Quaternary of the East Coast of India

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The East Coast plain of India is made up predominantly of deltaic sediments of Kaveri, Penner, Krishna, Godavari, Mahanadi-Brahmani-Baitarani, Subarnarekha and Hooghly (Ganga) rivers, besides aeolian and marine patches. The configuration of coastline in the Hooghly delta front is conspicuously different from those of others. The eastern coastline of the Peninsular India originated in the post-Cretaceous times though it was modified considerably during the Quaternary due to progradation of deltas and impacts of glaciation and deglaciation.

The Quaternary sediments comprise laterites and unconsolidated gravels, sands, silts and clays, with occasional horizons of caliche. Numerous surfaces have been recognized and mapped, most of them being depositional. Correlation has been attempted particularly among surfaces in Ganga (Hooghly) and Mahanadi deltas. Preliminary dating of samples (^{14}C, TL, ESR) collected from different horizons from Kanyakumari in the south to Calcutta in the northeast, invariably indicates Holocene age, though some dates point to Upper Pleistocene. That some parts of the plains have been affected by neotectonism is evident from the abrupt changes in the courses of rivers, the anomalous orientation of coastlines, and the juxtaposition of different lithological units within the Quaternary.

Introduction

THE West Coast plain is relatively narrow, but the East Coast plain is of varying width (Figure 1). The conspicuous difference in the morphology of the West and East Coast plains is the almost negligible existence of deltas in the West Coast and their presence in force in the East Coast.

Along the East Coast, besides unconsolidated deposits of fluvial, aeolian, lacustrine and marine nature, there are monadnocks in certain sections, with minor outcrops of Precambrian formations. Most of these unconsolidated deposits were till recently considered Quaternary in age, partly Pleistocene and mostly Holocene. In earlier geological maps, these are invariably shown as 'alluvium', while in geomorphic maps of small scale these are designated as plains. The deltas show wide variation in their morphology. The presence and absence of some features among the deltas are due to variations in the nature and materials of the drainage basin, tectonics, hydrodynamics of the fluvial regime and coastal processes. To what extent these have been responsible in the variations in the morphology of the different East Coast deltas has been recently brought out[1]. The coastal depositional plains include floodplains, abandoned channels, levee, point bars, meander scroll, oxbows, beach ridges, swales, tidal flats, spits, etc.[2] Mangrove swamps and lagoons are common in certain sections. Figure 2 shows some of these features as identified from aerial photographs on a scale 1:60,000 (approx.) and generalized to a smaller scale. Almost similar features occur in other deltas in the East Coast.

In non-deltaic areas, the coastal plains are made up of certain denudational and depositional landforms. The former contain pediments (exhumed, dissected, buried etc.) occasional monadnocks, sea cliffs, and depositional forms include narrow floodplains, strand plains, terraces, dunes of various forms and sizes, beach ridges (abandoned and modern), tidal flats, tombolo, spits etc[3,4]. Though not very common, the East Coast does present some erosional landforms like wave-cut platforms, sea caves, cliffs and stacks along parts of it[5,6]. Of relatively larger extent in the Coast are the planar surfaces, most of which are erosional.

Practically the entire coastal plains from Kanyakumari to the Sunderban have been mapped from a geomorphic point of view. Whereas the Geological Survey of India has justifiably laid greater emphasis on the stratigraphic part of it, the studies in the research institutions and by individuals have been more on the morphological features. In a majority of these studies, aerial photographs and satellite imagery have been used. Generally the scale of mapping has been 1:63,360 or 1:50,000 and in rare cases 1:25,000. Of course, where satellite pictures have been used, the scale has been 1:1 million and recently 1:250,000. In all these cases the classification of the features and mapping have been mainly on a genetic basis (erosional, depositional, fluvial, glacial, aeolian, estuarine, marine, etc.). It may be admitted that of late the availability of TM data and access to digital analysis has enabled more detailed subdivisions of morphological and associated features, particularly along the coast[7], which otherwise would not have been possible.

The material presented here is divided broadly into two major regions along the East Coast, the first one covering West Bengal and Orissa and the second Andhra Pradesh and Tamil Nadu. Since a substantial part of geomorphic, structural and to some extent

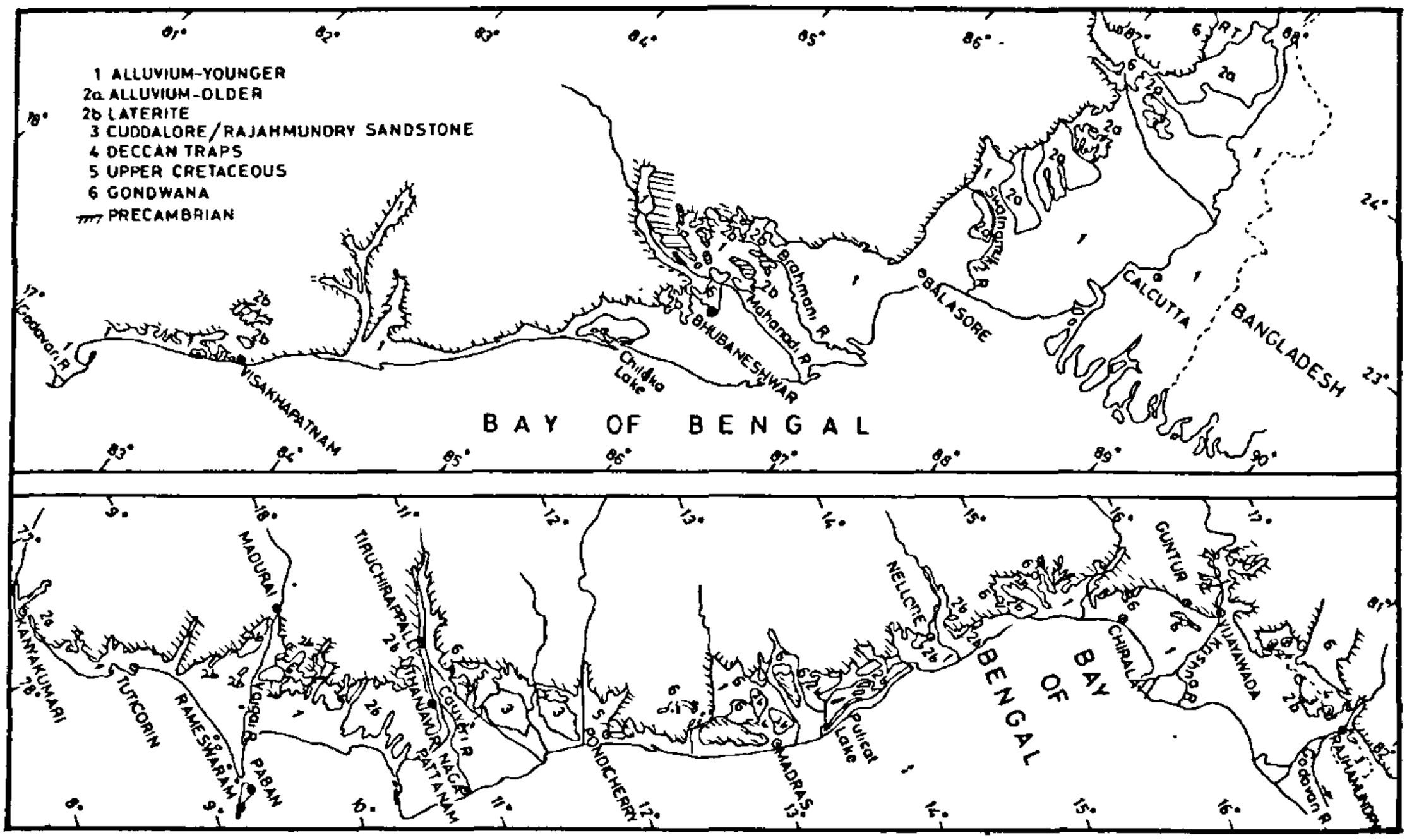

Figure 1. Geological map of East Coast of India (from *Geological Map of India*, Sixth Edition, 1962, Published by the Geological Survey of India, scale 1:2M).

stratigraphic data of the Tamil Nadu region has been published recently[1], only some of the important findings are included.

