Major neotectonic events during the Quaternary in Krishna–Godavari Basin

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The Krishna–Godavari Basin is an onland petroliferous basin under active stage of exploration. Situated on the East Coast of the Indian subcontinent, the basin developed as a result of continental rifting of the Gondwanaland and a subsequent drift phase during Mid-Cretaceous. It has thus a long history of basin development stretching from Jurassic to Quaternary. The Quaternary events of the basins are best reflected by surface landforms.

The basin can be divided into three broad geomorphic units: Fluvio-deltaic complex of continental environment, Beach-Ridge complex of fluvio-marine environment and Bay-Estuary Lagoon Complex of shallow marine environment.

Lineament studies indicate three dominant trends ENE-WSW, NW-SE and NE-SW. The dominant NE-SW trend is related to the Eastern Ghat orogeny, along which rifting and separation of Antarctica took place in Mid-Cretaceous. Some of the major ENE-WSW and NE-SW trends are correlatable to subsurface faults which divide the basin into horsts and grabens, indicating their active role in the basin development.

On the basis of interpretation of satellite images and data obtained from few shallow bore holes, five Quaternary events reflected as palaeostrand-line shifts have been recognized. These indicate rapid growth of delta, the progradation rate being roughly 3.5 kilometre per thousand years after 10,000 ± 155 yr B. P.

Introduction

THE Krishna–Godavari Basin situated on the East Coast of the Indian subcontinent (Figure 1) is a newly emerging petroliferous basin. It came into existence as a result of rifting of the Gondwanaland during Early Cretaceous times, and its subsequent drift. A series of NE-SW trending high-angle extensional faults subdivide the basin into horsts and grabens. These horsts and grabens follow the NE-SW trending Precambrian Eastern Ghat tectonic trend[1]. The grabens are filled up dominantly by Mesozoic sediments, which constitute the rift fill sequence tilted landward. The Early Tertiary sediments mark the beginning of post-rift oceanic stage with a basinward slope.

The offshore Tertiary sequence of the Krishna–Godavari basin is very thick, having been deposited under deltaic to sub-sea fan conditions. Godavari offshore, in particular, has over 3000 m thick Neogene deltaic sediments.

On land, adjoining the metamorphic basement complex, only a small area of about 4000 km^2 exposes ancient sedimentary rocks. According to the various detailed investigations by Geological Survey of India (GSI) and in particular by the Oil and Natural Gas Commission (ONGC) since 1959, the earliest Gondwana sediments are Early Jurassic in age (Figure 2), and the sedimentary rocks range from Upper Jurassic to Recent, with a number of unconformities, and three basaltic lava flows i.e. Deccan Trap (Late Cretaceous-Early Palaeocene) are seen between the Gondwana and Tertiary rocks.

During the Mesozoic the sedimentation was dominantly fluvial. The sedimentation pattern changed in the Tertiary. The rivers brought large amounts of sediments to the sea-shore initiating deltaic processes. Ranga Raju *et al.*[2] have inferred carbonate build-ups on most of the shelf breaks during the Eocene, recognized canyon cuts and fills, particularly in the Pre-Miocene shelf, and canyon related turbidite deposits during the Miocene.

