Shelf Delta to Deepwater Basin: A Depositional Model for Krishna-Godavari Basin*

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Abstract

Krishna-Godavari basin, located on east coast of India, is in a passive-margin setting with a lateral (coastal) extent of 500 km, and it extends more than 200 km from the coast into the deep sea. This basin has been fed dominantly by Krishna and Godavari river systems, along with numerous tributaries. The basin represents a depositional setting of a well defined shelf to shelf-edge delta to deepwater. The area is adequately covered by several vintages of 2D and focused 3D seismic data which have been primarily used for subsurface imaging. Further, the depositional units have been identified by interpreting seismic stratal patterns and facies distribution in a sequence stratigraphic framework. This is supplemented by information from wireline logs and cores. The gradational facies pattern, sequence boundary, transgressive surface, maximum flooding surface, channel architecture, etc. have been demonstrated in selected seismic sections for developing the concept. The study is not only useful in understanding the depositional processes in shelf/shelf-edge/deepwater and their linkages but also as a good guide for the deepwater hydrocarbon exploration targets.

Introduction

The Krishna-Godavari basin (KG basin) along the east coast of India (Figure 1) covers the deltaic and interdeltaic areas of Krishna and Godavari rivers and extends into the offshore. This stretch of sedimentary tract contains a vast range of geologic settings, such as costal basin, delta, shelf-slope apron, deep-sea channel, and deepwater fan complex. The basin has emerged as one of the frontier areas for future hydrocarbon exploration--after the multi-trillion cubic feet supergiant gas discovery in the recent years. The basin has significant hydrocarbon potential both in the Tertiary delta as well as in the channel-levee-overbank play types in deepwater. In this article, an attempt has been made to develop the linkage between the delta and deepwater depositional processes.

Figure 1. Location map of Krishna and Godavari delta, east coast of India.

Tectonic History

The basin was a major intracratonic rift within Gondwanaland until Early Jurassic. Exposures of Upper Cretaceous sedimentary rocks demarcate the basin margin toward the northwest (Rao, 2001). Onshore parts in the basin record a good account of Gondwana sediments. The basin evolved as a composite of rifted grabens, beginning in Late Jurassic, and formed a part of the development of the east coast divergent margin. The horsts and grabens were separated by vertical or steeply dipping faults. Since the Cretaceous, the basin has become a pericratonic rift basin. The initial rifting-drifting phase during this time generated fluvio-lacustrine sediments all over the basin. However, the transportation was over short distances, and therefore clastics of that time are devoid of sorting and are mainly argillaceous arkosic sandstones. The first marine incursion appears to have occurred during the Albian. The rift phase terminated by the end of Turonian in most parts of the basin, and subsequently, the post-rift sedimentary sequences prograded to the east with development of a continental shelf-slope system. The shelf areas received deposits of clastics and carbonate sediments while the slope registered deeper-water fan sediments. This setting, during which progradation was dominant, persisted throughout the Tertiary. The Paleocene and Eocene, in part, are considered to have been deposited during sea-level lowstands, thus forming fan complexes. From Oligocene onward, sea level began to rise, and more accommodation was available.

In the Tertiary, the deepwater area became structurally deformed by numerous sets of growth faults and related features. In most areas, a major decollement surface is present near or at the top of the Eocene and marks a major tectonic event. A series of growth fault systems progressively developed, with increased sediment influx during the Oligocene through Miocene time. The onset of the Pliocene is marked by major sea-level fall and a prominent erosional surface. These lowstand conditions prevailed into the Pleistocene.

The regional basement horsts (Bapatla, Tanuku, Kaza-Kaikalur, Kavali, Nellore and Nayudupeta) divide Krishna-Godavari basin into several sub-basins such as Pennar, Krishna, West Godavari, and East Godavari

(Figure 2). These sub-basins contain thick Cretaceous and older sediments above the Archaean basement, with several intervening unconformities. The basin contains a 4-7-km-thick sediment column, ranging in age from Late Carboniferous to Holocene (Figure 3).

