The Turtle Bank, Sherbro bay, west Africa: estuarine-modified inner shelf shoal?

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Abstract
The Turtle Bank (ca. 450 km²) forms shallow subtidal sand ridges, waves, dunes, arcuate shoals and islets that occupy part of the mouth of a large estuarine bay that took its present shape through progressive progradation of wave-formed Holocene beach ridges. The bank is oriented perpendicular to the axis of the main bay channel and abruptly ends in deeper water in the vicinity of this channel. The bank is contiguous with a major set of linear sand ridges on the inner Sierra Leone continental shelf, the St. Ann’s Shoal, located in an area of abrupt shelf widening. The bank may have originated in situ as part of this open-shelf shoal, or developed from this shoal as a bay-mouth flood-tidal delta, the bay acting as an estuarine attractor for marine sand through tidal and non-tidal processes.

1. Introduction
The diversity of sand bank morphology, genetic origins and morphodynamics has recently been highlighted by Dyer and Huntley (1999) who clarified the range of conditions under which these deposits occur, and proposed a classification scheme aimed at unifying former descriptive or genetic approaches. Type 2A sand banks are recognised by these authors as associated with large estuarine embayments or estuary mouths and are generally characterised by mutually evasive ebb and flood channels. They form linear ridges aligned with the flow and which migrate away from their steeper face. The aim of this paper is to describe briefly a large sand bank complex, the Turtle Bank, associated with the mouth of a tropical estuarine embayment, Sherbro Bay, in Sierra Leone, West Africa (Fig. 1). The possible origin(s) and reasons for the location of the Turtle Bank at the mouth of this bay are briefly discussed. The results, from aerial photography and limited field work, suggest that the Turtle Bank may not be rigidly classified into any one type identified in the recent classification scheme by Dyer and Huntley (1999).

2. Setting of the Turtle Bank
The Turtle Bank occupies part of the mouth of Sherbro Bay, and protects much of the mangrove-fringed low-energy shoreline of central Sierra Leone from direct wave influence. The bank is also important for fishing activities and offers grounds for egg-laying by marine turtles. The bank area has a very low population density, and in spite of its attractive beaches and clear tropical waters, has been largely spared by tourism development, a situation reinforced by the recent civil war in Sierra Leone. Sherbro Bay is a still largely unfilled estuarine complex created by the progradation of 60 km-long Holocene beach-ridge plain composing Sherbro Island (Anthony, 1991a). The present funnel shape of the bay is due to both orientation of the inherited terrestrial shoreline and the pattern of beach-ridge development. The Sherbro Island beach-ridge plain developed astride a coastal re-entrant, and comprises two distinct barrier sets, an inner and outer barrier, separated by a lagoon. The plain developed first as successive spit recurves, then as linear ridges that progressively encroached on the shallow inner shelf in this re-entrant configuration, leading to the creation of Sherbro Bay. The reason for this configuration is shoreface widening induced by a change in coastal orientation in the vicinity of Sherbro Island. The main bay channel has a 38 km-wide mouth that narrows towards Bob’s Island (Fig. 1). The bay is protected from Atlantic swell by Sherbro Island, and by the Turtle Bank. Terrigenous and marine sediment inputs have not sufficed to fill the accommodation space created behind the Sherbro Island beach-ridge complex as the bay started taking its shape at the end of the Holocene marine transgression 5500 years ago. On the northern flank of the bay, Late Pleistocene continental runoff and sheetwash deposits, which crop out as a low coastal terrace, form a shallow (6-10 m) substrate on which accumulated Holocene organic-rich muds colonised by mangroves (Anthony, 1996). Progradation of the
flanks of the bay has resulted in the formation of a tidal plain linking up the various estuarine river mouths, and dissected by a dense network of tidal channels.

