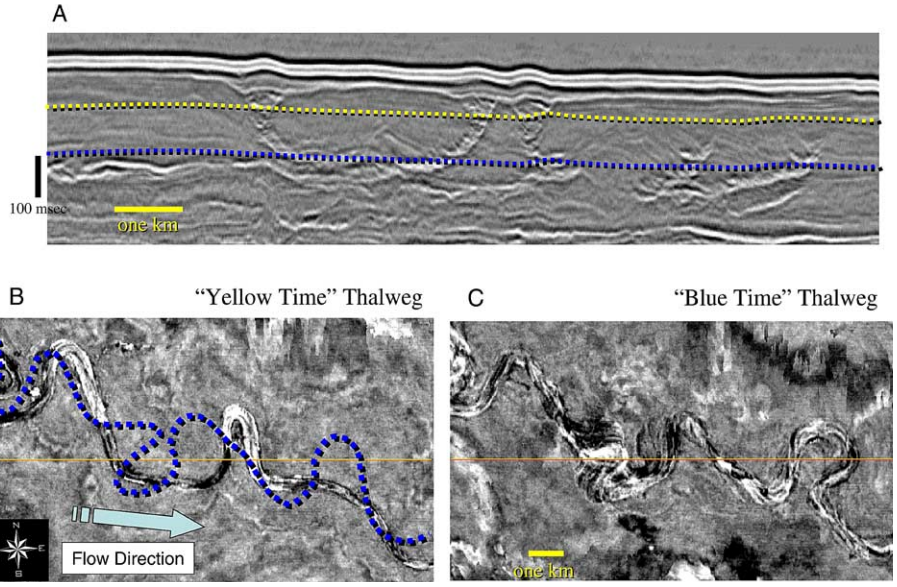

Fig. 10. (A) axial transect through the channel belt. A horizon slice at the upper dashed line (B) and the lower dashed line (C) illustrates the extensive shift in position of the channel axis through time. Part C also illustrates the tendency towards down-system meander loop migration (i.e. sweep).

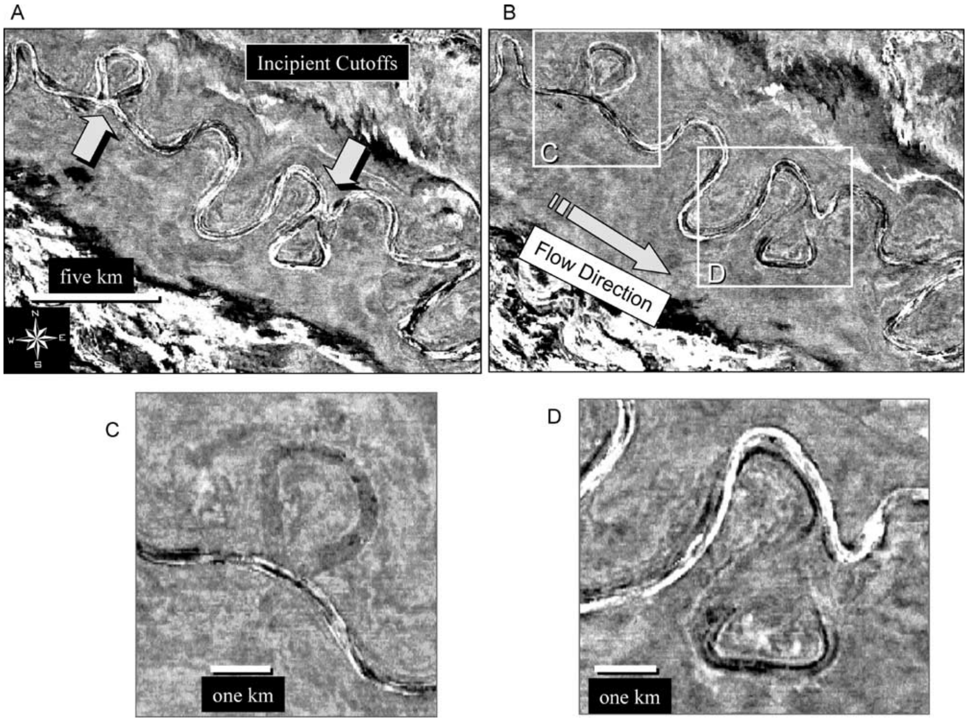

Fig. 11. Detail of the Joshua channel illustrating meander loop cutoffs and oxbows.

a result of overspill from the channel belt. These levees are markedly different from the levees that bound the Joshua channel itself insofar as they are more consistent in height, they do not track any single channel but rather the entire channel belt, and consequently they are far less sinuous. The geomorphic elements that lie between the master-bounding levees include the Joshua channel and its associated levees, as well as what could be described as a floodplain, using a term borrowed from fluvial settings. The master-bounding levees are characterized by low-amplitude continuous to discontinuous reflections.