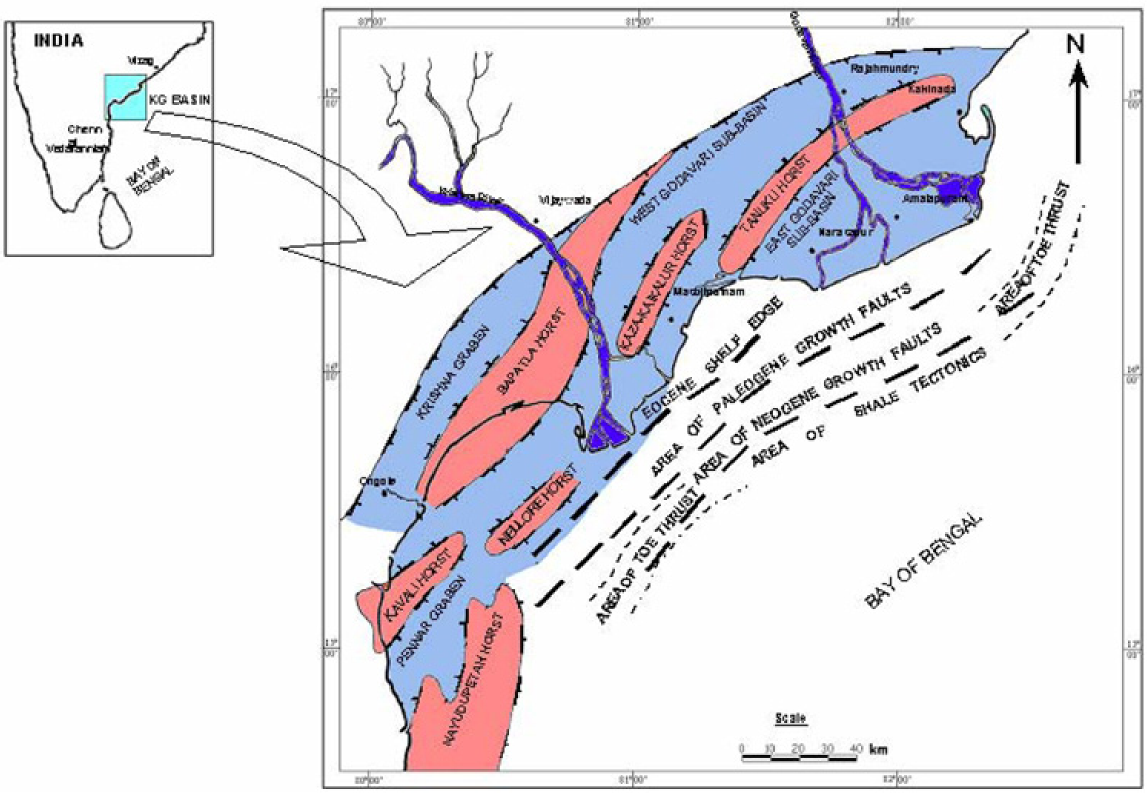

Figure 2. Map showing the structural trend and tectonic framework of Krishna-Godavari basin.

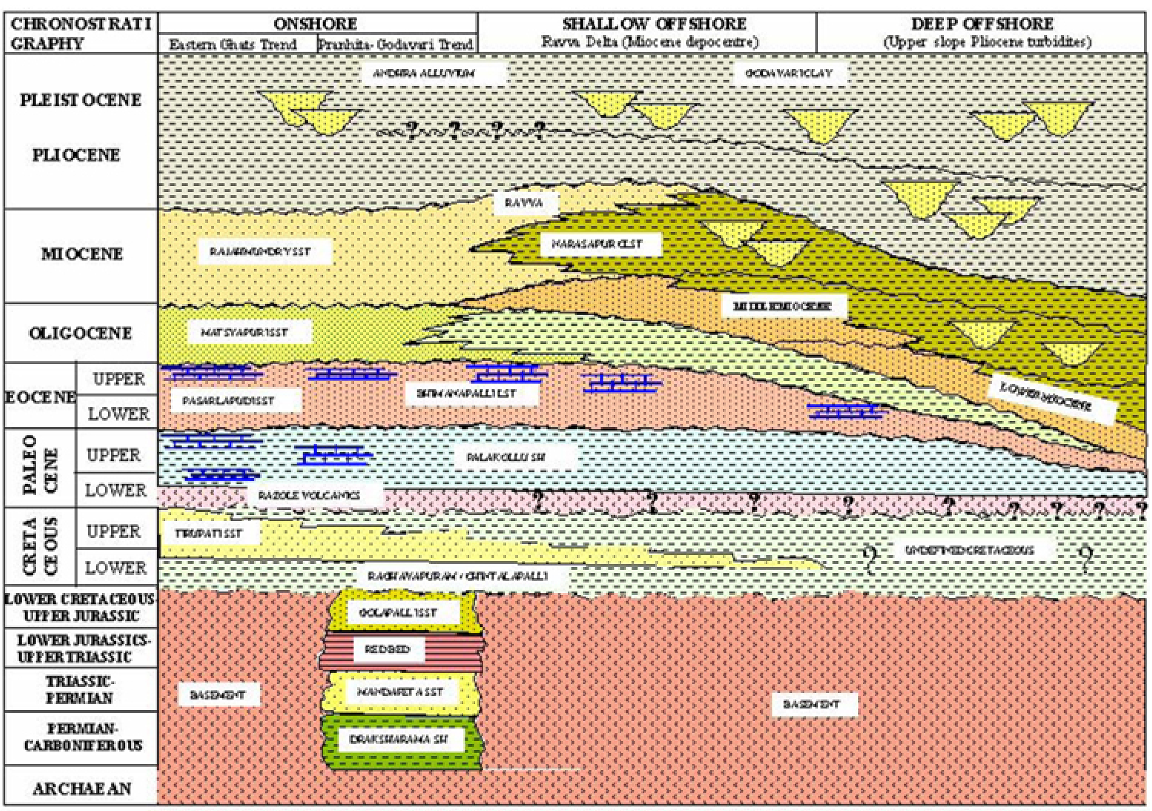

Figure 3. Generalised stratigraphy of Krishna-Godavari basin from onshore to deep offshore.

Sequence Stratigraphic Framework

Sequence stratigraphic framework indicates that, during lowstand period, sediments on the shelf are transported across the subaerially exposed shelf by fluvial systems and deposited as deep-marine sediments (Posamentier and Vail, 1988). Deep-marine deposition significantly increases after delta progradation to the shelf edge. Many modern deltas are known to have prograded throughout much of the Holocene marine transgression and resultant highstand. This indicates that the formation of shelf-edge deltas and consequent deep-marine deposition are not limited to times of relative sea-level lowstand and early transgression. According to Burgess and Hovius (1998), transport of considerable sediment volumes, including significant volumes of sand into the deep marine realm via shelf-edge deltas, is common during highstand times and may be enhanced by subsequent submarine canyon development. Highstand coast lines commonly are characterized by prograding deltas deposited during a period of decelerating relative sea-level rise. Times of sea-level lowstand have been associated with periods of high sedimentation rates. During early lowstand, because of sea-level fall, shorelines tend to prograde rapidly across the shelf, forcing depocenters to reach the shelf edge. This results in accumulation of large volumes of sand and mud at the shelf edge. Rapid sedimentation on the shelf edge and upper slope gives rise to frequent slumping, which can generate sediment gravity flows into the deep basin.

Deepwater sedimentation is likely to be most rapid during periods of sea-level lowstand because depocenters are most likely to be located at or near the shelf edge. However, deepwater sedimentation also occurs during highstands of sea level. Canyons that extend across the shelf and capture fluvial flow are active feeders as deepwater systems form during relative sea-level highstands (as in case of Congo River).

The facies and log expression of deepwater sandstone deposits are highly variable. In deposits resulting from confined flows in turbidite-levee complexes, a blocky to fining upward log pattern can be observed within the channels, whereas serrated log patterns and thin sand-shale alterations are more common in the levees and overbank deposits (Figure 4). In deepwater turbidite systems that were deposited by essentially unconfined flow (i.e., flow not confined by levees), tabular-bedded deposits commonly result.