Fig. 1. The general morphosedimentary setting of the Turtle Bank and its location in relation to Sherbro Bay, Sierra Leone, West Africa. Coastal areas in black correspond to open-coast and estuarine mangroves and mudflats.
Sherbro Bay shows two distinct sectors of advanced infill, separated by relatively deep portions of channel (Anthony, 1996). The first is formed by the Turtle Bank at the mouth of the bay, and the second by a series of islets and bars in the inner bay, in the immediate vicinity of the main river mouths debouching into the bay (Fig. 1). The inner islets and bars are generally elongated sandy-muddy deposits, largely colonised by mangroves, formed where the various fluvial jets enter the bay. They are quite distinct from the Turtle Bank and are related to the rapid bay-ward deceleration of the debouching sediment-charged fluvial jets. These inner bar deposits constitute a major pathway for infill of the bay. The sands and muds deposited in this inner bay area are derived from the river catchments and from erosion of the surrounding beach-ridge plains. These inner islets and bars are highly dynamic forms.

The bay tides are semidiurnal, and characterised by two progressive waves, the more important of which enters through the large western entrance. The other wave penetrates through the narrow Mania channel between Sherbro Island and the mainland Turners Peninsula (Fig. 1), an important Holocene beach-ridge complex that stretches 120 km down the coast. The mean spring tidal range is 2 m at the western entrance, and only 1.3 m in the Mania channel. From the western entrance, the spring tidal range increases progressively to attain 2.6 m at York Island (Fig. 1), before decreasing rapidly (Africa Pilot, 1967) through frictional dissipation caused by the numerous bars and islets in the inner bay. The main bay circulation is characterized by water mass segregation marked by flood tidal wave penetration along the southern shores of the bay, and by the ebb tidal discharge, reinforced by freshwater flow from the continental catchments, along the northern shores. The two water masses, distinguished in terms of their salinity (Anthony, 1990), are separated by a well defined front visible from low-flying aircraft. The water mass along the northern flank of the bay is characterised by high suspension concentrations probably related to a density circulation associated with the development of turbidity maxima in the various river mouths debouching into the bay, and which have high rainy-season liquid discharges. Other smaller turbidity plumes occur elsewhere on the flanks of the bay, always in association with sediment discharge from mangrove swamps. The Turtle bank area of Sherbro Bay is dominated by clear saltwater intrusion. Topographic differences in the main bay channel, the presence of these two tidal waves and the considerable delay in the restitution of tidal waters caused by the vast complex of mangrove swamps lead to the complex circulation system mentioned above, characterised by distinct water masses and fronts, and by simultaneous mutually evasive flood and ebb flows in the main channel (Anthony, 1996).

3. Bank morphosedimentary characteristics and sediment circulation

The Turtle Bank forms a broad shoal platform with an area of about 450 km². The bank exhibits a complex pattern of shallow subtidal ridges, arcuate shoals, sand waves and dunes of various sizes, as well as intertidal shoals, and islets, large parts of which lie above high spring-tide level (Fig. 2). These deposits have a general southwest-northeast orientation and bedform development abruptly wanes out in the vicinity of the main bay channel. The overall bank platform orientation is therefore orthogonal to the axis of the bay channel. The bank is a tide- and wave-affected feature. Field observations show that the bank deposits are subjected to strong tidal flow, and are characterized by large-scale bedform migration under both flood and ebb flows as well as by mutually evasive ebb and flood channels. There seems to be, however, an overall flood-dominant asymmetry with residual transport towards the deeper bay channel. The overall southwest-northeast orientation of the ridges, shoals and islets probably simply reflects the pattern of penetration of the tidal wave into the bay, in the Turtle Bank area. Tides propagate northwestwards along the straight microtidal sandy coast bounding the narrow shelf of southern Sierra Leone before veering northeastwards into Sherbro Bay in the Turtle Bank area. The large-scale bedform orientations (Fig. 2) do not suggest axial migration eastwards and inwards towards the inner estuary, but rather towards the deeper southeast-northwest-trending main bay channel. This suggestion is also supported by the occurrence, just inwards of the bank, of well developed mangrove-colonised muddy deposits that have accumulated on the beach-ridge shore lining the bay, and that are not being intruded on by the bank sands. It is not clear whether the bank is growing. It seems likely that sand driven into the main bay channel is recycled seaward towards the western part of the bank.

