MARINE BIOLOGY OF THE SIERRA LEONE RIVER ESTUARY

I. THE PHYSICAL ENVIRONMENT

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The Sierra leone River Estuary is in effect the drowned estuary of the Rokel River or Seli as it is known in its upper reaches. It is bounded on the north by a coastal plain indented by creeks and on the south by a mountainous peninsula with peaks ranging from 1000-2900 ft (330-950m) in height. It extends 27 miles (44Km) from its mouth to Tumbu Island, beyond which the Port Loko Creek joins the Rokel River (Fig 1). From Tumbu Island southwestwards the Estuary assumes a width of 2.5 miles (4Km) until it reaches Tagrin Point, where it turns northwestwards and widens gradually to about 7 miles (11Km) before it reaches the Atlantic Ocean.

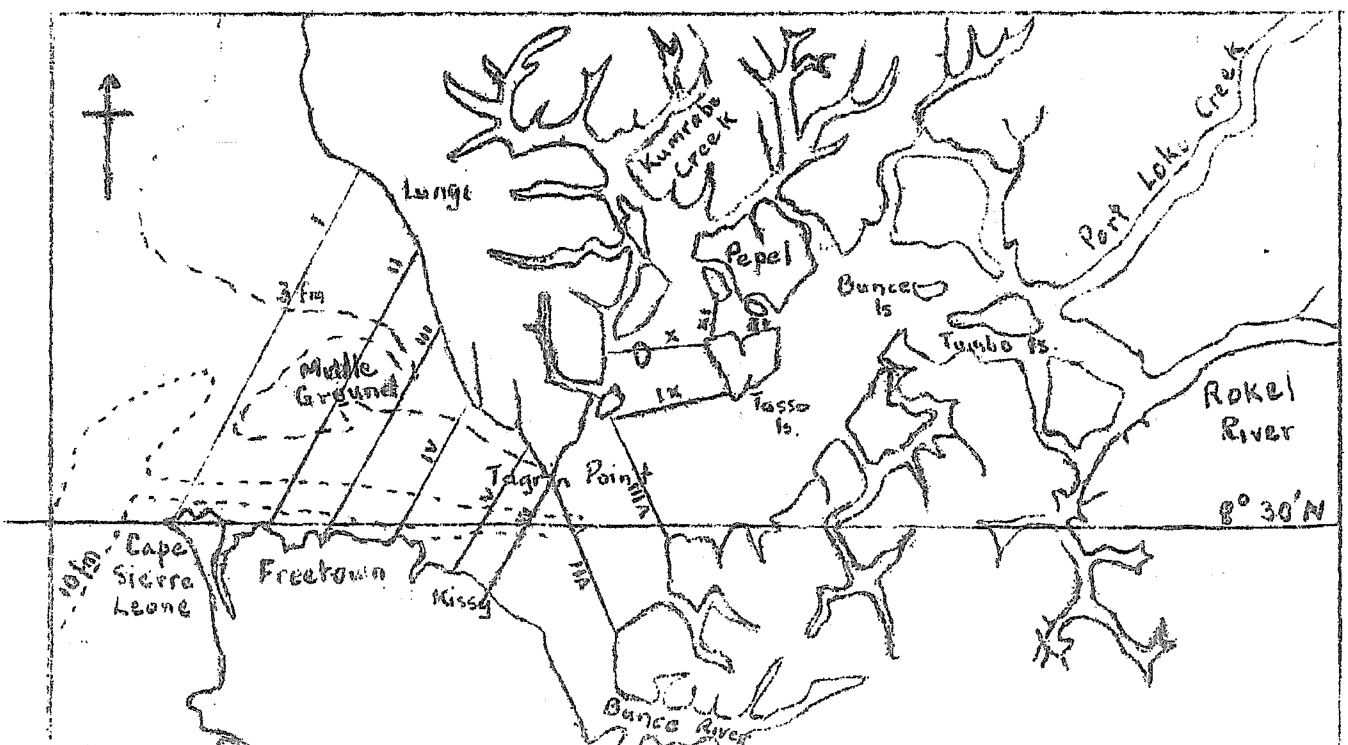


Fig. 1

The Rokel River rises in the Futa Jallon Highlands on the border of Guinea and Sierra Leone at an altitude of approximately 1600ft (500m). It is about 180 miles (290Km) long, being the longest river in Sierra Leone. It makes a marked westward swing as it leaves the interior plateau near Magburaka (100 miles or 160 Km from source) for the plains. This change in direction of flow probably results from processes of river capture consequent on a period of uplift or emergence; but subsequent submergence has resulted in the present form of the estuary (Clarke, 1966).

