*University of Houston*
**Department of Geosciences**
**MS Thesis Proposal**

# Growth-Faulted Delta or Mass Transport Complex: Seismic expression evidence

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***Thesis Committee:***

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# Abstract

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Title: **Growth Faulted Delta or Mass Transport Complex: Seismic expression evidence**

Committee: **Dr.Bhattacharya (Advisor, UH), Dr. Marfurt (Member, UH) John Sharp (Outside Member, BP)**

Date: April, 2007 Time: Location:

The Northern Gulf of Mexico is dominated by salt tectonics. The central shelf, shelf-margin area lies in two tectono-stratigraphic provinces: the Plio-Pleistocene detachment province and the salt dome minibasin province. The latter consists of residual vertical salt massifs and related deep minibasins filled predominantly with deltaic deposits of paleo Mississippi delta. This study is focused on the deltaic successions of one of the minibasins interbedded with enigmatic sequences about 100m thick which can be interpreted as either growth faulted deltas or mass transport complexes. These intervals show very incoherent and chaotic reflections on conventional seismic data images with subtle patterns resembling growth faults.

I will use 3D seismic attribute images to create the model of the internal structural and stratigraphic framework of one of the complexes at depths of about 600m below sea level. The main goal is to define the origin of the depositional system in which the interval of interest was deposited.

Two interpretations are possible on which depends the possible implication of this work. If the interval is proved to be a growth faulted delta then 3D models of this feature could serve as a good analog for the petroleum reservoirs in overthickened sands on the hanging walls of the normal faults with seals by prodelta shale formations juxtaposed by growth faulting. Reservoir heterogeneity studies can benefit from the model also. If this interval represents mass transport complexes then my work will change its course and I will assess the sealing potential of mass transport complexes. The results of the present research will give an insight into the depositional processes which were active in this region and will show the significance of the application of seismic attributes in the interpretation of structure and stratigraphy in shelf-edge areas characterized by instability.

APROVED as PROPOSED APROVED as MODIFIED DISAPROVE

Modifications ______________________________

Committee Chairman ______________________

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## Introduction

### Geological setting

Generally the shelf is defined as the area from the shoreline up to water depths of 200m. The continental shelf of the Gulf of Mexico represents a continuous terrace along the passive margin of the North America. My area of research is located offshore Louisiana about 150 km south of the shoreline. 8000 square km are covered by a 3D seismic survey within the Vermilion and South Marsh Island areas (Fig. 1, 2, 3). The water depth in this region is around 150-200m.

Tectonic evolution of this area is largely controlled by salt deposition and withdrawal forming an extensional regime. Diegel et.al., (1995) divides the Northern Gulf of Mexico basin into several tectono-stratigraphic provinces (Fig. 3). The area of this study lies in the Plio-Pleistocene detachment province to the south and salt-dome minibasin province to the north. Plio-Pleistocene detachment provinces are associated with large salt withdrawal surfaces and regional basinward dipping listric growth faults detached on those salt welds. These normal faults accommodate the extension in the area. The salt dome minibasin province is characterized by salt diapirs intervening with large minibasins bounded by large throw, arcuate and dominantly counter-regional growth faults.

The depositional history of the region is characterized by transgression up to Early Tertiary time followed by progradation. Holocene transgression is in power for almost 6000 years already which started after Pleistocene glaciation. Cretaceous deposition is dominated by carbonates whereas silisiclastics were deposited during Tertiary time. The region is characterized by thick accumulations of sediment and rapid subsidence. The formation of minibasins began in Early Miocene at the time of active salt tectonics. Silisiclastic sediments were supplied by the Mississippi river from the North-East and these basins were filled with predominantly deltaic deposits up to several kilometers thick. Great thicknesses of these sediments are explained by large scale salt withdrawal processes in the basinward direction. Successive deltaic sequences comprised typical clinoforms and are separated by the flooding surfaces that can be clearly seen on the dip oriented seismic cross-sections through the study area. Layers of deltaic deposits capped by flooding surfaces represent high impedance reflection boundaries and therefore are imaged as continuous reflectors on seismic profiles (Fig. 5).

### Interval of Interest

My research is focused on one of the hanging wall minibasins in the south-western part of the study area that is flanked by residual vertical salt bodies (Fig. 4). I'm particularly interested in the interval of deposits enclosed between two deltaic sequences that look quite different in terms of seismic reflections (Fig. 6). About 100m of sediments show discontinuous reflections. Such incoherent data may represent a mass transport complex or deltaic deposits disrupted by growth faults detached on the underlying flooding mud veneer.

## Thesis statement

The main goal of this study is to determine the depositional origin of the interval. There are two possible interpretations: small scale growth faulted delta and mass transport complex. I'm going to test the interpretation by evaluating the internal character of the unit. Relict diapirs suggest that this unit might be a prograding delta. The disruption may represent growth faults. Alternatively, this unit may represent a slumped shelf delta or mass transport complex.

## Literature Review

This section reviews the salient characteristics of mass transport complexes and compares them with growth faults to develop criteria for distinguishing them in 3D data.

### Growth Faults

Growth faults, also referred to as contemporaneous faults are defined as normal faults which are active during deposition and result in increased sediment thickness on the hanging wall compared to the footwall R. J. Twiss, E. M. Moores, (2007). They are generally of listric nature. The term listric is related to the morphology and means that the dip of the fault plane decreases with depth. The necessary factor in the formation of the listric faults is the presence of the detachment surface which can be composed of either salt or shale. Two mechanisms were proposed for the formation of the faults: differential compaction of shale layers in a sandstone-shale sequence and gravity sliding toward the basin, R. J. Twiss, E. M. Moores, (2007). Listric faults vary in scale from regional extent with throws of 100 meters and lateral extent of hundreds of kms to local with throws on the order of meters. Shale based detachment systems are dominated by extension whereas salt based – by subsidence.

I will be focusing on small scale growth faults which lie within a formation of less than 100 m thick. Faulting and folding character of the hanging wall of growth faults was studied by several workers. Withjack et. al., (1995) conducted experimental studies of normal faults and their hanging wall deformation using clay models. These studies provide information on how a master fault shape and displacement distribution influences the style of secondary faulting and folding. Mostly antithetic normal faults form above concave upward fault bends, whereas mostly synthetic normal faults form above low angle fault segments and convex upward fault bends (Withjack et al., 1995). The secondary faulting system becomes older as it passes the bending parts of the master fault and faults cease to be active. Displacement distribution effects were studied using mylar sheets as a fault plane. When mylar sheet is present the displacement magnitude is constant along the fault and very few secondary faults are formed most of them propagating downward and, thus having less displacement at depth. Without mylar sheet we have variations in the magnitude of displacement and greater numbers of secondary normal faults propagating upwards and having bigger displacement at depth. I think that these experiments are crucially important in aiding the interpretation listric faults on the real seismic data (Fig.7).

Xiao and Suppe, (1992) expanded the understanding of rollover mechanisms acting on listric faults. Rollover anticlines are formed by bending of the hanging wall strata in response to slip along the fault plane. Among other factors, the authors highlight the effect of the sedimentation rate relative to the slip rate of the faults as well as the slip magnitude after deposition (Fig. 8, 9). They also established fault-rollover models that help in the interpretation process in case one of these elements is not well imaged and requires predictions. (Fig. 10).

I think that considering the abovementioned achievements and comparing the pattern from my seismic interval with the models developed will help me create the spatial image of the growth faulted deltas.

### Deltas

Deltas are discrete shoreline protuberances formed where a river enters a standing body of water and supplies sediments more rapidly than they can be redistributed by basinal processes, such as tides and waves (Bhattacharya, 2006). Deltas differ from estuaries and lagoons by their regressive nature. The geomorphology of deltas is influenced by many factors, such as relative dominance of river, tide or wave processes, the depth of the basin receiving sediments, density contrast between river and basin water, sediment supply and grain sizes. Deltas can be predominantly river, tide or wave dominated. Delta successions in dip cross-sections are divided into topsets, foresets and bottomsets which correspond to delta plain, delta front and prodelta in plan view respectively (Fig. 11, 12). A separate unit of deltaic deposits is referred to as clinoforms. Adjacent clinoforms are separated by the ravinement surfaces which represent the times of transgression and erosion of 5-10 m from the topset parts of the delta. General pattern of delta deposits is upper coarsening as the sandier facies of delta plain and front prograde above the muddy prodelta facies. Shelf-edge deltas cover the shelf area and terminate close to the shelf margin. Such deltas are often growth faulted with thick upper-coarsening successions on the hanging walls of the faults. The formation I will be interpreting is potentially a shelf-edge delta cut by numerous growth faults.

### Growth faulted deltas

Several examples of small scale shelf delta have been studied. Most of the studies involve observations of outcrops in order to make conclusions about kinematic history and geomorphology of the deltaic sequences. Bhattacharya and Davies, (2001, 2005), Fig. 13, divide the deltaic sequence in Ferron sandstones, Upper Cretaceous, into pre-growth, growth and post-growth strata relative to the development of growth fault complexes. Observed sedimentary structures in the pre-growth section suggest high sedimentation rates of highly porous muds overlaid by less porous and thus less dense sands. Muddy layer begins to flow and accommodates the displacement created by the faults. Growth strata interpretation suggests that the faulting occurred at very shallow water depths before the significant compaction took place. The upper tips of listric growth faults terminate at the muddy facies of the overlying flooding surface whereas lower parts of the faults sole into prodelta muds underlying prograded sand. Edwards, (1976) presents the results of the observations and interpretation of the outcrops of Upper Triassic deltaic sequences exposed in coastal cliffs on Edgeoya in southeast Svalbard. He lists an additional element, namely, small scale anticlines developed beneath the concave upwards growth faults. Among the above mentioned possible reasons for the initiation of the growth faulting during deltaic sedimentation is triggering mechanism, such as earthquakes. A model of deltaic sedimentation during growth faulting is shown on Fig. 14

### Mass Transport Complexes

Mass transport complexes have become a very important research topic nowadays because of their potentially high sealing properties. Posamentier and Walker, (2006) identify mass transport processes as mainly debris flows and discuss their characteristics by interpreting seismic images. One of the distinctive features of MTCs is deep erosion up to 250m (Fig. 15) and grooves or striations diverging downsystem left by the eroding clasts present in the flow mass. (Fig.16). Mass transport deposits can be found in both shelf-edge and mid-slope environments (Fig. 17). MTCs can form lobes (Fig. 18), and sometimes take the route of the former turbidity-flow channel. At the terminal point of the debris flow compressional features can be observed, such as small scale thrust faults (Fig. 19). MTC deposits are characterized by their very low sorting and thus contorted seismic reflections (Fig. 20). Their upper surface can be wrinkled in some cases and affect the relief of the younger turbidite deposits (Fig. 21).

