DETERMINATION OF BOTTOM SHIFTS IN RIO NUNEZ ESTUARY

by Lt Cdr P. L.C. MARTIN, French Navy Reserve
Head of Port Installation Research Mission
Société Générale d'Exploitations Industrielles (SOGEI)

Lieutenant Commander MARTIN, who has specialized in coast surveying for the past twelve years in Africa and South America, and to a lesser extent in Europe (1952 survey of Larvotto Cove, in Monaco), entered the hydrographic field in 1928. At that time he was active in the China Sea, first with Hydrographic Engineer MARTI at Kwangchowan and Poulo Cecir de Mer, and later with Hydrographic Engineer GOUGENHEIM (who now heads the French Navy Hydrographic Office) at Phanrang.

He had previously undertaken extensive studies of the following estuaries : Cua Ba Lat Dong (an arm of the Red River) in Tonkin; Oued Sebou in Morocco; Rio Maipo in Chile; and Rio Ararangua in Brazil, before his survey in 1956 on behalf of the *Société Générale d'Exploitations Industrielles* (SOGEI) of the Rio Nuñez in French Guinea (now the Republic of Guinea).

IHB NOTE

The following article is not confined to hydrography in its ordinary sense, in that it stresses one of its major aspects : the application of hydrographic surveys. These are not exclusively used for chart construction; any projected development of marine shore installations such as the creation of harbors and port facilities, improvements to river entrances and sea reaches, beaconage, etc. must be based on a faithul portrayal of the terrain. If this type of work is carried out without prior research supported by reliable survey documents, considerable sums may be wasted in building installations which not only fail to achieve the desired objectives but seriously injure future prospects.

The Directing Committee accordingly believes that this article will interest hydrographers by showing how surveys can be of service in the economic development of the seaboard, which incidentally is connected with navigational progress.

INTRODUCTION

Among the various types of nautical charts issued by national hydrographic offices, coastal hydrographic surveys (mainly large-scale) are used by engineers as a basis for their port-installation projects. Yet these official documents, although perfectly suited to navigational requirements in the vicinity of harbors, are apt to give the misleading impression that both the shore and neighboring shallows are stable.

At greater depths, changes occur at long range, apart from the appearance of islands as a result of submarine volcanic upheavals as shown by recent oceanographic work on turbidity currents. Such phenomena are sporadic, however.

Shore areas composed of loose materials, on the other hand, have a marked activity of their own, as may readily be observed on beaches where the combined action of turbulence and tide constantly shifts the berm on the foreshore (shift in profile). A coastal strip which appears unchanging owing to the homogeneity of material and the absence of reference marks is usually subject to shift, either in one or alternate directions, and the amount of material displaced may be considerable (700 000 m^3 per year at Abidjan). Engineers responsible for the construction of a number of ports have learned this to their sorrow : gravel, sand and mud have occasionally piled up and blocked the channels between the structures raised as protection against turbulence as they were extended seawards. We personally witnessed such an occurrence in 1926 at Safi, which we were eventually destined to survey (1948-1949).

No doubt powerful dredging methods are now available which enable maintenance of port approaches. But these operations are costly, increase shipping expenses and sometimes prevent maintenance of the desired depth at all seasons.

As a result, hydrographers who specialize in surveys required for port construction no longer merely produce a single plan showing depths at a given date. In conjunction with geologists, who supply detailed information on the nature and origin of the materials constituting the loose-lying bottom and foreshore, they investigate shifts over a period of time as governed by meteorological and oceanographic factors (wind, swell, tides, and the discharge of rivers into estuaries).

To obtain a reliable analysis of the general mechanics involved in the transportation of materials, and accurate solid-output figures for each type of shift or deposit, a minimum five-year period is necessary, or a corresponding volume of previous technical investigations must be available (as in the case of regularly inspected harbors, like the main French ports).

But prior to the projected creation of a port in the Rio Nuñez described in these pages, apart from a survey carried out in 1831 by Captain Belcher, R.N. and completed by Commander Kerhallet, French Navy, from 1841 to 1847, not even a partial depth check had been made in the estuary for over a century. The problem thereupon arose of shipping bauxite out from the Boké area by sea.

