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Sequence Stratigraphy and Evolution of the Miocene to Recent Deepwater Dispersal System in the Distal Part of The Krishna – Godavari Basin, India

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Abstract

The study area, located in the abyssal plain of the Krishna Godavari basin, in water depths exceeding 3000m has more than 4km of sediments deposited from Early Cretaceous till Recent times. The Bengal Fan is the main sediment dispersal system in the area. Significant surfaces of erosion and continuous conformable condensed sections help to define the sequences from Miocene to Recent. Amalgamations of sequence significant surfaces, due to the distal setting of the area are observed. The equivalents of the maximum regressive surface and the maximum flooding surface amalgamate in the condensed sections. Tectonic control on sequence development is interpreted at the base of Mid Miocene. Differentiation among sea level, tectonic or climatic causes are difficult in case of most other sequences. Sequence analysis of this interval reveals both autogenic as well as allogenic controls were responsible for the formation of ten major sequences. Possible interplay between the Bengal fan and Krishna- Godavari dispersal system is observed.

Introduction

The passive margin deepwater Krishna-Godavari (KG) basin is situated along the Eastern Continental Margin of the Indian Plate (ECMI). The basin evolved as passive margin basin, after the Late Jurassic- Early Cretaceous break-up of India and Antarctica (1 & 2).The the syn-rift and early post-rift basin history is recorded in the onland to proximal deepwater areas. Oceanic crust was emplaced from the Early Cretaceous onwards, after which the distal deepwater area of the basin started receiving sediments during the passive margin stage. The study area is situated nearly 250 km SE of the Godavari Delta and is flanked on the East by the NS extending volcanic 85° E Ridge (Fig. 1). The main source of sediment in the study area is from Bengal Fan (Ganges-Brahmaputra system), whereas K-G system is also thought to have dispersed sediments especially in the early times of the passive margin phase. The events related to the Himalayan orogeny from Mid-Miocene onwards bring a remarkable change in the sedimentation style and rates in the area and major progradation of the Bengal Fan is known. The present study analyzes the Miocene to Recent sedimentation history of the area based on sequence analysis.

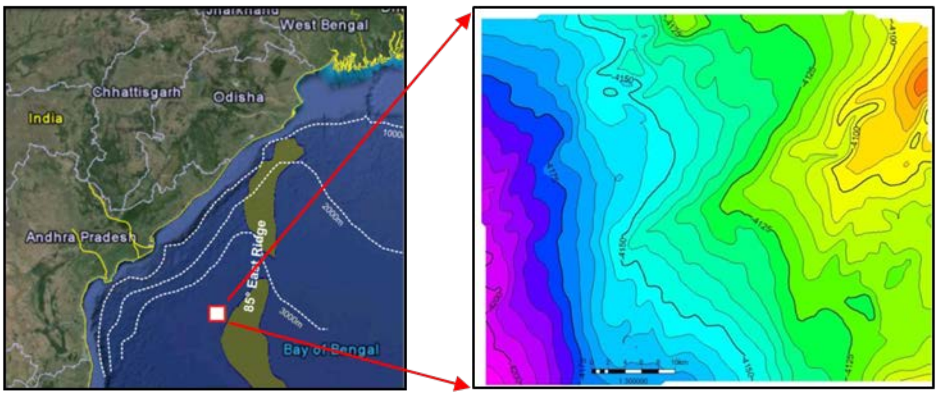


Figure 1: Location Map of study area and time structure map at sea floor.

Methodology

The present study is based on analysis of 2200 sq km of 3Dseismic data. Seismic facies have been used to interpret the architecture of depositional elements. Truncations and discordant relations between seismic events have been interpreted to represent erosional surfaces. Parallel continuous events are interpreted as pelagic deposits, while sub parallel to downlap events are mainly associated with levee or splay facies. Chaotic and sigmoid events are present within channel belts. High amplitude continuous seismic events & erosional surfaces (correlatable) have been interpreted and correlated. In the deep water realm these are the two most significant surfaces for definition of sequences (3). In the present context, erosional surfaces could be caused by relatively local shifts in major dispersal elements, while continuous events, recognized as condensed surfaces have been used to define the sequence boundaries. Age calibration of the Miocene to Recent sequences is based on regional correlation with drilled wells. Attribute analysis (mainly RMS amplitude) of these surfaces and the sequences bounded by them have been carried out to understand spatial and temporal variations of depositional elements.