The Estuary is about 100 square miles (259 Km^2) in area. Most of it is shallow except for a narrow, moderately deep channel which follows its course until off Tagrin Point it becomes nearly parallel to the northern shores of the peninsula. The channel varies in depth from 4 fathoms (7m) opposite Pepel to about 18 fathoms (33m) opposite Cline Bay through to its mouth in a downstream direction. On either side of the channel the depth of water is considerably less than 5.5 fathoms (10m) and in the upper reaches extensive mud flats are exposed during low tide. There is no sand bar at the mouth of the Estuary where the deep channel joins the Atlantic Ocean off Cape Sierra Leone. However, the deposition of sand, especially on the northern side of the Estuary results in the formation of a relatively broad sand bank, the Middle Ground, which becomes exposed at low water springs. This sand bank reduces the depth of the mouth of the Estuary but does not seem to reduce the amount of the water entering or leaving it as the strength of the tidal stream is often very great and keeps the channel clear. Leigh (1973) has accounted for the sand bank by the change in direction of flow of the riverine water from southwest to northwest coupled with the setting of the tides in a NW-SE direction across the mouth of the Estuary. Bainbridge (1958) found greater turbidity at springs than at neaps in the mid-estuarine region and suggested that it was due to the greater scouring action of very strong tidal streams (4 knots) on the ebb of springs. However Watts (1957) has shown that the soft black muds deposited in the mid-estuarine region of the estuary is favoured by the water being at rest for a sufficient length of time at each turn of the tide.

The amplitude of the tide ranges from about 2.8 ft (0.9m) at lowest neaps to 10.2 ft (3.0m) at highest springs, with a mean of about 6.2 ft (1.9m). Strong tidal currents are characteristic of the Estuary as large areas are flooded and drained during a tidal cycle. During the dry season the stream on the flood runs at 1-1.5 knots (2-3 km/hr) and on the ebb at 2-2.5 knots (4-5 km/hr) at springs. At neaps it is about 0.5 knot (1 km/hr) on the flood and 1 knot (2 km/hr) on the ebb. During the wet season it is much faster on the ebb, reaching up to 5 knots (10 km/hr). The duration of the flood stream is about 5 hours and the ebb about 7 hours (Admirality Hydrographic Department, 1953).

On the northern side of the Estuary are numerous creeks, principal of which is the Port Loko Creek. It is tidal and navigable for about 15 miles (24 km). On the southern side a few mountain streams enter the Estuary and at the southwestern corner the Bunce River forms a confluence with it. The creeks and upper reaches of the Estuary are lined by large areas of mangrove swamp.

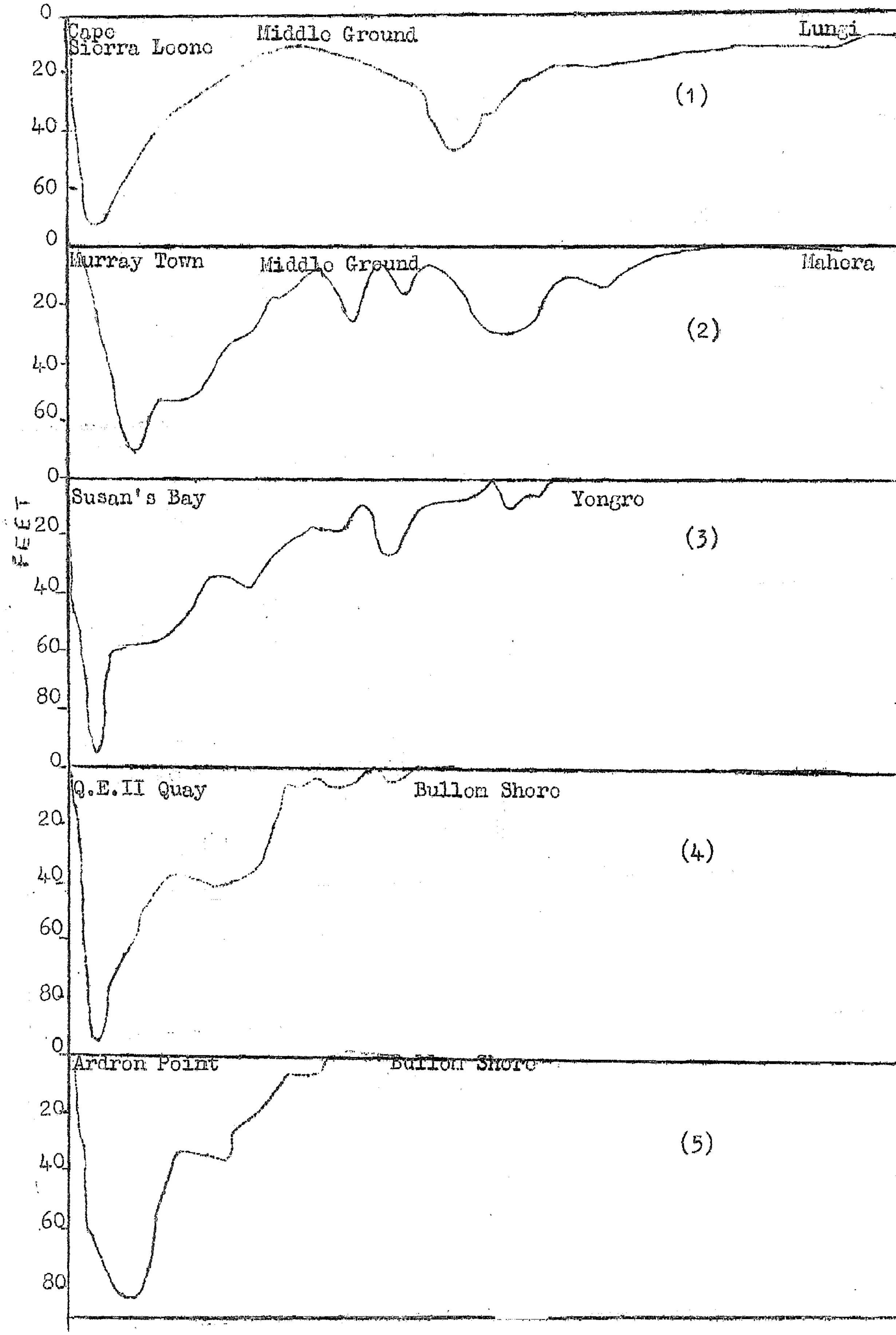
Some sectional profiles of the Estuary are given in Fig 2 and the location of the sections are shown in Fig 1. The profiles show that the deepest part of the channel lies very near the northern shore of the Freetown Peninsula between White Man's Bay and Cline Bay.