The Krishna–Godavari delta has been studied by a

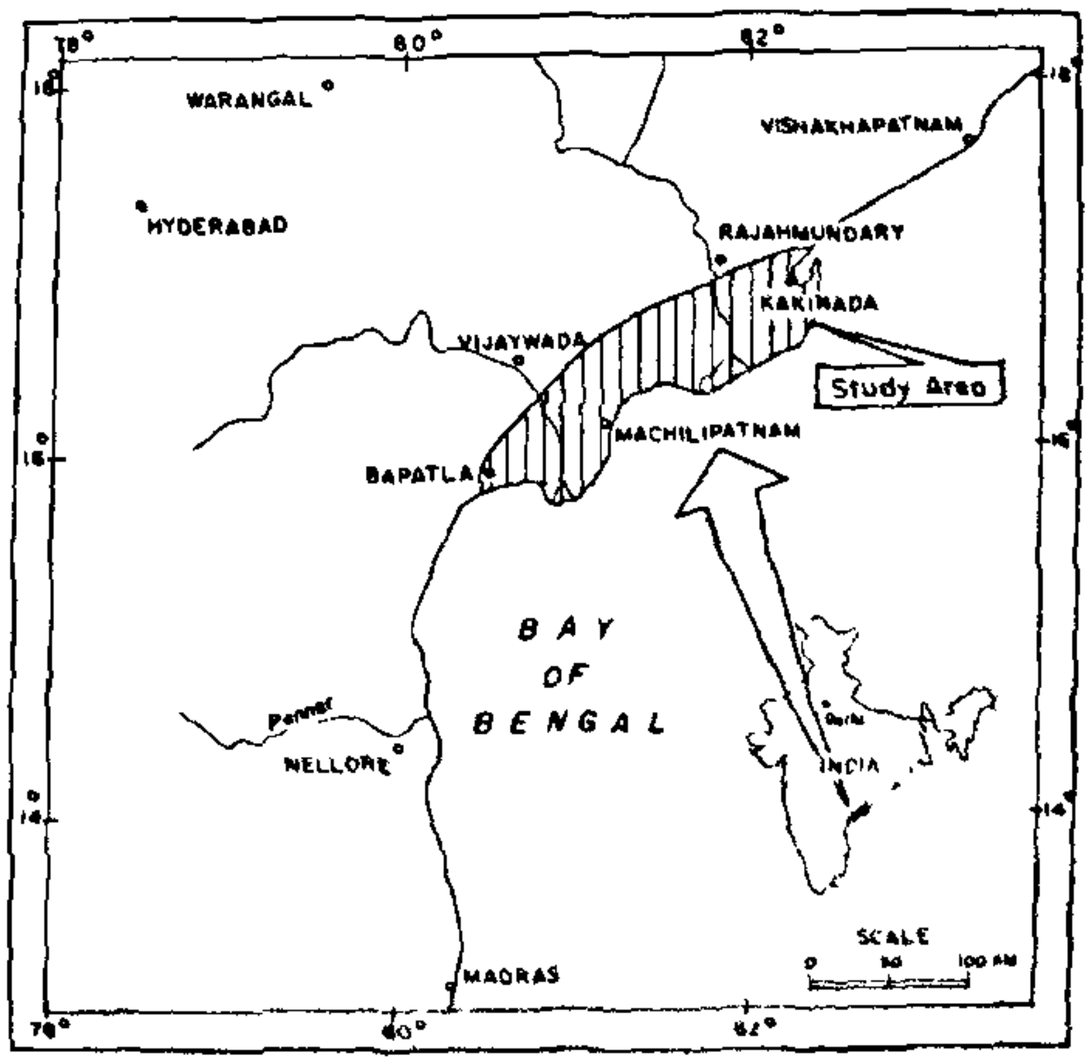

Figure 1. Index map.