Evolution of the East Coast

The East Coast is characterized by several river deltas, the notable ones being those of Kaveri, Penner, Krishna, Godavari, Mahanadi-Brahmani-Baitarani, Subarnarekha and Ganga-Brahmaputra. From Kanyakumari to Digha-Contai the coastline is backed up by Precambrian to Tertiary rocks of the continental crust (Figure 1). However, the Orissa-Bengal coastline is formed over a deep tectonic trough underlain by older rocks of the continental crust at a great depth (Figure 3). The processes responsible for shaping this narrow part of the coastline are different from those along the other major part of the coast.

It is envisaged that the coastline of India started evolving after the dismemberment of India from the Gondwanaland. On the basis of the study of sediments and fauna from the borewell logs of the subsurface basins along the southern part of the East Coast, particularly that of the Palar basin in Tamil Nadu, Sastri *et al.*[8] postulate a Permian palaeo-shelf intervening between Peninsular India and a landmass that lay to its east. According to Markl[9] and Larsen[10] the date of separation of the Indian segment of the Gondwanaland from the Antarctic-Australian segment may be placed in early Cretaceous (127 m.y.). Duncan[11] suggests that the Rajmahal Volcanics (R. T. in Figure 1) were the earliest manifestation of volcanic activity that later produced the Ninety East Ridge. As rifting widened, a new sea floor was created upon which the Indian Ocean entered as a bay (Bay of Bengal). The newly created Bay of Bengal gradually spread over a wide area and reached northwards up to the Garo Rajmahal (Rangpur) saddle during the Tertiary period. The whole of the present-day Bengal Basin (including the Ganga-Brahmaputra delta) was under water until the Mio-Pliocene period, and the then strandline grazed the eastern margin of the Peninsular shield, i.e., much inland from the present-day coastline. It was only towards the beginning of the Quaternary period that the sea receded to almost the present strandline partly because of tectonic uplift of the Bengal Basin and partly due to glaciation. Based on seismic stratigraphic analysis of data[12], it has been inferred that the Ganga–Brahmaputra delta evolved in three stages, namely (i) the proto-Ganga delta developed immediately after the break-up of Gondwana at approximately 126 m.y. (ii) the transitional delta developed following a major eustatic sea level low at 49.5 m.y. (iii) Bay of Bengal

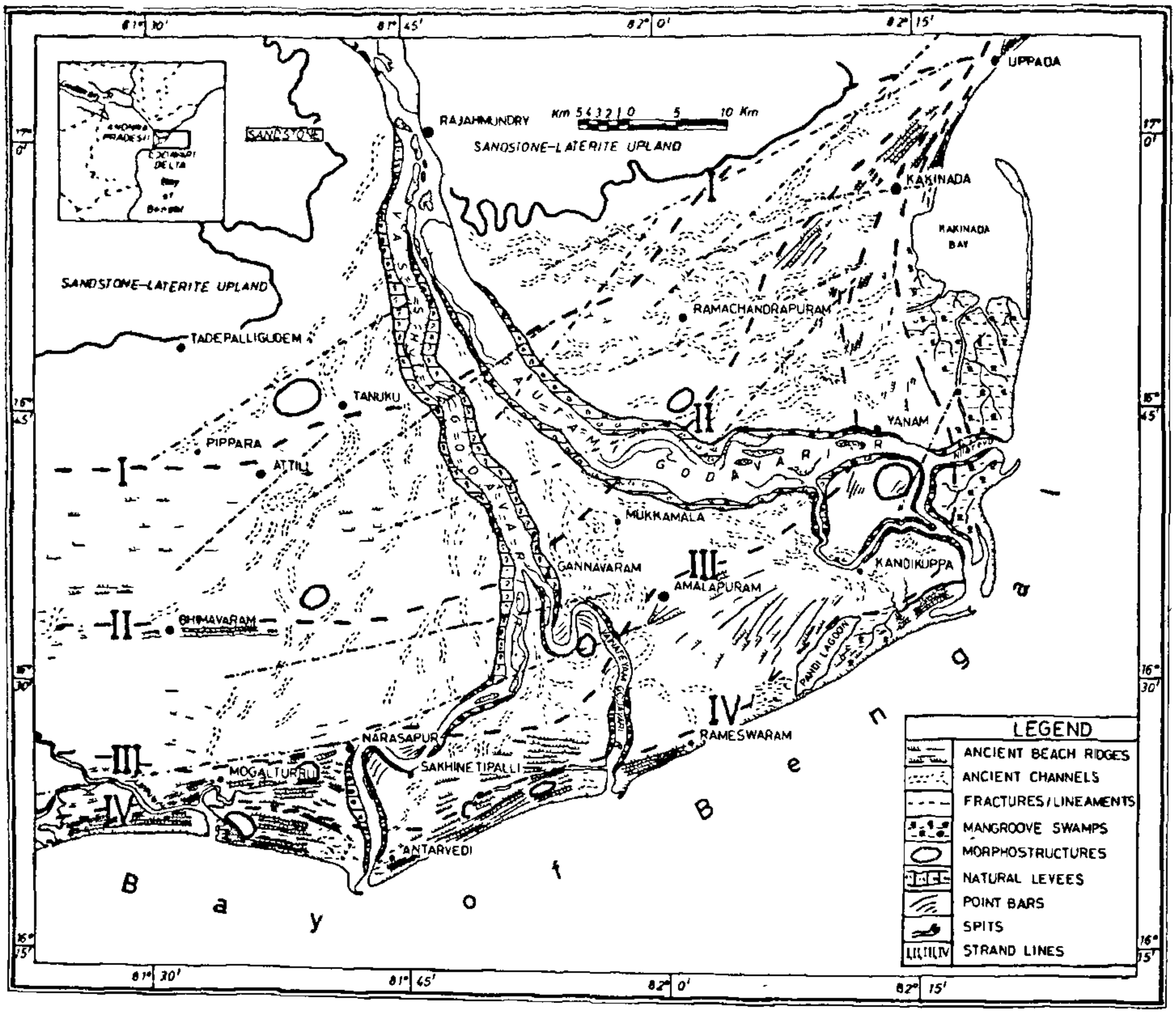

Figure 2. Photogeomorphic map of Godavari delta (Reproduced from ref. 2).

became a well-developed deep embayment at about 21 m.y. and (iv) the modern delta began to appear in its present form following a major eustatic sea level low and erosion at 10.5 m.y. The existence of Holocene strandline has been worked out at about 25 km offshore by the marine geological studies carried out recently by the Geological Survey of India.

Ganga Delta

The development of present-day serrated coastline of the Bengal Basin is influenced by Quaternary processes related to the Bhagirathi-Hooghly delta formation. There are three well-defined sections described in the following pages.

Shelf zone

This zone stretches from the margin of the cratonic mass in the west to Bhagirathi-Hooghly river in the east and from Farakka in the north to Digha-Haldia line in the south. This zone has been studied intensively by many workers[13–20].