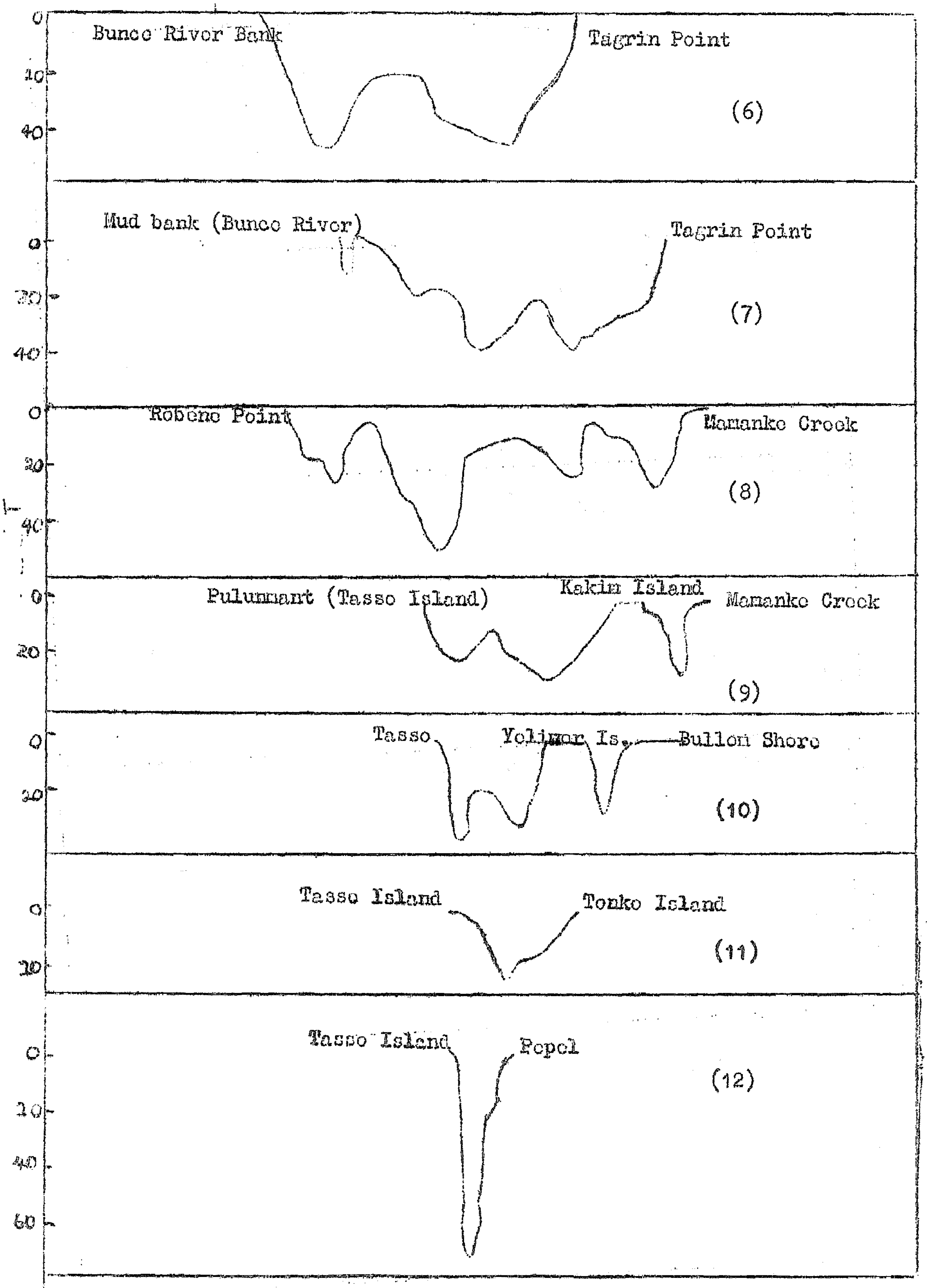
Along the Estuary are two ports - Freetown and Pepel. Freetown is the only importing port whilst Pepel (until recently) was used for the export of iron ore. Freetown has the best natural harbour in West Africa with the deepest part of the channel near its shore. The entrance to the harbour is three quarter mile wide and a controlling depth of 6 fathoms (11m) and lies between O'Farrell Shoal and Aberdeen Point. The harbour extends 8 miles in length with a width of $1\frac{1}{2}$ miles and has anchorage room for 240 ships of unrestricted depth. Along the northern shore of the Freetown Peninsula are located some of the major industries as well as the Queen Elizabeth II Quay which is at the eastern extremity of the harbour. The industries include the Kissy Oil Refinery Terminal, the Sierra Fish Industries also at Kissy, the Wellington Distilleries and Brewery, all of which discharge raw or partially treated waste waters directly into the Estuary.