The SOGEI concern was given a brief span of two years (1956-1958) in which to ascertain the elements of estuarial behavior, and thus enable the engineers to select the best possible berthing sites, settle on construction methods, and adopt the final course of the entrance channel for partial dredging.

Since readers of the International Hydrographic Review are familiar with survey techniques, current measurements and meteorological studies, discussion is limited in this article to the shifting of materials in the Rio Nuñez estuary, and to the old or new methods used to determine such shifts.

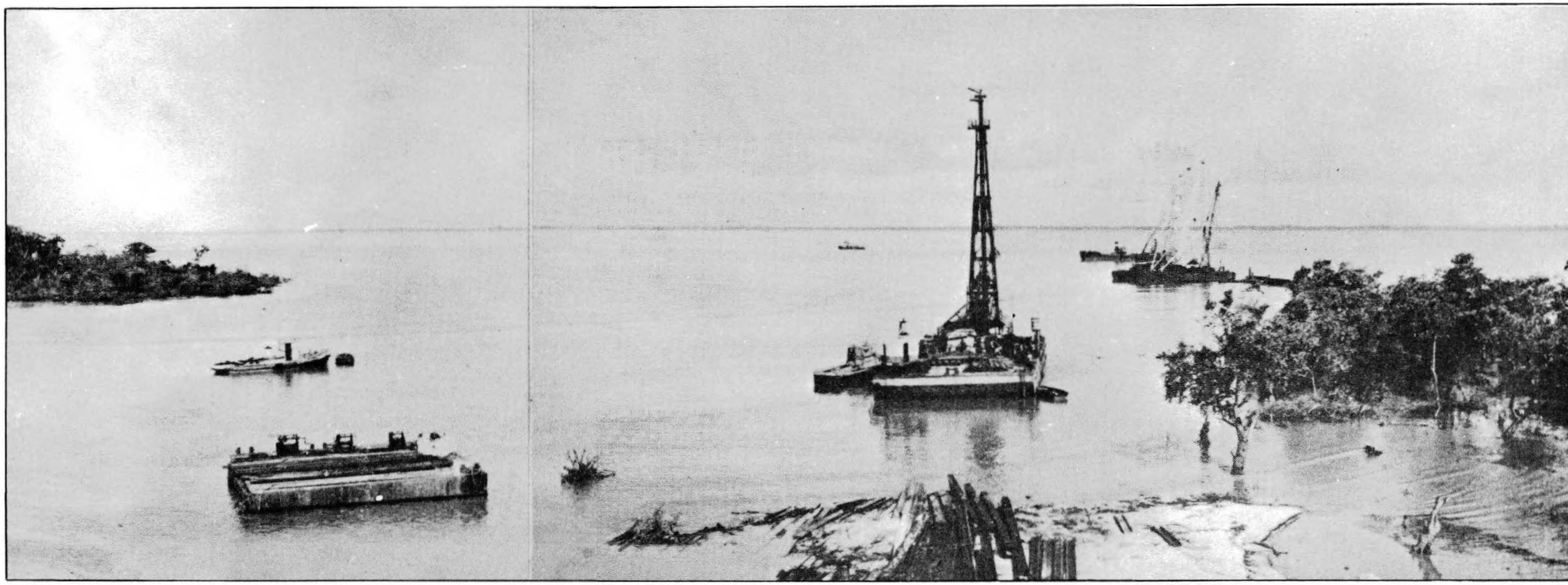


Fig. 1. — Confluence of Rio Nunez and marigot of Dougoufissa
during preparatory survey period

The vital need for speed, in a remote area where it would have been difficult to ship and maintain delicate equipment, precluded the use of the modern method of radioactive tracers. We believe, however, that we did initiate the extensive use of frogmen teams, which were provided by SOGETRAM (1) and enabled shifts of bottom material to be observed and checked directly, without recourse to measurement instruments. We hope that this procedure, which the International Hydrographic Review is the first publication to describe, may receive support and pave the way towards a new, effective method of port planning.