Ghosh and Majumdar[18] place the Neogene-Quaternary boundary between the Mio-Pliocene Bhatrab Banki Formation and the Pleistocene Lalgarh Formation in the Lalgarh section (type section) of the Kasai sub-basin. The Lower Lalgarh Formation occurring at a higher topographic level (90–120 m above msl) represents primary laterite developed over the Pleistocene boulder conglomerate. The Upper Lalgarh Formation occurring at a lower topographic level (up to 60 m above msl)

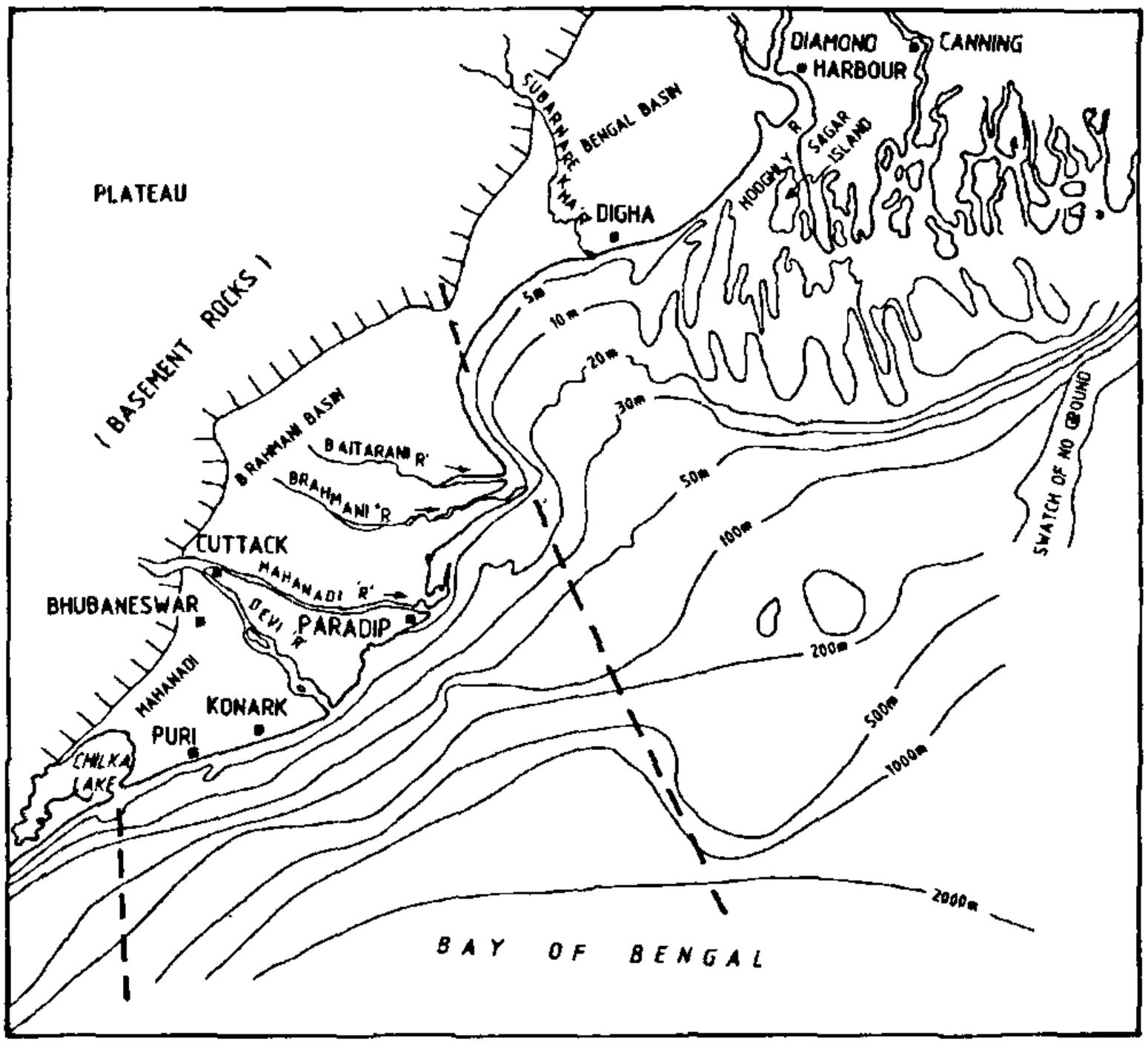

Figure 3. Configuration of the East Coast between Chilka lake in Orissa and Sunderbans in West Bengal. (Reproduced from ref. 19).

represents reworked laterite and contains vertebrate fossils of Middle to Upper Pleistocene age along with Palaeolithic tools[18]. The same stratigraphic sequence has been mapped as Baltora Formation in Bankura district by Sastry *et al.*[16], as Illambazar Formation in Bhirbhum and Murshidabad districts by Bhattacharya and Banerjee[17] and as Kharagpur Formation in Midnapore district and as Worgram Formation in Burdwan district by Niyogi[15]. This flat-topped but dissected tableland representing the lateritized boulder conglomerate of Lalgarh Formation is regionally developed not only along the entire western margin of the Bengal Basin but also along the western fringe of the Mahanadi delta in Orissa. Deep dissection of this tableland resulted in the formation of gullies and ravines which often expose the underlying Mio-Pliocene rocks (Figure 4).

Stratigraphically younger than the Pleistocene Lalgarh Formation is a thick sequence of alluvial terrace (T_3) sediments comprising ferruginous, brown, compact, sandy loam with more than one caliche horizon. These sediments have been mapped as Sijua Formation in the Kasai sub-basin[18], Babladanga-Bamundiha Formations in Bankura district[16], Belda Formation and Kusumgram Formation respectively in Midnapore and Burdwan districts[15], Rampurhat Formation in Bhirbhum and Murshidabad districts[17], and Nutanhat Formation in Ajay sub-basin. These alluvial terrace sediments characterized by more than one horizon of palaeosol (caliche) are often referred to as *Older Alluvium* in the Peninsular India. Ghosh and Majumdar[18] reported several fragmentary mammalian fossils and microlithic artifacts from the Sijua Formation. The age of this formation is Late Pleistocene to Early Holocene. This formation represents an alluvial upland forming the highest terrace (T_3) and attaining an altitude of 26–50 m above msl (equivalent to Barind Surface of Rangpur saddle region). This alluvial upland (T_3) touches 100 m altitude further west because of reverse faulting and tilting due to neotectonism.

Another sequence of alluvial terrace (T_2) sediments (without any palaeosol horizon) bordering the Shelf zone is extensively developed at a much lower topographical level (10–20 m above msl) over the eroded surface of the Lalgarh Formation and Sijua Formation. These sediments, comprising greyish black to black fine sand, silt and clay have been mapped as Daintikri Formation in the Kasai sub-basin[18], Panskura Formation in Midnapore district, Bansol Formation in Bankura District[16], Kandi Formation in Bhirbhum and