Browne et al., (2006), worked on observing MTC outcrops and in his studies divided in terms of scale into: type 1 or seismic scale MTCs comprising blocks thicker than 10m, type 2 – outcrop scale MTCs, up to 10m thick and type 3 – bed scale which are only a few meters thick.

MTC complex which I may be looking at is on the order of 100m in thickness and therefore is of seismic scale.

### Seismic attributes

A seismic attribute is a quantitative measure of a characteristic of interest, Chopra and Marfurt, (2005). Seismic attributes are generally divided into three groups: amplitude-derived (root mean square, average peak amplitude, etc.); time-based attributes (time structure, dip magnitude, dip azimuth, curvature, etc.) and waveform similarity attributes, such as coherency. I’ll be applying reflector dip, azimuth, curvature, coherence and amplitude extractions attributes to the dataset.

Reflector dip and azimuth attributes are very useful in interpreting stratigraphic elements, lineations and collapse features. Curvature is simply the reciprocal of the curvature radius of the reflector. Most positive and most negative curvature attributes are the best in delineating stratigraphic features. Seismic coherency is a measure of lateral changes in the seismic response caused by variation in structure, stratigraphy, lithology, porosity, and the presence of hydrocarbons, Marfurt et. al. (1998).

## Approach/methods

In order to make a decision on the origin of the incoherent complex within the study area I'm going to construct a 3D model of the interval using conventional seismic data and various seismic attributes. I will observe in details and interpret the internal structural and stratigraphic characteristics of the model and then compare the results with the studied outcrop examples and published seismic examples. Seismic interpretation software will be used to pick one of the horizons in the proximity to the interval of interest and seismic attributes, such as coherency, curvature, reflector dip and azimuth, etc. will be extracted for the horizon. I will generate successive time slices and cross-sections of the area to enhance the effectiveness of the interpretations and presentation of the results. As my task is decide whether this complex represents mass transport deposits or growth faulted deltaic deposits. I will compare the obtained 3D model with the seismic models of each of these two depositional systems and look for similarities and differences. I will also try to literally find seismic expressions of typical elements of mass transport complex and/or growth faulted delta in the seismic cube present. The lithology of the interval is very important to know, therefore I'll try to obtain well-log data through the interval and make some inferences about composition interpreting gamma ray and spontaneous potential curves. Impedance inversion may also be used to obtain the lithology of the interval, it works best in areas of nearly exposed salt bodies.

## Preliminary results and discussion

I have become confident in using the seismic interpretation software to create seismic attribute images of the interval of interest. Time slices and cross-sections show the general tectono-stratigraphic framework in the region and the extent of the depositional feature under study. I have interpreted an easily definable horizon below the complex under question (Fig. 22). I have flattened it and extracted all available attributes for this horizon. This way I can create successive horizon slices of conventional seismic data and attributes to better understand the depositional elements (Fig. 23). Generally horizon slices show more accurate images of the area than time slices. Constructing a 3D model of the unit I have to understand what was the tectonic regime, extension or compression, interpret complex faulting and folding pattern and focus on the shapes of deposited blocks as they may represent overthickened sandy or muddy bodies of the hanging walls of the faults. Tectonic regime and its footprints will tell me a lot about the origin of the depositional unit. Normal faults formed by basinward extension and detached on the ravinement surface of underlying deltaic sequence are typical of growth faulted delta. Thrust faults, if revealed, will indicate the mass transport complex. The underlying surface can be grooved if MTC took place so I will be looking at the striations on the timeslice beneath the complex. In general, I'm comparing 3D model of the interval of interest with relevant seismic expression of growth faulted delta and mass transport complex and with outcrop analogs.

## Implications of research

So far only 2D outcrop descriptions of small scale growth faulted delta are present in the literature. It would be useful to describe a 3D seismic volume of a growth faulted delta.  It's clear that there are some processes acting in that area at that time which we don't fully understand. This study will give an insight in the depositional history of the seismically incoherent unit between two deltaic sequences. As far as implication in the petroleum exploration, although there barely are economically significant hydrocarbon reserves in that area, growth faulted deltas represent good analogs for petroleum systems. Overthickened sand bodies deposited on the hanging walls of the growth faults can be an excellent example of good reservoirs and normal faults themselves can trap the hydrocarbons by juxtaposing sands against impermeable shale beds. The 3D model of the growth faulted delta could serve as a tool for reservoir heterogeneity studies in the productive areas.

**Work plan including time table**

| Task # | Description | Deadline |
|---|---|---|
| 1 | Literature review | April 10, 2007 |
| 2 | Proposal submission | April 16, 2007 |
| 3 | Proposal presentation | April 23, 2007 |
| 4 | Seismic interpretation workflow | May 2007-January 2008 |
| 5 | Outcrop visits | June 2007 |
| 6 | Paper submission | January 2008 |
| 7 | Thesis submission | April, 2008 |
| 8 | Thesis presentation | May, 2008 |

## References

1. Anderson, J. B., 2005, Diachronous of development Late Quaternary shelf-margin deltas in the North-western Gulf of Mexico: Implications for sequence Stratigraphy and deep-water reservoir occurrence
2. Atwater, G. I., 1959, Geology and petroleum development of the continental shelf of the Gulf of Mexico
3. Al-Dossary, S. and Marfurt, K., 2006, 3D volumetric multispectral estimates of reflector curvature and rotation
4. Badley, M. E. et al., Fault interpretation during seismic interpretation and reservoir evaluation
5. Bhattacharya, J. P., 2006, Deltas
6. Bhattacharya, J. P. and Davies, R. K., 2005, Sedimentology and structure of growth faults and the base of the Ferron sandstone member along Muddy Creek, Utah
7. Biles, N. E. et al., 2003, Regional evaluation and hydrocarbon potential of the deep section of the Gulf of Mexico offshore Louisiana continental shelf from modern 3D seismic data
8. Busch, D. A. 1975, Influence of growth faulting on sedimentation and prospect evaluation
9. Chopra, S., 2002, Coherence cube and beyond
10. Chopra, S. and Marfurt, K. J., 2005, Seismic attributes – a historical perspective
11. Christiansen, 1983
12. Diegel, F. A. et al., 1995, Cenozoic structural evolution and tectono-stratigraphic framework of the Northern Gulf Coast continental margin.
13. Dula, W. F. Jr., 1991, Geometric models of listric normal faults and rollover folds
14. Edwards, M. B., 1976, Growth faults in Upper Triassic Deltaic Sediments, Svalb
15. Marfurt, K. J. et al., 1998, 3D seismic attributes using a semblance coherency algorithm
16. Marfurt, K. J., 2006, Robust estimates of 3D reflector dip and azimuth
17. Roberts, A., 2001, Curvature attributes and their application to 3D interpreted horizons
18. Rowan, M. G. et al., 1999, Salt-related fault families and fault welds in the Northern Gulf of Mexico.
19. P. Weaver, Continental shelf of Gulf of Mexico
20. Wignall, P.B. and Best, J. L., 2004, Sedimentology and kinematics of a large, retrogressive growth-fault system in Upper Carboniferous deltaic sediments, western Ireland
21. Withjack, M. O. et al., 1995, Normal faults and their hanging-wall deformation: An experimental study
22. H. Xiao and J. Suppe, 1992, Origin of Rollover
23. H. Xiao and J. Suppe, 1989, Role of compaction in listric shape of growth normal faults