As illustrated in Fig. 12, the master levee crests are at a level below the channel and associated flood plain, suggesting that the levee sediments are seemingly more compactable and therefore finer grained than the channel and channel belt. Fig. 12C illustrates a qualitative restoration of the channel-levee system. Because of differential compaction, the channel belt currently lies above the adjacent levee deposits (Fig. 13). The channel belt has formed a ‘channel-belt ridge’ that lies over 65 m above the surrounding basin plain (Fig. 14). The positive relief is in part attributable to aggradation above the basin plain and in part to differential compaction, which has enhanced the relief from basin floor to channel axis.

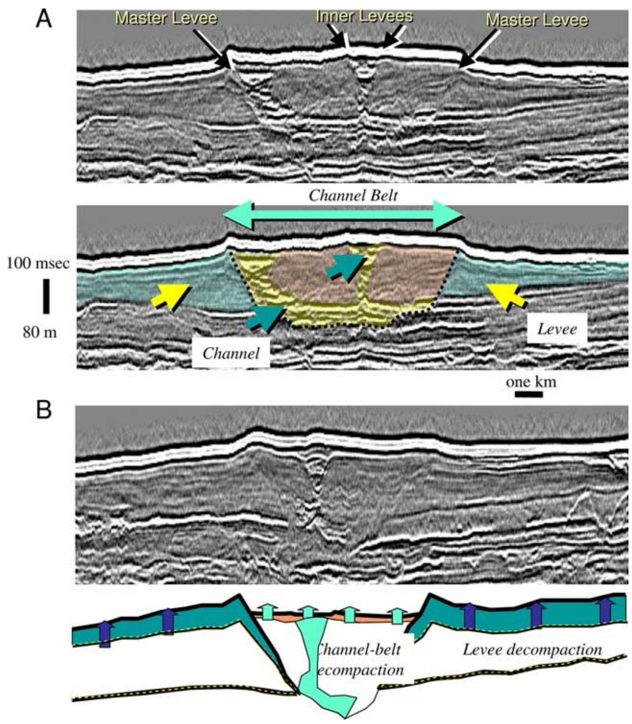

Fig. 12. (A) Transverse seismic reflection profile across the Joshua channel belt and associated levees. The master bounding levees as well as the levees bounding the Joshua channel are shown. The channel is inferred to be most sand prone, followed by the channel belt, which is less sand prone, and the overbank, which is least sand prone. (B) illustrates the decompacted configuration of the leveed channel system.

2.4. Sediment waves

Linear features described as sediment waves characterize the overbank areas associated with the Joshua channel (Fig. 15) and are related to overspill and flow stripping from

