The depositional history of late Quaternary sediments around Mangalore, west coast of India

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Netravati and Gurpur are relatively large rivers drain the hinterland near Mangalore, form a common estuary before they debouching into the Arabian Sea. Lithologic successions observed in a number of bore holes and dug wells indicate that Netravati and Gurpur rivers drained into the Arabian Sea independently during the last glacial period when the sea level was about 100-138 m below the present level. In contrast to Netravati, the lower course of Gurpur has migrated southerly in four stages for a distance of 8 km and at present forms a common estuary with the Netravati river. This is because of drowning of the river channel due to rapid rise in sea level during the early Holocene and growth of barrier spit under the strong influence of southerly littoral currents during late Holocene when the sea level was relatively stable. The rate of infilling of alluvial and marshy sediments during late Pleistocene to early Holocene (0.5-5.0 mm/yr and 0.33-4.33 mm/yr respectively) is about two-three times slower than that for barrier spit sands accumulation (0.14-1.14 mm/yr) during the late Holocene.

West coast of India is characterized by both emergent and submergent features because of long term changes in sea level, climate, lithology, structure and local tectonic movements. Nevertheless, submergent features like estuaries, marshes, tidal swamps, mud flat deposits, spits and bars, tombolos etc. dominate the coastline. The Maharashtra coast is dominated by ria-type estuaries into which seawater intrudes up to 30-45 km inland and river mouths are widened into broad creeks. Estuaries of the Karnataka coast are shallow, characterized by narrow river mouths and seawater intrusion can barely be traced beyond 15-20 km inland. The Kerala coast is characterized by estuaries and lagoons.

The Karnataka coastline is generally straight, trending NNE-SSW of the Precambrian (F2) folding. The coastal tract can be demarcated into the northern Uttara Kannada and the southern Dakshina Kannada districts. The former has a coastline of 150 km, covering an area of 8000 km², whereas the latter has 140 km long coastline and an area of 8440 km². The coastal zone is characterized by heavy rain fall (>3000 mm/yr) and generally high temperature (>30°C). The coastal tract is highly dissected and the landscape is the result of extensive Tertiary denudation because of effect of tropical climate. The west coast of India, particularly Konkan, Karnataka and Kerala coasts, is relatively tectonically stable. Therefore, sea level changes observed here are due to glacio- eustacy whose impact on Quaternary sedimentation processes can be best understood by the study of sediments in these coasts.

The major part of the Karnataka coast comprises of sandy beaches, which vary in width from a few meters to 200 m. Beaches of the Uttara Kannada district occur in between estuaries and rocky headlands, whereas that along Dakshina Kannada are almost straight, interrupted by a number of estuaries without headlands. Therefore, the study of the Dakshina Kannada coast is ideal for understanding long-term depositional history of coastal sediments.

The study area includes the Netravati-Gurpur estuary and the adjacent landmass (Fig. 1). Netravati and Gurpur rivers originate in the Western Ghats, flow for 148 and 87 km respectively covering a total area of 4257 km². These two rivers unite to form a common estuary before debouching into the Arabian Sea. However, observation of lithologic succession in a number of drilled boreholes and dug wells indicate that these rivers had independent confluence points with the Arabian Sea. The objectives of this paper are to: (1) identify reasons for shifting of the river course,
(2) correlate the coastal sediments of the study area with others along the west coast of India, and (3) characterize and quantify sedimentation rates in the land-ocean boundary around Mangalore since the late Quaternary.

Materials and Methods
This part includes reconnaissance survey of the area to tentatively reconstruct the stratigraphy on the basis of lithologic successions observed in a number of bore holes and dug wells around NMPT and Someswar respectively (Fig. 1). Among 25 bore holes drilled around New Mangalore port (NMPT; Figs. 1 and 2), 14 are from the land and remaining ones are from the sea bed. Lithologic succession of the study area has been correlated with other formations along the west coast of India since the samples of the NMPT are quite old and are not available for laboratory work. The depth ranges of each litho units and their thickness, age of the corresponding formation along the west coast of India are given in Table 1. The sea level fluctuations data have been taken from Kale & Rajguru and Hashimi et al.

Sedimentation rates have been calculated on the basis of radiocarbon ages of the corresponding sequences along the west coast of India and the thickness of the sediments in the area of study.