## Figures

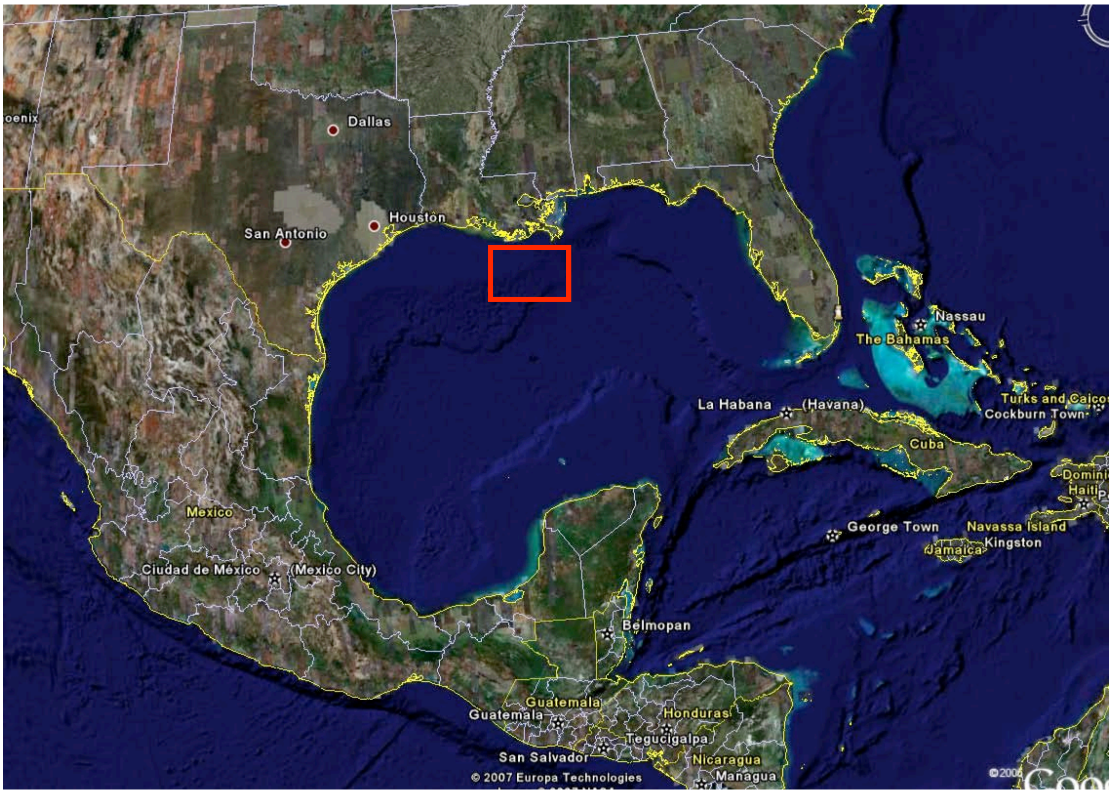

**Fig. 1 Geographic position of the area covered by seismic survey. Shelf, shelf-margin zone, Northern Gulf of Mexico.**

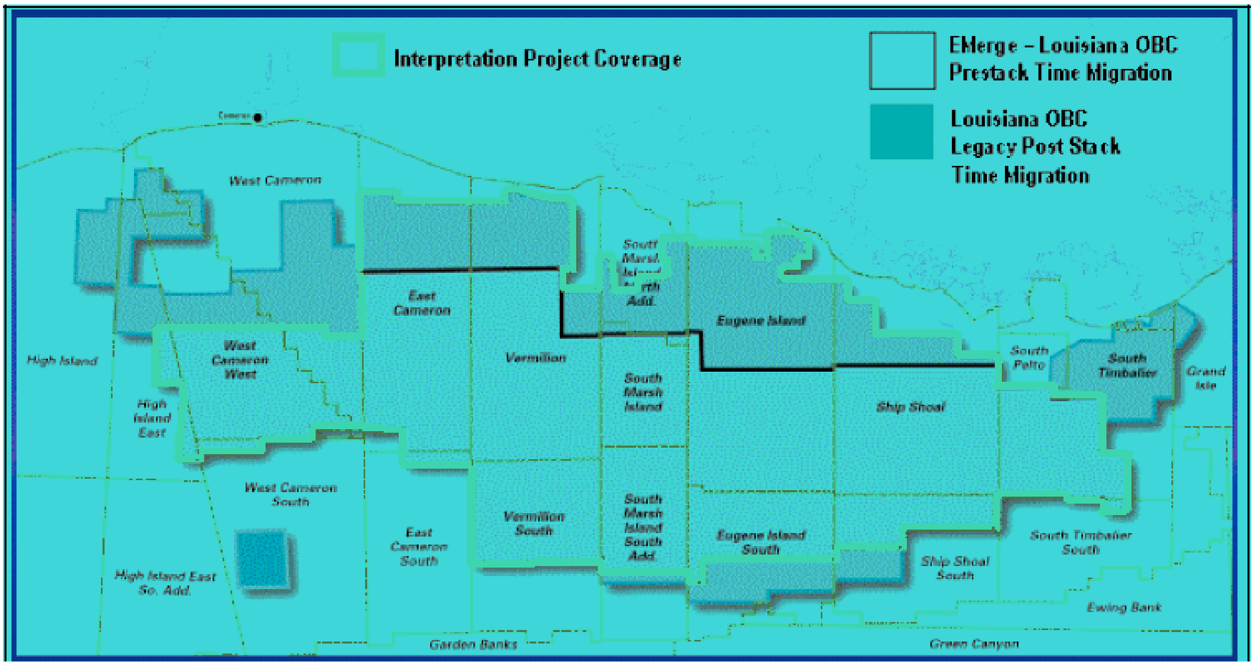

**Fig. 2 Seismic data cover parts of Vermilion and South Marsh Island areas**

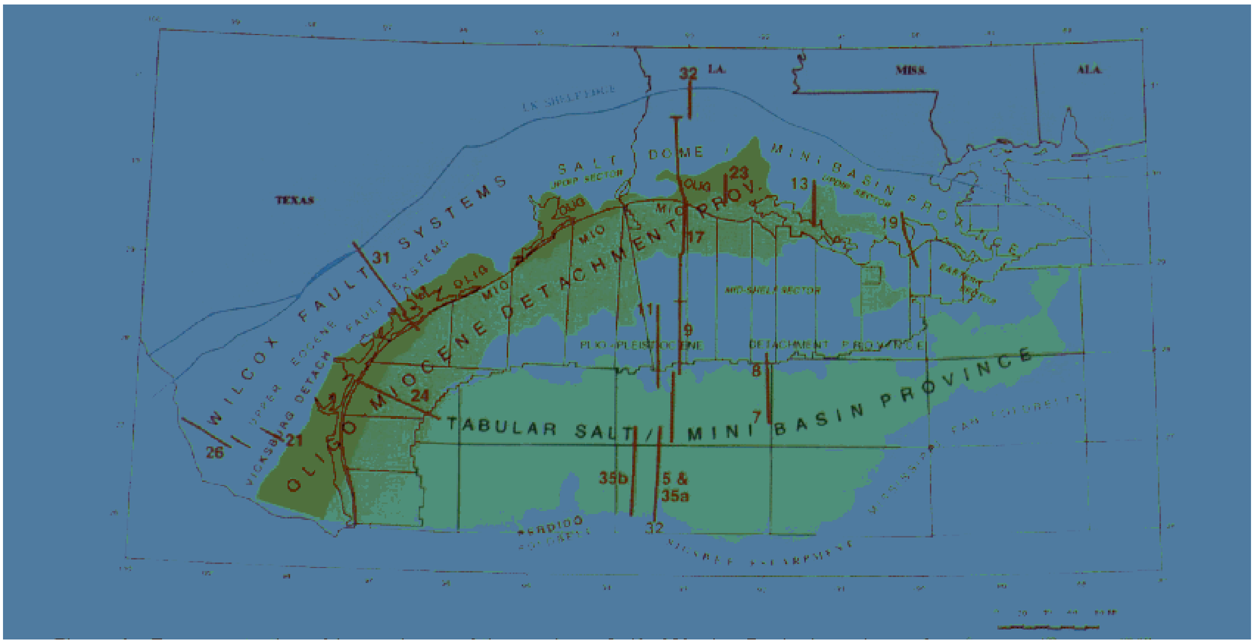

**Fig. 3 Tectono-stratigraphic provinces of the northern Gulf of Mexico Basin**

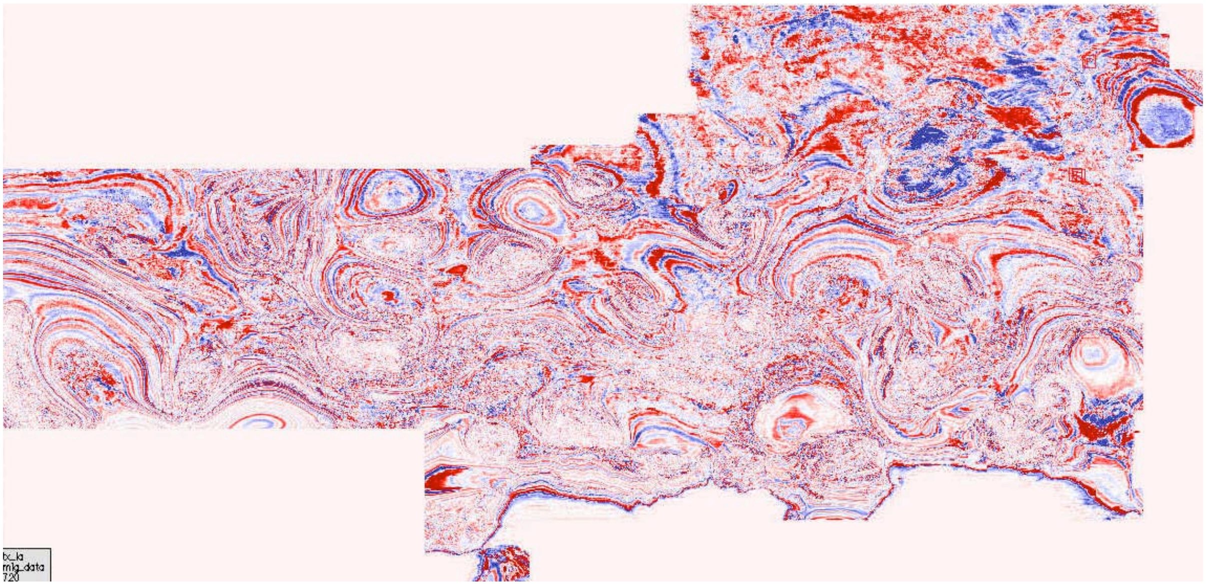

Fig. 4 Timeslice through the seismic data, overall area is about 8000 km$^2$. Note numerous salt bodies showing incoherent reflections.