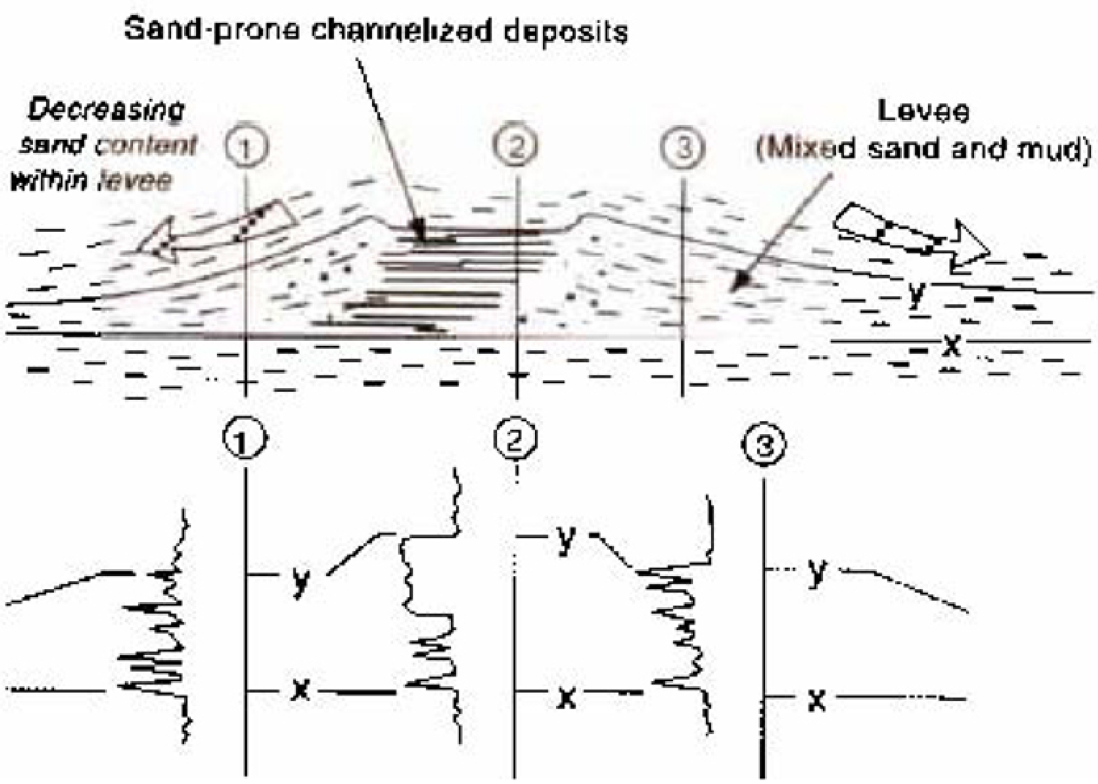

Figure 4. Schematic cross-section through a channel-levee complex illustrating sand and mud distribution. Image adapted from Posamentier and Allen (1993).

Interpretation

Several dip-oriented seismic profiles (Figure 5) are selected to link the shelf-edge delta systems of Krishna and Godavari deltas to the deepwater depositional systems. Interpretation processes involve identification and sampling of relevant seismic lines showing depositional features of different geological age, identification and marking of reflection geometries and patterns, establishing major bounding surfaces, identification and marking of major bounding surfaces on deepwater depositional features, and developing a sequence stratigraphic framework for shelf to deepwater depositional processes.

Line-1

The seismic line is chosen in a way that reflects the slope from shelf to deepwater and is oriented NW-SE. Since the seismic reflectivity data was non-optimal in continuity, the phase section has been used to identify seismic reflection geometries, truncation patterns, and hierarchy of major bounding surfaces in a seismic sequence stratigraphic framework.

The interpretation (Figure-6) aims to bring out spatial and temporal relationship between highstand delta system, shelf-edge delta system, and slope/basin-floor fan systems.

The stratal pattern showing erosional cut defined by a truncation boundary at the base and onlapping fill is indicative of incised valley. In correlation, the base of incised valley was carried along the truncations to define the sequence boundary. Down the slope, bimodal downlaps are noticed on marked sequence boundary and interpreted to be basin-floor fan. Identification of the above-mentioned features is indicative of rapid relative sea-level fall, marking the beginning of an early lowstand system during which the shelf was subaerially exposed and cut through by incised valleys to discharge sediments into the basin floor. This process highlights the genetic link between basin-floor deposition and highstand shelfal facies, which are actually the substrate for incision. If sediment supply is low, then basin-floor complex will consist predominantly of reworked sediments of the previous highstand system.

The downlap reflection terminations onto basin floor fan and onlap to the sequence boundary are indicative of a lowstand wedge complex (LSW) formed when the rate of relative sea level fall slowed. During this late lowstand period, sediment supply systems came very close to the shelf edge and discharged sediments down the basin, as shown by down-stepping shelf-edge deltaic progradations. This period marks the vital link between the shelf-edge processes and deepwater subaqueous channel-levee complex.

Tracing the last downlap event on basin floor fan updip to the shelf will mark the maximum flooding surface (MFS). Sandwiched between the first transgression at the shelf edge and maximum flooding surface is the transgressive system tract (TST) indicated by backstepping – the termination of events. Incised valleys tend to be filled during early transgressive time and to be overlain by finer clastics during late transgressive time.

The highstand delta system represents the time when the rate of relative sea-level rise slowed down and with increased sediment supply shoreline started to regress, as indicated by prograding clinoforms downlapping on the maximum flooding surface. Interpretation of a highstand delta, in general, is difficult and tentative, owing to cannibalization by the next lowstand depositional cycle. This framework can further be used to analyse the facies distribution within the sequence.