Sequence Analysis

On the basis of regionally correlatable condensed surfaces, ten major sequences are recognized, in the Miocene to Recent times, though finer sequences with local extent are also present (Fig. 2).

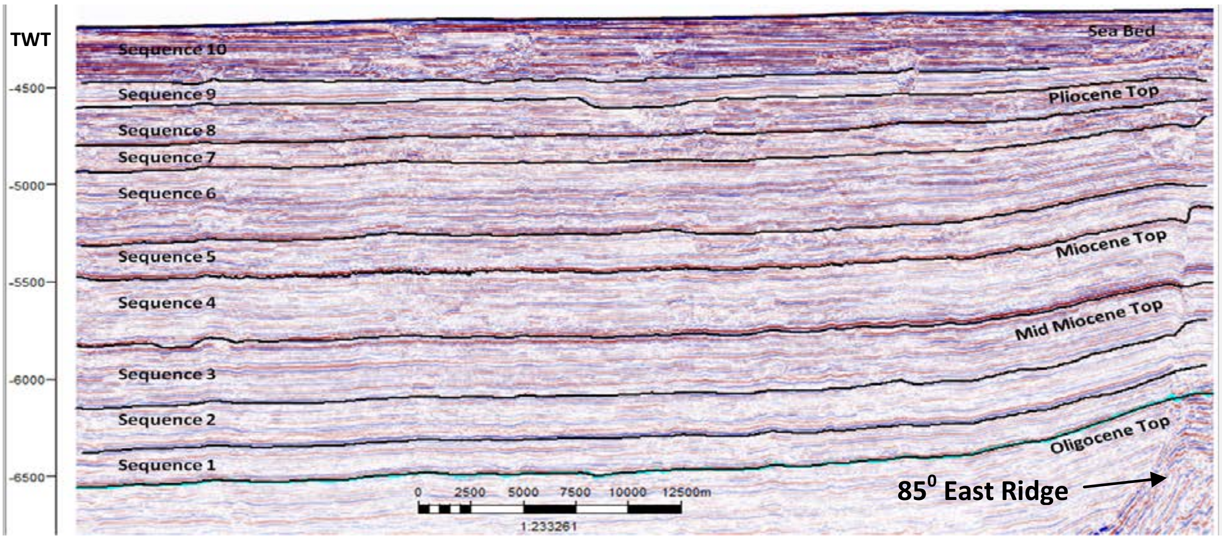


Figure 2: E-W Seismic section showing 10 sequences

Miocene Base to Mid-Miocene Top

Sequence 1: In the basal part of the Miocene sequence NE to SW flowing meandering and straight channels are present, with low channel density. While the meandering channels are concentrated in the SE, the straight channels are present to the NW (Figure 3a). Upward in the sequence, the meandering channel density increases while the major channel in the central part develops levees and overbank deposits with bright amplitudes (Fig. 3b).

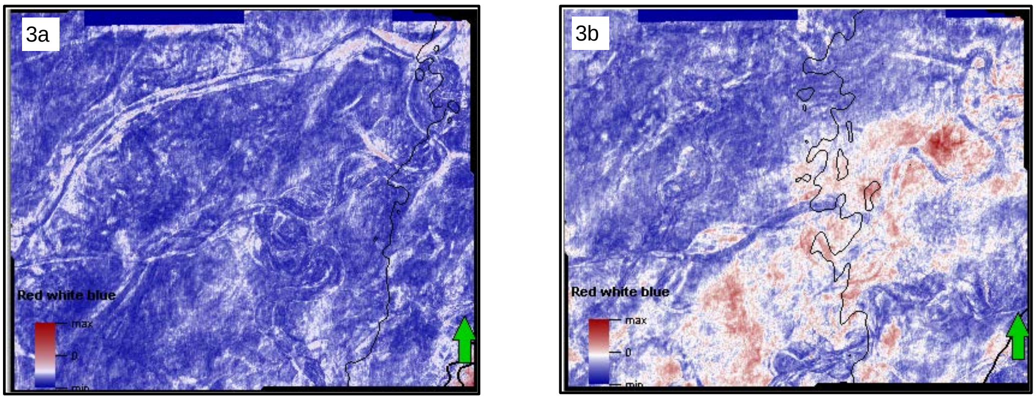


Figure 3: RMS Amplitude slices: a) Straight and meandering channels with feebly developed levees. b) Meandering channels and high amplitude over bank deposits.