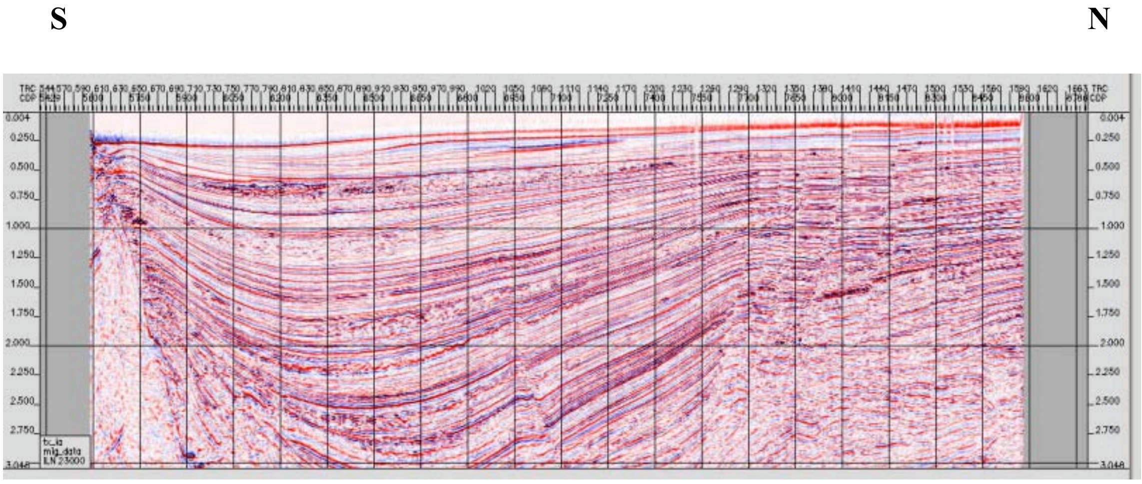

Fig.5 Cross-section through the minibasin of interest, for location, see Fig. 4

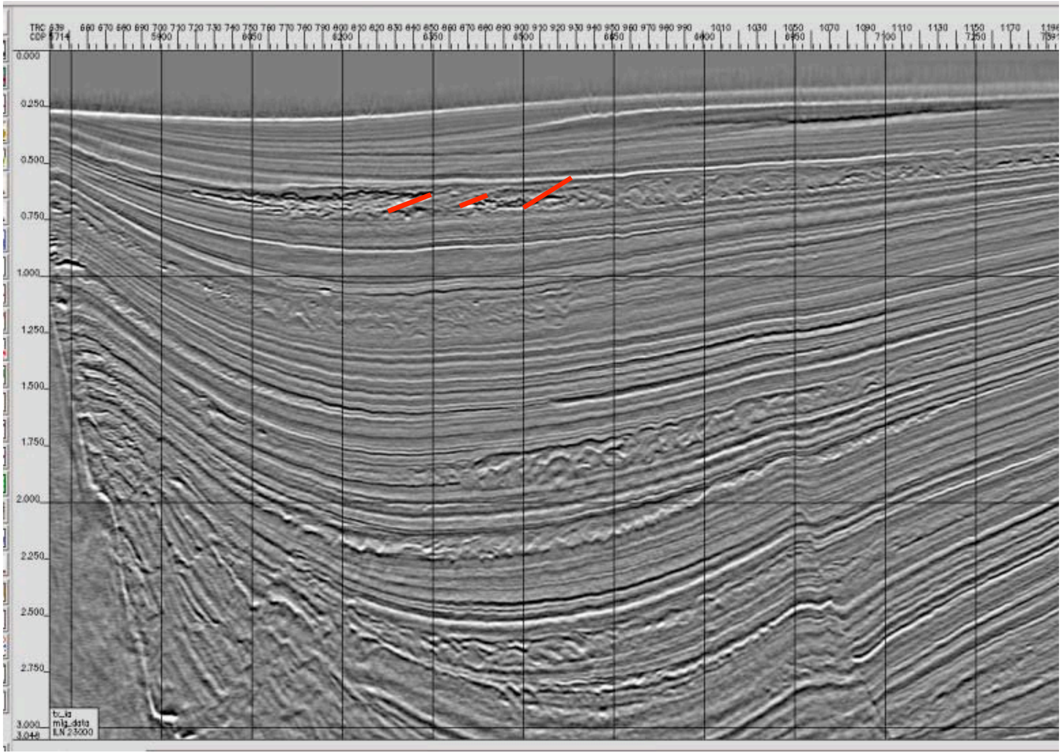

Fig.6 Cross-section through the interval of interest. Note incoherent complex at 0.6ms, relict clinoforms can be seen suggesting a prograding deltaic system.

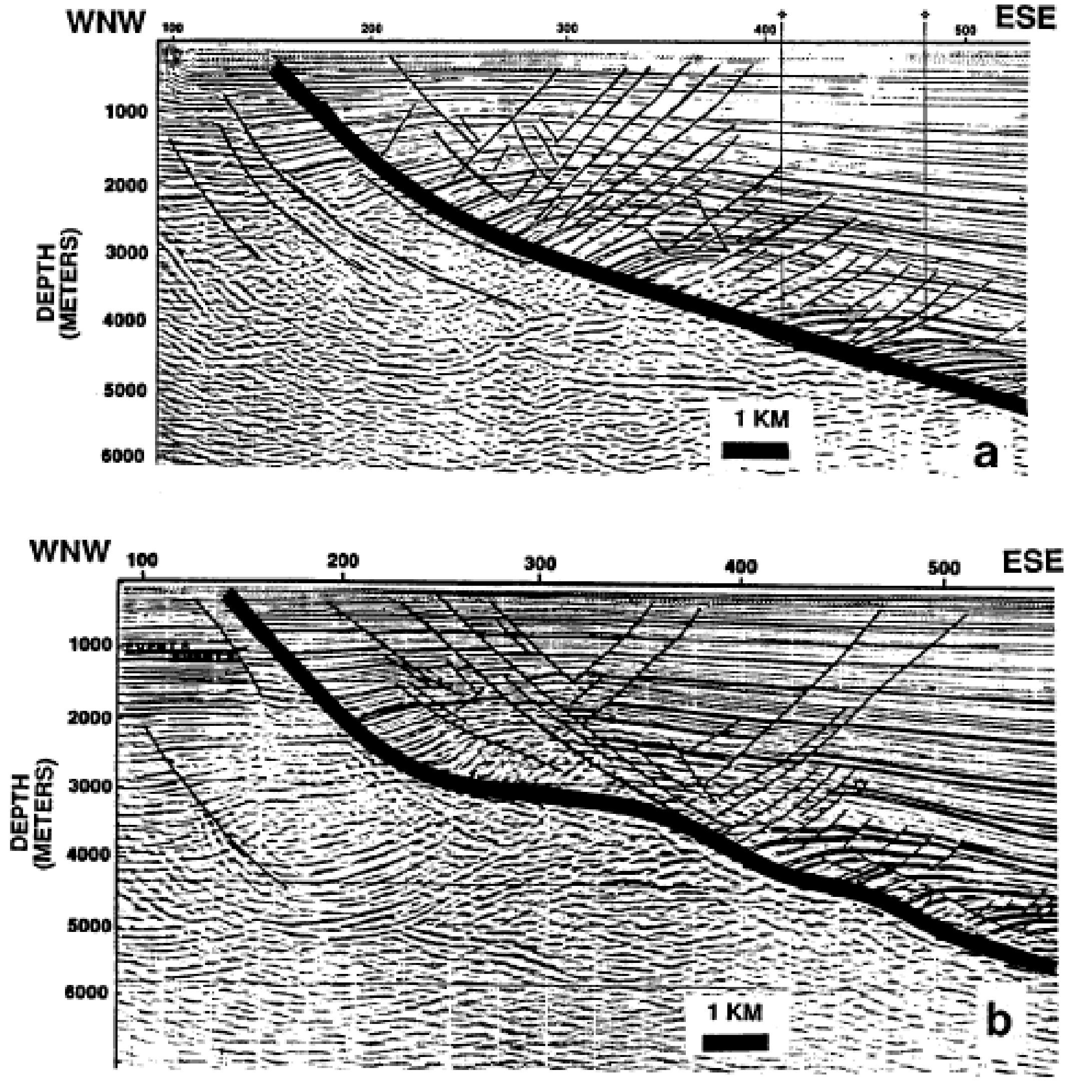

Fig. 7 Application of the results of experimental studies in the seismic interpretation of listric faults, (from Withjack et al., 1995)

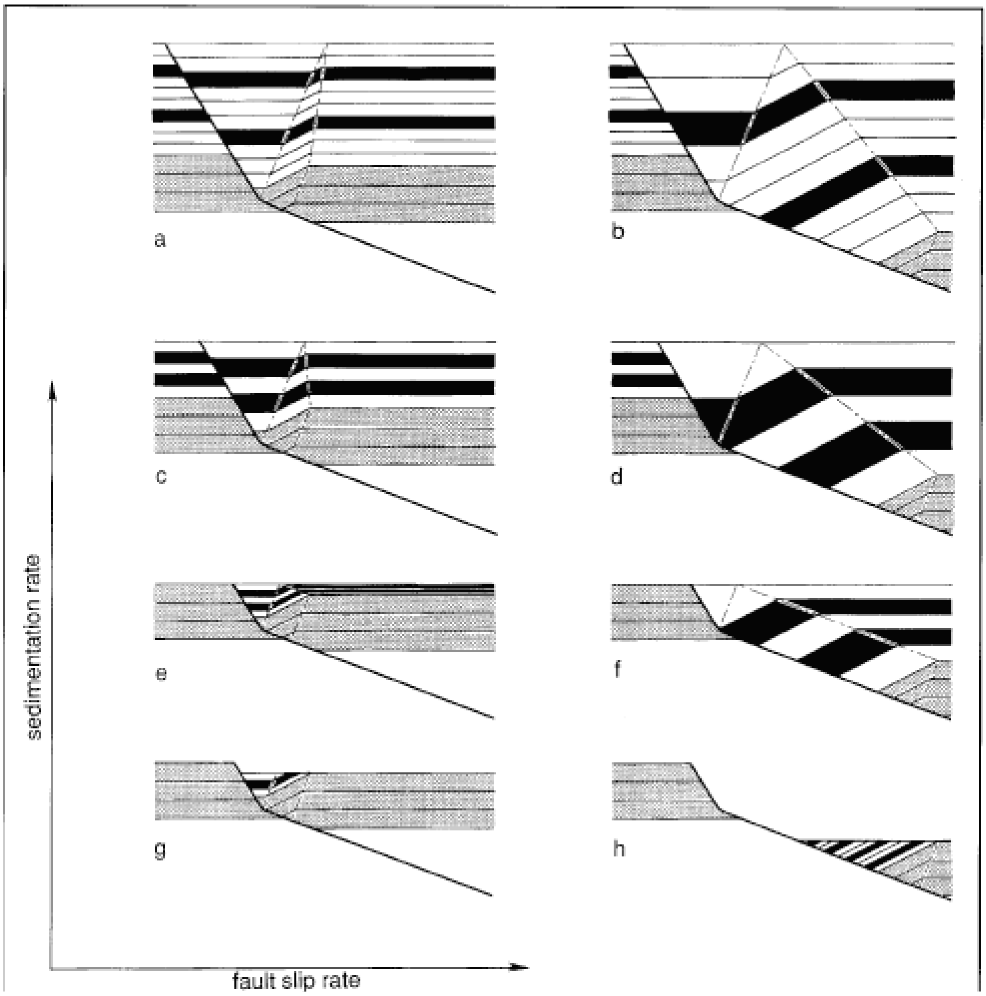

Fig. 8 Interpreted, depth-migrated seismic lines from the Corsair (Brazos Ridge) fault of offshore Texas (after Christiansen, 1983). (a) Section showing Corsair fault with concave-upward fault bend and secondary normal faults. (b) Section showing Corsair fault with concave-upward and convex-upward fault bends and secondary normal faults. (From Xiao and Suppe, 1992)