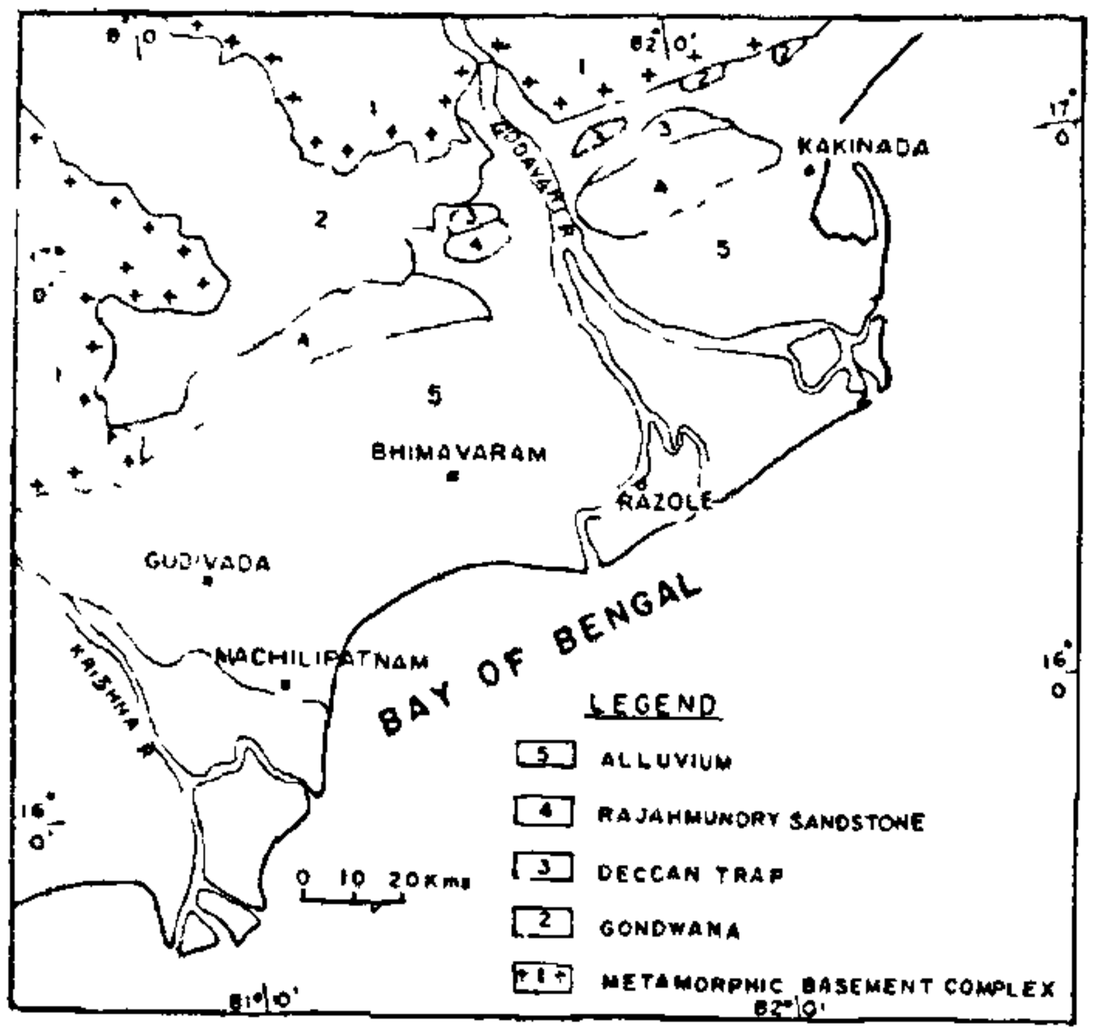

Figure 2. Geological map of Krishna–Godavari area.

number of workers who contributed a wealth of information on various aspects of the delta[3-13].

The Mio-Pliocene deposits of the Krishna–Godavari Basin consist of 660 m of continental Rajahmundry Sandstone (Figure 2). This is represented in the subsurface by the 2000 metre thick marine claystones and shales with minor sandstone. These sediments form the floor of the Quaternary deposits.

Geomorphology

The geomorphology of the Krishna–Godavari area has been studied earlier[6,14-17]. The present-day onland Krishna–Godavari Basin with a relief less than 20 m gently slopes towards the coast. The drainage is very coarse and dendritic, the main river channels exhibiting anastomosing patterns. The Godavari River with three distributaries forms a symmetrical delta, while the Krishna River has built a typical bird-foot delta with four main distributary channels. The Godavari delta is a complex wave-dominated Pacific type delta. In the Krishna–Godavari area the various landforms identified on the basis of remotely sensed data (Figure 3) are categorized into three dominant geomorphic units each having its specific environment (Figure 4):

Fluvio-deltaic complex

The fluvial channels grading into estuaries give rise to deltaic features. The flood plains in the upper reaches exhibit moderate to coarse drainage, with abandoned channels, natural levees and backswamps. The abandoned meanders, scars, scrolls and old pointbars indicate migration of channels. Evidence of palaeo-channels draining south and east are observed west and north of the Gautami Godavari. Braiding and drainage anastomosing are quite common. River terraces are developed along the Vasishta and Gautami Godavari channels.

Beach ridge complex

A group of low-lying sub-parallel ridges up to 15 km inland along the beach mark successive shorelines through times and indicate the prograding nature of the Krishna–Godavari delta. Each cluster of beach ridge is observed as a wedge in plan where the tapering edge is away from the mouth of the distributary that is bringing sediments. Thus the truncating relations of such ridge clusters can be attributed to the shift in the estuaries.

Beach ridges are very prominent northwest of Kakinada, around Bantumilli and within the inter deltaic zone (between Krishna and Godavari deltas) (Figure 4).

Bay-estuary-lagoon complex

This unit is a product of processes dominated by tidal action in the fluvial regime. It may be emphasized that there is a gradation from fluvial towards bay-estuary-lagoon association, the lagoons being most prominent near the coast (Figure 4). Sedimentation continues to take place within these lagoons even today. Mangroves associated with these lagoons, such as seen in south and southeast of Kakinada, also suggest that it was the former site of confluence of Gautami Godavari with the sea which was much in the interior.