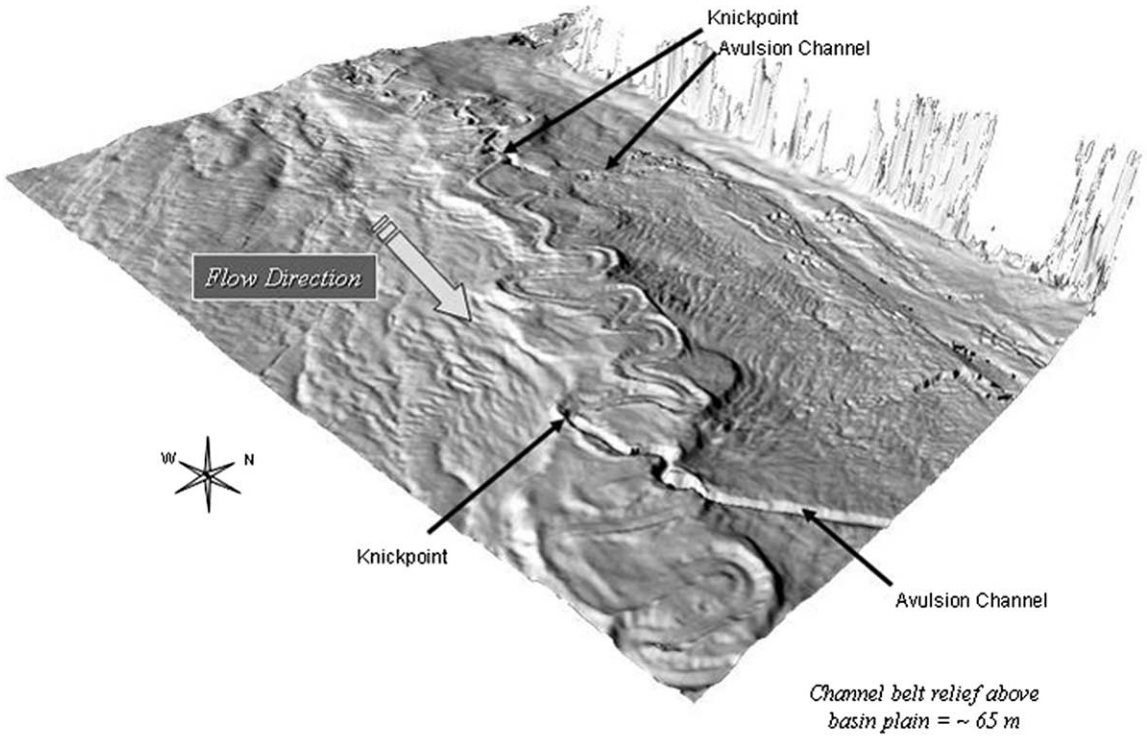

Fig. 13. Three-dimensional perspective view of the Joshua channel belt. The channel belt can be seen to lie above the adjacent levee. Two knickpoints are indicated. Note that the channels are concave-up troughs down-system from each knickpoint and the knickpoints mark the transition from concave-up to convex-up channel character. For scale, note that the convex up Joshua channel fill is approximately 625 m wide.

the channel. These features characterize vast expanses of the overbank area and are similar to those described by Posamentier et al. (2000) and Posamentier and Kolla (2003) in deep-water settings offshore west Africa and offshore Kalimantan, Indonesia. The waves are moderately straight crested and are oriented with their long axes normal to the inferred direction of overbank flow. The spacing is variable ranging from 50–250 m. These features are not associated with crevasses and therefore must have been sourced from and stripped off the upper parts of turbidity flows. Consequently, these deposits would tend to be less sand-prone than deposits associated with avulsion events, insofar as such deposits are sourced from the lower as well as the upper parts of flows. These deposits were formed while the channel was active and ceased to be active once the channel was abandoned (Fig.16) judging from the infilling nature of the overlying unit which has tended to heal over the irregular sediment-wave dominated overbank areas.

2.5. Levee crevasses and avulsion channels

The levees of the Joshua channel are characterized by a number of crevasses feeding avulsion channels associated with flow directed across the levee crest and the adjacent overbank (Figs. 13 and 17). The avulsion channel observed toward the southeast end of the channel illustrated in Fig. 13 is expressed as a negative feature, or an unfilled channel. The channel expression changes abruptly from unfilled and characterized by negative relief, to filled and characterized by positive relief. The transition from filled channel to unfilled channel is marked by a knickpoint (Fig. 13). The presence of a preserved knickpoint suggests that channel flow abruptly ceased, resulting in cessation of up-system knickpoint migration. The abrupt drop in flow probably was caused by flow diversion associated with development of another crevasse and associated avulsion channel at a location farther up-system.

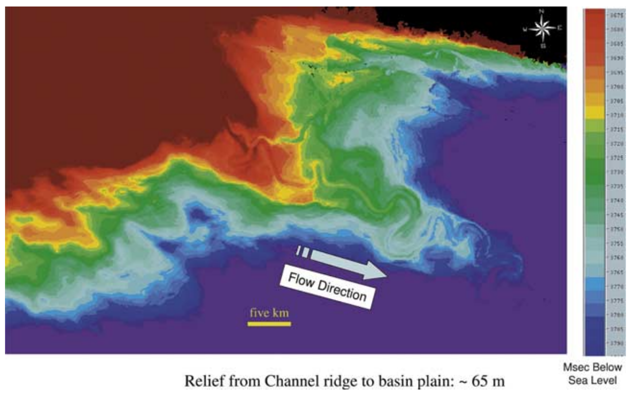

Fig. 14. Time structure map of the Joshua channel-levee system. The channel belt lies approximately 65 m above the surrounding basin plain.