In the central part of Freetown, at King Tom, there is an Electric Power Station which uses the estuarine water for its secondary cooling circuit and discharges the heated water into the Estuary. The main concentration of industry is found to the east and west of the centre of Freetown in a government established industrial zone, stretching from Kissy to Wellington. At present most of the factories are small but pose a threat to the water quality of the Estuary as most of them do not treat their wastes which eventually get into the estuarine water.

The City of Freetown is largely unsewered except for four short sewer lines which discharge untreated sewage at two point directly into the Estuary and at a third near the shore. The sewer lines serving the hotel complex at Aberdeen also discharge untreated sewage directly into the Estuary.

Fig. 3 - Sectional profiles of the Sierra Leone River Estuary drawn from the Admirality Chart 689 (New editions 1967) and from the entrance in an upstream direction. The Admirality Chart Datum is 20.43 ft (6.23m) below the base of the harbour lighthouse on Aberdeen Point (Cape Sierra Leone), or 5.57 ft (1.70m) below Sierra Leone Datum.


FEET
Cape Sierra Leone
Middle Ground
Lungi
(1)
Murray Town
Middle Ground
Mahera
(2)
Susan's Bay
Yongro
(3)
Q.E.II Quay
Bullom Shore
(4)
Ardron Point
Bullom Shore
(5)
0
20
40
60
80


Bunco River Bank
Tagrin Point
(6)
Mud bank (Bunco River)
Tagrin Point
(7)
Robene Point
Mamanke Creek
(8)
Pulunmant (Tasso Island)
Kakim Island
Mamanke Creek
(9)
Tasso
Yelimor Is.
Bullom Shore
(10)
Tasso Island
Tonko Island
(11)
Tasso Island
Pepel
(12)

The Shores and Bottom

The northwestern shore (Bullom shores) facing the Atlantic is characterised by extensive mud banks. On the estuarine side of Bullom shores are creeks and islands whose shores are lined with mangrove swamps. The southern shore, from Cape Sierra Leone up to the mouth of the Bunce River, is rocky as the deep channel passes close inshore and the tidal streams along the shore are very strong. However, the rocky shore is indented by creeks and bays where mangrove swamps are found. Beyond the Bunce River estuary in an upstream direction until Bunce Island is reached, there appears to be no rocky shore except at Bunce Island and the neighbouring Trinidad Rocks. In the mid-estuarine region between the entrance to the Bunce River and Tasso Island there are relatively small banks of mud and stones which become exposed at low water.

Immediately outside the mouth of the Estuary there is a wide area of largely sand or shell sand deposits whereas at the other end of the Estuary above the Tasso Island they are predominantly of coarse sand. At the lower reaches of the Bunce River the deposits are largely of mud while Kumrabi Creek is mainly sandy. (Longhurst, 1958). The bottom deposits on the northern side of the Estuary are mostly sand along the region of raised beaches, giving way to an admixture with silt further up as the region of fringing mangrove swamps is reached. Watts (1957) found the bed of the mid-estuarine region is composed of alternating patches of black mud and sand mixed in varying proportions. The unconsolidated nature of the deposits and the strength of the tidal stream results in a rapid and uninterrupted redistribution of the sediments, such that the character of the bed of the estuary is continually changing. Where the current slackens silt is deposited, such that intertidal rocks in sheltered bays are coated with soft brown mud e.g. at Cline Bay. In the deep channel and the channel between Kakim Island and the Bullom shores where the bottom currents are most intense, the bottom is largely composed of broken shells and fine lateritic gravel. Between Tasso Island and Robene Point there are extensive flat areas of reddish muddy sand.

The black muds of the mid-estuarine region have a relatively high organic content attributed to the presence of undecomposed or partially decomposed organic matter. In general the estuarine muds contain relatively large amounts of sulphur. In the muds of the mangrove swamps, the sulphur is in the reduced state but becomes oxidized as the soil becomes extremely acid on drying out (Jordan, 1964).

Geologically speaking, the Estuary is considered relatively young. Dixey (1919) and Gregory (1962) have suggested a Pleistocene dating for the series of raised beaches in this region. Many youthful drainage systems traverse the raised beaches, whose distribution in the Peninsula, suggests their formation before the Estuary. It is believed that the rise in sea level which followed drowned the Estuary and generated the present accumulation on the Middle Ground and the formation of the Mangrove swamps.

Climate

The climate of the Guinea coast, from Cape Palmas in the south to the north of Conakry, is directly influenced by the inter-tropical or trade wind belt. Consequently the "Tropical Continental" airmass or dry N.E. Trades or Harmattan from the Sahara and the "Equatorial Maritime" airmass or the Monsoon or humid South Westerlies dominate the climate of this region. In the Freetown area the rains last from May to November with two maxima during May/June and September/October. The dry season extends from December to April, during which period the area comes under the influence of the N.E. Trade winds blowing from the Sahara.

The mean temperatures are lower in the middle of the rains than at any other times of the year, with a diurnal range of about 72°-82°F (22°-28°C). The skies are often overcast with relative humidity over 80%. Visibility is generally better than during the middle of the dry season, but worse than at the beginning and end of the rains. Winds are mainly from the south-west bringing heavy rains at the beginning and towards the end of the season.