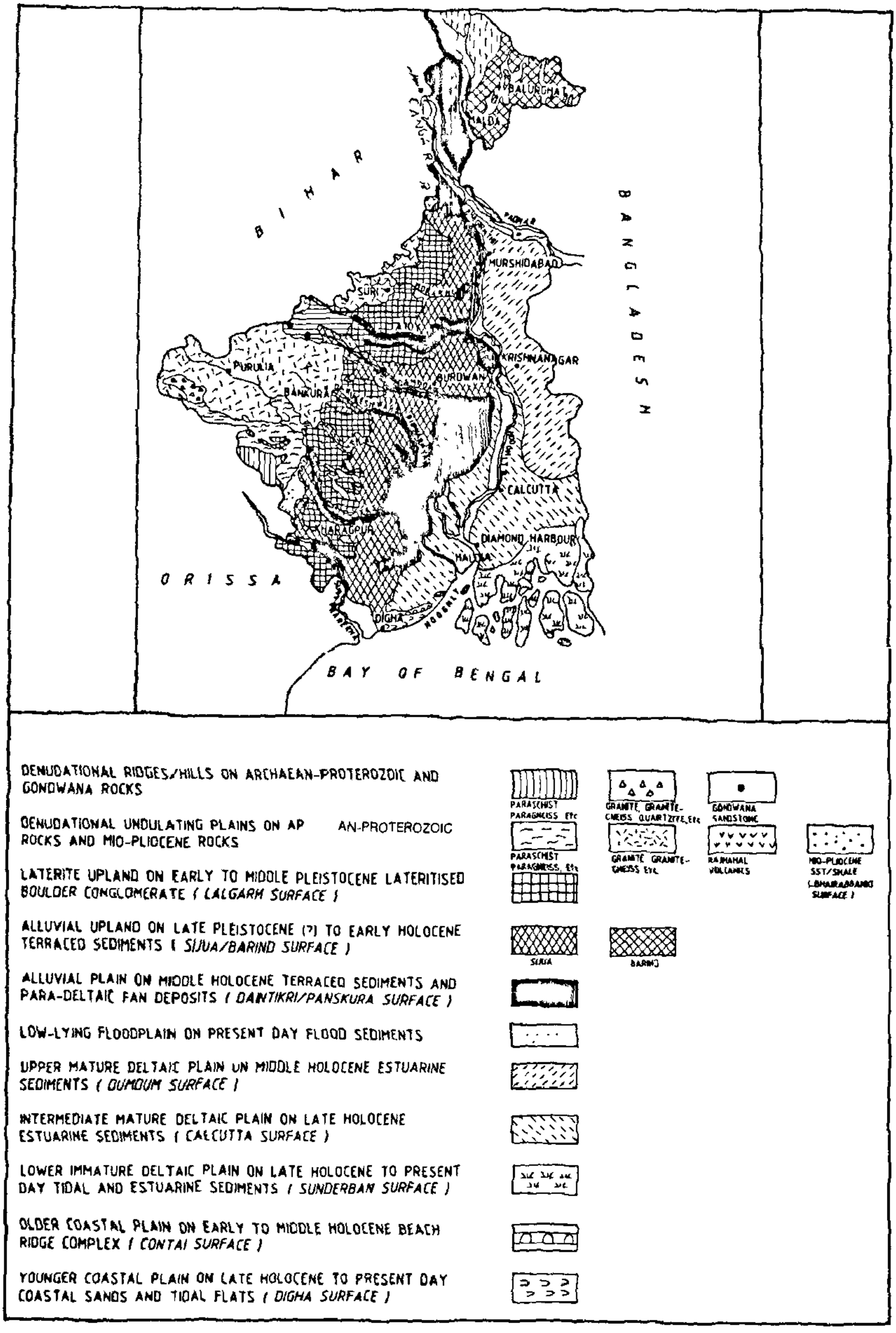

Figure 4. Sketch map showing distribution of morphostratigraphic units in West Bengal (Bengal Basin). (Reproduced from ref. 19).

Murshidabad district[17], Kanthi Formation and Kalna Formation respectively in Midnapore and Burdwan districts[15]. These sediments are often referred to as *Younger Alluvium* in Indian Geology. Decomposed wood sample from Daintikri Formation has yielded an age of 4810±120 YBP, based on which the stratigraphic age of this formation has been assigned to Middle Holocene. The Daintikri/Panskura Formation forms a lower level alluvial plain which fans out towards east. Typical paradeltaic fluvial fans, like the Damodar fan (east of Burdwan town) and the Kasai fan (around Panskura town), are characteristic geomorphic elements contained in it. Other geomorphic elements in it are aggraded relict channels, meander scars, oxbow lakes etc. This alluvial plain is poorly dissected by aggraded rivers with wide floodplains. In the Shelf zone, Late Holocene to the present-day sediments form the floodplains (T_0) and locally form a narrow low-relief incipient terrace (T_1) in channels of only the major rivers.

Mid-basinal zone

This zone extends from the eastern bank of the Bhagirathi-Hooghly river to the India-Bangladesh border. Low-lying alluvial plains comprising Holocene deltaic and estuarine sediments characterize this zone. Three different deltaic plains sculptured by fluvial, estuarine and tidal processes have been identified. Greyish black, muddy and clayey mature sediments of migrating meandering channels and Mid-Holocene tidal mudflat sediments occupying a relatively high topographic level (10–20 m above msl) have been designated as the Dum Dum Formation. It covers Murshidabad, Nadia and North 24-Parganas districts. Mangrove wood from Dum Dum gave ^{14}C date of 6175±125 YBP[21]. The deltaic Dum Dum Formation of Middle Holocene age is thus equivalent to the paradeltaic Daintikri/Panskura Formation of the Shelf zone.

Greyish black, muddy sediments of estuary deltaic origin and occurring at a level of 4–9 m above msl and discernible around Calcutta, are designated as Calcutta Formation, which covers parts of Nadia, North and South 24-Paraganas, Burdwan, Hooghly, Howrah and Midnapore districts. Geomorphic forms like tightly compressed two-phase meander channels having bimodal sinuosity, partly alluviated palaeo-meander scars, tidal mudflats, infilled tidal channels and creeks, salt marshes and swamps, and dry salt pans characterize the surface of this formation. Here the channel type shows meander shift through chute cut-off and neck cut-off. Peat samples collected from Metro rail excavations yielded ^{14}C dates of 3470±110 to 2640±150 YBP[21], thus assigning Late Holocene age to the Calcutta Formation.

Immature deltaic sediments, greyish black, sticky fine sand-silt-clay-mud and constituting a tidal-estuary-delta have been recognized as Sunderban Formation of Late Holocene to the Present as evident from radiocarbon dating which indicate 2900±40[22], 3170±70 and 1710±110 YBP[23]. Less than 4 m above msl, this formation occupies the southern part of South 24-Parganas district, which is regularly inundated by tidal waters. Extensive mudflats, mangrove swamps, marshes, creeks and estuaries are key geomorphic forms on this active delta plain. A stretch of the east coast is characterized by innumerable muddy islands supporting thick mangrove forests.

Coastal domain

It is a narrow coastal tract with beach ridges and intervening tidal flats between Digha and Haldia in the Hooghly estuary (Figure 4). Morphostratigraphically, this coastal complex can be divided into two units, the Contai Formation (older) and the Digha Formation (younger).

There are four dissected and partially peneplaned beach ridges, parallel to the present coastline, in the Contai-Paniparul belt of Midnapore district, far inland from the present-day coast. Each set of these beach ridges signifies a palaeo-strandline. Occurring at the level of 6 m above msl, the older coastal plain is made up of red and brown sediments. ^{14}C dates assign an age of 5760±140 YBP to the Contai Formation, thus equating it with the Daintikri/Panskura Formation of the fluvial domain (Shelf Zone) and the Dum Dum Formation of the deltaic domain (Mid-Basinal Zone).

The area south and southeast of the Contai Formation is flat with sandy beach and intertidal mudflats extending up to the beach–dune complex of the present-day coast. The younger Digha Formation 2–3 m above msl has been dated Late Holocene to the Present on the basis of ^{14}C dates of 2920±120 YBP. Thus the Digha Formation is time-equivalent of the Sunderbhan Formation.