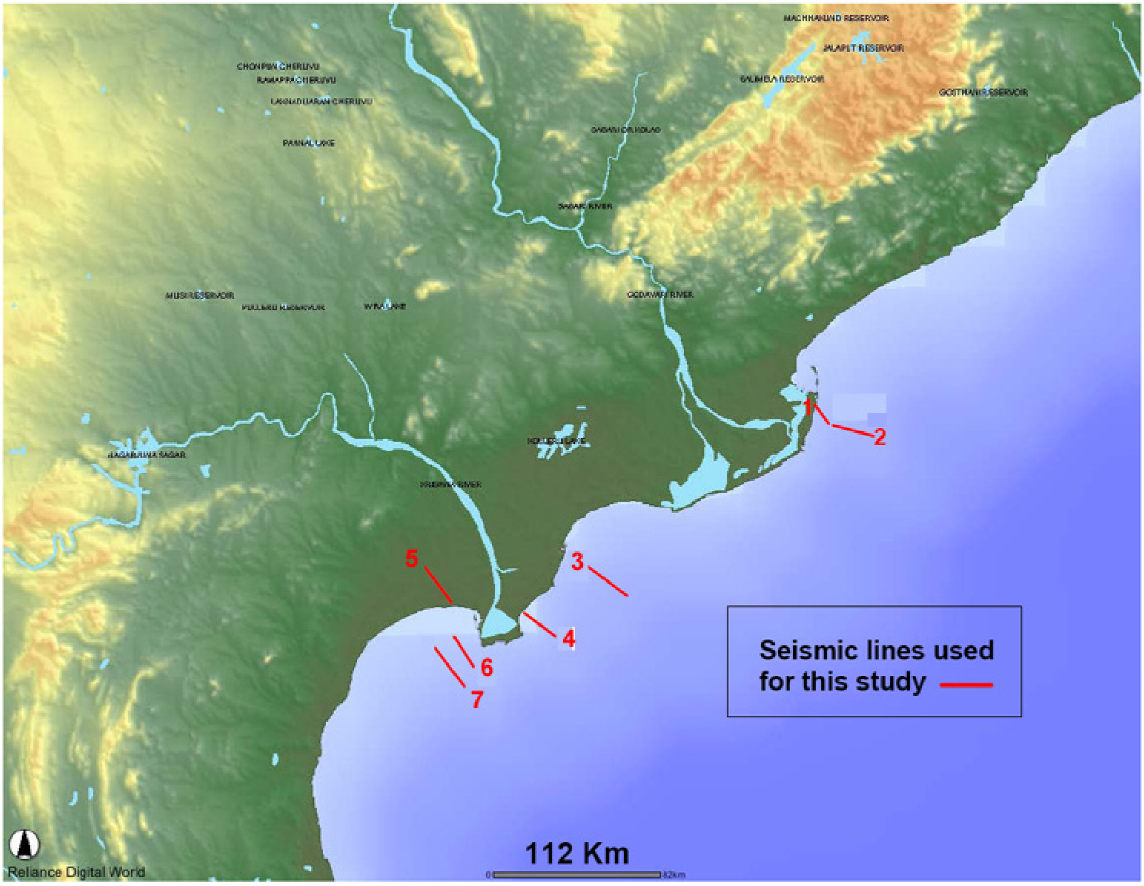

Figure 5. Map showing dip-oriented seismic profiles used for this study.

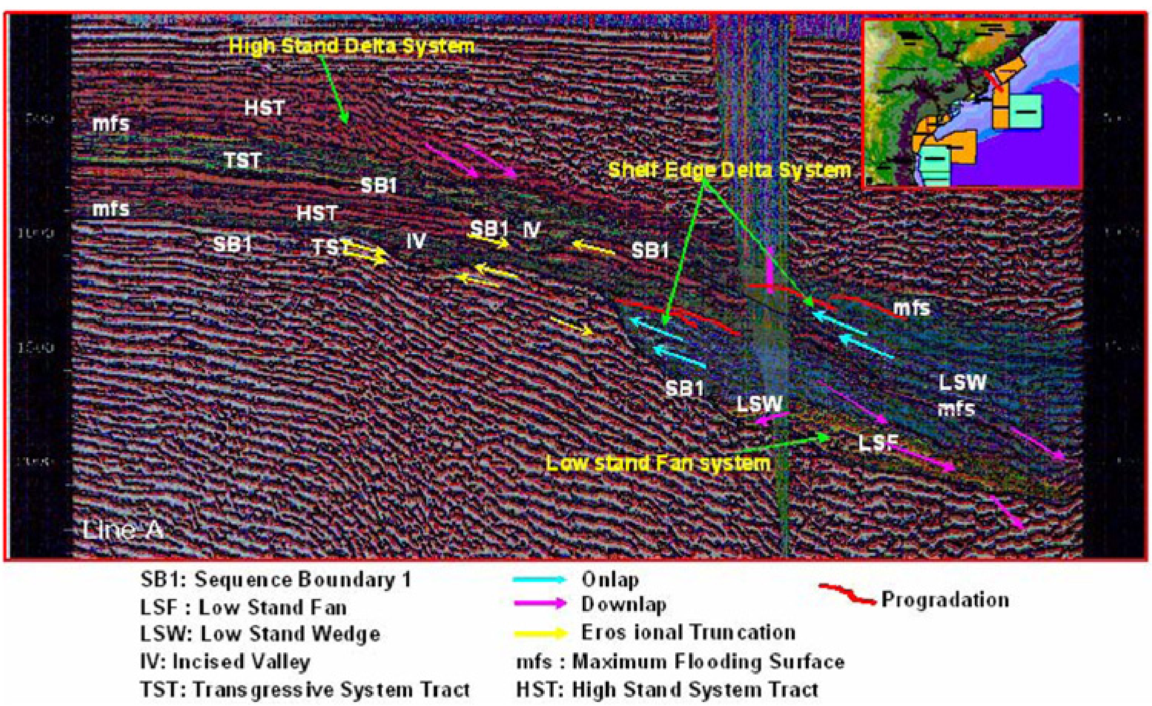

Figure-6: Seismic Phase section (Line-1: location in Figure-5) showing major sequence stratigraphic elements connecting highstand prograding delta on the shelf (HST), lowstand wedge (LSW), and slope/basin floor fan (LSF). During HST period shoreline transgressed the coast with increased accommodation space on the shelf whereas during LST period shoreline regressed because of decreasing accommodation on shelf, thereby bringing sediment discharge systems close to shelf edge. During early lowstand period, sediment discharge systems incised the shelf and deposited lowstand fans (LSF) on the basin floor and, subsequently, on the slope. During late lowstand period, river systems discharged sediments at the shelf edge, forming lowstand wedge.