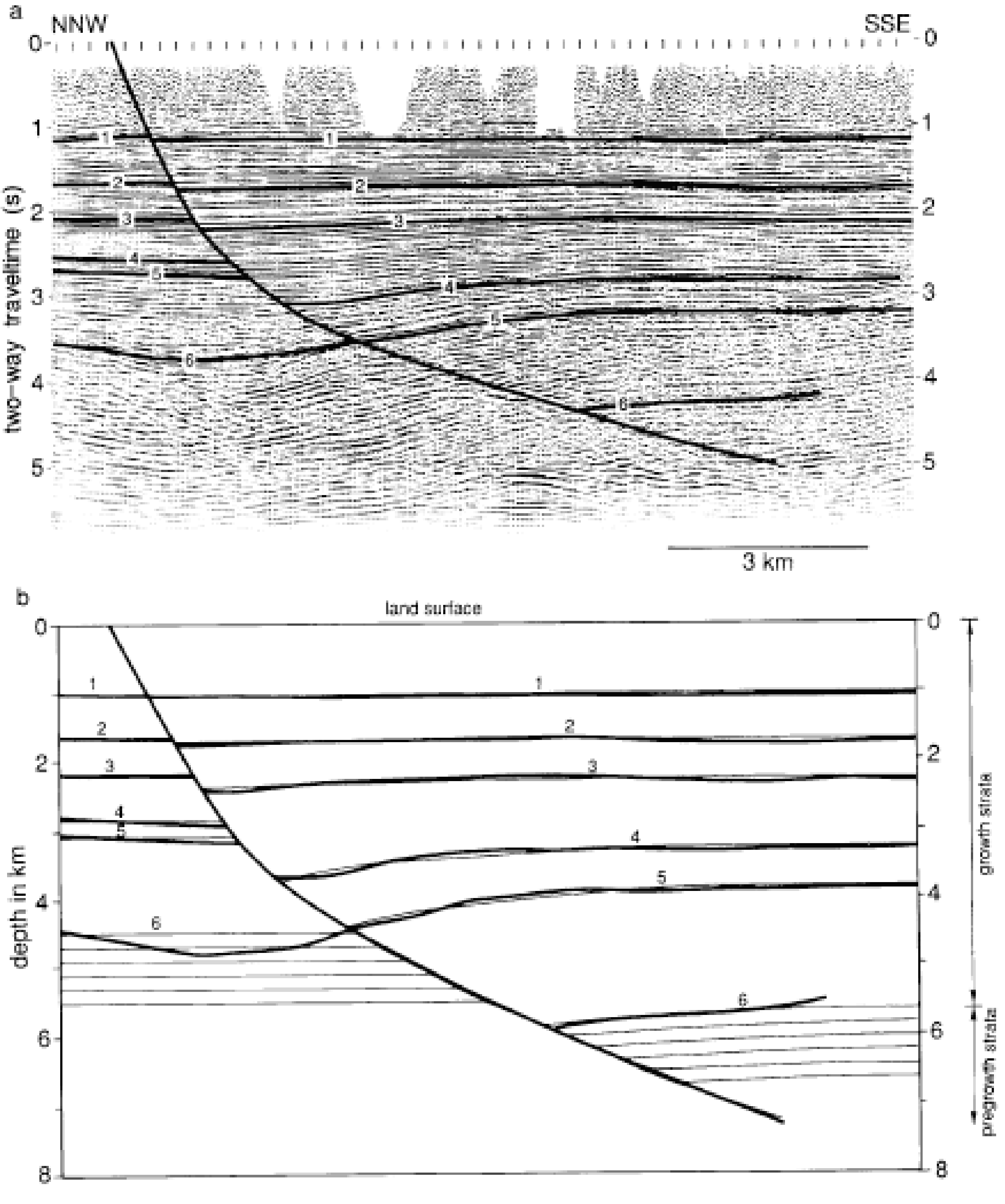

Fig. 9 (a) Seismic line showing an interpretation of a southern Louisiana rollover. (b) The depth conversion of seismic interpretation in (a) is shown in thick lines. (From Xiao and Suppe, 1992)

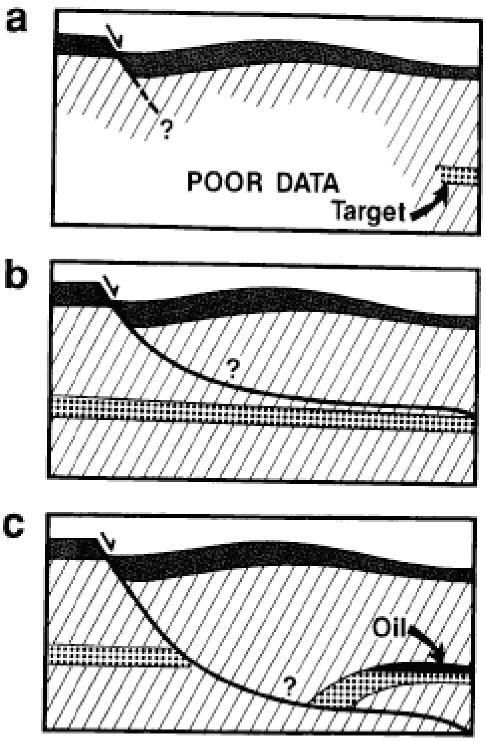

Fig. 10 (a) Rollover shape in the shallow section is well constrained, but extrapolation of the fault to depth is ambiguous, (b) Master fault is interpreted as being detached above the target horizon, and a structural trap is not developed, (c) Master fault is interpreted as being detached below the target horizon, and a structural trap is developed. Geometric models permit the fault shape to be constructed at depth from the shape of the rollover in the shallow section. (From Dula, 1991)

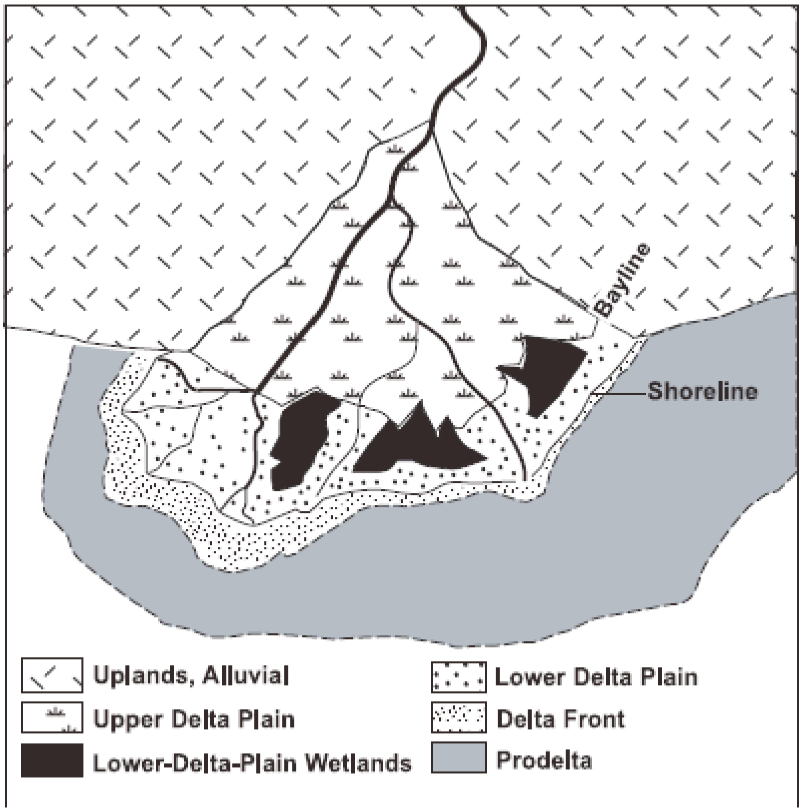

Fig. 11. Major areal subdivisions of a delta. The upper delta plain is essentially nonmarine and characterized by distributive river systems.

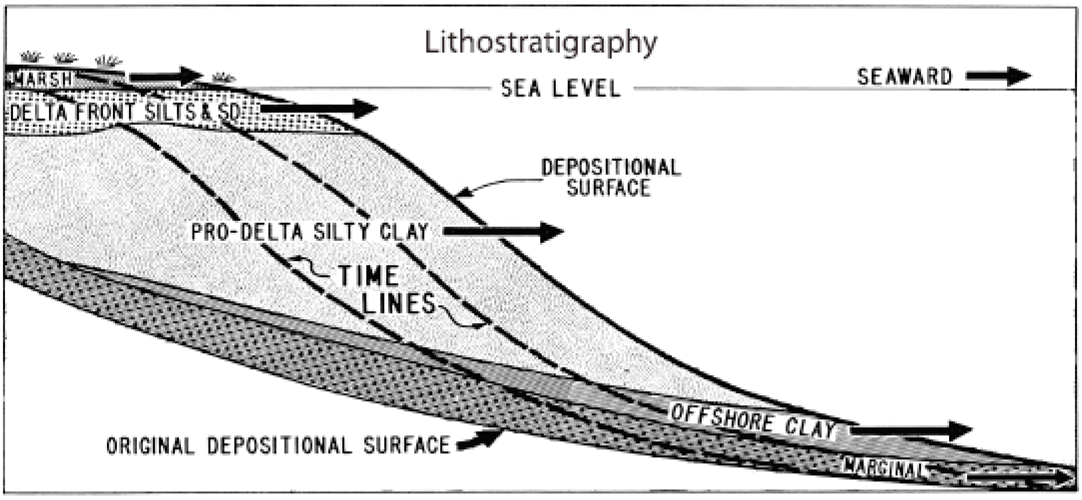

Fig. 12. Early example of a delta clinoform, showing topset, foreset, and bottomset strata (Scruton, 1960). Lithostratigraphic representation shows facies boundaries as undulating but apparently sharp. Arrows indicate direction of progradation. Most modern delta studies still show facies contacts in this manner.