Although the transport of materials in an estuary is an extremely complex process, since it is affected by the action of tides, swell and river outflow, it may be divided into the following categories :

(1) *Littoral shifting,* by saltation (generally by swell action in an oblique direction to the average orientation of the coast).

(2) *Transportation along the bottom,* by rolling, saltation or sliding (in the bed of rapid currents).

(3) *Transportation in suspension,* of fine particles maintained above the bottom by turbulence.

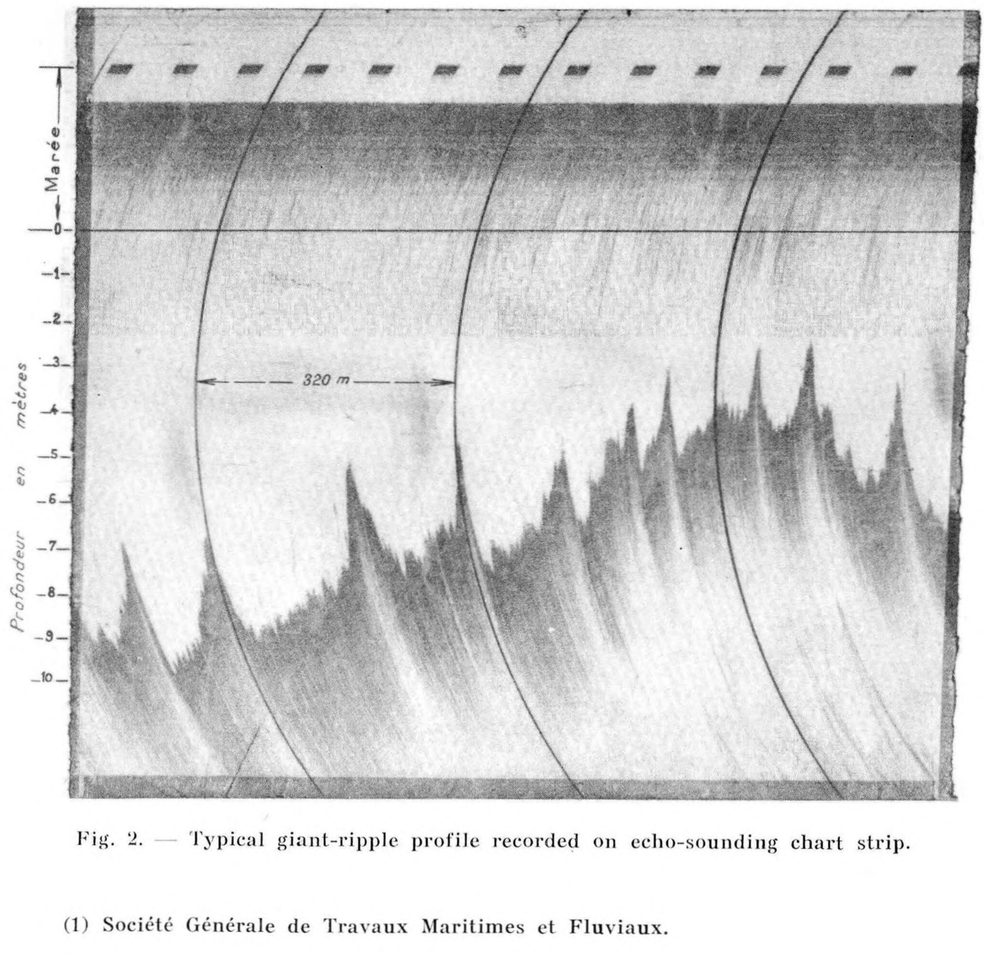
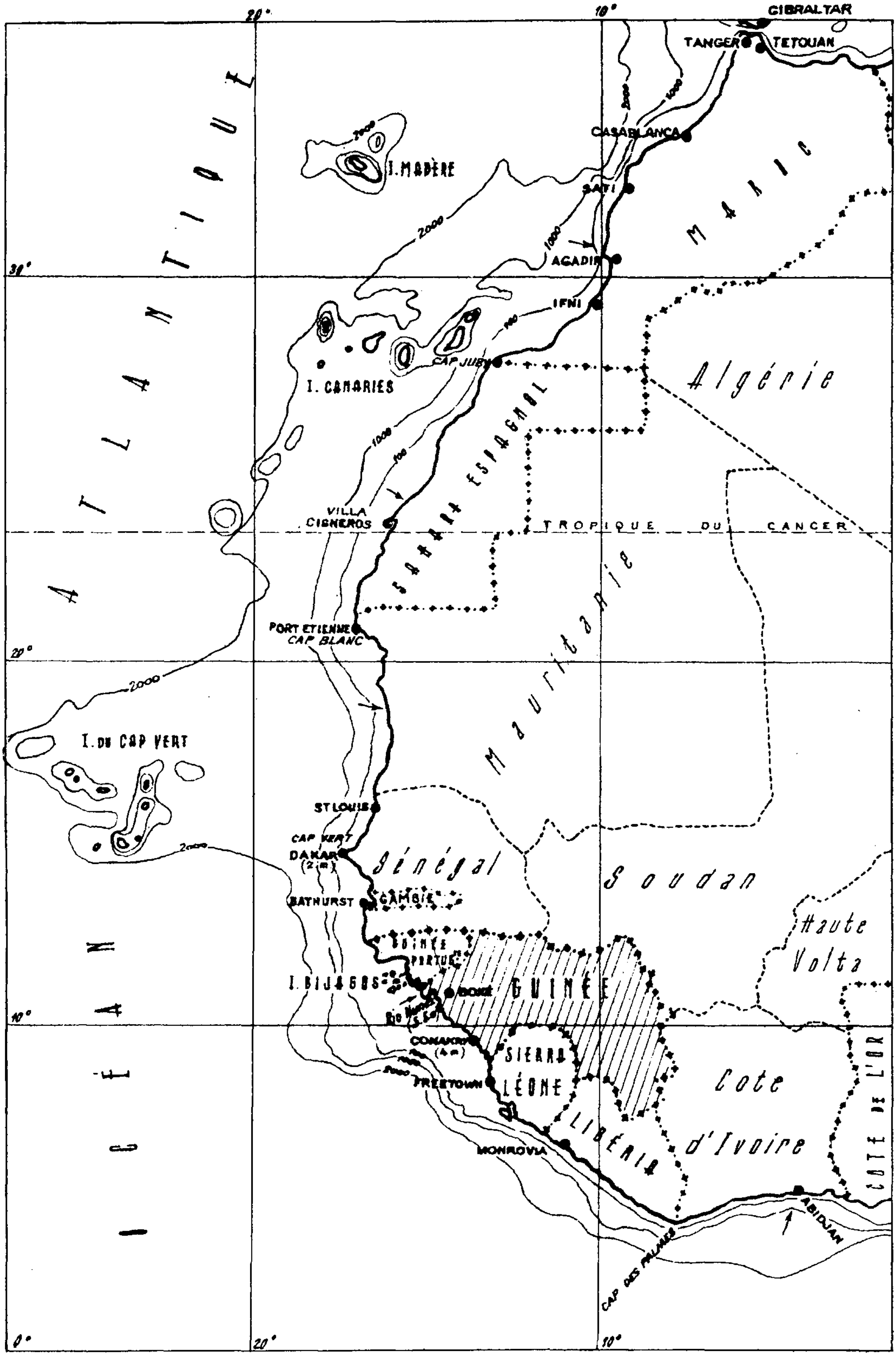