Line-2 (Figure 7)
This 3D seismic section is through a deepwater well drilled in the Godavari basin. The gamma-ray log is superimposed on seismic section to indicate lithology, as deflections to the right indicate higher gamma-ray count and therefore more shaly units. LSF is indicated by blocky low-gamma ray sections. The bottom part of this unit is a basin-floor fan deposit, whereas the upper part is a channel-levee complex of a slope fan. Fining-upward sequence is indicative of TST. The upper part of a TST, where gamma-ray log shows the highest value, is identified as a maximum flooding surface. As this is a deepwater depositional sequence, HST and SB signatures are not evident but are represented by their correlative conformities.

Line-3 (Figure 8)
This dip-oriented seismic line is located north of the Krishna Delta connecting the shelf to the upper and lower slope. Interpretation is made only for Late Miocene-Pliocene sequence. Vertical aggradation is more common during shelf-edge migration from PS1 to PS5, and progradation becomes dominant during shelf-edge migration from PS5 to PS6. The seismic line is along the sinuous channel between surface H1 and H2 (embedded in Figure 8). The slope channels are identified between H1 and H2. In three dimensions, it takes a sinuous channel shape.

The surface H1 can be interpreted as a sequence boundary with onlap (marked by green arrow) and the channel features evolving from the shelfal area. The surface H2 cannot be extended into the slope area with confidence, and the package of sediment from H2 to H3 can be thought of as downlap onto H2, probably in an increasing shelfal accommodation setting. Unit F shows a bidirectional downlap onto H3, and also there is evidence of onlap onto H3, indicating sequence-boundary conditions. The emphasis is the linkage of the shelf between H1 and H2 with the slope channels downdip. This may be delta building on the shelf, giving rise to slope sedimentation in the form of deepwater sinuous channels.

Line-4 (Figure 9)
This seismic line is located near to mouth of the present-day Krishna River. Seismic section shows the shelf-edge delta system and lowstand fan complex. The lowstand fan complex consists of slope fan and basin-floor fan deposits. In the proximal part of the slope fan complex, subaqueous, high-sinuosity, sand-rich channel with associated levees may be present, although the whole system of slope fan complex is likely to be mud-rich.

Line-5 (Figure 10)
The seismic line is located in the KG onland basin, near to the Krishna River. The line shows the shelf-edge-deltaic, prograding clinoforms of Cretaceous-Paleocene age. The downstepping clinoforms indicate subaerial erosion and sediment bypass to the slope/basin floor. The bright amplitude of foresets at the shelf edge indicates the presence of coarser clastics at the mouth of the delta.

Line-6 (Figure 11)
This seismic section is from the Krishna delta and shows a lowstand shelf-edge delta system. The younger canyon system cannibalized the shelf and subsequently dumped these sediments on the basin floor as a basin-floor fan complex.

Line-7 (Figure 12)
This seismic section shows the features from shelf to deepwater. Typical reflection geometries defined either by bimodal downlap on a sequence boundary or downlap downdip and onlap updip reflection geometries are indicative of lowstand fan complex.

Key to identify the shelf-edge delta system was to identify prograding and downstepping reflection characteristics at the shelf edge.

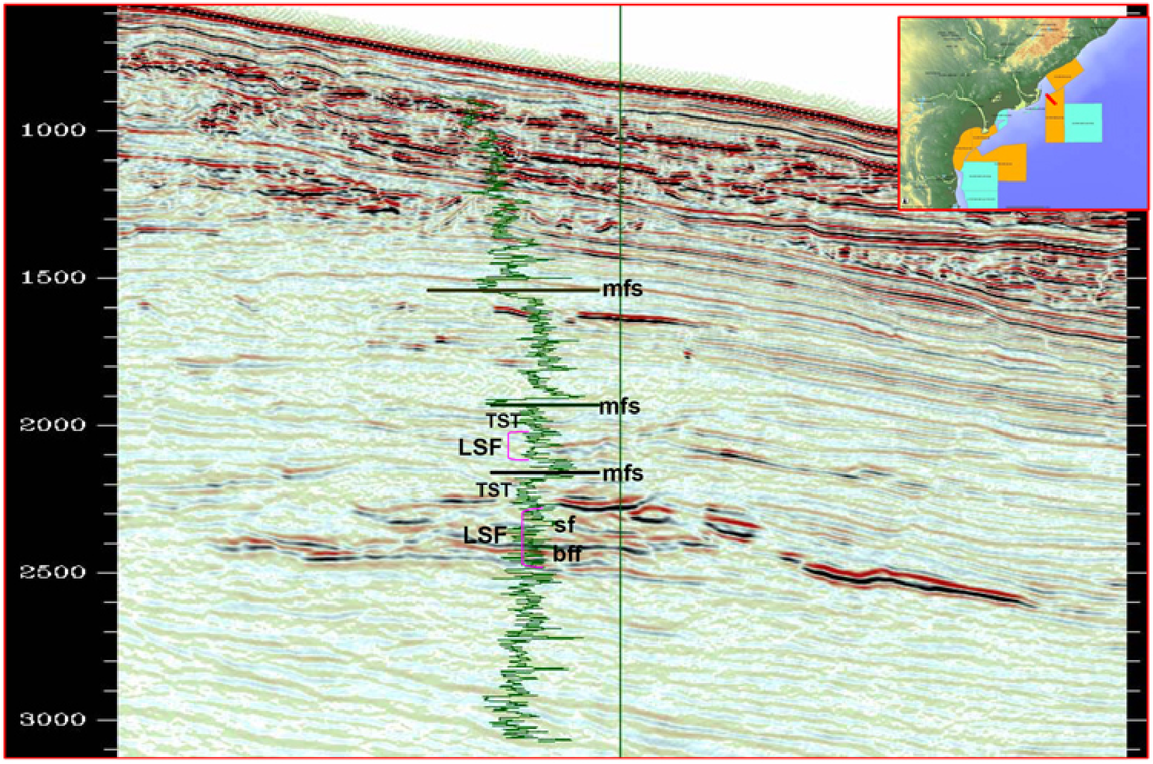

Figure 7: Seismic Line-2 (location in Figure-5) showing deepwater channel-levee complex. The superimposed well information confirms the predicted lithology, consistent with the depositional model. The log pattern also characterizes various depositional units.