Results and Discussion
The lithologic succession of 25 bore holes and their locations are given in the Fig. 2. The lithologic sequence of the NMPT area can be categorised into six units (Table 1), of which units 1 and 2 belong to Precambrian, unit 3 is Tertiary, and units 4, 5 and 6 are Quaternary. As the prime objective of this study is to trace the history of Quaternary sedimentation processes, units 4, 5 and 6 are discussed. There is no repetition or cyclicity of the units 4, 5 and 6 in the above classified lithogenic sequence, which is suggestive of the absence of last interglacial marine formations in the area of study (Fig. 2). Bruckner also has made similar observations that there are no Pleistocene marine deposits along the northern part of the west coast of India. The unit 4 comprises of cobble, pebble and coarse sand and is devoid of calcareous shell suggesting its origin from fluvial activity. These are scattered throughout the site of investigation around NMPT. However they are concentrated at areas close to the present day shoreline in sandy layers at different depths. They are found on land from surface to 27m depth, ranging in thickness from 1 to 9m. They are even extended below the sea bed (9-25 m depth) having thickness range from 1 to 10 m. This indicates that the last glacial sea level (14.5 kyr) was as low as 25-27m below the present sea level in the area of study. However, on an average the sea level was as low as 100-138m along the western continental shelf of India during the last glacial maximum (14.5 kyr). As the sea level rose, marine waters invaded the Gurpur valley and submerged land resulting in the deposition of fluvial (unit 4), estuarine/marsh (unit 5) and shoreline (unit 6) sediments. The unit 4 has been deposited as valley filled deposit due to reduction in the gradient of river channel because of the rise in sea level. The recent sea level curve proposed for the west coast of India shows that the sea level was lowered by about 100-138 m at 14.5 kyr B.P. as compared to the current level. It rose by 20 m from 14.5 kyr to 12.5 kyr B.P. with an average rise of 10 m/kyr, resulting in the decrease of river flow which in turn allowed to accumulate fluvial sediments. The
rate of channel filled deposits, i.e. sedimentation rate of cobble, pebble and coarse sand sequence was deduced from the duration of initial rise of sea level from 14.5 kyr to 12.5 kyr and the thickness of the unit 4 as 0.5-5mm/yr.

From 12.5 kyr B. P. to 10 kyr B.P., the sea level was relatively stable and from 10 kyr to 7 kyr B.P., the Holocene sea level rise was as high as 18-20m/kyr. Similarly Kale & Rajguru have obtained similar value (18 m/kyr) on the basis of computation of Holocene sea level curve. This rapid rise has resulted in the retreat of the coast, drowning the river channels, as well as the submergence of the marshy land, thereby displacing estuaries landwards. This disequilibrium in estuaries serve as effective filter for continental materials. This episode can be correlated to the accumulation of soft, medium and stiff clay, with wooden pieces, leaves and occasional shells in the NMPT area. This unit comprises of the remains of tree branches, wooden pieces and leaves, which is distributed throughout the NMPT site, except in the lateritic belt. This sequence is similar to those reported for the western continental shelf sediments of India. The sedimentation rate of this sequence has been calculated on the basis of duration of rapid sea level rise during the early Holocene and thickness of the sediment sequence as 0.33mm/yr to 4.33mm/yr for the entire study area. The sea level was close to the current level around 7-6 kyr B.P., but has fluctuated thereafter. High sea levels are
Table 1—Lithologic succession, sedimentation rate of New Mangalore port sediments and stratigraphic relations.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Lithology/ sediment type</th>
<th>Depth range below surface (m)</th>
<th>Thickness range (m)</th>
<th>Age of corresponding sequence (kyr)</th>
<th>Sea level rise (cm/yr)</th>
<th>Sedimentation rate (mm/yr)</th>
<th>Stratigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Sands with/without shells</td>
<td>0-11</td>
<td>0-5</td>
<td>7</td>
<td>0.03-0.08</td>
<td>0.14-1.14</td>
<td>Late Holocene</td>
</tr>
<tr>
<td></td>
<td>Onshore</td>
<td>0-8</td>
<td>1-8</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Offshore</td>
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</tr>
<tr>
<td>5</td>
<td>Soft, medium and stiff clay with wooden pieces, leaves and occasionally shells</td>
<td>0-20</td>
<td>1-12</td>
<td>10-7</td>
<td>1.8-2</td>
<td>0.33-4.33</td>
<td>Early Holocene</td>
</tr>
<tr>
<td></td>
<td>Onshore</td>
<td>0-22</td>
<td>1-13</td>
<td></td>
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<td></td>
<td>Offshore</td>
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<tr>
<td>4</td>
<td>Cobble, pebble, secondary laterite coarse sand but no shell</td>
<td>0-27</td>
<td>1-9</td>
<td>14.5-12.5</td>
<td>1.0</td>
<td>0.5-5.0</td>
<td>Late Pleistocene</td>
</tr>
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<td></td>
<td>Onshore</td>
<td>9-25</td>
<td>1-10</td>
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<td>3</td>
<td>Primary and lateritic clay</td>
<td>0-25</td>
<td>1-7</td>
<td>1.6-65 ma*</td>
<td>—</td>
<td>—</td>
<td>Tertiary</td>
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<tr>
<td></td>
<td>Onshore</td>
<td>10-25</td>
<td>10-25</td>
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<tr>
<td>2</td>
<td>Soft/weathered rock</td>
<td>7-30</td>
<td>1-16</td>
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<td>—</td>
<td>—</td>
<td>Precambrian</td>
</tr>
<tr>
<td></td>
<td>Onshore</td>
<td>1-16</td>
<td>1-6</td>
<td></td>
<td></td>
<td></td>
<td>peninsular gneiss</td>
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<tr>
<td>1</td>
<td>Hard/fresh rock</td>
<td>&gt;7</td>
<td>—</td>
<td>3200 ma</td>
<td>—</td>
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<td>—</td>
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<tr>
<td></td>
<td>Onshore</td>
<td>&gt;30</td>
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<td>Offshore</td>
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ma=million years; — no data

represented by occurrence of raised beaches along the west coast of India\(^4,14,15\). Radiometric ages of these ridges\(^4\) suggest that the Holocene transgression reached its maximum around 2000-2800 yr B.P.