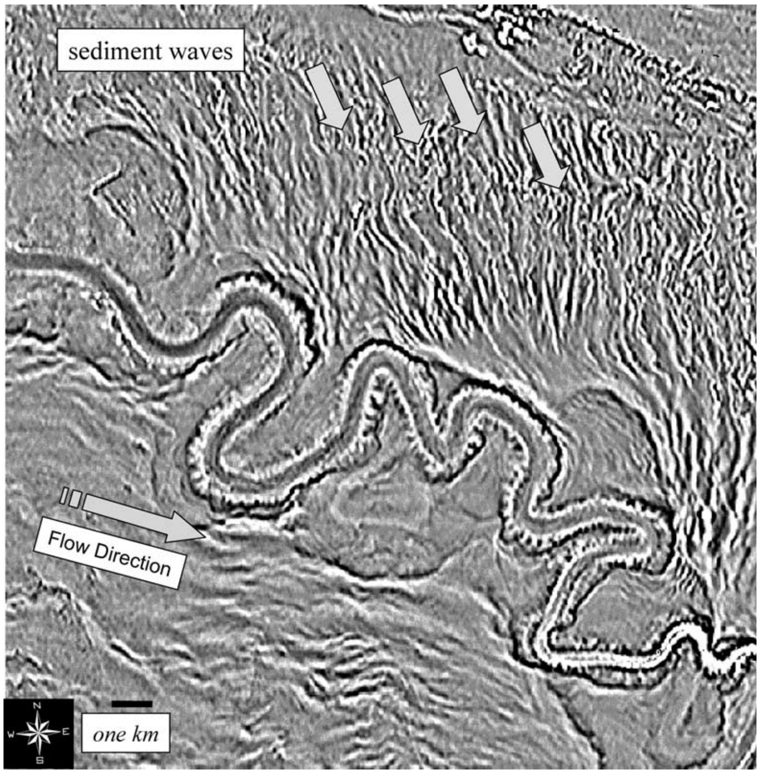

Fig. 15. Curvature map of upper bounding surface of Joshua channel-levee system. Depositional elements shown include overbank sediment waves, channel, channel belt, and slump scars on the inner flank of the levee. Arrows indicate sediment waves.

Each of the seven avulsion channels observed in the study area is directed through and across the left bank of the Joshua channel system. The marked absence of avulsions directed across the right bank likely is because the Joshua channel tracks along the northeastern margin of the greater Mississippi fan lobe. As the Mississippi fan lobe was buried it experienced compaction. This compaction probably resulted in a progressively increasing slope at

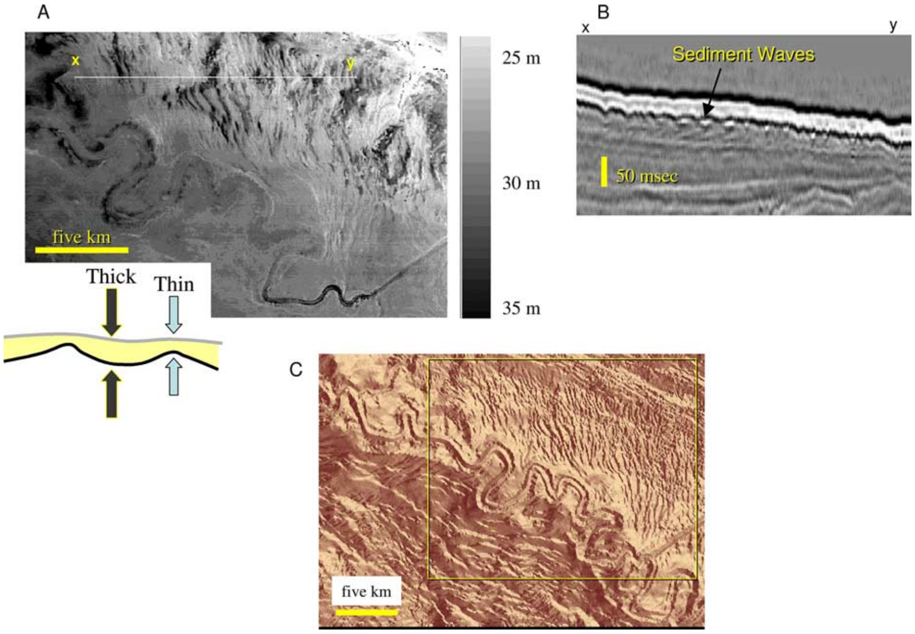

Fig. 16. (A) Time-thickness map between sea floor and the upper bounding surface of the Joshua channel-levee system. Varying thickness of this section suggests that these deposits represent progressive passive infill of low areas rather than continued active sediment wave aggradation or drape. (B) Seismic reflection profile oriented normal to long axes of sediment wave field illustrating the fill geometry of this overlying section. (C) Dip azimuth map of top of Joshua channel-levee system.