Subarnarekha Delta

The East Coast takes an almost arcuate turn in Orissa. The shoreline is dominantly sandy with rows of dunes or beach ridges parallel/sub-parallel to the present-day strandline. Niyogi[24] and Chakrabarti[25] provide a detailed account of this delta.

The Quaternary delta building starts from the edge of the Upper Tertiary marine sediments, which occur between Nilgiri and Balasore, followed by thick Pleistocene laterite in patches. Thereafter extensive alluvial upland formed by the Sijua Formation occurs which is cut-off by the ENE-WSW trending ancient beach complex, developed in the continuity of the

Table 1. Quaternary lithostratigraphic units in West Bengal, part of Bengal Basin

Probable age	Lithostratigraphic units		
	Fluvial domain in shelf zone	Deltaic domain in mid-basinal zone	Coastal domain
Late Holocene to Recent	Present flood-plain sediments (T_0)	Sunderban Formation	Digha Formation
Late Holocene	Incipient terrace sediments (T_1) in large rivers	Calcutta Formation	—
Middle Holocene	Daintikri/Panskura Formation	Dum Dum Formation	Contai Formation
Late Pleistocene to Early Holocene	Sijua/Barind Formation	—	—
Early to Middle Pleistocene	Lalgarh Formation	—	—
Pliocene (?)	Upper Bhairab Banki Formation	Debagram/Jalangi (?)/ Matla Formation (Borehole information)	—
Miocene to Mio-Pliocene	Lower Bhairab Banki Formation	Pandua Formation (Borehole information)	—

coastal Contai Formation (Middle Holocene) of the Bengal Basin. Situated about 15 km inland the complex represents an ancient strandline of 5760 ± 140 YBP[25]. A wide fluvio-tidal flat of analogous antiquity borders this ancient beach-ridge complex in the south. Late Holocene to the Present fluvio-tidal deposits comprising inter-tidal mud/sand flat and beach ridge occur further south of the Subarnarekha estuary.

Mahanadi-Brahmani-Baitarani delta

The combined Mahanadi-Brahmani-Baitarani delta complex (Figure 3) occupies 12,500 km^2 area in Orissa. Underlain by the Gondwana sediments, the deltaic sediments have a minimum thickness of 500–600 m along the western periphery near Puri and the maximum thickness near Konarak, Devi river mouth (>2400 m), and Paradeep (>2000 m).

Tectonic framework

The deltaic plain is characterized by a number of ENE-WSW trending basement faults which were reactivated during Tertiary and Quaternary periods as evident from gravity, magnetic and seismic refraction studies. The delta is tectonically quite active[26]. This is obvious from the displacement of the Holocene sediments across the lineaments which control the shifting of drainages.

The Mahanadi-Brahmani-Baitarani basin appears to have been created due to rifting in the Cretaceous period. Subsidence of the basin continued throughout the Tertiary, Pleistocene and Holocene. Different thicknesses of Quaternary sedimentary column in resulting horsts and grabens explain the continuity of the same tectonic movements through time and the accumulation of huge thickness of deltaic sediments particularly during the Pleistocene-Holocene period. In the off-shore part of the basin similar down-to-basin NE-SW faults have been recognized through marine seismic surveys supported by drilling. Geological cross-section drawn across the Mahanadi basin by Bharali *et al.*[26], shows that the Quaternary sediments have been affected by a series of faults onshore, and offshore in the prodeltas.

Geomorphology

Pioneering work on the geomorphology of Mahanadi delta and adjoining areas has been done by Sambasiva Rao *et al.*[27], Babu[28], Mallick *et al.*[29], Meijerink[30] and Mahalik[31] among others. Quaternary lithostratigraphy and morphostratigraphy in Mahanadi delta have been attempted by De and Ghosh[32,33]. The varied geomorphic features can be classified under four broad categories: (1) the fluvial landforms which include laterite tableland, river terraces (alluvial upland) and valley fills; all these are seen near the delta-apex skirting the delta; (2) the deltaic landforms which include extensive alluvial and tidal flats and depressions, meander scrolls and oxbow lakes, abandoned channels and aggraded river segments, levees, backswamps, floodplains and braids; (3) the coastal landforms which include lagoons, estuaries, spits and bars; tidal and estuarine marshes and swamps; foreshore beach, beach ridges, berms; onshore bars and troughs, and backshore sand/mud flats, sand ridges and ancient beach ridges

(much inland); (4) aeolian landforms which include parabolic, transverse, barchan and obstacle dunes formed from reworking of marine and fluvial sands by wind action.

Stratigraphy

Precambrian khondalites, charnockites, and anorthosites occur as discontinuous hills and mounds mainly to the north and west of the delta complex. Bornhardts and inselbergs of these rocks also occur within the delta around Bhubaneswar and along Daya river course. A small patch of marine Upper Tertiary rocks is located north of Bada Gengut river around Chowdula village. Laterite tableland skirts the older rocks and defines the delta margin. The laterites are found on the Pleistocene boulder conglomerate. These sediments, clearly of fluvial origin, are variously named and mapped as Khurda Formation and Belgarh Formation. This Pleistocene Formation forms the base of the younger sediments constituting the delta. It is equivalent to the Lalgarh Formation of the western shelf margin of the Bengal Basin.

Younger than the Belgarh Formation is an alluvial valley-fill deposit forming the oldest terrace in the upper part of the delta. The sediments of the Kaimandi Formation of Late Pleistocene to Early Holocene age, are mainly greenish grey to greenish yellow hard clay, silt and fine sands with more than one horizon of caliche. Its shallow marine to estuarine equivalent sediments of correlatable age occur extensively in the lower part of the Mahanadi delta below younger sediments and crop up only where there is deep incision (more than 4–6 m). These sediments under the name of Belipada Formation, are sub-lithified clay beds containing layers of calcareous concretions and ferruginous nodules indicating chemical weathering and pedogenesis. Borehole logs indicate that the Belipada Formation is underlain by laterite-wash and hill-wash which in turn are underlain by laterites. The shallow marine to estuarine clay of the Belipada Formation was deposited extensively during Riss-Wurm interglacial and was weathered and pedogenized during the Wurm glaciation (19,000 YBP). Both the alluvial Kaimundi Formation and the estuarine Belipada Formation are time-equivalent of the Sijua Formation of the Bengal Basin.

Holocene sedimentation under fluvial domain took place in the basin margin forming a younger terrace at lower topographic level along major drainage channels. These terrace sediments are recognized as Bankigarh Formation of Middle Holocene period. The sediments consist of alternate layers of brownish silt and very fine sand with intermittent mottled silty clay. Ghosh and De[33] recognized four generations of deltaic sediments in the Mahanadi delta (Figure 5), viz. 9–4 m high Prachi (7000–6000 YBP) (^{14}C dates of 5880 ± 120 to 4250 ± 210 YBP), 8–2.5 m high Devi-Kushabhadra-Bhargavi (2300–750) (^{14}C dates of 1590 ± 150 to 1220 ± 180 YBP), 5–1.5 m high Kadua (750–50 YBP) and 2 to >1.5 m high Nuagar (50–0 YBP). Four sets of beach ridges, corresponding to and chronologically correlatable with those four deltaic formations have been named by Ghosh and De[33]: Anantapur-Goda Formation (7000–6000 YBP), Konarak Formation (2300–750 YBP), Chandrabhaga Formation (750–50 YBP) and Nuagar Coastal Formation (50–0 YBP) (Figure 5). In general the coastal formations attain topographic levels of 1.5–3.0 m higher than those of their corresponding deltaic counterparts.