During the dry season the diurnal range of temperature is 70°-90°F (21°-32°C), becoming hotter as the season advances. Relative humidity varies between 65 and 90% during the day. The skies are fairly clear although the predominant north-easterly winds during the period December to March frequently bring dust from the Sahara thus reducing visibility.

The catchment area of the Rokel River has a mean annual rainfall of between 90 and 130 inches (2286-3302mm) of which just over 90% falls between May and November. Most of the rainfall enters the Estuary as run-off due to the topography of the drainage basin and the relatively impermeable soil structure. Within the catchment area there is a longitudinal change in intensity and duration of the wet season from west to east - intensity being greatest in the west and duration greatest in the east, (Gregory, 1966). Consequently there is a seasonal fluctuation in the river discharge which complicates the hydrography of the Estuary.

HYDROGRAPHY

The Estuary is tidal and of the semi-mixed type with the saline water from the Atlantic Ocean entering it on a diurnal cycle. Tidal variations are recorded as far as 42 miles inland along the watercourses of the Rokel River and its tributaries as well as the Bunce River and several small streams, Kumrabi and Port Loko Creeks. The rate of outflow of the Rokel River has so far not been investigated but the extent of its discharge into the Estuary can be roughly estimated from salinity values.

Salinity

Watts (1958) has shown that there is a very strong seasonal fluctuation of salinity due to the heavy precipatation between May and October (Table I). He suggested that the distribution of salinity in the main estuary is a result of the circulatory current system. There is a tendency towards a two layered transport system with an offshore movement of relatively brackish water compensated for by an onshore counter current of saline water close to the bottom of the estuary. As a result the water becomes stratified and the salinity increases with depth. This vertical salinity gradient is influenced by the changes in tidal range and the rate of river discharge. Inthe wet season the stratification is more marked at springs whereas in the dry season it is generally not appreciable. The large dilution of the surface waters results in low salinity in the rainy season. The bottom waters near the mouth are relatively immune except during heavy floods when large changes in salinity become noticeable at neaps. This is not the case in the dry season when conditions are such that the water column is almost homogenous.

Leach (1973) found that in the main estuary the differences between surface and bottom water salinities during the dry season were comparatively small but increased upstream. These differences tended to be large towards the end of the rainy season at the mouth of the Estuary but extended to early dry season in the middle and upper reaches. The observed trends result from considerable long and short term variations in the amount of water entering the Estuary from the sea as well as the amount flowing out.

So far there is little hydrographic data for the higher reaches of the Estuary and for the creeks. However, the data available (Longhurst,1958) indicate that during the dry season, fairly saline water reaches the heads of the creeks and fresh water is only found in the Rokel River 20

TABLE I

Seasonal fluctuations in the vertical and horizontal salinity profiles at the times when the maximum and minimum values were obtained.

(Watts, 1958)

		DRY SEASON		WET SEASON	
		L.W.	H.W.	L.W.	H.W.
Mouth (Cape S.L.)	Surface	33.3	34.1	27.2	29.3
	Bottom	34.0	34.3	30.1	30.5
Middle Reaches (Tagrin Point)	Surface	27.5	31.5	16.1	20.9
	Bottom	29.8	32.9	23.0	26.7
Upper Reaches (Pepel)	Surface	21.6	26.8	8.2	9.8
	Bottom	22.6	27.6	11.0	12.9

miles beyond Pepel. During the wet season surface salinity may drop to about 8ppt at Pepel, and to 16ppt at the head of the Bunce River (a mangrove creek) and fresh water probably occurs 9 miles beyond Pepel.

Temperature

Leigh (1973) has shown that the annual difference between the maximum and the minimum temperatures were of the order of 2° to 7°(air), 2° to 4°C (surface water) and 2°to 3°C (bottom water, depth : 17.4 to 29.3m) from the mouth of the Estuary upstream to a station on the axis between Tagrin Point and Robene Point. Also the monthly average temperature variations for air, surface and bottom waters were small; varying between 27.3° and 30.1°C (air), 26.6° and 29.7°C (surface water) and 26.4° and 28.7°C (bottom water). In general the average monthly air temperatures were higher immediately towards the beginning and end of the rainy season and lower in the middle of the dry and rainy season. The monthly average surface and bottom water temperatures followed the same pattern as for the air temperature but with a month's lag at their maximum and minimum Leigh's findings confirm Watts' (1958) observations that both the horizontal and vertical range of temperature in the Estuary is small with only minor seasonal fluctuations. He observed that the minimum surface temperature occurred at the height of the monsoon period (August). The increase in temperature after the rains is related to the decreased rainfall until the maximum is reached in November, when the development of the easterly continental winds and later the Maritime trade winds cause a further fall in temperature, observed in March (Leigh, 1973). Watts (1958) felt that as the Maritime trade winds weaken and the Canary Current retreats northwards the sea and estuarine surface water temperatures rise to a maximum in May. He attributed the rise in temperature to the higher air temperatures and the northerly set in the coastal currents, which transport relatively warmer water from the Counter Equatorial Current northwards along the coast. Later, as the SW Monsoon strengthens and replaces the retreating Maritime trade winds, temperatures fall with the increased rainfall(Fig. 3).