The bank is abruptly limited seaward and semi-protected from direct swell by a set of islands bounded by oceanic beaches (Fig. 2). These islands have developed aligned with the beach-ridge complex of Sherbro Island. Residual swell working its way onto the bank complex is refracted and dissipated by the shallow subtidal and intertidal deposits. A comparison of two sets of old aerial photographs (1954 and 1976) shows changes in island shape that suggest that these deposits are constantly reworked by waves and...
Fig. 2. 1976 aerial photograph showing part of the complex pattern of shallow subtidal ridges, arcuate shoals, sand waves and intertidal shoals and islets of the Turtle Bank.

tidal currents. This fact was confirmed by island inhabitants. One of these inhabited islets, Foto, actually disappeared in July 1969, gradually eaten away by tidal scour and wave erosion. Erosion scarps on these islets show swash laminae, suggesting that the islets develop from intertidal shoals or ridges that are gradually built up by wave swash activity, aided by mild aeolian activity.

The bank consists of fine to medium (1-3 $\phi$), well to very well sorted (0.27-0.59 $\phi$), clean, rounded quartz sands (Anthony, 1990). The grain-size is finer than the medium to coarse sand size commonly associated with sand banks (Dyer and Huntley, 1999). The sand composing the shoal strongly contrasts with the iron-coated medium to coarse quartz sand that composes the beach-ridge complex of Sherbro Island. The islands limiting the bank ocean-ward have the same grain size characteristics as the bank itself but are bounded by beaches of medium to coarse iron-coated quartz sand similar to that of the Sherbro Island beach ridges. The beaches show strong longshore drift and grain-size gradients related to refraction of the southwesterly swell waves. These gradients include bi-directional drift that tends to sequester sand drifting alongshore under wave action within the bank area itself.
Discussion and conclusion
The distinctive grain-size characteristics of the Turtle bank and their marked difference from the Sherbro Island beach ridge sands suggests two distinct sedimentary sources for the two types of deposits. The Sherbro Island beach ridges have been shown to have been formed from inner shoreface and riverine sands under conditions of mild longshore drift to the northwest (Anthony, 1991a, 1995). An interesting element in considering the origin of the Turtle bank is that this sand platform is contiguous with a major sand shoal massif on the inner continental shelf, the St. Ann’s Shoal, which stretches along the central shelf off Sierra Leone for nearly 100 km at depths of 10 to 40 m (Fig. 3). The St. Ann’s Shoal forms Type 1 open shelf ridges in the Dyer and Huntley (1999) classification. This shoal occurs in an area where the continental shelf undergoes a sharp and significant increase in width, attributed to left-lateral offsetting by a major transform fault fracture zone, the Sierra Leone Fracture Zone (McMaster et al., 1975). The width of the shelf increases abruptly from about 50 km to about 120 km in the vicinity of Sherbro Island, creating the re-entrant conditions that have favoured the development of Sherbro Bay as the Sherbro Island beach ridges were formed. Descriptions of the St. Ann’s Shoal are scanty (McMaster et al., 1970, 1971). The morphology and orientation of the ridges can be picked up from old British Admiralty charts. The shoal comprises ridges and swales of medium to fine quartz sand (similar to that of the Turtle Bank). These ridges are several kilometres wide and are oriented southwest-northeast, at an angle to the tidal flow on the shelf. The St. Ann’s Shoal has been considered as a relict lower-stand sand barrier complex on the inner shelf that was drowned in place by the post-glacial marine transgression (McMaster et al., 1970, 1971). The present southwest-northeast trend of the ridges probably reflects tidal and wave reworking of these deposits following the post-glacial transgression, in an area where widening of the shallow shelf results in tidal amplification and stronger tidal currents (Anthony, 1990). The marine transgression off Sierra Leone was characterized by highly variable rates of landward shoreline translation hinged on these sharp differences in continental shelf width. Rates were low and surface reworking processes highly efficient on the narrow southern shelf, resulting in the formation of a smooth inner shelf and shoreface from which sand was driven onshore following the Mid-Holocene stillstand to form the successive beach ridges of Sherbro Island and Turner’s Peninsula. Rates were much higher on the large and shallow central and northern inner shelves, probably resulting in preservation of drowned shelf facies (Anthony, 1991b) that were subsequently reworked by stronger tidal currents and by swell wave dampening to form the present southwest-northeast-trending ridges of the St. Ann’s Shoal.