The regional correlation of all these categories of sediments is shown in Table 2.

Sedimentation pattern

The sedimentary column in this deltaic plain is lithically quite complex, being made up of fluvial, fluviomarine, marine and aeolian sediments, accumulated on the deltaic plain and coastal tract[34].

Offshore domain

Information on the prodeltaic part of the continental shelf is available from seismic refraction studies and offshore drilling done for oil exploration. Valuable data are presented by Bharali *et al.*[26].

In general, the prodelta is characterized by a uniformly gentle slope up to a depth of 50–60 m. A sharp change in gradient is indicated thereafter demarcating the continental shelf. A number of ENE-WSW longitudinal faults occur within 200 m isobath which displace the basement rocks at great depths of 2000–2500 m. The combined thickness of Pliocene-Pleistocene-Holocene sediments varies widely from 400–1100 m to 2500 m. The sediments in the nearshore comprise of an admixture of sands, silts, clays. There is a sandy layer, between Sonapurampeta in Andhra Pradesh to Digha in West Bengal, which extends down to the depth of 25–30 m and rich in ilmenite, zircon, rutile, monazite sillimanite and garnet. Off Puri-Devi river mouth, the unit seems to be interleaved locally with silt and clay layers. The Mahanadi river mouth has probably shifted from southwest to its present position in the northeast abandoning its palaeochannels in the nearshore continental shelf.

Presence of coarse sands, with local pebble zones at depths 30 m, 60 m and 100 m indicate deposition during low stands in the Pleistocene period. Submerged beaches indicating Pleistocene glacial strandlines occur between Kalingapatnam and Gopalpur offshore at

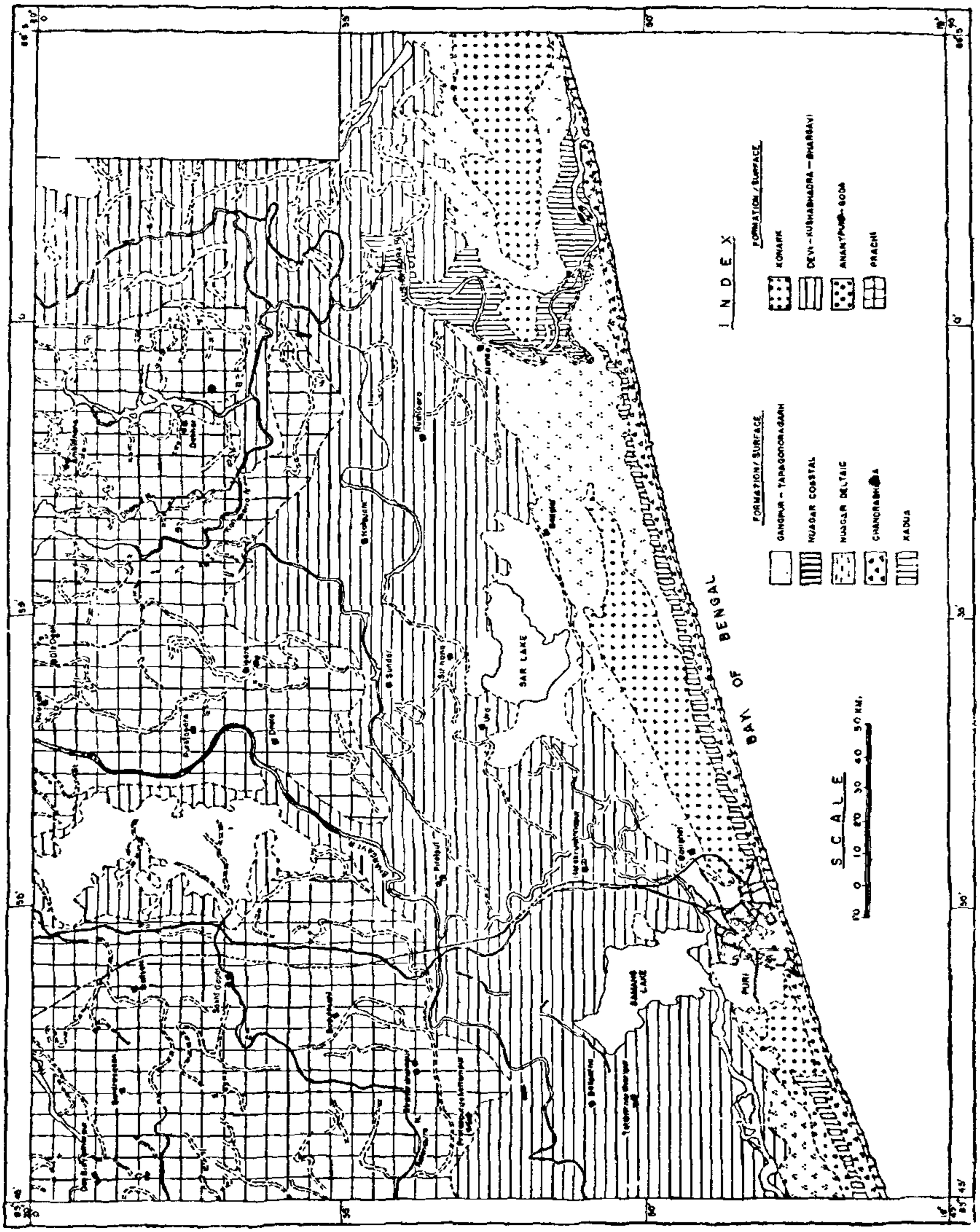

Figure 5. Quaternary geological map of Mahanadi delta, Puri district, Orissa. (Reproduced from ref. 32).

Table 2. Quaternary lithostratigraphic formations in Mahanadi-Brahmani-Baitarani delta

	Lithostratigraphic (mappable) Formations		
Probable age	Fluvial domain in basin margin	Deltaic domain in mid-basinal zone	Coastal domain
Late Holocene to Recent	Present flood-plain sediments (T_0)	Kadua Formation (=Sunderban Formation)	Chandrabhaga Formation (=Digha Formation)
Late Holocene	—	Devi-Kushabhandra *Bharvagi Formation* (=Calcutta Formation)	Konark Formation
Middle Holocene	Bankigarh Formation (=Daintikri/Panskura Formation)	Prachi Formation (=Dum Dum Formation)	Anantpur-Goda Formation (=Contai Formation)
Late Pleistocene to Early Holocene	Kaimundi Formation (=Sijua-Barind Formation)	Belipada Formation	—
Early to Middle Pleistocene	Bolgarh Formation (=Lalgarh Formation)	—	—

Names in parenthesis are the time-equivalent sediments of the Bengal Basin.

depths 20–25 m, 30–35 m, 40–45 m and 55–60 m. The 50–60 m isobath at a distance of 25–30 km in the offshore Mahanadi basin is interpreted as indicating low strandline of the Wurm Glaciation period (19000 YBP?).

Coastal Andhra Pradesh and Tamil Nadu

Stratigraphy

Outcrops of Mio-Pliocene and some Pleistocene to Holocene sandstones are seen in parts of East Coast of Andhra Pradesh, particularly in the districts of Srikakulam, Vizianagaram, Visakhapatnam and East Godavari.