Fig. 2. — Typical giant-ripple profile recorded on echo-sounding chart strip.

(1) Société Générale de Travaux Maritimes et Fluviaux.



Pl. I. — Geographical and oceanographical situation of Guinea coast.

(4) *Shifting of submarine equilibrium forms* of certain materials (ripple marks, giant ripples) capable of reducing dredged channel depths.

During the Rio Nuñez operations, no attention was paid to the littoral drift; even though perceptible, its effects are minor. The three other forms of transportation, however, were carefully examined.

After a brief review of the geography, we propose to discuss the results obtained from a comparison of the successive hydrographic surveys, as these — especially those carried out a century apart — indicate the extent of shift of materials. We shall then show how stability of the principal ridges was checked by marking positions with stakes, from which frogmen took three separate sets of readings with reference to the bottom surface. Three subsequent sections will deal with the transportation of materials along the bottom, transportation in suspension, and the giant-ripple pattern at the river mouth.

The data thus obtained were referred to international experts, and following discussion at various meetings determined selection of the port location and entrance channel specifications. It need scarcely be added that such estuarial projects are subject to hazard owing to a possible slow or sudden change in natural conditions, which may or may not be upset by the port structures. The purpose of the research was the substantial reduction of such risks, if not their complete elimination.

LOCAL GEOGRAPHIC AND OCEANOGRAPHIC CONDITIONS

A. General location of coast

The Rio Nuñez estuary is located a short distance away from the northern extremity of the coast of Guinea, at 10°35′ N by 13°40′ W.

Examination of a general map of Africa (see plate I) shows that Guinea is in the centre of a coastal area between Dakar and Cape Palmas, with an appreciable NW-SE orientation. The considerably indented coastline is in contrast with the two extensive coastal sections at either end, i.e. :

— to the north the area between Dakar and cape Spartel, the coast of Mauritania oriented from south to north, and finally the coast of Morocco oriented from SSW to NNE;

— to the east, the coast bordering on the Gulf of Guinea and lying in a general east-west direction.

Whereas these latter two areas are subjected to strong oblique swells which break over shallows and are generally responsible for the considerable shifts of coastal materials noted therein, the Guinea area is characterized by :

(1) Considerable development of the continental shelf;

(2) A series of islands, reefs and shoals;

(3) An extremely uneven submarine topography in which deep troughs — such as the Rio Nuñez trough — extend the beds of streams on land far to seawards.

Pl. II. — General chart of Guinea coast and approaches to Rio Nunez.

Within the vast shoreline of the African continent subjected to powerful surf action, therefore, a gap exists in which Guinea is enclosed. Although the coast is well protected against swell, which seldom exceeds a range of 4 metres, facilities of access leave much to be desired.

B. Nature of the coast

Beyond the narrow strip of sandy foreshore, the low-lying Guinea coast (under 100 m in elevation) largely consists of mangrove occasionally replaced by ricefields, and traversed by a dense network of often intercommunicating marigots (1). These are fed by a strong tide compared with the average along the African coast (a relationship exists with the considerable extension of the continental shelf), with a maximum range of 5.50 m in the Rio Nuñez as compared with 4 m at Conakry and 2 m at Dakar.

Here and there the monotony of the swampland is relieved by beach ridges corresponding to former shore areas, reshaped by the wind and which can be recognized by the type of vegetation.

The occasional mounds encountered are generally covered with a crust of laterite, which is also found in the northern part of Ile de Sable and on the principal ridges of the eastern trough of the Rio Nuñez, and constitutes most of the rocks awash in the marigots.

C. Hydrography (Watercourses)

The Rio Nuñez is the seaward portion of a river called the Tinguilinta, which has no appreciable outflow of solid materials. Its water output ceased completely at the end of the 1958 dry season, early in May; it only becomes of any real significance during the rainy season.

Between Boké, the farthest point within reach of the tide, and the ocean, the Rio Nuñez receives a number of affluents, the principal one being the Bourouma. Special mention must be made of the Kapachez, which formerly flowed directly into the sea. Its rapid, steady silting upstream from its mouth was detrimental to agriculture, and the Agricultural Hydraulics Service decided to divert it into the Kassani (or Dougoubona) in the centre of the east trough of the Rio Nuñez (see plate III). As this connection was only made in recent years, it would be premature to draw any conclusions regarding bottom maintenance in the east trough or the structure of the shoals making up Ile de Sable in the southwest. Yet it is obvious that turbidity at the confluence of the Kassani and Rio Nuñez is increased by new sedimentation, at least during the rainy season.