Fig. 3. Sketch map of the continental shelf of central Sierra Leone showing the St. Ann’s Shoal.
Three possible origins may be proposed for the Turtle bank: (1) an origin as a relict in situ feature that may have developed as part of the Type 1 open shelf ridges of St. Ann’s Shoal in an area hitherto characterized by open inner shelf water at the end of the marine transgression, before the construction of the successive inner beach ridges on Sherbro Island that now abut the bank at their distal ends; (2) the bank is a more recent feature that has formed from sand derived from the St. Ann’s Shoal and penetrating into Sherbro Bay under modern wave, tidal and estuarine-related processes as a distinct flood-tidal delta; (3) the bank represents a longshore drift terminus zone or sink where fine to medium sand not incorporated in the Sherbro Bay beach ridges was stored. The third hypothesis seems highly improbable, as: (a) the Turtle Bank stores a significant amount of sand relative to the longshore drift capacity on this coast, (b) this sand could have been incorporated in the prograding beach-ridge plain, and (c) the beach-ridge sand stock is quite different from that of the Turtle Bank. In the case of hypothesis 1, the Turtle Bank would be a complex in situ feature derived from relict drowned inner shelf deposits first reworked into linear Type 1 shoal ridges before being modified by subsequent wave and estuarine tidal processes associated with the formation of Sherbro Bay. In hypothesis 2, the formation of the Turtle Bank would have been conditioned by estuarine tidal wave penetration as Sherbro Bay progressively took shape as a wide-mouthed embayment following distal extension of the prograding Sherbro Island beach-ridge complex. In this case, sands derived from nearby sources, especially the St. Ann’s Shoal, would have progressively penetrated the bay under the influence of flood-dominated tidal asymmetry, probably enhanced by the Coriolis force, as suggested by the location of the bank on the south flank of the bay adjacent to Sherbro Island (Anthony, 1996).

The Turtle bank forms a bay-mouth shoal complex that cannot be simply considered as a Type 2A feature in the classification of Dyer and Huntley (1999). These workers also stressed on the importance of the local environmental context in generating diversity in the morphodynamics of Type 2A sand banks. The distinctiveness of this bank lies in the intermediate position it occupies between the open shelf Type 1 shoal that may have become integrated in situ in the extending mouth of Sherbro Bay, and a post-transgressive deposit having the makings of a flood-tidal body emplaced by hydrodynamic processes associated with flow segregation within the large mouth of the bay, under both classic tidal penetration and the Coriolis deviation effect. In this case, the developing bay would have acted as a typical estuarine sand attractor through such tidal and non-tidal processes. Neither of the hypotheses evoked above can be substantiated because of the lack of subsurface data and the limited data on long-term patterns of bank evolution. It is not clear, for instance, whether sand from the shoal is being actively transported (and trapped?) in the main bay channel. If this were the case, then there should be an active sand supply from the St. Ann’s Shoal to balance the sand lost by the Turtle Bank. What is clear is that the Turtle Bank owes its present morphology and dynamics to typical estuary-mouth processes that have been active as Sherbro Bay developed.

References
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