It has been generally presumed that most of the laterites in the East Coast, whether on hill tops or in the plains are of Pleistocene age[35], but some extending down to Eocene[36,37]. The *in situ* surface laterites over the East Coast plains serve as a marker horizon for they are associated with palaeolithic tools[38]. Rengamannar and Kameswara Rao[39] have identified in the northeastern part of the Godavari delta and further northeast along the coastal plains, three denudation surfaces (Kattipudi, Sriramapuram and Samalkot), four fluvial surfaces (Tapeswaram, Mandapeta, Eleru and Tandava) and three marine surfaces (Timmapuram, Kakinada and Uppada). In the Penner delta, Kameswara Rao[40] attempted to separate the Pleistocene erosional plain from the delta plain and marine plain of the Holocene (Figure 6; Table 3).

In the South Arcot district of Tamil Nadu, Ramalingam and Sona Ram Kiska[41] recognized a fluvial and aeolian Jayakondacholapuram surface of Middle Pleistocene (?), and a younger fluvial Kollidam-Vellar surface (Holocene). In the Kaveri delta there are patches of Pleistocene and Holocene sediments, the latter mainly made up of beach ridges, levee-complex and river floodplain (Figure 7). The base of the Pleistocene lies between 8 m and 100 m above sea level[42]. The surface near Madurai in southeastern Tamil Nadu is considered by Demongeot[43] to be Villafranchian (Lower Pleistocene).

Sediments

The subsurface sediments of the Quaternary are mainly brown to salt-pepper grey, ill-sorted, quartzose and gravelly sands with lignitic and silty clays, 280 m in the Krishna delta and 400 m in the Godavari delta[44]. The Krishna-Godavari basin gradually shifted to southwestwards during the Quaternary period as indicated by isopachs[44]. Heavy mineral content and textural characteristics of the coastal sands differ depending upon the part of the east coast where it is studied[45].

The Masulipatam bay, on the eastern part of Krishna delta has been dissected by canyons through which great volumes of sediments have been transported and deposited in deeper slope areas by turbidity current process[46].

Structure

Some of the coastal as well as inland features are attributed to the retrogression of the sea and others have resulted from elevation and subsidence of the land[47]. A very prominent ENE-WSW fault in lower Godavari delta (Figure 2) has caused changes in the trends of the meander scrolls of the Vainateyam and Vasishta distributaries of the Godavari River indicating neotectonic

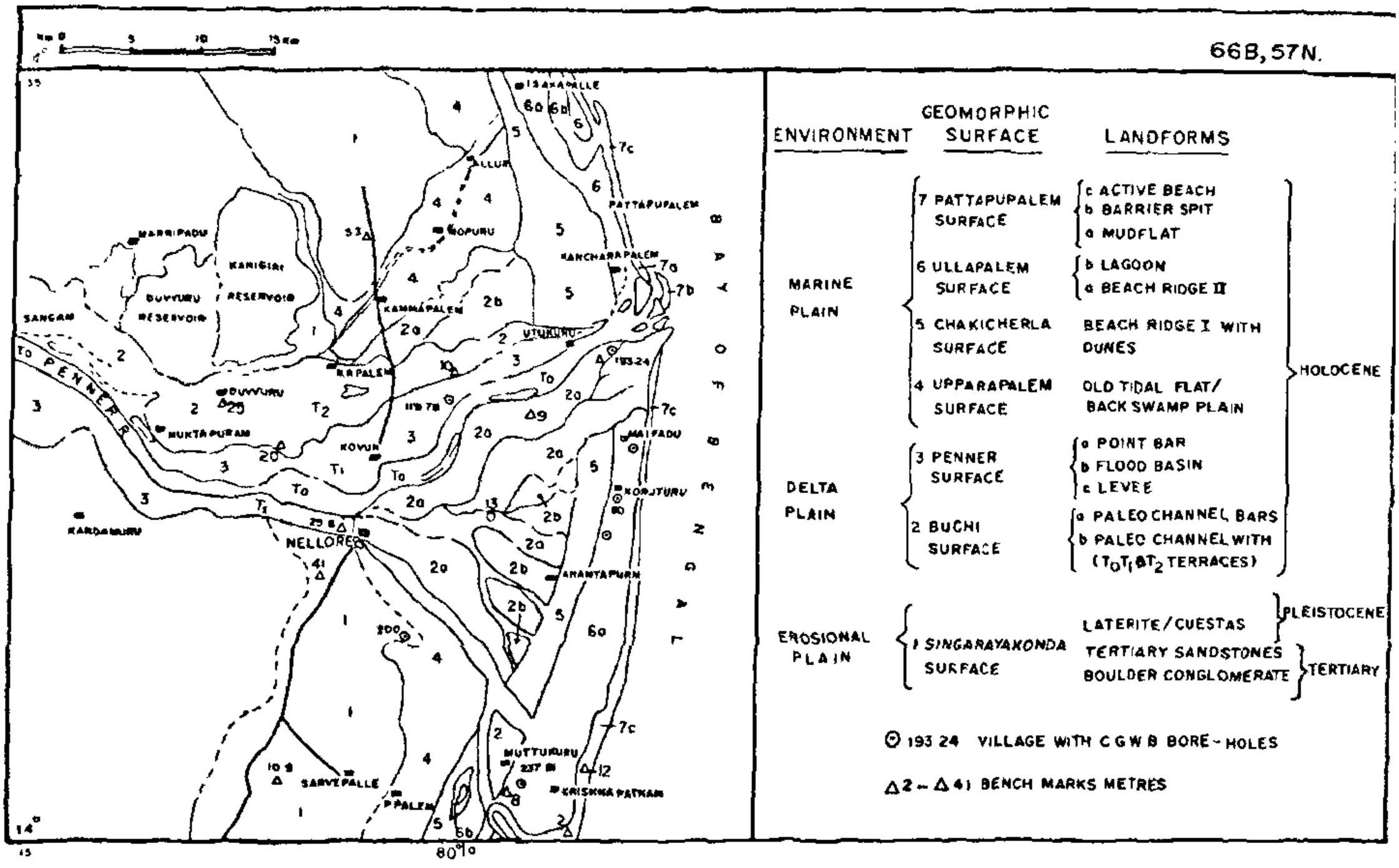

Figure 6. Geomorphological and Quaternary geological map of Penner delta, Nellore district, Andhra Pradesh. (Reproduced from ref. 40).

Table 3. Surfaces in Penner delta, Nellore district, Andhra Pradesh (extracted from reference 40).

Surface	Erosional/ Depositional	Approximate areal extent (km^2)	Range of altitude above msl (m)
Singarayakonda	Erosional	470	14–20
Buchireddipalem	Depositional	950	8–9
Penner	-do-	520	3–6
Upparapalem	-do-	150	4
Chakicherla	-do-	250	6
Ullapalem	-do-	220	3.5–4
Pattapupalem	-do-	450	2

movements (Figure 1). Sastri *et al.*[8] present a tectonic *map* showing horsts and grabens, along the East Coast and a little offshore. Seaward progradation of the shoreline might have caused growth faulting on the prodelta slopes and induce different types of faults[48] some along new trend lines, some along earlier lines of weakness due to reactivation.

The migration of some river channels may be due to vertical *movements* along these faults[49], but some others may have been induced by hydrodynamic conditions related to river regime at the delta front-lobe formation, reworking by rivers, newer lobes *downstream* as the sea level fell[50]. Varadarajan and Ganju[51] believe that movements along the NE-SW and ENE-WSW trends are responsible for shaping the entire Eastern coastal belt trends.