D. Climate

This entire section of low-lying Guinea coast is tropical in climate, with a marked rainy season. The first rainfall occurs in May, and the last in November, but the period of heavy precipation is only three months long,

(1) Marigot : a divergent channel from the main river (Ed. note).

from 15 July to 15 October. 4.03 m of rain fell at Dougoufissa during the 1958 season, which closely approximates the figure for Conakry (about 4.18 m).

The tornadoes which take place at the beginning and end of the rainy season are violent squalls from eastwards, when wind speed may reach 40 metres per second.

E. Living Conditions

Times have changed since Captain Belcher noted on his chart that " the natives here are armed with muskets and are mischievously disposed to strangers ", and our relations with the Bagas and Susus were quite satisfactory.

Crocodiles abound in the marigots, and sharks infest the estuary. But these reputedly dangerous animals actually are far less objectionable than the mosquitoes, which during a considerable part of the year, in spite of heavy precautions (screened-in living-rooms, DDT, etc.), are savage enough at dinnertime but become even more unbearable as the evening wears on.

REPETITION AND COMPARISON OF HYDROGRAPHIC SURVEYS

In an extensive zone which has had the advantage of a series of surveys, the first method of analysis for shift of materials, long used by hydrographers, consists in reducing plans to the same scale and the depth figures to the same datum. Similar isobaths are then compared.

Although this method is simple in theory, it is difficult to apply in practice and is subject to wide interpretation. Surveys which are compared are seldom homogeneous. The measurement standards (metres or fathoms), sounding methods (hand leads, fish leads, echo sounding) are often different, as well as the density of the soundings (related to the scale used), the accuracy of the control (triangulation), and especially the more or less reliable datums, which are consequently difficult to reconcile.

In the case of the Rio Nuñez estuary, divided into two separate troughs by Ile de Sable and the banks which extend it, the following surveys were available, listed in chronological sequence :

(1) General survey of estuary by Captain Belcher, R.N. 1831

(2) Complementary survey by Commander Kerhallet, French Navy 1847

(3) Reconnaissance survey of east trough by West Africa Coast Survey (Sauzay), scale 1/25 000 1954

(4) Surveys of east and west troughs by Kelvin Hughes, Ltd. and by the West Africa Coast Survey (Peluchon), scales 1/10 000 and 1/25 000 1956

(5) Surveys of east trough by SOGEI, scale 1/10 000 .... 1957 and 1958

A. Comparison of 1831 and 1847 surveys and general aspect of estuary at this period

This comparison is not particularly significant, since the 1847 survey only served to complete the previous one. Yet allowing for the difference in the standards of measurement and datums, KERHALLET's chart shows no great departure from BELCHER's. Evidently he noticed no spectacular change in either the coast or bottom during the intervening 13 years. From these two surveys, it is possible to deduce the general appearance of the estuary a century ago.

The Ile de Sable then already divided the triangular-shaped estuary into two parts — the east trough and west trough — and a bank awash located farther upstream towards Pointe Malouine split the entrance to the west trough.

From the laterite crust which uncovered at low water and firmly contained the northern extremity of the island, the Ile de Sable extended in a general southwest direction in the form of a large bank of muddy sand, followed by several banks separated by passes, such as Banc du Milieu, as far as Banc du Sud, over a total distance of 15 kilometres.

From Pointe Malouine to Pointe Bencer, the east trough contained three bottom elevations interfering with navigation :

— Dougoufissa ridge
— Amarante ridge
— Petit Banc, west of Pointe Dapiar.

Between these were invariably found areas over 8 metres deep, at least in the middle section of the estuary bed.

B. Comparison of 1847 survey with 1956 surveys of Kelvin Hughes, Ltd. and West Africa Coast Survey

The 1954 survey was purely of a reconnaissance character, and mainly served to show that the east trough had been unaffected by any great changes rendering it unsuitable or unsafe for navigation. We may therefore disregard this survey, and compare the regular surveys carried out immediately thereafter, on a similar or larger scale, with the 1847 document (see plate III).

In 1956, an outline corresponding to the 5-metre isobath limiting the east trough was found which was approximately identical to the 1847 isobath. The Dougoufissa and Amarante ridges and Petit Banc were still in evidence, but boundaries had changed. These differences are impossible to attribute with certainty to bottom changes, and may simply be due to improved sounding methods and to the increased density of soundings.