Spits, barrier bars and shoals are the dominant aggradational landforms of this geomorphic unit.

Barrier bars, tidal flats and shoals are common in the offshore belt. They trap sediments from the channel mouths. The tidal flats with marshes are characterized by dendritic drainage pattern.

Lineament analysis

Lineaments are identified on the basis of tonal contrast, alignment of major fluvial forms, deflection in major river courses and other linear features observed in the Landsat images.

The lineaments in these deltaic areas, as seen on LANDSAT, are assumed to have been formed earlier than the Quaternary along primordial weak zones. They were reactivated by neotectonic movements. Three prominent lineament trends observed in Krishna–Godavari Basin are ENE-WSW, NW-SE and NE-SW (Figure 5). The most prominent NE-SW and ENE-WSW are correlatable with the Eastern Ghat trend.

Figure 3. *LANDSAT mosaic of Krishna–Godavari basin.*

One of the important lineaments passing from west of Mogalluru to the south of Amalapuram seems to represent an active fault that has caused sudden bends in the courses of Vashistha and Vamateyam Godavari channels (L-L' in Figure 5).

The NW-SE lineament coinciding with the Godavari graben is related to the Dharwarian grain. The Razole lineament (Figure 5) suggestive of neotectonic reactivation, cuts across the Mio-Pliocene Rajahmundry sandstone.

The NE-SW and ENE-WSW trending lineaments seem to have controlled the evolution of the Krishna-Godavari basin itself. These trends seem to be responsible for the block faulting, as a result of which the distributaries of the Godavari (Figure 5) show anomalous flow during their final stage. Many of the lineaments shown by bold lines in Figure 5 correlate with the subsurface faults and ridges interpreted from bouguer gravity and seismic data.

Observations through well data

The various shallow wells drilled under the ONGC's hydrocarbon exploration programme have provided valuable information. Various cross-sections both along