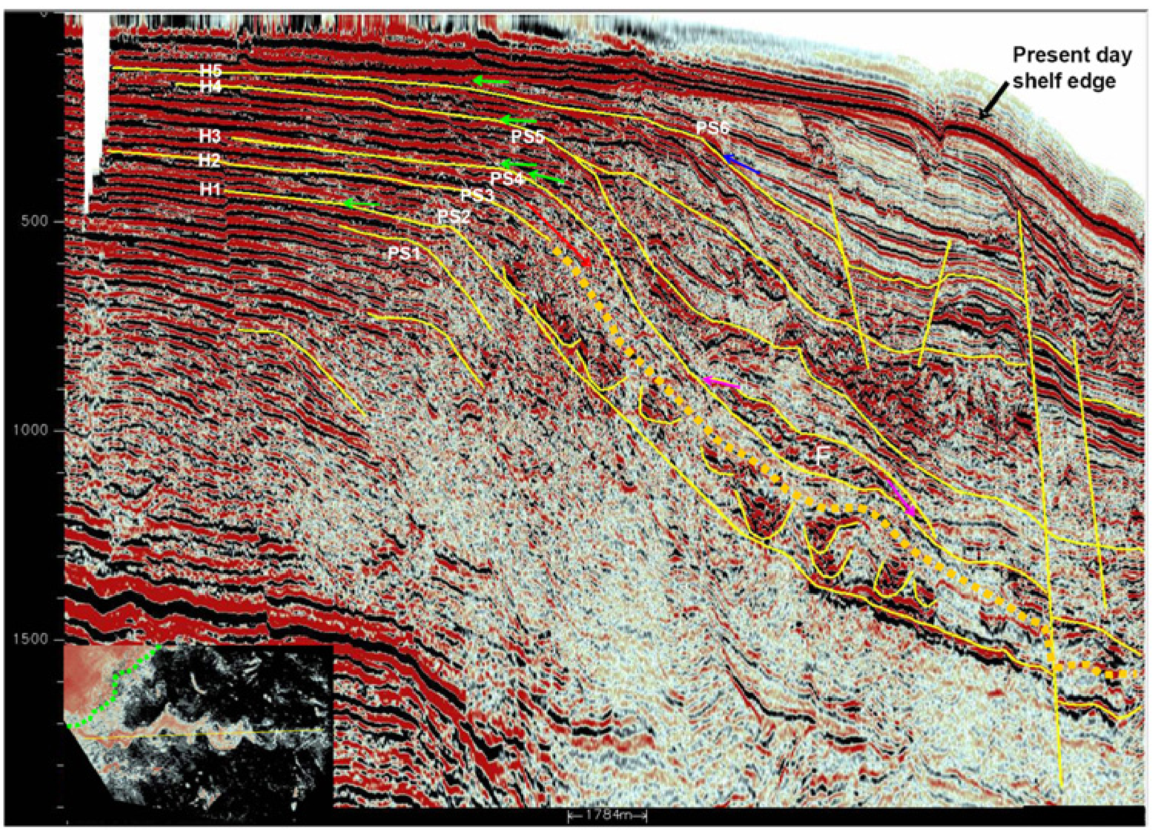

Figure 8. Seismic Line-3 (location in Figure 5) showing deepwater channel-levee complex. Bff indicates basin-floor fan and sf indicates slope fan.