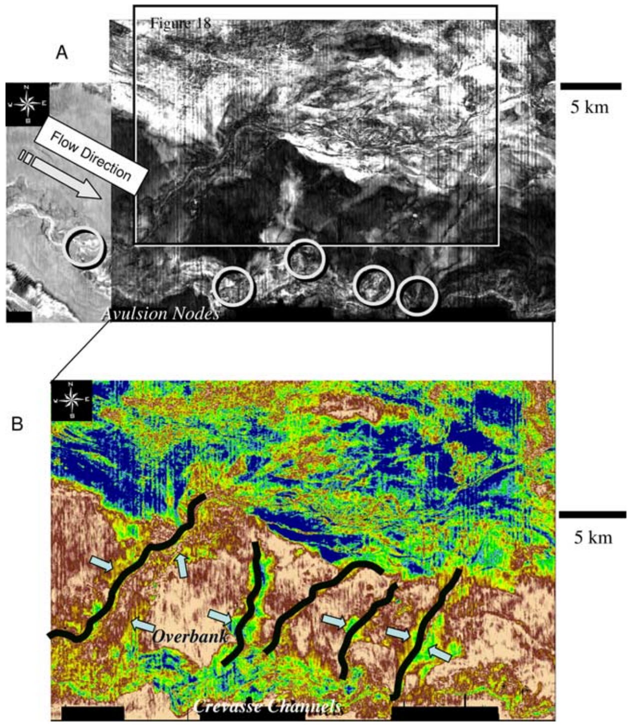

Fig. 17. Horizon slice illustrating five avulsion nodes with associated avulsion channels. The amplitude brightening on either side of the avulsion channels suggests the presence of sand there. The western-most avulsion channel feeds a frontal splay. This feature is characterized by numerous small channels.

the lobe margin producing enough tilt of the Joshua channel system to cause avulsions to occur on the side away from the underlying Mississippi fan lobe.

Each of the avulsion channels appears to be associated with seismic reflection amplitude anomalies along both levees up to approximately 2 km away from the channel axes (Fig. 17). These anomalies are interpreted to represent the distribution of relatively coarser clastics in the overbank environment.

2.6. Frontal splays

The most proximal avulsion channel observed (Fig. 17) is the best developed and seems to have been the longest lived and seemingly has evolved into a leveed channel in its own right. It is wider and has aggraded more substantially than the other avulsion channels (Fig. 18). Moreover, it is the only avulsion channel that feeds a significant frontal splay. The term frontal splay as discussed by Posamentier and Kolla (2003) alludes to a feature variously referred to as a channel termination lobe, lobe, lobeform, distributary channel complex, and HARP. Each of these terms highlights a different aspect of the same feature. The terms lobe and lobeform describe a rounded projection with expression in plan view and an implied convex upward profile. A channel termination lobe describes a lobe that has formed at the mouth of a channel. A distributary channel complex describes a complex of shallow channels with minimal levee construction, arranged in a distributive pattern. A HARP, an acronym for High Amplitude Reflection Package alludes to a package of high amplitude reflections that commonly map out in lobe form. The terms lobe, lobeform, channel termination lobe, distributary channel complex, and HARP, are all descriptive. This is in contrast to the term frontal splay, which implies both a map distribution (similar to that of a lobe) as well as a process (that of spreading or fanning out of small channels), and in this way has genetic as well as descriptive significance. The term frontal splay therefore inherently integrates the concept of lobate depositional element with the concept of a distributary channel pattern coupled with a mode of formation.

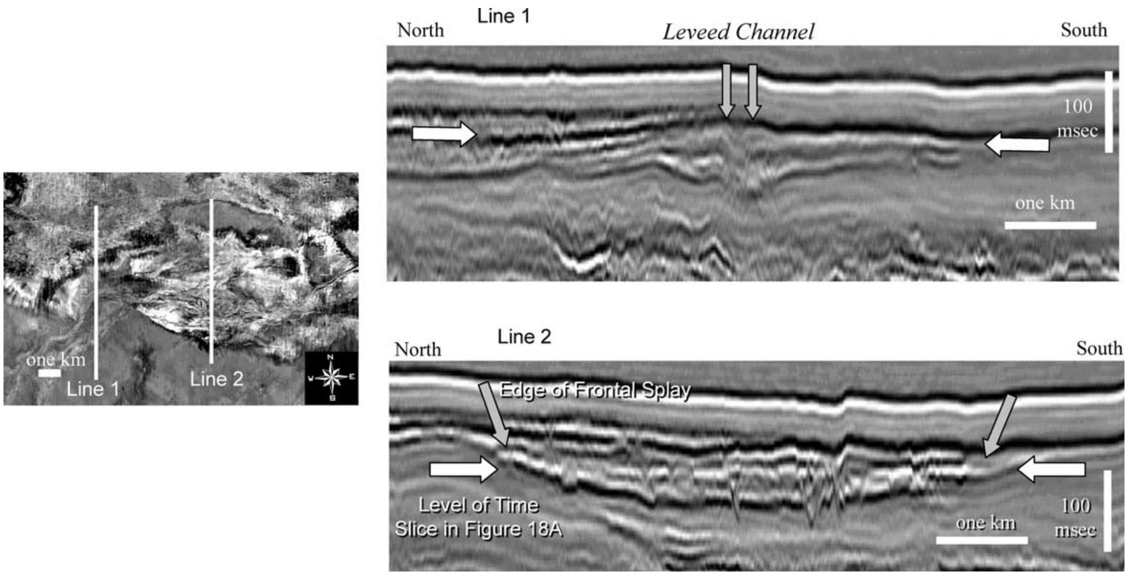

Fig. 18. Seismic reflection profiles oriented transverse to avulsion channel (A) and frontal splay (B). Note the numerous channels that characterize the frontal splay (B). Location shown in Fig. 17.