Life and palaeoclimate

There are but very few studies on life in the Quaternary period. The fauna include *Asterorotalia trisponsa*, *Pseudorotalia* sp., *Elphidium advena* recovered from wells at Nizampatnam, Koduru and Masulipatam (all in Krishna delta) suggesting normal, marine, tropical conditions of deposition[44], while, *Asterorotalia pulchella*,

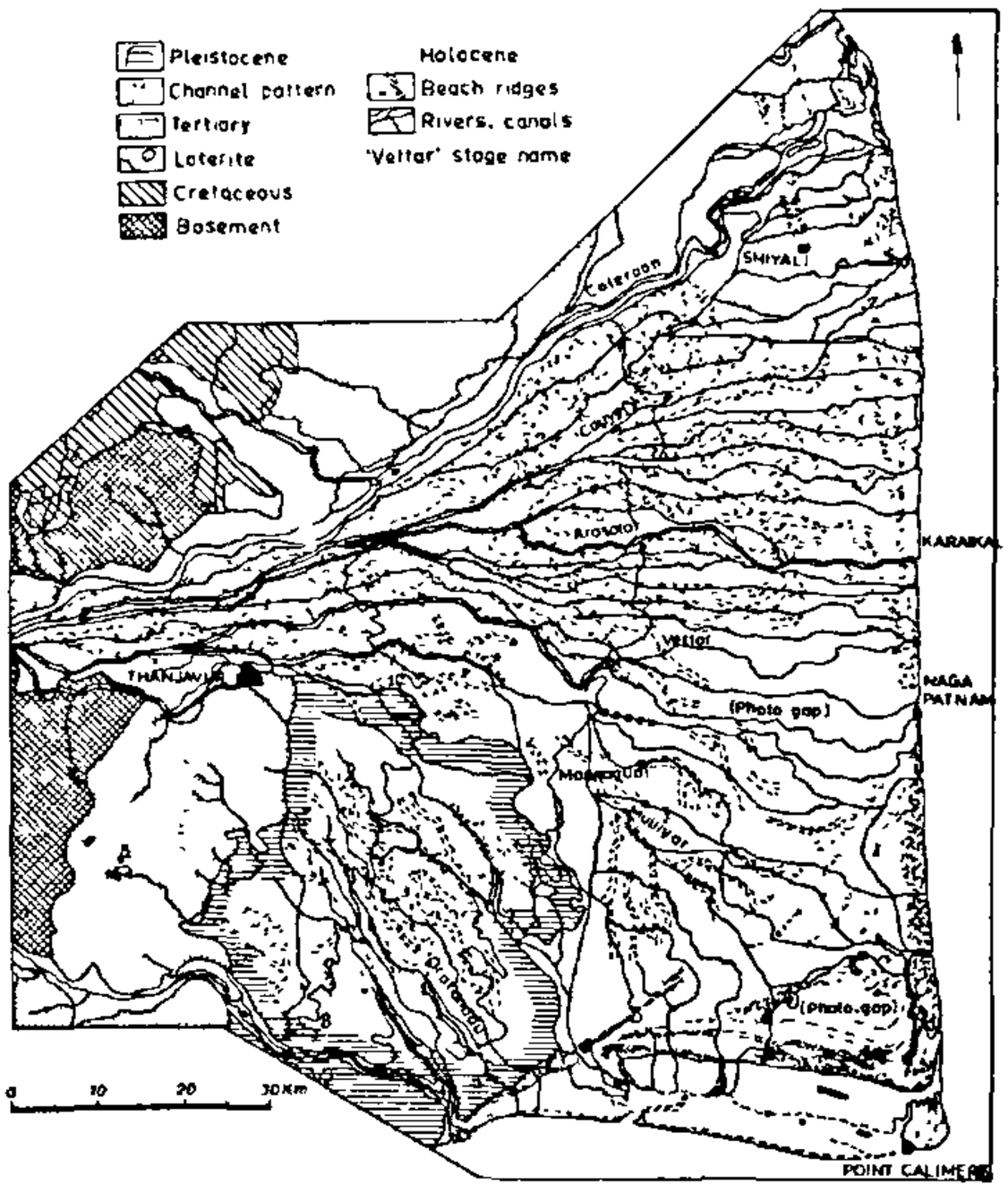

Figure 7. Reconnaissance Quaternary geological map of Cauvery delta (Reproduced from ref. 42).

collected from the marine Kolleru Formation, indicates Pleistocene and Holocene[52].

Some of the flora, north of Madras, indicate a tropical climate[53], and gypsum pseudomorphs in the inner shelf sediments off Masulipatnam Bay, off Krishna delta front, indicate aridity during the Late Pleistocene[54]. During the Holocene, particularly around 6500–6000 YBP and again 2500 to 2000 YBP there was substantial development of calcrete in the beach ridges and dune sheets in the Krishna delta[55].

In the Kortalayar river section near Kondakkarai (13° 14′ 10″ : 80° 16′ 30″) dicotyledonous plants, carbonized bark, stem pieces, seeds, peat, spores and pollens indicate a tropical climate[53]. In southeastern coastal Tamil Nadu certain mammals in the Quaternary sediments suggest warmer climate during the Pleistocene[56].

South of Vaigai river, the Quaternary sediments, have a rich assemblage of invertebrate fauna, mainly gastropods and bivalves[57].

Dating

A calcareous oolite off Godavari delta[58] dated as 10,800 ± 155 YBP suggests that most of the modern delta sediments are Holocene in age[2]. Seismic stratigraphic studies of Ongole (A.P.)-Paradip (Orissa) continental shelf indicate the existence of a chaotic facies of Early Pleistocene period, followed by a layered sequence of parallel to subparallel reflectors of Pleistocene period (18,000 YBP?) of 30–80 m thickness, followed by carbonate reefs of 11,000–12,000 YBP (?), and finally an unconsolidated layer of Holocene (?) sediments, all within the top 100 metres of the shelf sediments[59]. Gravel and pebble layers encountered at a depth of 95–120 m at Kudithipalem and Durgarajupatnam in Penner delta in Nellore district are considered to be Pleistocene glacial deposit. The Chenier plain upto 18 km inland and the beach ridges are considered to be Holocene[60]. Further south the Pondicherry surface was possibly initiated in Villefranchian (Lower Pleistocene) (Figure 4, p. 66 (ref. 43)). The ^{14}C dating of concretions in the red sediments along the coast, north of Visakhapatnam, gave ages of 5840 ± 170 and 5810 ± 120 YBP[61]. A shell collected from Gangavaram bay, south of Visakhapatnam, gave an age of 5100 ± 70 YBP[62]. Perhaps this represents the peak of Holocene transgression in this part. Bruckner[62] dated dune sand samples from beach ridges of the Godavari delta and found them to vary from about 3600 to 1000 YBP from inland towards the coast. It is quite possible that the oldest ridge further west could be 5000–4000 YBP old. Rhizoconcretions, at a uniform depth of about 6 m from the ground level collected from boreholes, from the coast towards inland, at Mollagunta, Allaparru, Peralli and Bapatla in Krishna delta gave ages of 2150 ± 100 YBP, 2450 ± 75 YBP, 2350 ± 50 YBP and 6450 ± 150 YBP, respectively[55].

Between Kanyakumari and Mandapam, aragonite of the pelycypods, gave an age of 38,100 + 1260, −1100 YBP. Shells above them in an aeolinite layer gave ages of 25,400 ± 750 YBP and 21,000 ± 400 YBP[63]. Samples collected from Mandapam and the neighbourhood indicate evidence of Holocene transgression (6240 ± 50 YBP). Two other dates are 3660 ± 65 YBP and 2740 ± 60 YBP[64]. In the southwestern and southern coast of Sri Lanka the dates fall into two age groups, — 6170 ± 70 to 5100 ± 70 YBP and 3210 ± 70 to 233 ± 60 YBP[65], implying that the mean sea levels between the two epochs were at least 1.0 m higher than the present mean sea level.

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