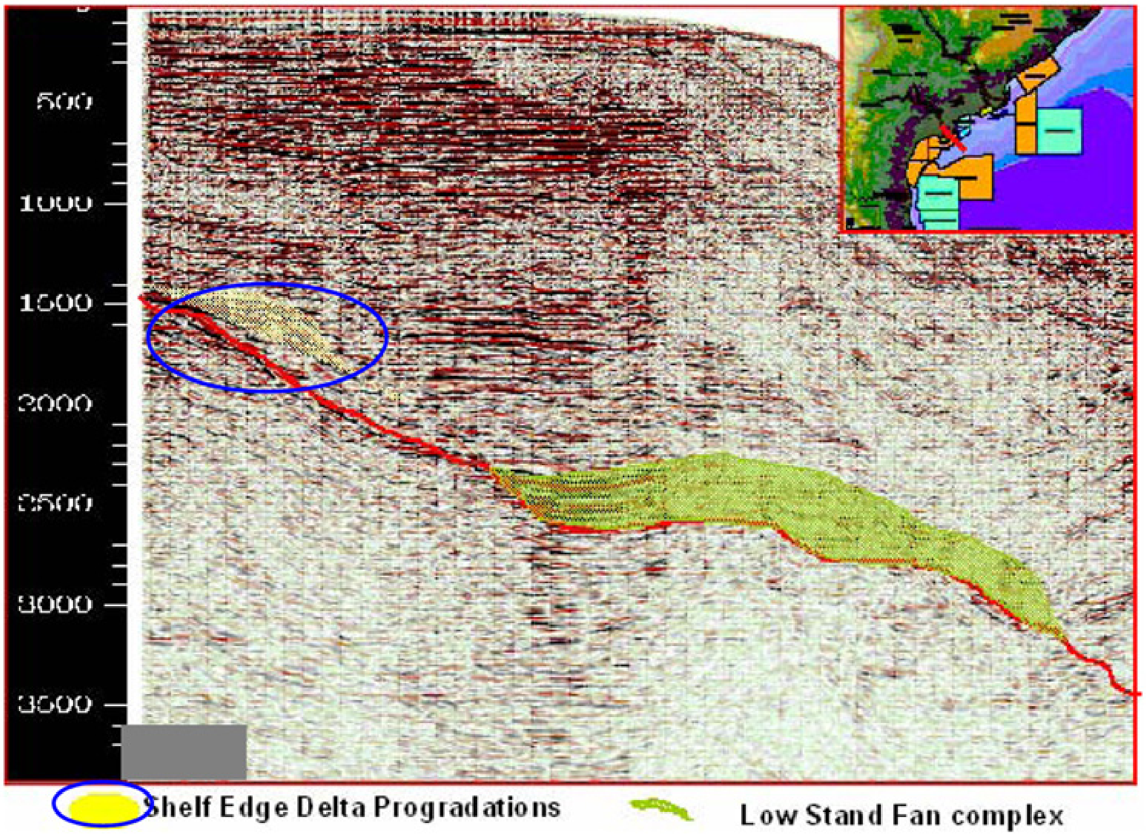

Figure-9: Seismic Line-4 (location shown in Figure-5) showing shelf-edge delta progradation and lowstand fan complex

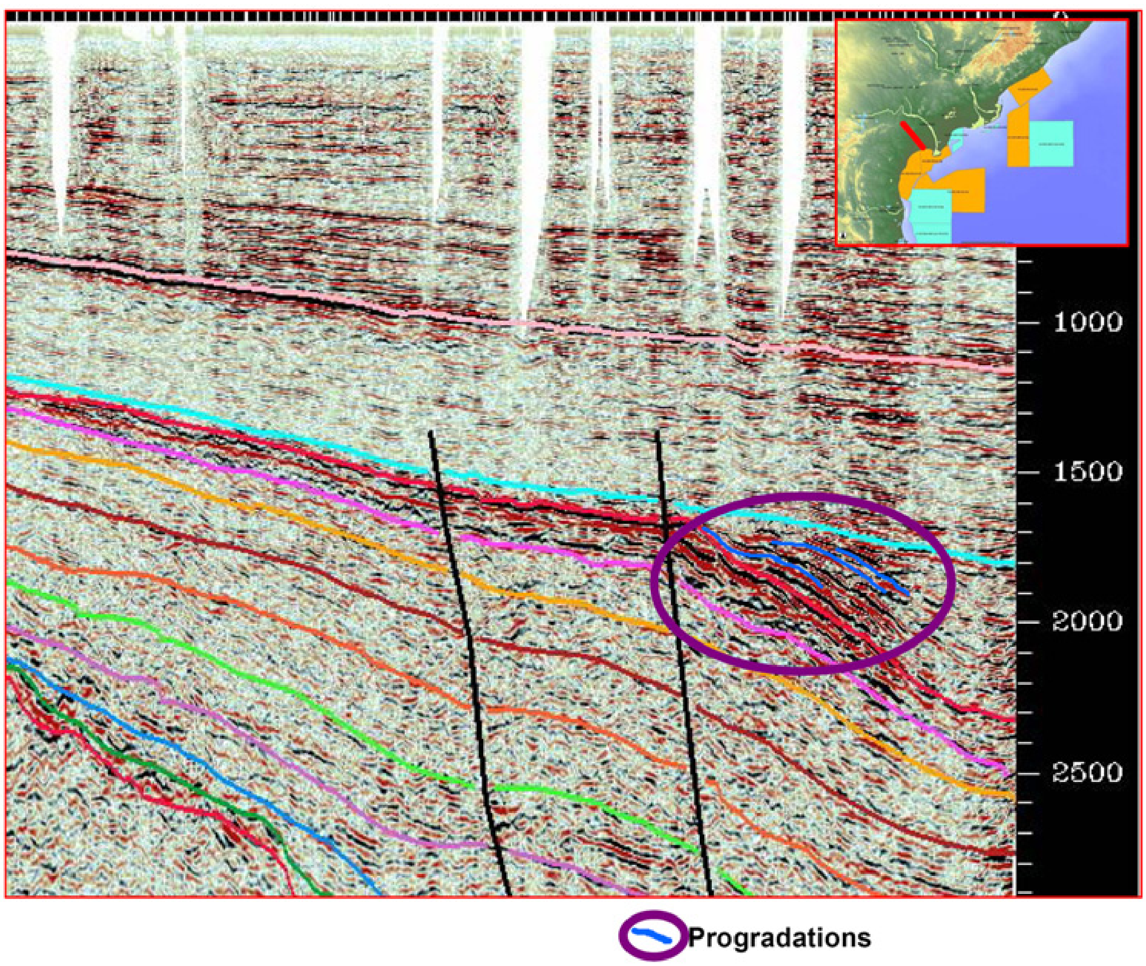

Figure-10: Seismic Line-5 (location in Figure-5) showing shelf-edge progradation.