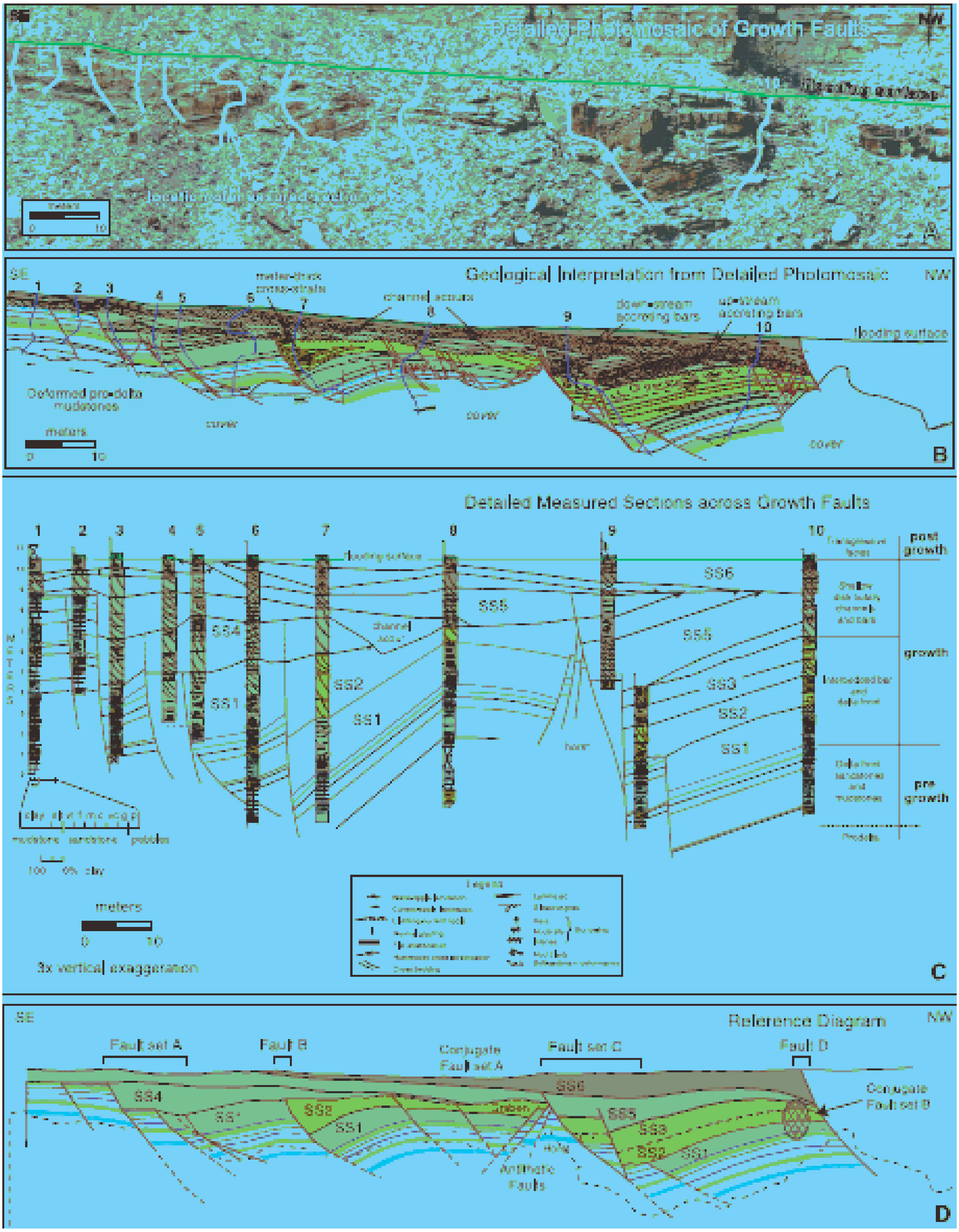

Fig. 13. Cross section and interpretation of growth faults formed in prodelta and delta-front strata of the Cretaceous Ferron Sandstone exposed along Muddy Creek, Utah, U.S.A. A) Detailed photomosaic, B) geological interpretation of structure, C) detailed measured sections, and D) a reference diagram. The growth interval consists of upstream- and downstream-accreting cross-bedded sandstones deposited in shallow distributary channels and proximal distributary-mouth bars. Successive sandstones in the growth section are labeled SS1 to SS6 (from Bhattacharya and Davies, 2001, 2004).

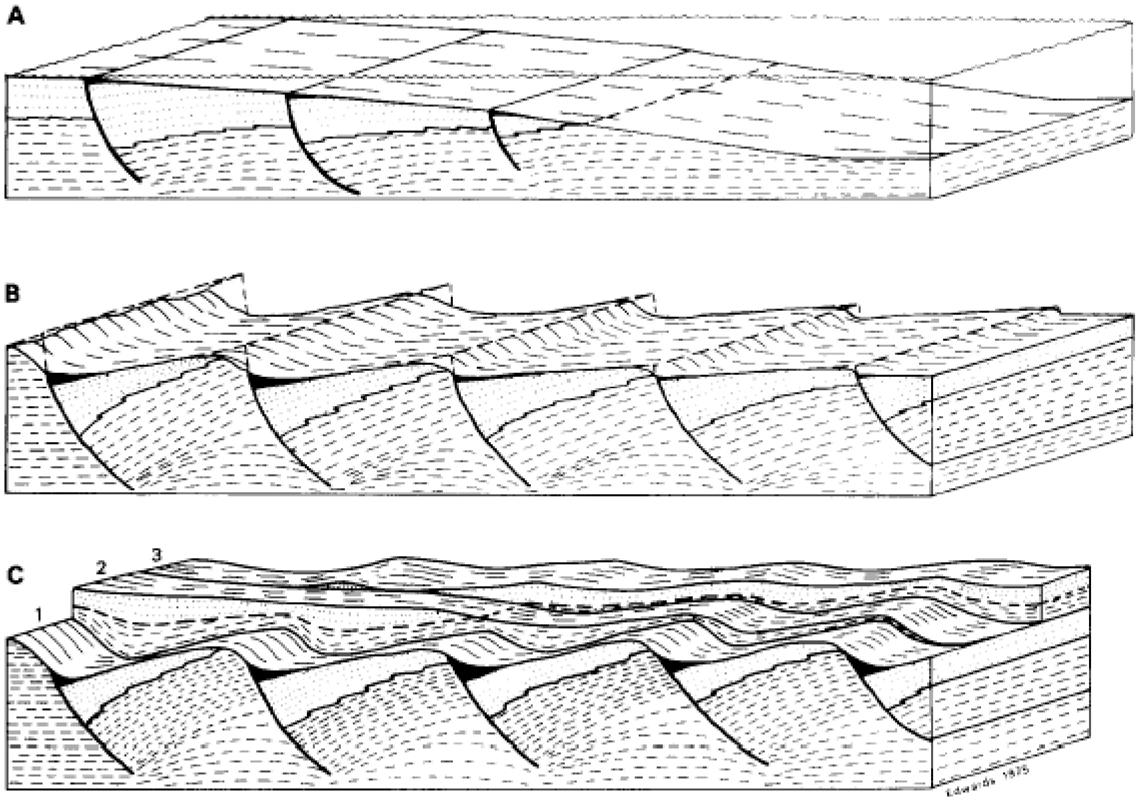

Fig. 14 Model of deltaic sedimentation during growth faulting, with some vertical exaggeration. A, Initiation of growth faulting during first major regression. B, Late-stage tilting on delta top, associated with underlying shale diapirism, forms scarps and scarp debris and erosion surfaces. Progressively less tilting is present on right toward delta margin. Black represents massive sandstone. C, Irregular delta top 1 is buried by prograding delta equivalent to fourth sequence 2, which in turn is deformed by deferential compaction 3.

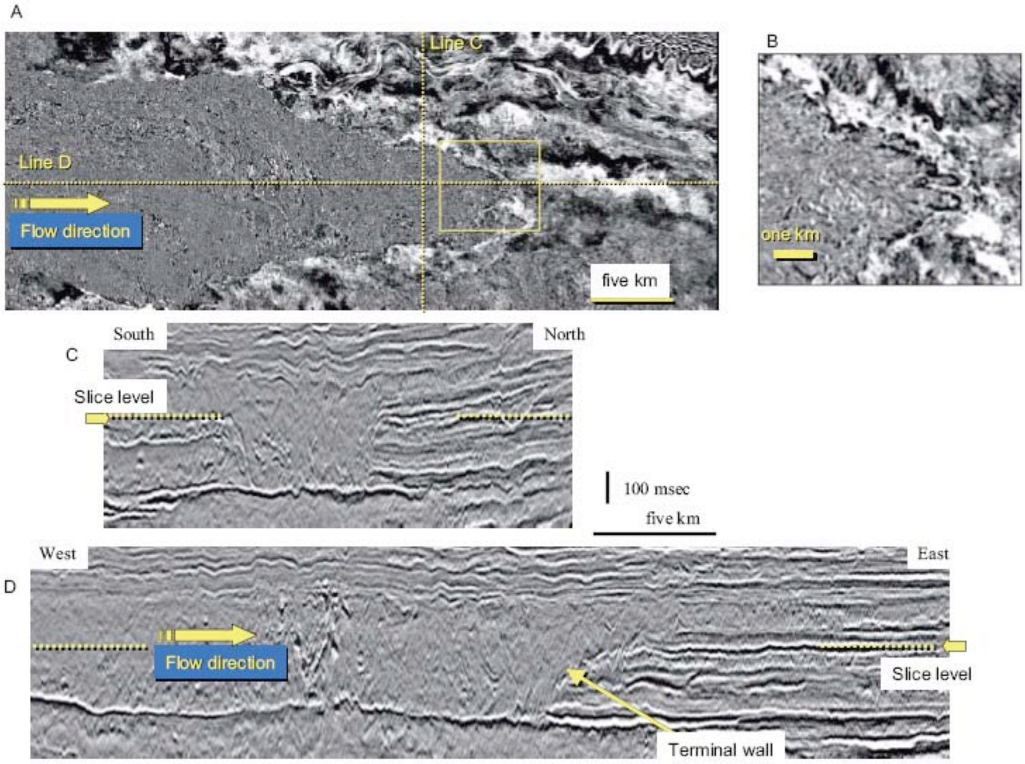

Fig. 15. – A) Mass-transport complex in the basin floor environment, eastern Gulf of Mexico, which lies within a broad, flat-floored channel C) that ends abruptly at a terminal wall D). These sediments likely did not travel far but rather comprise a mass of material that was pushed from behind and slid to some degree along a decollement surface at the base (note the relatively flat base in section view (C and D). The complex rheology of this deposit is illustrated by the chaotic nature of the seismic reflections within the mass-transport complex as well as the tongues of sediments that extend beyond the terminal wall B). The relief of the channel is approximately 240 m.

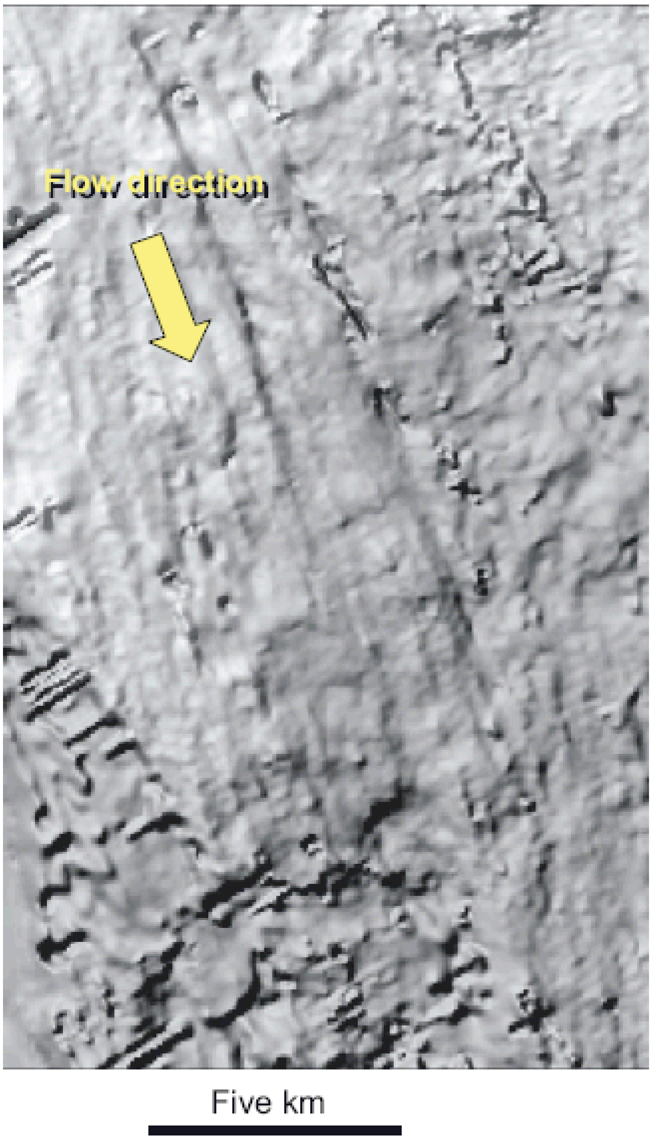

Fig.16. - Grooves beneath mass-transport complex deposited in a continental-slope environment (image courtesy of D. Mosher).