Sequence 2: This sequence starts with low frequence of low sinuosity, SE flowing channels. Higher up in the swquence, an avulsion nodes are seen in the northern parts of the area, from which multiple moderate sinuosity channels emerge indicating several episodes of avulsion (Fig. 4a). The avulsion nodes seem to be plugged by a relatively coarser clastic fill, represented by brighter amplitudes. The change from low channel frequencies in the lower part of the sequence to higher frequencies and greater channel depths in the upper part is a distinctive feature (Fig. 4b). An erosional surface with truncation of underlying events seen in the section which can be taken as equivalent of the correlative conformity *sensu* Hunt and Tucker, 1992 (4). This surface separates underlying interval with relatively straight channels from the overlying interval with entrenched meandering channels.

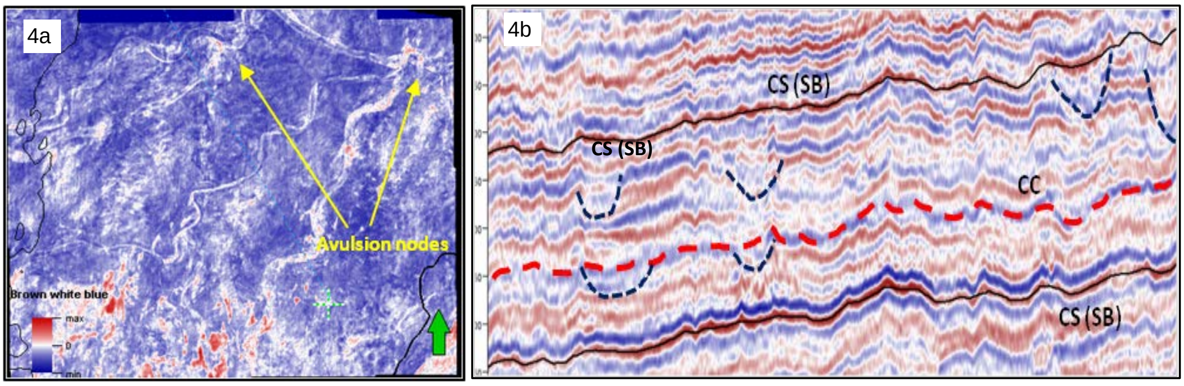


Figure 4: a) Avulsion nodes in northern parts of the area. b) Sequence 2: Dashed red line showing possible correlative unconformity, channels are marked in red.

Sequence 3: The sequence starts with highly sinuous but wider channels which erode the underlying condensed section, probably indicating higher sediment supply. Higher up in the sequence the channels become less sinuous and relatively confined indicating increase of mud in the sediment load and formation of levees. Overall the channel density is relatively less than the earlier sequence but presence of levees and crevasse splays indicate increased sediment load (Figure 5a). In the lower part the channels flow towards SE and could be sourced either form the Godavari Fan or from an avulsed channel further to the NW. Further up in the sequence the channels flow from NE to SW (Figure 5b), with moderate to high sinuosity. The dominant lithology in the overbank as well as the channels seems clay, indicated by the low amplitudes, implying the system has prograded and the coarser clastics have bypassed the area and deposited further downstream. The internal switches in the flow directions could be either due to autocyclic process of channel system adjustment or due to dominance of one dispersal system over the other, rather than changes in sea level.