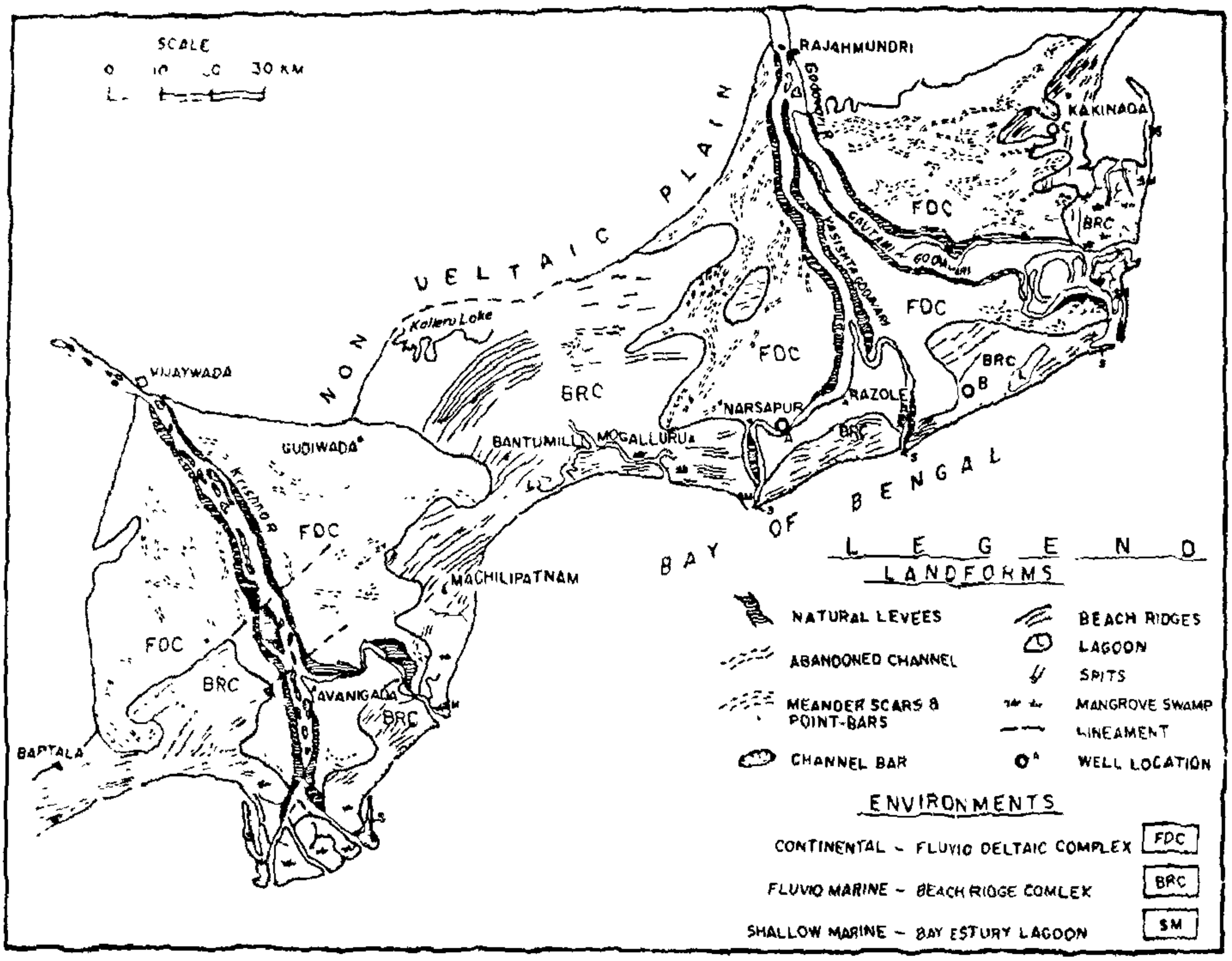

Figure 4. Geomorphological map of Krishna–Godavari basin.