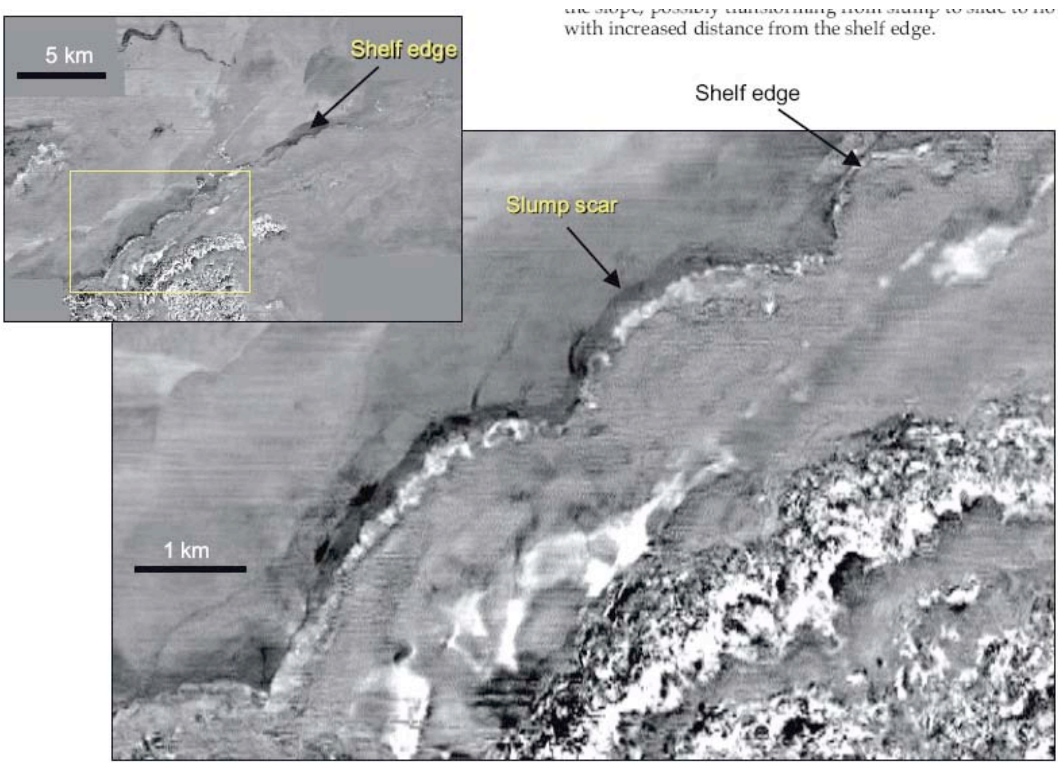

Fig.17. - Shelf-edge-detachment slump scars offshore Indonesia. These slump scars likely represent the point of detachment or staging area of sediments that traveled down the slope, possibly transforming from slump to slide to flow with increased distance from the shelf edge.

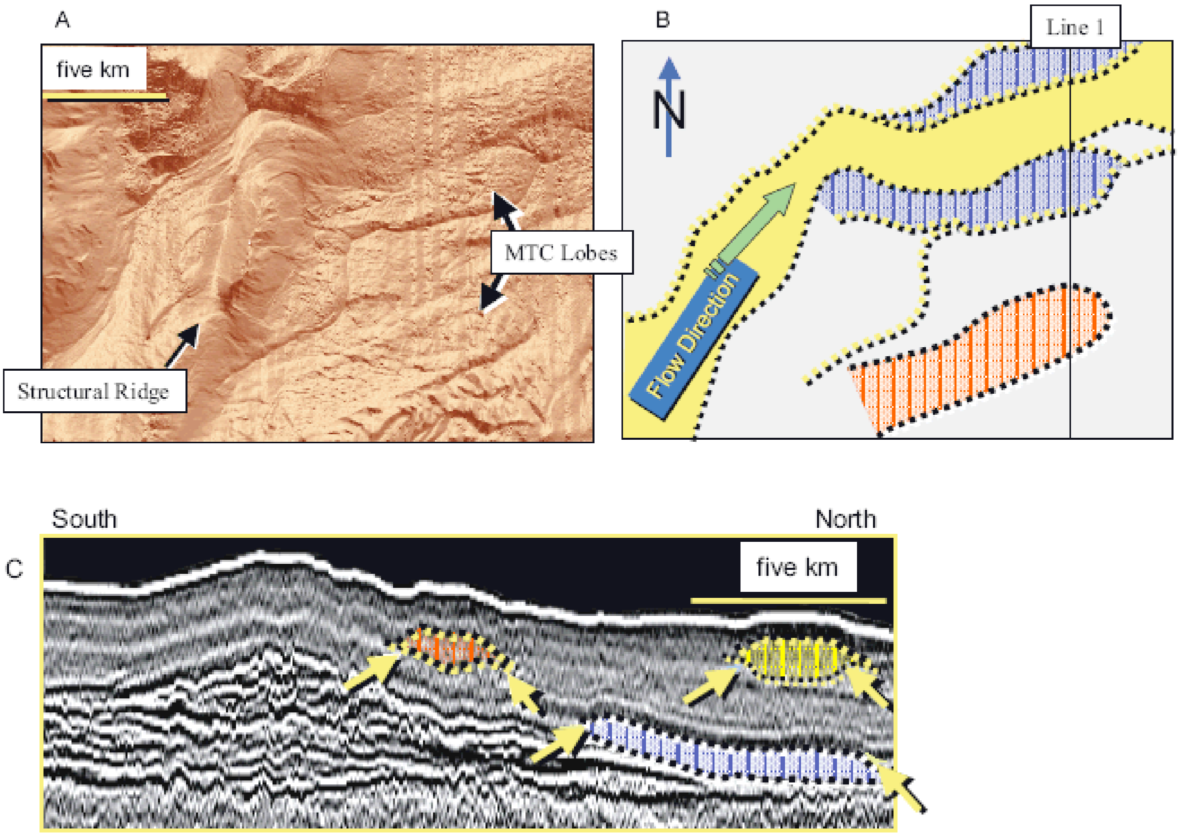

Fig.18. - Illuminated sea floor based on 3D seismic data A) and interpretation of mass-transport deposits B) on the basin floor of the Makassar Strait, Indonesia. Section view C) through several shallowly buried mass-transport lobes of various age. Note that these elongate lobes represent flow complexes imbedded within a low-amplitude seismic reflection package suggestive of hemipelagic to pelagic sedimentation. Because of the draping effect of the hemipelagic and pelagic sediments, these buried lobes all have sea-floor expression.

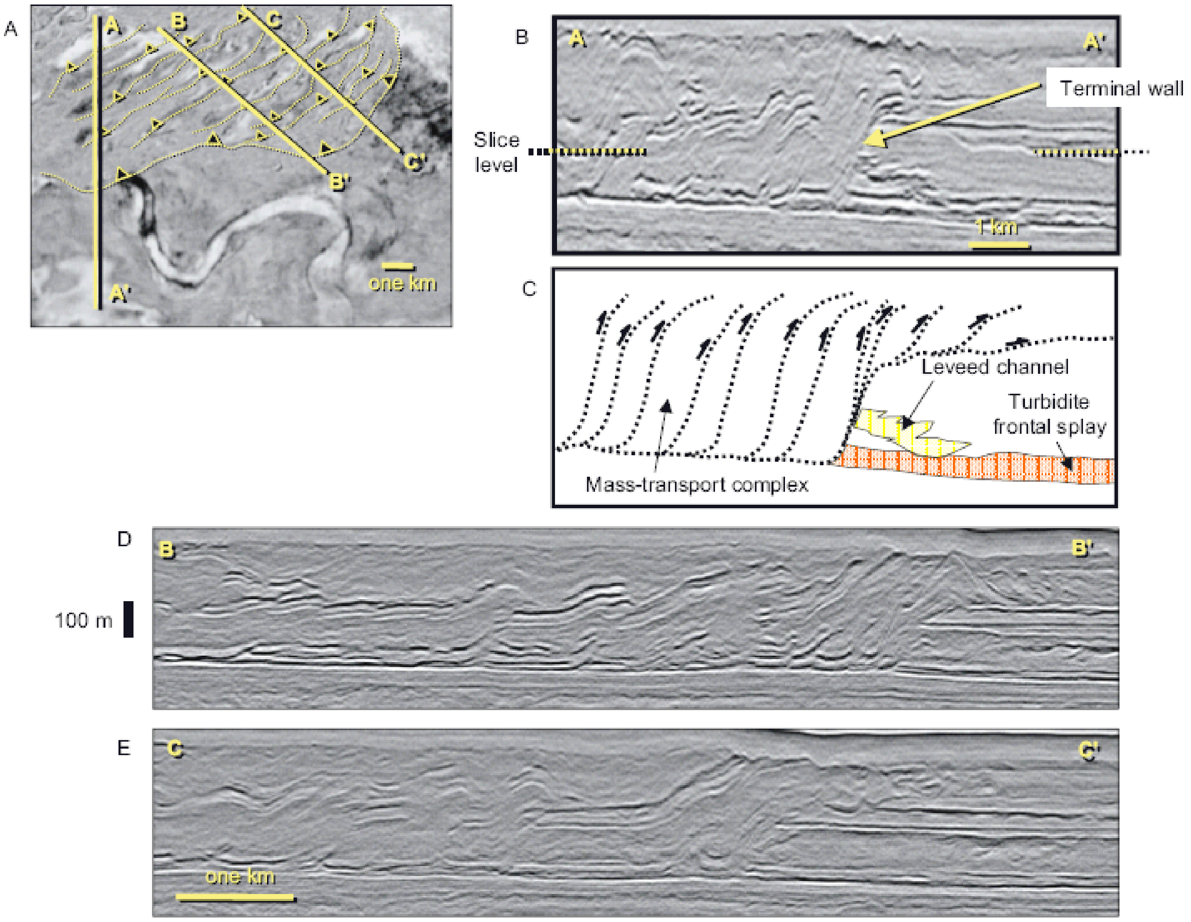

Fig. 19. - Example of the terminus of a mass-transport deposit, eastern Gulf of Mexico. This deposit shows evidence of having been transported across a decollement surface that likely was located within a condensed section at the base of a frontal-splay complex. In response to compression against a terminal wall, internal deformation in the form of thrust faulting occurred. The plan-view A) as well as the section views B–E) the clearly show the mass-transport unit entraining earlier deposited, sand-prone leveed-channel and frontal-splay deposits.