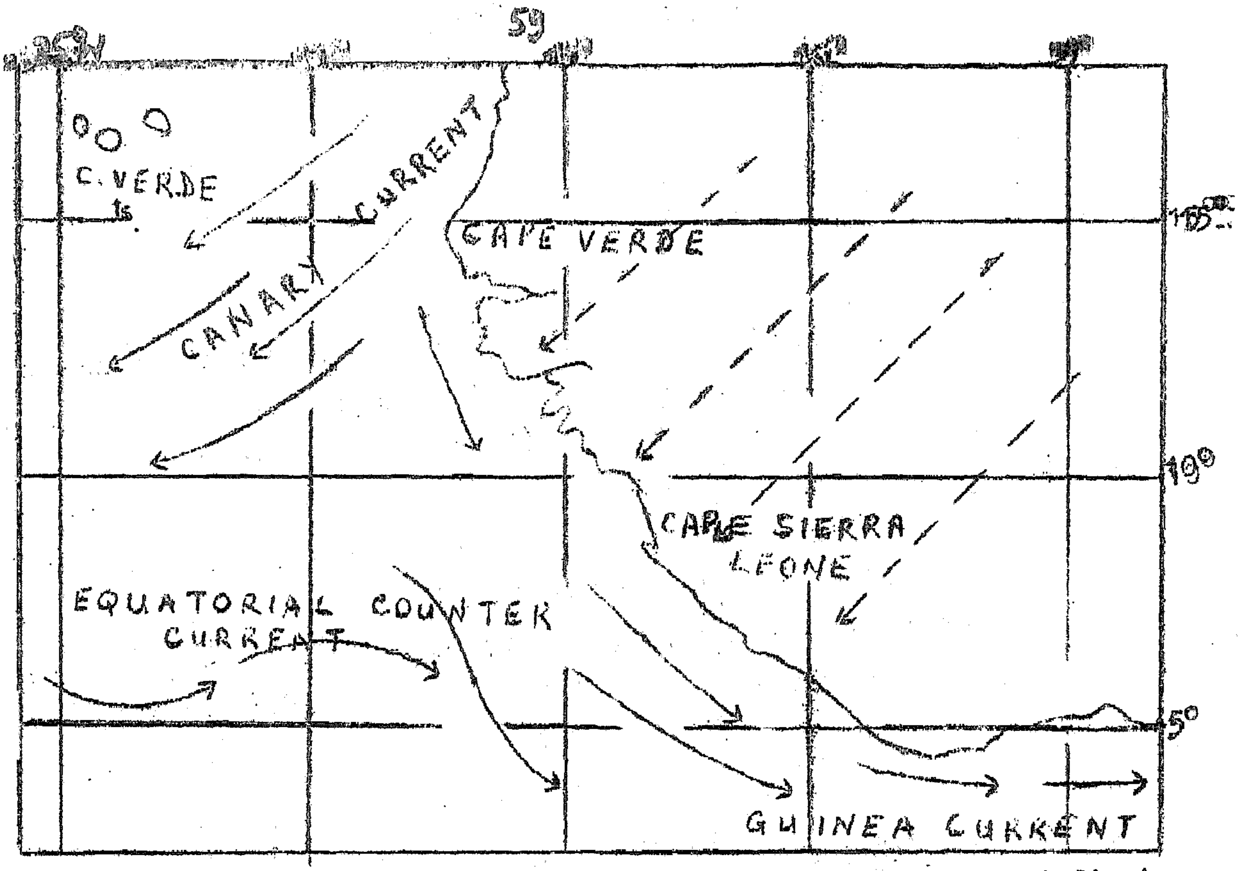
Turbidity

Turbidity is a very variable and transient property, depending upon the weather and tide. Bainbridge (1960) observed that the colour and turbidity of the Estuary water are conspicious features of the central and upper reaches when considered against the background of the spring to neap cycle ofthe tidal range. They are most pronounced during the dry season. At springs the water is brown and turbid whilst at neaps it is green and more transparent in contrast to the blue-grey colour and fairly transparent water outside the mouth of the Estuary. He obtained a mean extinction coefficient from weekly measurements during the period December, 1954 to August, 1955 in the central part of the Estuary shortly before low water of 1.26 (range 3.4 to 0.6) at springs, and a mean of 0.54 (range 0.9 to 0.3) at neaps. He found that outside the mouth of the Estuary there was no clear cycle of turbidity between springs and neaps and the extinction coefficients varied between 0.5 to 0.1 with a mean of 0.27. Plankton samples taken simultaneously showed that the estuarine water carried much organic detritus, especially during spring tides when the current velocities are highest and larger areas of the mangrove swamps are scoured.

Watts (1958) found that turbidity is greater in the wet season than in the dry and the concentration of suspended matter increased in an upstream direction. Taylor (1966) noted that during the wet season solar radiation is also decreased, thus greatly reducing the depth of the photosynthetic zone. However it would appear that with the increased inflow of sea water into the Estuary from October to May when freshwater discharge is diminishing consequent on dereasing rainfall, flocculation