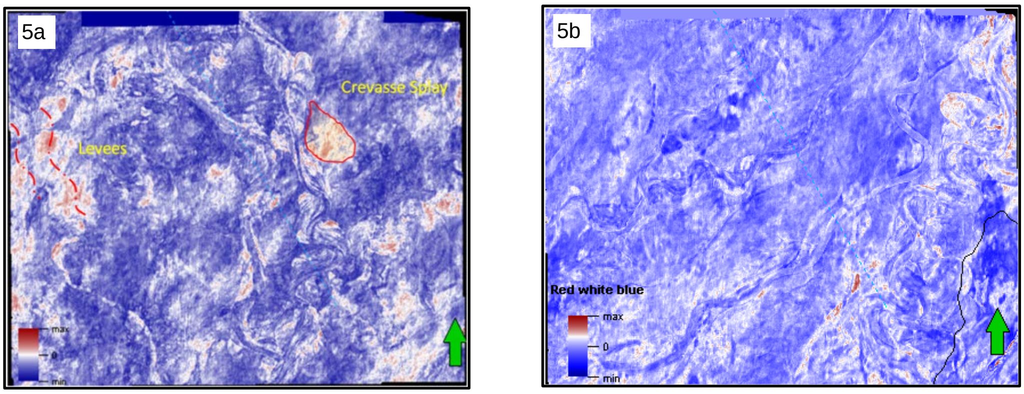


Figure 5: a) Map showing principally S flowing channels with levees and side lobes, the central channel shows SE flowing direction before taking Southward trajectory. b) SW flowing channels.

Sequence No. 4, Mid Miocene to Miocene Top: At the Mid Miocene Top, low frequency but bright continuous events are observed. Truncation of underlying events is seen at their base (Fig. 2), which is a widespread feature in the area. RMS slice in the interval show uniform amplitudes with a near absence of channels (Fig. 6a), indicating retrogradation of the dispersal system and pelagic deposition. The immediate overlying interval shows presence of high frequency of straight SW flowing channels with low amplitude fills (Fig. 6b). This indicates a rapid progradation of the dispersal system with high bed loads.

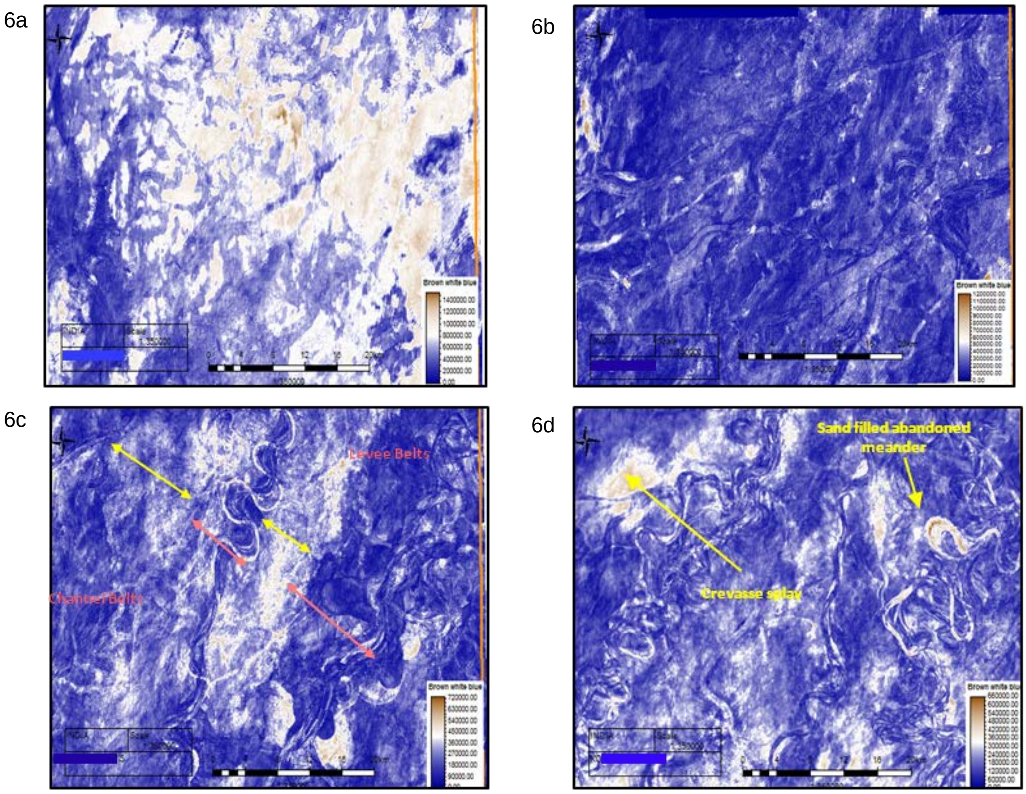


Figure 6: RMS a) At Mid Miocene Top, b) ~40ms above Mid-Miocene Top, c) ~300ms below Miocene Top and d) ~100ms below Miocene Top