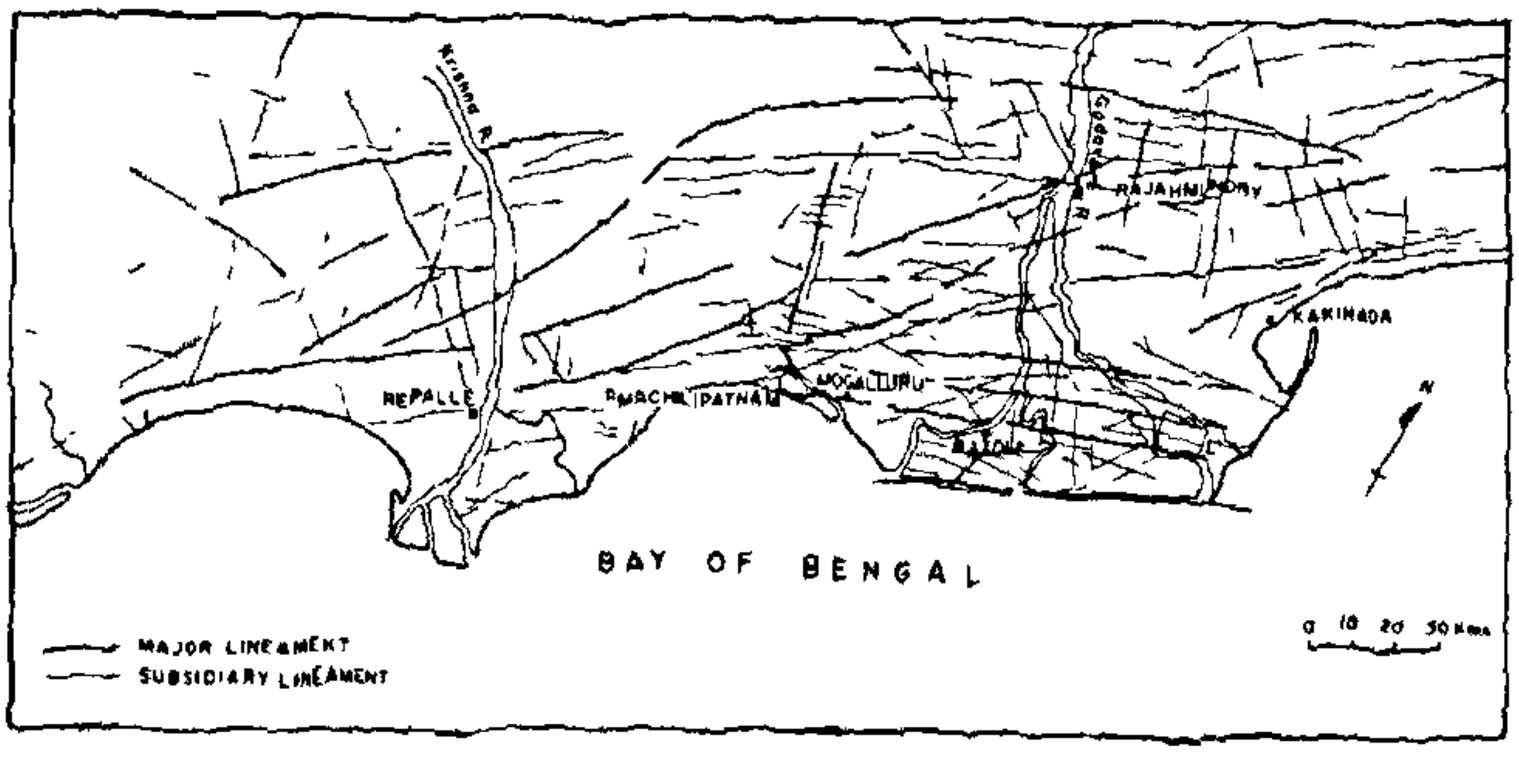

Figure 5. Lineament map of Krishna–Godavari basin.

and across the area using well data have identified various aggradational and transgressive facies[18] and have further helped in understanding palaeoenvironment facies relationships (Figure 6). Results indicate that the facies of the upper deltaic plain (natural levee, flood plain, channel/distributary channel, channel fill and lacustrine), are essentially of fluvial environment while the lower deltaic plain, is fluvio-marine. The upper deltaic plain is either enclosed by beach ridges or passes into tide dominated lower deltaic plain. The distributary channels