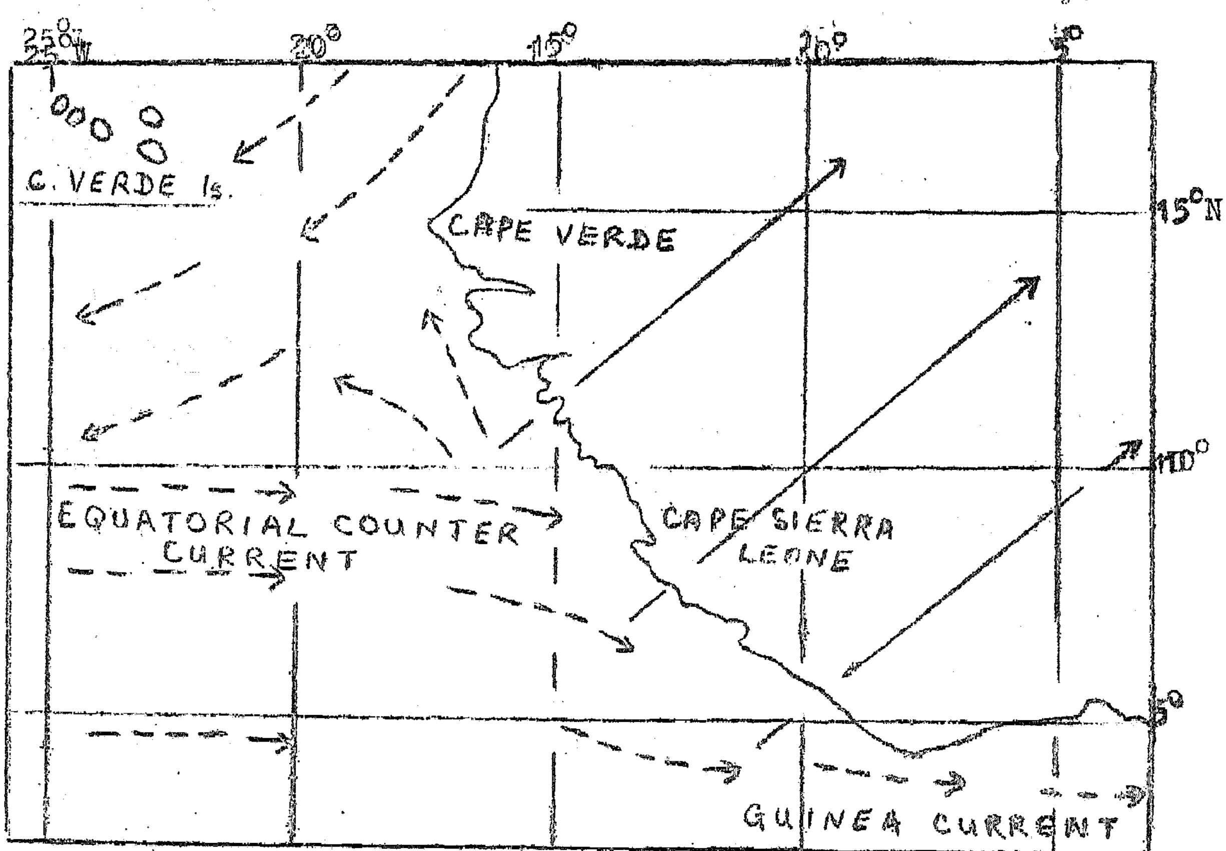
FIG. 3 A&B. The general pattern of winds and surface currents off the Guinea coast.
(Adapted from Bainbridge, 1960)

(A)



Arrows show currents from February to April; broken arrows indicate the direction and southward extent of the Harmattan in January.

(B)



Broken arrows show currents from May to July; arrows show the direction and extent of influence of the Monsoon in July.

reduces the amount of suspended matter. As a result transparency is increased during the dry season - December to February - as was observed by Watts (1958).

Dissolved Oxygen

Watts (op. cit.) made monthly determinations of the concentration of dissolved oxygen in a series of water samples of different salinities taken over a period of six months (September 1954 to February 1955). The period covered the last three months of the rainy season and the first three months of the dry season. He found values ranging from 109 to 56% saturation, with no seasonal variation, the maximum and minimum values both occurring in February. A few observations in the upper reaches and creeks gave values ranging from 66 to 83% saturation, while outside the mouth of the Estuary values ranged from 63 to 103% saturation. He also found that the average concentration varied from 80 to 86% saturation within the salinity range of 5 to greater than 30ppt and a temperature range of 25° to $30^{\circ}C$.

Leigh (1973) made determinations from weekly samples taken at 5m depth intervals from surface to bottom at high and low tide during the period October 1970 to November 1971. One station was located just outside the mouth of the Estuary and another in the mid-estuarine region. He found no seasonal variation although concentrations tended to be slightly higher during the rainy season than during the dry season especially in the mid-estuarine region. Also the oxygen content of the surface water was continuously higher than those of the bottom water throughout a greater part of the period except at low tide immediately outside the mouth of the Estuary during September when the bottom water concentrations were higher than those at the surface. Generally there was not much difference in the dissolved oxygen concentration between each of the stations at all depths. The concentration ranged from 55 to 90% saturation immediately outside the mouth of the Estuary and 55 to 97% saturation in the mid-estuarine region.

Leigh has proposed that the slightly higher surface values are a consequence of wind action on the surface waters; the slight increase in concentration in the mid-estuarine region during the rainy season could be due to the influx of freshwater from the Rokel River. Moreover the drop in the oxygen content of the bottom water could result from the breakdown of organic matter which Watts (1957) found to be abundant in the bottom deposits of the Estuary.