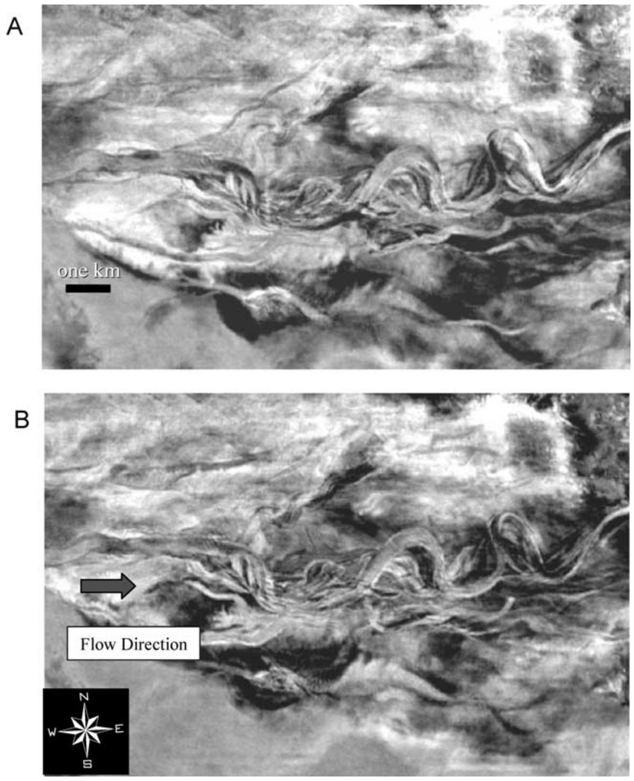

Fig. 19. Moderate to high-sinuosity channel at the top of the frontal splay deposit illustrated in Fig. 18. This channel is characterized by down-system meander loop migration.

Frontal splays are similar to crevasse splays with one significant distinction; frontal splays form at the termini of channels, whereas crevasse splays form in close proximity to breaches in a levee. Though similar in plan view and morphology, sedimentary structures that characterize the deposits of each may be different in view of the fact that flow expansion is a more significant factor with crevasse splays than with frontal splays. Therefore, sedimentary structures such as climbing current ripples, which commonly are associated with rapid sedimentation out of suspension such as would characterize flow expansion just distal to a levee crevasse, may be more common to crevasse splays than frontal splays.

The frontal splay is characterized by numerous small channels arranged in a distributive pattern. The entire frontal splay complex measures approximately 20 km along dip and 10 km along strike. The frontal splay channels range from straight to highly sinuous. The last channel to form across the top of the splay complex is the most sinuous (Fig. 19). Posamentier and Kolla (2003) have suggested that the change from a distributive frontal splay to a sinuous channel pattern occurs in response to a decrease in sand to mud ratio in the flows and therefore representative of the waning phase of turbidity flow channel evolution.

2.7. Mass transport complexes

A mass transport complex (MTC) can be observed to overlie the frontal splay deposits just to the north of the sinuous channel shown in Fig. 19. The basal surface of this MTC is characterized by relatively straight grooves presumably carved by debris being transported within the basal part of the mass flow unit (Fig. 20). Note that the grooves seem to terminate against the flanks of the sinuous channel shown in Fig. 19. Similar grooves at