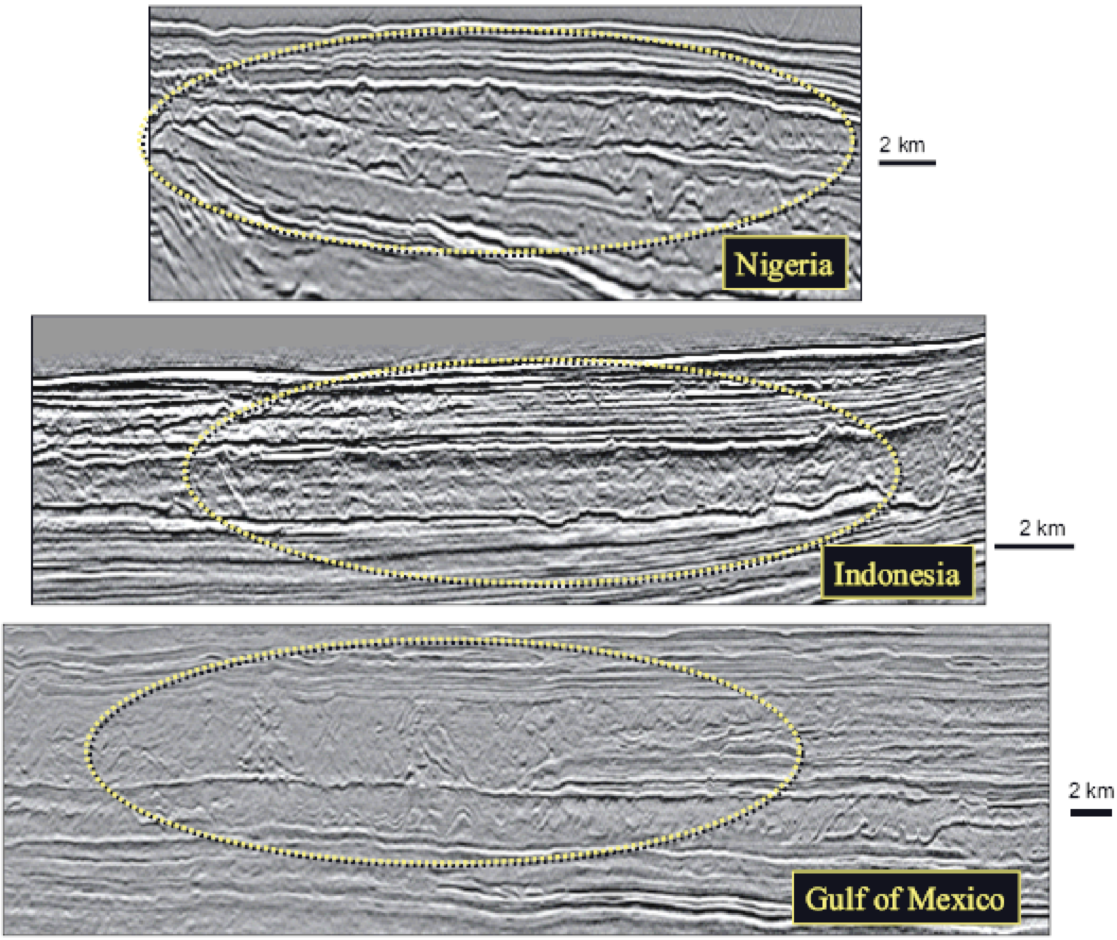

Fig. 20. - Cross-section view through three mass-transport deposits. Each is characterized by chaotic and contorted seismic facies pattern.

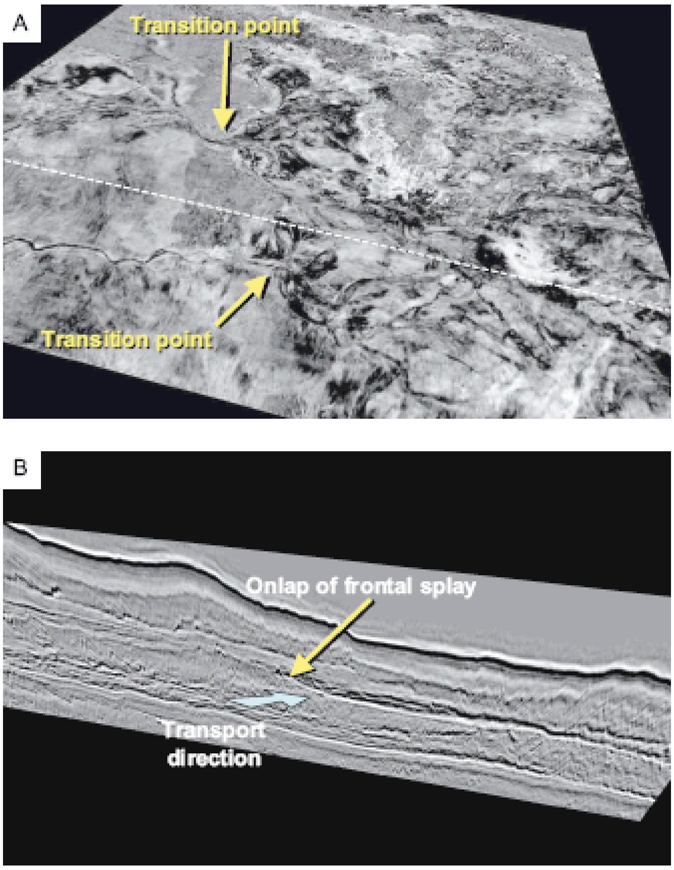

Fig. 21. - Influence on turbidites by rugosity atop mass-transport deposits. A) Seismic time slice that shows the transition point of a frontal splay, with extensive frontal-splay deposits seaward of that location. B) Seismic section that illustrates the onlap of frontal-splay deposits against a bathymetric high associated with the irregular top of a mass-transport complex.

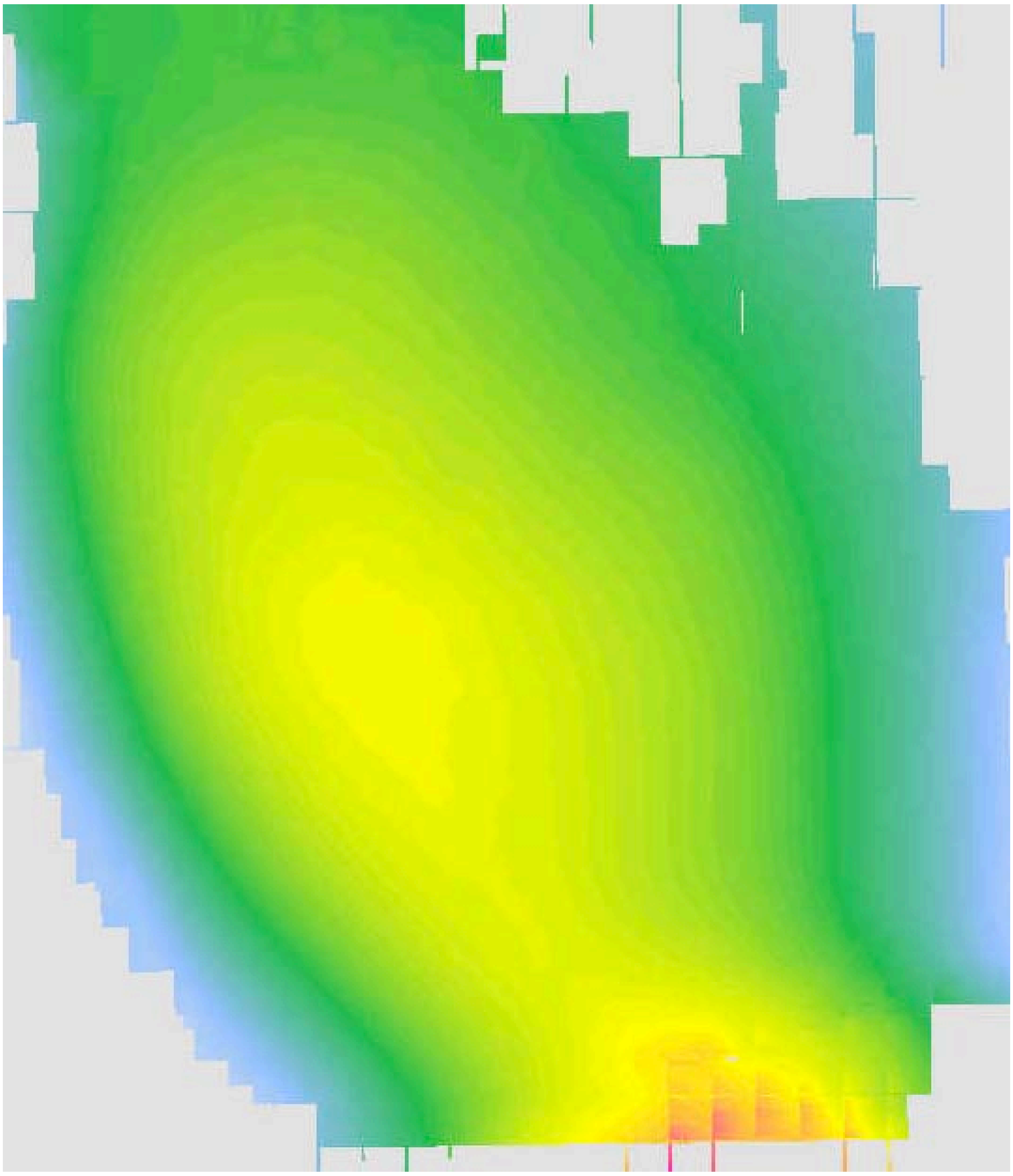

Fig. 22 Interpreted horizon