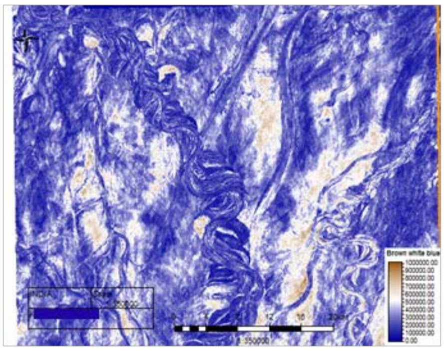
The overlying interval shows presence of sigmoid to oblique reflections occupying channel belts with asymmetric flanks and surrounded by levees with distinct 'gull wing' geometries. The width of channel belts is at times more than 4km, with levees on either banks spreading upto 20km away from the channel belt. Higher up in the sequence the channels become entrenched with high sinuosity and probably richer in coarser clastic content, indicated by higher amplitudes both within channels and the levees, implication being progradation of the system. This major progradation with channels of much larger dimensions represents initial rapid progradation of the Bengal Fan system.

Sequences 5 to 10: Miocene Top to Recent

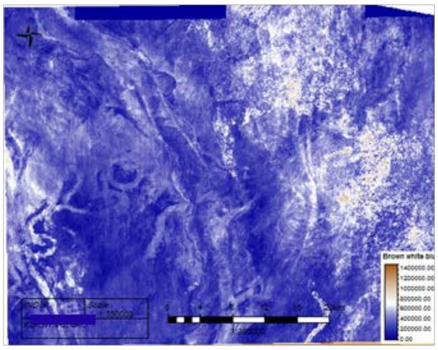
From Miocene top to Recent the sedimentary column is divided into 6 sequences separated by condensed sections. These sequences show a higher frequency of cyclicity, with distinct condensed surfaces, overlain by intervals with straight to low sinuosity channels and finally entrenched highly sinuous channels with well developed levees. The sinuous channels commonly occur in belts, with meanders eroding and cutting into older beds. For most part they are southerly flowing, however in rare intervals channels flowing from NW towards SE are present (Fig. 7a), which may possibly represent occasional progradation of the KG dispersal system.

The oldest amongst these i.e. Sequence 5, comprises mainly wide 5a trenched meandering channel belts. The sequence 6 is thicker with discrete but broad channels with well developed levees. Some channels are filled with coarse clastics as indicated by their positive compactional relief (Fig. 2). Sequence 7 is dominated by narrower meandering channels, with occasional channels flowing towards SE (Fig. 7a). These channels when abandoned are passively filled by pelagic deposits (Fig. 7b). In sequence 8 the broad south and southwesterly flowing entrenched channel belts are again dominant and its top corresponds with the Pliocene Top. Sequence 9 above Pliocene top starts with a relatively passive fill of an existing channel belt (Fig, 2) and for most part is dominated by small shoestring meandering channels. The upper part of this sequence comprises a relatively thick low frequency and amplitude continuous seismic events, This relatively thick interval, pelagic with narrow meandering high sinuosity channels, filled with finer clastics and condensed in part (?), represents a major retrogradation of the system (Fig 7c). Sequence 10, the youngest, is dominated by two channel-levee complexes of S/SSW flowing systems. These are broad with widths of >2km, but presently abandoned. This is indicated by the presence of passive fill and younger shoestring relatively straight channels cutting across them (Fig. 7d).

7a



7b



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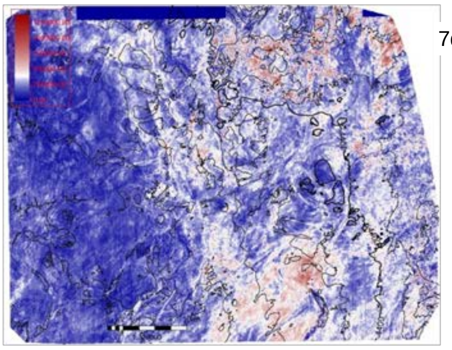

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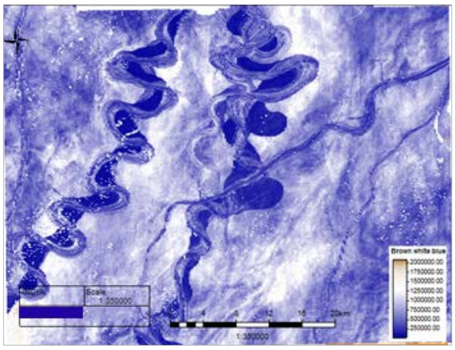