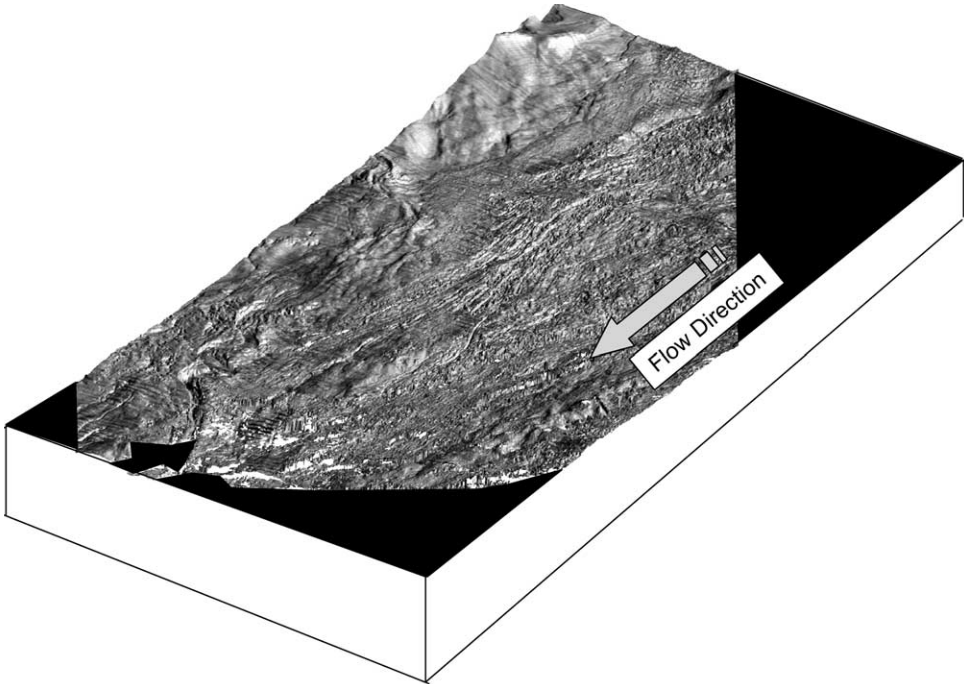

Fig. 20. Three-dimensional perspective view of base of mass transport complex shown in Fig. 21. This stratigraphic unit overlies the frontal splay; its areal extent seems to have been limited by the relief associated with the small leveed channel that caps the frontal splay deposit (Fig. 19).

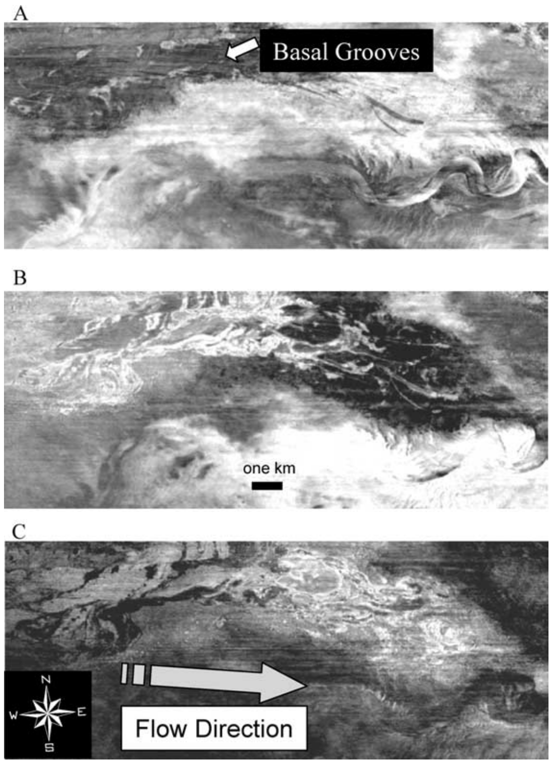

Fig. 21. Three horizon slices through the mass transport complex shown in Fig. 20. The lowest slice (A) illustrates the grooves probably formed by blocks at the base of the flow being dragged across the substrate. Two possible outrunner blocks are identified; note that their tracks are isolated and end abruptly, in contrast with the grooved surface that characterizes the area just to the west-northwest. (B) and (C) are slices through the middle and upper parts of the mass transport complex. These slices suggest a convolute internal architecture to this stratigraphic unit.

the base of mass flow units, some in excess of 250 m wide and 50 m deep, have been reported elsewhere (Posamentier, 2002; Posamentier et al., 2000). The internal architecture of this MTC is illustrated in Fig. 21. This MTC is characterized by a highly convolute seismic facies pattern (Fig. 21) suggesting a flow character transitional between purely laminar and turbulent.

Additional MTC's can be observed in Fig. 1. These MTC's range from steep sided and smooth-topped on the west side of the seascape, to lobate forms with indistinct margins and highly irregular surfaces on the east side of the seascape. The irregular surface on the large MTC on the eastern side probably is associated with discrete large blocks located at the top of the deposit. In contrast, the MTC's on the western side, with their smooth tops are inferred to be more homogeneous and contain few, if any, large blocks at least within the upper part of the deposit. The steep margins of the MTC's on the western side of the study area probably are indicative of greater cohesiveness of the constituent material than the MTCs on the eastern side, which are characterize by more tapered margins.