Nutrients - Inorganic Phosphorus

Bainbridge (1960) gave the results of a series of dissolved phosphate determinations carried out by P. Hansen from April to December, 1953. The dissolved phosphate content of the water was found to be slightly higher in the central region of the Estuary (0.3 - 0.97 ug-at P/l) than at its mouth (o.25 - 0.72 ug-at P/l). These amounts were considerably higher than those of Wattenberg (1957) obtained for the open Atlantic Ocean water just off the West African coast (0.0 - 0.36 ug-at P/l at 25m, and at the surface it was undetectable). At the upper reaches of the Estuary Watts (1958) found that the average concentration was 0.15 ug-at P/l. Bainbridge (1960) therefore concluded that the relatively high concemtrations of dissolved phosphate in and off the mouth of the Estuary may be due to the continual tidal mixing and frequent re-suspension of organic detritus derived from the river, the mangrove swamps and the plankton.

Leigh (1973) carried out weekly determinations of inorganic phosphate and nitrate-nitrogen concentrations at 5m depth intervals down to 15m in the sea at the mouth of the Estuary and in the central region of the Estuary from October 1970 to November 1971. He found that the inorganic phosphate concentration ranged from 0.10 to 0.76 ug-at P/l; that during the dry season (especially from late January to the end of March) it was undetectable at all depths from just outside the mouth up to the central region of the Estuary. With the onset of the rains (April) the concentration increased and was maintained at a high level till the end of the rains. There was an increase in concentration with depth at all states of the tide during most of the rainy season (April to September) just outside the mouth of the Estuary. The same pattern was observed in the central region of the Estuary but in May and June the concentration was not uniformly distributed in the water column as higher concentrations were detected at either 5m or 10m depths. During the rainy season at the entrance to the Estuary the concentrations at the surface and bottom were higher at high tide than at low tide whereas during the dry season there was little difference in concentration at both states of the tide. In the central region of the Estuary the concentration at low tide in the surface water in June, and from September to November was higher than that at high tide. The pattern was reversed during May and July whilst during August the surface concentration at both states of the tide were almost similar (0.15 ug-at P/l). The bottom concentrations at low tide was higher than that at high tide during April, July and September, whereas the opposite trend was observed in May, August and November. During the dry season the concentrations at both states of the tide were almost similar.

Leigh (1973) has suggested that the absence of inorganic phosphate in the estuary water during late January to early March in the lower reaches and the central region could be due to its rapid uptake by phytoplankton which is usually in great abundance from January to June/July (Bainbridge 1960, Watts 1961). Associated with the latter is the penetration of sea water into the Estuary during this period when land run-off has decreased. Wattenberg (1957) has shown that the open sea water outside the Estuary is usually poor in inorganic phosphate, hence the total absence of phosphate at all depths. The increase of inorganic phosphate concentration from late March to November is attributed to tidal mixing and turbulence generated by the strong incoming westerly winds. Such a view has buttressed that of Bainbridge (1960) that the inorganic phosphorus is brought into circulation from re-suspension of the bottom sediments and can account for the increased concentration with depth during a greater part of the period.

Nitrate-Nitrogen

Single nitrate analysis carried out by Watts in November 1954 and reported in 1958 gave an average concentration of 5.29 ug-at N/l for both the central region of the Estuary and at its mouth. In the upper reaches he obtained an averageof 10.13 ug-at N/l and suggested that river discharge must make a significant contribution to the nitrate concentration of the Estuary.

Leigh (1973) found that the concentration of nitrate-nitrogen range from 0.1 - 66.6 ug-at N/l. Except on a few occasions the concentration increased upstream and was more pronounced during the rainy season. The concentration at the mouth of the Estuary was generally low from mid-January to mid-September (below 5.5 ug-at N/l) and the lowest concentrations were observed in the central region in late February (0.3 - 0.1 ug-at N/l from surface to bottom). In general the concentration was higher during the rainy season than during the dry season; it decreased with depth except during the dry season; the greatest difference in concentration between the surface and bottom waters was observed at low tide during January and that the concentration was usually higher at low tide than at high tide. His findings support Watts' view that increased river discharge during the rainy season contributed largely to its level of concentration in the Estuary water

SUMMARY

The Sierra Leone River Estuary is a relatively young drowned river valley, probably formed in Pleistocene times when there was a general rise in sea level. Most of the Estuary is shallow except for a deep channel which passes close to the Freetown shoreline. The upper reaches merge into a network of creeks and channels fringed by large areas of mangrove swamps. It is a tidal estuary of the semi-mixed type with the saline oceanic water entering it on a diurnal cycle.

The climate of Sierra Leone is marked by a very distinct change between a very wet rainy season and a dry season. The rainfall pattern comprises the conventional thunderstorm rains of the early and late wet season, mainly related to disturbance lines moving from east to west across the country, and the steady monsoonal rains of the main wet season, roughly from mid June to late September, moving into the country from the south-west off the Equatorial Atlantic. The tidal range of the Estuary (spring 3.03m; neap 2.28m) does not impede normal use of the harbour. The tidal variations can be felt as far as 42 miles inland along the water courses of the Sierra Leone River and its tributaries. The volume of fresh water entering the Estuary is large during the rainy season and greatly reduced during the dry season. Consequently there is a marked fall in salinity during the rainy season and higher salinities due to the marine influence prevail during the dry season.

The nature of the shores and bottom, the hydrography and chemistry of the estuarine system have been outlined in relation to the prevailing climatic conditions.

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