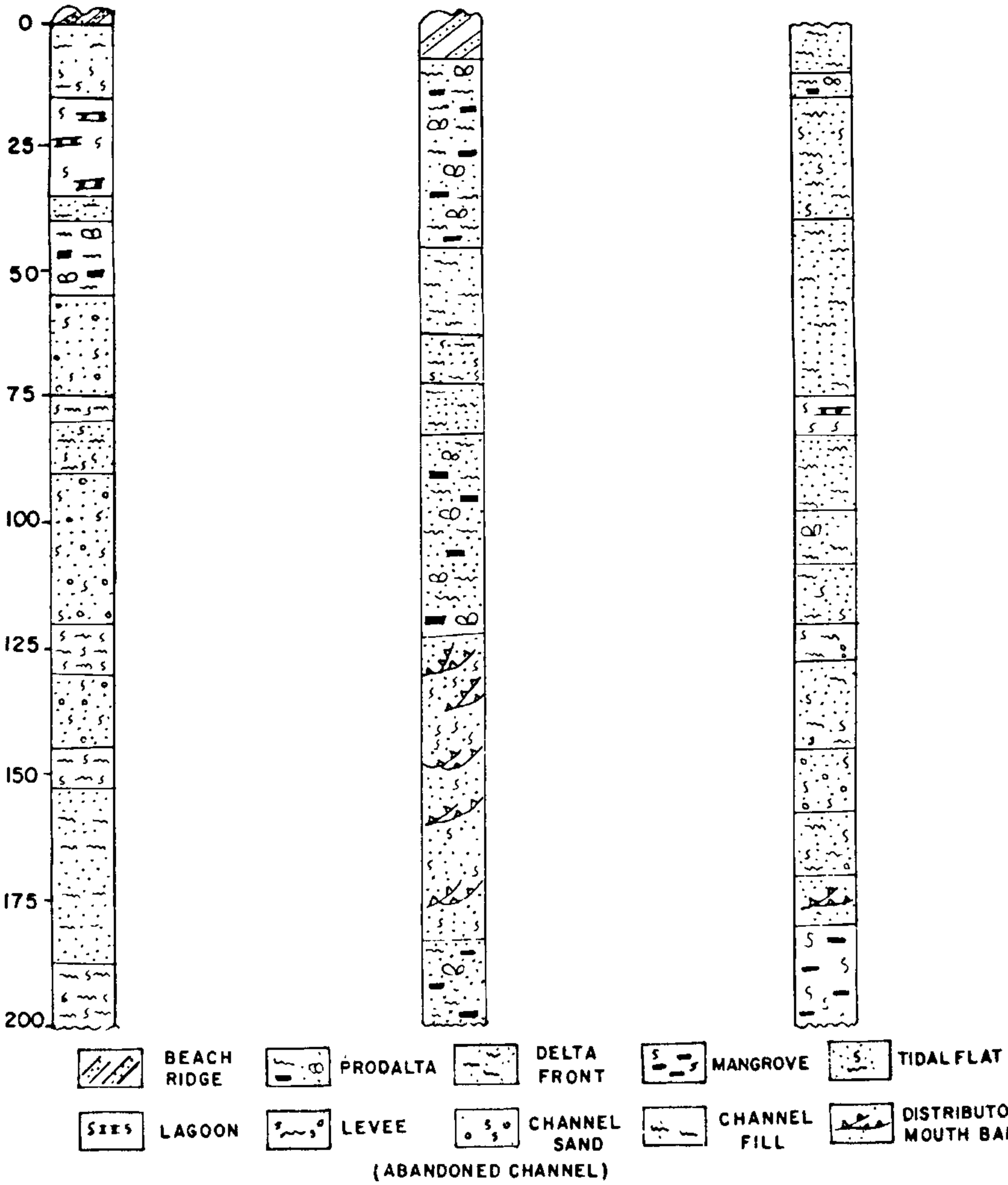

Figure 6. Palaeoenvironmental facies observed in a few shallow wells. (Modified after Satyanarayana *et al.* 1985). For well location see Figure 4

and channel facies are stacks of vertically and laterally interconnected sands and the low-lying inter distributary areas are covered by tidal flats.

Quaternary evolution

The landform studies reveal existence of five strandlines

in the Krishna–Godavari deltaic region, indicating five stages in the delta growth (Figure 7) beginning from near Kolleru lake as indicated by the shallow well data. Remnants of landforms such as palaeochannels, natural levees, backswamps, point bars, Chenier plain, beach ridges are left behind as the delta prograded. This is evident from the subsurface aggradational facies.

It is inferred that the shallow marine processes, which are currently shaping the present-day coastline and which gave rise to the 'bay-estuary-lagoon complex', were also the dominant cause for delta progradation in the past. King[19] also had earlier described the Kolleru lake as an ancient lagoon. Such lagoons are integral landforms of present-day coast. Enclosed by spits and bars, such lagoons appear to have formed during strandline shifts and are thus related to beach ridges.

Carbon dating of a calcareous oolite sample separated from a subsurface layer of a deep marine sediment about 200 km northeast of Kakinada, suggests that there was a lowering of the sea-level due to glaciation, off the East Coast of India around 10.8 Ka ± 150 yr BP[20]. This coincides with the last glaciation. It is deduced that after the lowering of sea level during the last glaciation, the Krishna–Godavari delta started growing as the agraded rivers brought huge volumes of detrital material from the uplifted land in the west. The mega-regressive cycle responsible for delta progradation, was interrupted by short transgressive phases during sea level high strands or still strands. During such phases, marine currents and waves reworked the delta sediments and the older landforms were overlapped by ancient beach ridges and related features.

Assuming that the growth of delta started after the sea level restoration (10.8 ka ± 150 yrs BP), Naidu[20], estimated the rate of progradation at 3.5 km per thousand years.

Effect of neotectonism

It is obvious that the NW-SE trending lineaments controlled the course of Godavari in the northern part of the Godavari delta, while the ENE-WSW and NE-SW trends caused changes in courses of old channels. A major dislocation extending ENE from west of Mogalluru to South of Amalapuram seems to be responsible for major bends in the distributaries of the Godavari. The morphostructures associated with these