The top most sequence of fine sand with shells i.e., unit 6 has been accumulated since late Holocene. Radiometric ages of Holocene shell sequence in the sediments of west coast of India\(^11\) range from 1400 to 3410 yr B.P. However, as per the recently updated sea level curve for the west coast of India suggests that the sea level has fluctuated little since 7 kyr. The rise in sea level since the late Holocene has been very less\(^7,16\) which has not varied beyond 0.3 - 0.8mm/yr. During this period, the top sequence of sediments has been accumulated at a slower rate of 0.14-1.14mm/yr. The accumulation of fine sand with shells in the top sequence clearly suggests that it has been deposited due to marine activity thereby shifting the Gurpur R. southwards, whereas Netravati river mouth shifting northwards.

Geological and geophysical studies of coastline between NMPT and Netravati - Gurpur river mouth indicate that the Gurpur river has four submerged paleovalleys of which the southern most is coinciding the present river mouth\(^17\) and the northern most is below the NMPT. However, in contrast to a number of paleovalleys of Gurpur river, there is only 'one' palaeovalley of Netravati river traced on land as shown in the Fig. 1, but there is none reported below the seabed. The paleochannel deposits of the Netravati river is observed in a number of wells consisting essentially of fluvial sediments but no marine /marsh/or estuarine sequences as observed in NMPT area. Fluvial sediments consisted of iron-stained, coarse, medium and fine grained sand with rock fragments and occasionally pebbles.

The southerly shifting of Gurpur river mouth to a greater distance\(^2\) (8 km long, 200-800m wide; Fig. 1) in relation to Netravati river mouth could be due to (1) the net movement of sediment through littoral
drift that is from north to south\(^{17,18}\). (2) Gurpur is a small river and soon becomes dry during the summer as compared to the Nethravati, therefore, the river mouth could have been blocked due to accumulation of sand due to littoral drift; and (3) the net longshore sediment transport in the Ullal spit is as high as 4.1x10\(^5\) m\(^3\)/yr compared to the Bengre l9 spit which is 0.44x10\(^5\) m\(^3\)/yr 18 which may not induce the faster growth rate of the Ullal spit further northwards. The river mouth of Nethravati-Gurpur is quite narrow (Fig. 1) due to the predominance of marine agency in an estuarine dominated coast like the west coast of India. However, the river mouth remains open throughout the year. In small river-estuaries along the west coast of India, eg. Talapadi Lagoon will be closed by the barrier spit during the non-monsoon seasons due to insignificant river discharge.

Similarly, there are a number of barrier spits developed along the west coast of India. Of these, the longest one is along the Kerala coast (55 km long, 10 km wide) formed between Alleppey and Cochin, enclosing the Vembanad lake\(^5\). Barrier spits are long, narrow sand accumulations that are generally parallel to the mainland and formed due to\(^{20}\) (1) littoral transport of sand along a barrier spit connecting one headland to another and then migrating landward or seaward, (2) emergence of offshore sand bars in a stable /rising sea level condition, (3) rising sea level and drowning shore - parallel feature such as coastal dunes and (4) multiple causality combining elements of the other three processes.

The probable reasons for the formation of barrier spit along the west coast of India, particularly in the area of study is due to littoral transport of sediments particularly during the stable sea level condition. Further, the significant growth of the Bengre spit in relation to Ullal spit (Fig. 1) is because of the prominent southerly transport of sediments. In the coastal Arabian Sea, the seasonal reversal of surface water currents is the characteristic feature of the monsoon systems.

This is further evidenced by seasonal variations in physical oceanographic processes like (1) the southerly moving currents those are much stronger (mean speed = 50cm/sec) during southwest monsoon than the northerly moving currents those are weaker (mean speed = 15cm/sec) during the northeast monsoon\(^{21}\) and (2) wave activity is also higher during SW monsoon than that during NE monsoon\(^{22}\).

Lithologic successions observed in a number of bore holes and dug wells around Mangalore can be concluded that the Nethravati and Gurpur had an independent exit to Arabian Sea during the last Glacial period. In contrast, the submergence of river channels and growth of 8.0 km long barrier spit under the strong influence of southerly littoral currents are responsible for unification of Gurpur river with the Nethravati before they drained into the Arabian Sea during the late Holocene.

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