Yet it can be stated definitely that over the space of a century considerable changes affected the banks constituting the sides of the east trough.

The necessity remained of determining consistency and checking the stability of soundings obtained for depths in the east trough, since these were factors controlling the holding qualities of the entrance channel.

C. Comparison of 1957 SOGEI survey with 1956 Kelvin Hughes survey on Amarante ridge

The ultrasonic soundings carried out on the Amarante ridge in 1956 by the Kelvin Hughes group were repeated a year later by SOGEI's hydrographic section on the same scale (1/10 000), with the same sounding datum and tidal-correction formulas.

Corresponding isobaths were extremely close in outline, but complete reliability was not obtained for the following reasons :

(1) *Accuracy of measurement*

Although the repetition of large-scale hydrographic surveys enables considerable shifts of material to be recorded to the extent of 1 or 2 metres, such as along beach ridges, *it is more difficult to deduce perfect bottom stability from them.* Between two successive surveys of an absolutely flat bottom, an error in measurement invariably exists (zero set of recording equipment; tide reading and correction; wave disturbance; faulty plotting of stations and of intermediate soundings) which despite all precautions will seldom be less than 0.30 metres (mean square error).

If the bottom is not flat and shows certain minor elevations (rocks, wrecks), the bulge may, since positional accuracy is not absolute and lines do not strictly coincide, be indicated in one survey and be absent from the other.

(2) *Cyclic development of bottom*

Loose-lying bottoms are subject to cyclic variations with a varying period (wave processes and seasons). When two surveys carried out at the same time of year are compared (in the present case during the dry season), it can never be certain that the bottom relief will not show an appreciable difference during the rainy season.

In order carry out a more accurate study of bottom stability, therefore, SOGEI resorted to the brand new method of planting stake markers on the ridges by frogmen, and inspecting at various intervals for over a year.