Figure 7: RMS Slices a) SE flowing meandering channel cutting across southerly flowing relatively straight channels, sequence 7, b) Passive filling and general retrogradation of the system toward top of sequence 7 (20 ms above 7a), c) Pelagic interval above Pliocene top with a very high density of meandering shoe-string passively filled channels and d) Abandoned, entrenched channel levee complex cut by younger shoestring SW flowing channel, top of sequence 10.

Discussion & Conclusion

In context of the relative dimensions of the study area (~50x50 km), with respect to that size of the Bengal fan, with a length > 3000 km and a width of ~1400 km (5), indicates the mapped features and sequences represent a very small sample. Further considering that the area is located in the mid fan area (6), only distal elements of the fan are present. The cyclicity of the sequences, their extent and depositional elements imaged could represent mainly auto-cyclic changes in the dispersal system. However, with regional correlation, the significance and causes of the sequence cyclicity can be better established. On the other hand effect of major tectonic and climatic events is recognizable with calibration of age boundaries.

The two most prominent of tectonic events affecting the Indian Plate, during the Tertiary are the Oligocene–Early Miocene welding of the Indian Plate with the Asian Plate and subsequent Mid-Miocene rise of the Himalayas, resulting in major changes of rivers draining across the ECMI. These bring about a major change in the depositonal rates all across the ECMI. The progradation of the deep sea dispersal systems was initiated in Oligocene, but the major progradation started in along with the rise of the Himalayas from Middle Miocene onwards. The maximum progradation and aggradation of the Bengal Fan is observed post Mid-Miocene, depositing over 2.5 ms twt of sediments (~ 2.5km). This interval shows widespread development of sigmoid and oblique reflection patterns. Widespread and entrenched channelized systems are interpreted, which for most time are highly sinuous and meandering with well developed levees. The channels for most part show a southerly to south-westerly flow, indicating that for most part the Bengal Fan system predominates. Although in a few intervals channels flowing from NW to SE direction are seen, their possible origin from K-G system needs further confirmation from the intervening areas. The cyclicity observed in the Pliocene to Recent times is interpreted by the channel dominated intervals (Fig. 2), separated by relatively channel free intervals which may represent interglacial and glacial period respectively. The prominent pelagic interval in Sequence 9 could represent a major inter-glacial period when sediment supply to the deep waters is reduced.

Presence of active channel system from Miocene to Recent indicates that the area continuously received sediments except in episodic intervals where sediment supply get reduces due to either rise of base sea level or autocyclic adjustment of channel systems. The basic depositional elements in the study area are channel-levee-splay complexes, pelagic deposits and mud flows in decreasing order of volumes and frequency of occurrence. Due to the deep water basin floor setting, submarine channel systems have deposited significant volumes of terrigenous sediments via subaqueous gravity and turbidity flows.

In deep water basins, allogenic controls include changes in sediment supply to the area controlled by either sea-level cycles on the shelf or major tectonic and climatic events. Autogenic processes like avulsion of major channels also are responsible for the creation of sequences. Unlike a typical deep water sequence (3), mudflows and their associated features, representing early falling stage system tract (FSST) are absent in the area. The study area being distal to the base of slope, it is quite possible that the mud flows never reached the area and hence are absent, or they and their equivalents are present in seismically unresolved thicknesses. The changes from forced regression (FSST) to low stand normal regression (LST) across the correlative conformity (*sensu* Hunt & Tucker) is usually reflected by a switch from domination of high density to low density turbidity flows. In the present case due to the distal setting, this distinction though is possible only in few cases (Fig. 4b). In the present case the dominance of straight channels over meandering channels is interpreted to correspond to this change, as they point to a basic change in flow rheology. The pelagic dominated, relatively channel free, intervals are taken to represent the equivalents of the MFS on the shelf, as they represent the lowest rates of sedimentation, during which a major portion of the sediments are probably trapped on the shelf. In many a case the pelagic condensed sediments passively fill erosional surfaces, in such conditions they represent a composite equivalent surface, combining the maximum regressive surface and the MFS.

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