3. Discussion

The Joshua channel and related depositional elements probably were deposited during the mid to late Pleistocene. The absence of core calibration makes it impossible to determine with any degree of certainty the precise age of these deposits. The thickness of the overlying drape deposits, approximately 30 m, are inferred to correspond to distal sedimentation associated with a succession of lowstands and highstands of sea level. During its period of activity, the Joshua channel was characterized by a prolonged period of aggradation. For most of this time the aggradation of the levees that bounded the channel belt (i.e. the master-bounding levees, or outer levees) kept pace with the aggradation of the channel belt. The channel thalweg itself is bounded by small levees on either side. These levees formed concomitant with the master bounding levees and lie within the channel belt. With the exception of the very last stage of channel development, no avulsions characterized the stretch of the channel observed (approximately 60 km). Meander loops are observed to persistently migrate down-system. Isolated examples of meander loop cutoffs can be observed.

The final expression of the Joshua channel is that of a ridge, reflecting the effects of differential compaction. The channel is interpreted to have been nearly filled with relatively non-compactable sands as compared with the channel belt within which it lies, and therefore has compacted only minimally. However, the channel belt, which includes the Joshua channel and its levee, stands higher than its associated master-bounding levees, and therefore must also have been at least somewhat sandy in that it currently forms a ridge that stands higher than the adjacent overbank. Again, the effects of differential compaction account for this channel belt ridge. The total relief of the channel belt ridge reflects the effect of aggradation above the basin floor of both the channel belt as well as the levee that subsequently was enhanced by differential compaction.

The levees associated with the channel within the channel (i.e. the Joshua channel within the greater channel belt) are well expressed and stand higher than the adjacent channel belt. They commonly are higher at outer channel bends than inner channel bends as a result of preferential overspill on that side. The numerous small scooped-shaped scars observed along the inner side of these levees probably formed during the late stages or immediately after abandonment of the Joshua channel. They are best developed where the levees stand tallest, i.e. along outer channel bends, and are interpreted as small slump scars.

Just prior to channel abandonment, numerous avulsions are inferred to have occurred. These avulsion events, associated with breached or crevassed levees, all are associated with channels directed over the right bank. This preferred channel orientation probably is associated with regional tilting to the northeast associated with progressive compaction of the northeastern edge of the underlying Mississippi fan system. Each avulsion event resulted in formation of a channel over the adjacent levee and overbank area. These channels are preserved as trough-form, concave-up features, in marked contrast with the ridge-form, convex-up expression that characterizes the Joshua channel. The transition from concave-up to convex-up is marked in each instance by a knickpoint. The probable succession of events was (1) levee breaching forming a crevasse, (2) accelerated flow down the backside of the levee causing incision and channel formation, and (3) migration of a knickpoint from the location of the crevasse up-system along the main Joshua channel. (4) Subsequent knickpoint migration probably was aborted when an avulsion event occurred farther up-system diverting a substantial portion of the flow out of the Joshua channel, leaving the portion of the channel down-system of the later avulsion node abandoned, with little or no flow in the channel. This scenario was repeated numerous times within the limits of the study area as avulsion events occurred successively farther up-system.

The abrupt occurrence of numerous avulsion events during the latest stage of channel evolution suggests that a fundamental change of flow parameters must have occurred then. The most likely cause was increased flow discharge at that time. Such increased discharge would have resulted in enhanced overspill associated with now undersized levees. Such a misfit relationship between flow height and flow velocity, and levee height would have resulted in a greater likelihood of crevasse development. Increased flow discharge probably can be related to increased delivery of sediment volumes to the 'staging area'. Increased sediment flux at the shelf edge could have been related to Mississippi River discharge spikes caused by abrupt draining of Pleistocene pro-glacial lakes (i.e. jøkulhlaupts) or abrupt shifts of drainage divides resulting in glacial meltwater being directed down the Mississippi system vs. out the St Lawrence or Mohawk Valley systems (Teller, 1990; Licciardi et al., 1999; Blum et al., 2000).

4. Conclusions

A moderate to high-sinuosity channel and its associated depositional elements observed on the basin floor in the DeSoto Canyon area of the northeastern Gulf of Mexico has been described. The features observed include (1) a channel with (2) associated levees lying within (3) a larger channel belt bounded by (4) master bounding levees. The inner levees associated with the channel within the greater channel belt are characteristically higher at outer channel bends and are marked by scoop-shaped slump scars on their inner sides. Based on inferences regarding differential compaction effects, the sinuous channel fill likely is the most sand prone, followed by the sediments that comprise the channel belt, and finally the sediments that comprise the master bounding levee deposits. The channel is characterized by persistent down-system meander loop migration and in isolated instances by meander loop cutoffs that strongly resemble oxbows in fluvial settings. Numerous (5) avulsion channels are observed, some feeding (6) frontal splays. Overlying this leveed-channel succession is a (7) mass transport complex characterized by grooving at the base and convolute bedding architecture internally.

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