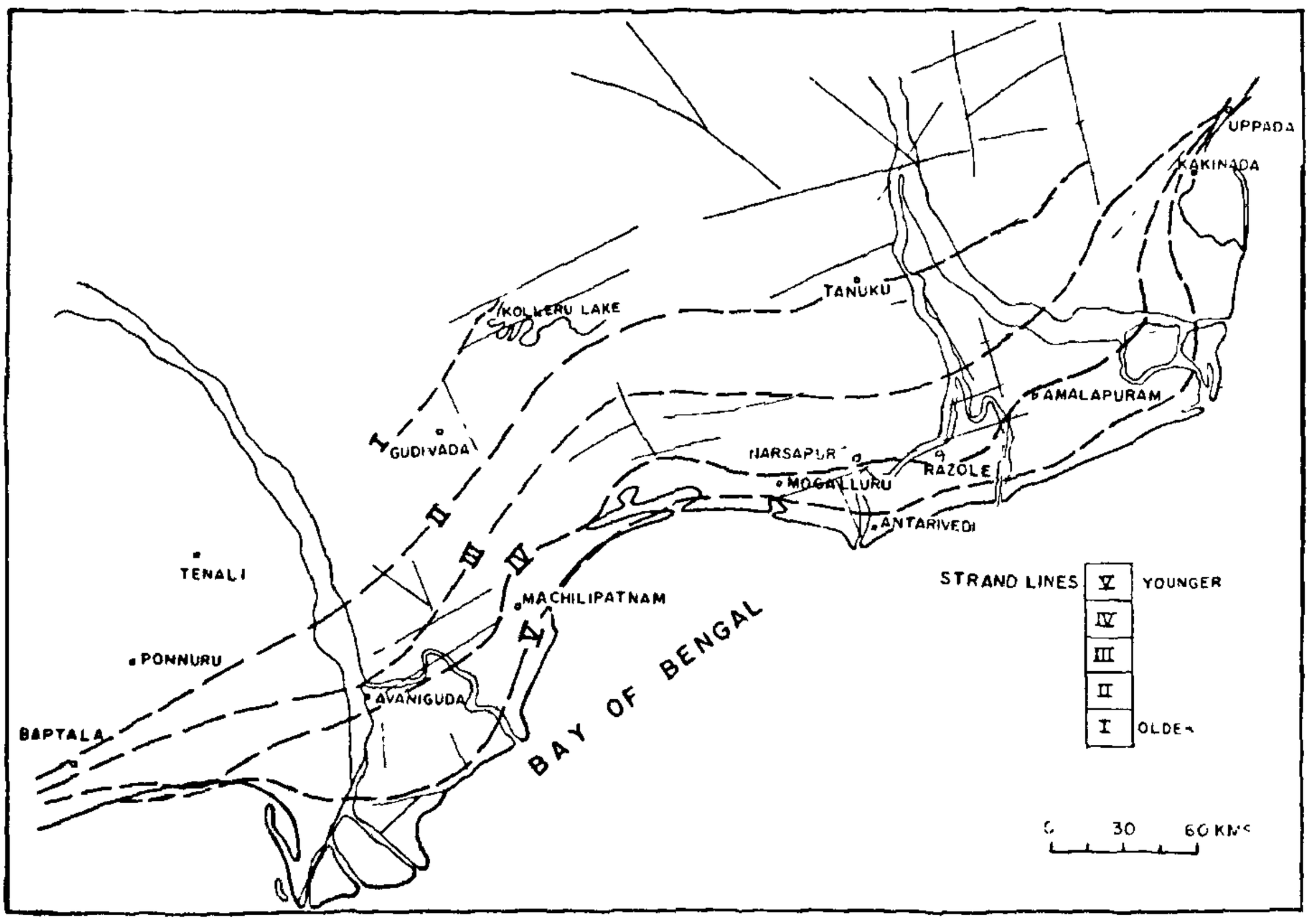

Figure 7. Probable Quaternary palaeostrand lines of Krishna–Godavari Deltaic region as interpreted from remote sensing data.

bends reflect the subsurface structures. Geophysical data indicate large sediment accumulations in the lower part of the delta. The NW-SE flowing superimposed rivers, however, do not show significant effect of neotectonism. The beach ridges by and large remain unaffected by neotectonic movements. Significantly, only the Eastern Ghat trend has been reactivated during the Holocene, when the formation of two deltas was at the climax.

Conclusions

Amongst the three geomorphic units identified in the area, landforms corresponding to the bay-estuary lagoon complex are dominant. Such features are predominant even in the present-day progradation of the Krishna–Godavari delta. These coastal landforms are influenced by the shallow marine processes and are actively modified by the waves and longshore currents. Five strandlines are observed, indicating five stages in the progradation of the delta.

Prominent lineaments in the area trend ENE-WSW, NW-SE and NE-SW. The NE-SW to ENE-WSW trends are rift-related and seem to have influenced the evolution of the Krishna–Godavari Basin. A major lineament from west of Mogalluru to south of Amalapuram is presumed to have caused major bends in distributaries of the Godavari. These bends are associated with morphostructures which also correspond to subsurface structures as inferred from geophysical data. These morphostructures bear promise of hydrocarbons. The NW-SE trend, orthogonal to the coastline and responsible for the Godavari graben faulting are neotectonically active. Shallow well-data indicate a harmony of surface landforms. The process related to the formation of palaeo-deltas since the Eocene is still dominant in the present-day delta buildup.

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