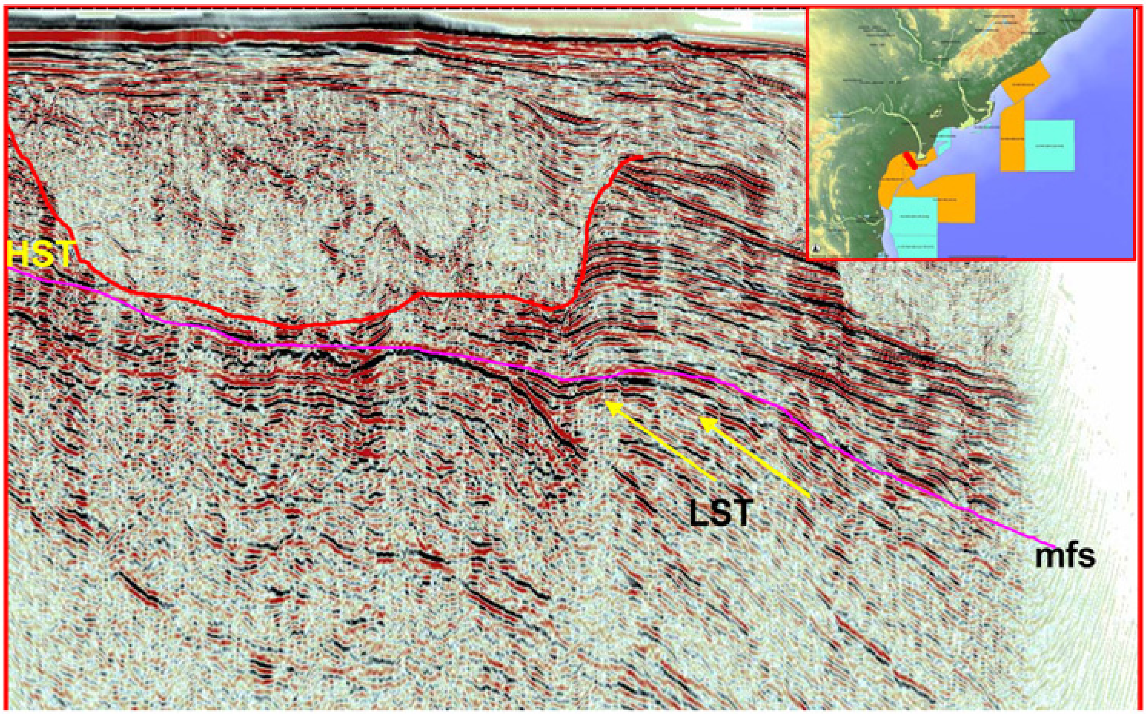

Figure-11: Seismic Line-6 (location in Figure-5) showing shelf-edge delta and younger canyon cut.

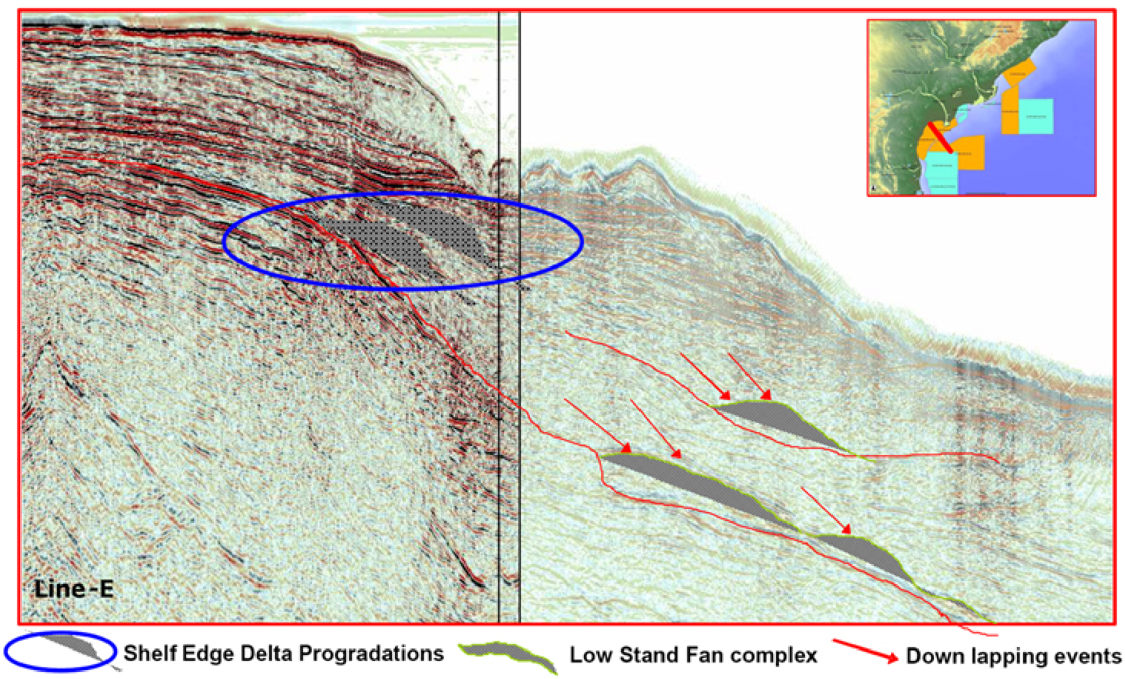

Figure-12: Seismic Liine-7 (location in Figure-5) showing shelf-edge delta build-up and lowstand fan complex.

Conclusion

Sequence stratigraphic approach provides a model to understand the sedimentological processes by interpreting the seismic stratal geometry and their facies assemblages. This approach helps in linking the depositional elements on a regional scale, ranging from fluvial to deepwater. During a lowstand period, the accommodation space in shelf environments decreases, facilitating the basinward migration of the fluvial delta. This process loads the shelf edge, forming shelf-edge delta. The collapse of a shelf edge due to slumping or direct fluvial discharge to deep basin, because of hyperpycnal flow, carries the sediments into the deep basin, forming the lowstand deposits in the form of basin-floor fan, slope fan (channel-levee complex), crevasse splay, frontal splays, etc., which are potential reservoir facies. Lowstand systems tract has its expression on the shelf as incised valleys, prograding shelf-edge delta, and sediment bypass zone and is recognized by an associated unconformity, whereas in deepwater the equivalent surface is represented by its correlative conformity. The concept helps in predicting reservoir lithofacies, thereby providing the identification of potential hydrocarbon play types in both shelf as well as deepwater settings.

References

Burgess, P.M., and Hovius, N., 1998, Rates of delta progradation during highstands: consequences for timing of deposition in deepmarine systems: Journal of the Geological Society, London, v. 155, 1998, p. 217-222.

Posamentier, H.W., and Allen, G.P., 1993a, Variability of the sequence stratigraphic model: effects of local basin factors: Sedimentary Geology, v. 86, p. 91-109.

Posamentier, H.W., and Vail, P.R., 1988, Eustatic controls on clastic deposition II—sequence and systems tract models, *in* Wilgus, C.K., et al., eds. Sea level changes: An integrated approach: SEPM Special Publication no. 42, p. 125–154.

Rao, G.N, 2001, Sedimentation, stratigraphy, and petroleum potential of Krishna-Godavari basin, East Coast of India: AAPG Bulletin, v.85, no.9, p. 1623-1643.