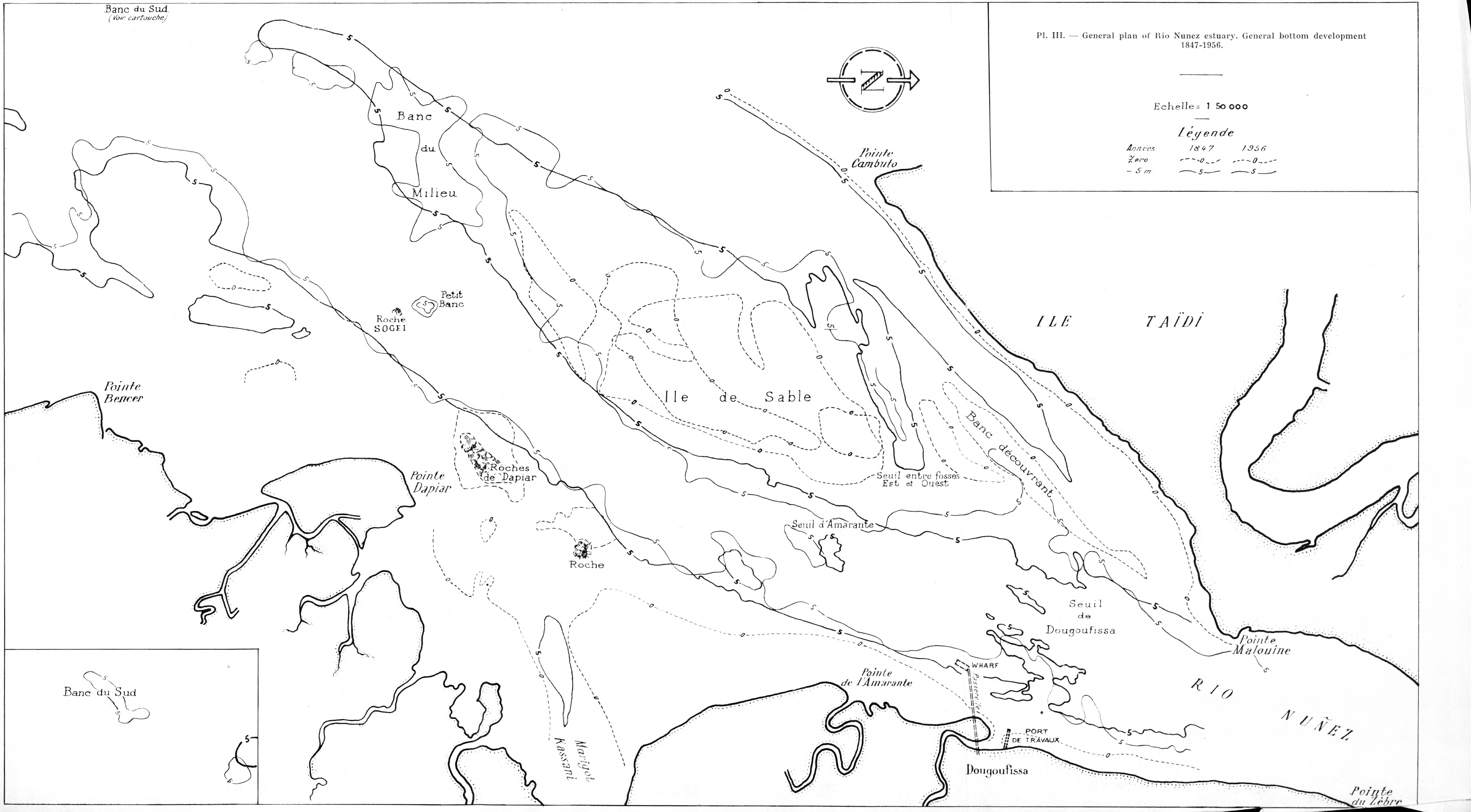
CHECKING STABILITY OF MAIN RIDGES BY STAKE MARKERS

A. Positioning of stake markers

In December 1956, ten stake markers consisting of hollow tubes of about 5-cm diameter and 3-m length were driven by water pressure into three ridges requiring particular study.

The locations for which a stability check was most urgently needed were the Dougoufissa and Amarante ridges, enclosing the proposed site of the port and ship-maneuvering area. Three stakes were planted on the Dougoufissa ridge and five on the Amarante ridge.

Two additional stakes were driven into the sandy sill, north of Ile de



Pl. III. — General plan of Rio Nunez estuary. General bottom development 1847-1956.

Sable separating the east and west troughs, which regulates the amount of flood water entering by way of the west trough and thus adding to the ebb current in the east trough (1).

The stake positions were first marked by concrete mooring blocks and buoys. A trawler would then drop anchor nearby, and a frogman supplied with air from a compressor through rubber tubing would go down carrying a stake connected by means of a hose to a force pump. The frogman guided the stake while it was being driven two metres below the bottom surface, released the pump hose, and attached a crosspiece 0.50 m from the bottom. The crosspiece was intended as a reference for determining the extent of possible later deposits.

These operations were complicated by the strength of the Rio Nuñez tidal current. Even during neap tides scarcely more than one hour was available for positioning the markers, limited to a maximum of two per run.

B. Direct investigation of bottom along lines between stake markers

The markers in each of the three groups were connected along the bottom by hemp lines which served to guide the divers and enabled them to follow and closely investigate three well-defined profiles, one on each ridge.

While the frogman moved along the bottom, an outboard motor boat carrying the air compressor followed him along the surface.

Samples and cores had of course given some idea as to the nature of the bottom, which was known to consist of gravel, shell, sand and *poto-poto* (2). But during the sampling operations, the material obtained was washed under heavy pressure and the sample was dissociated from the bottom environment. In particular, nothing was known of the microtopography.

Although the frogmen operated in absolute darkness on the Dougoufissa and Amarante ridges, they were able to ascertain the presence of a mass of fused rock, agglomerates, blocks and pebbles. This stable but friable (since tubes could be driven into it) armor was occasionally covered over with a thin layer of sand, and here and there contained basins 2 metres in diameter filled with poto-poto.

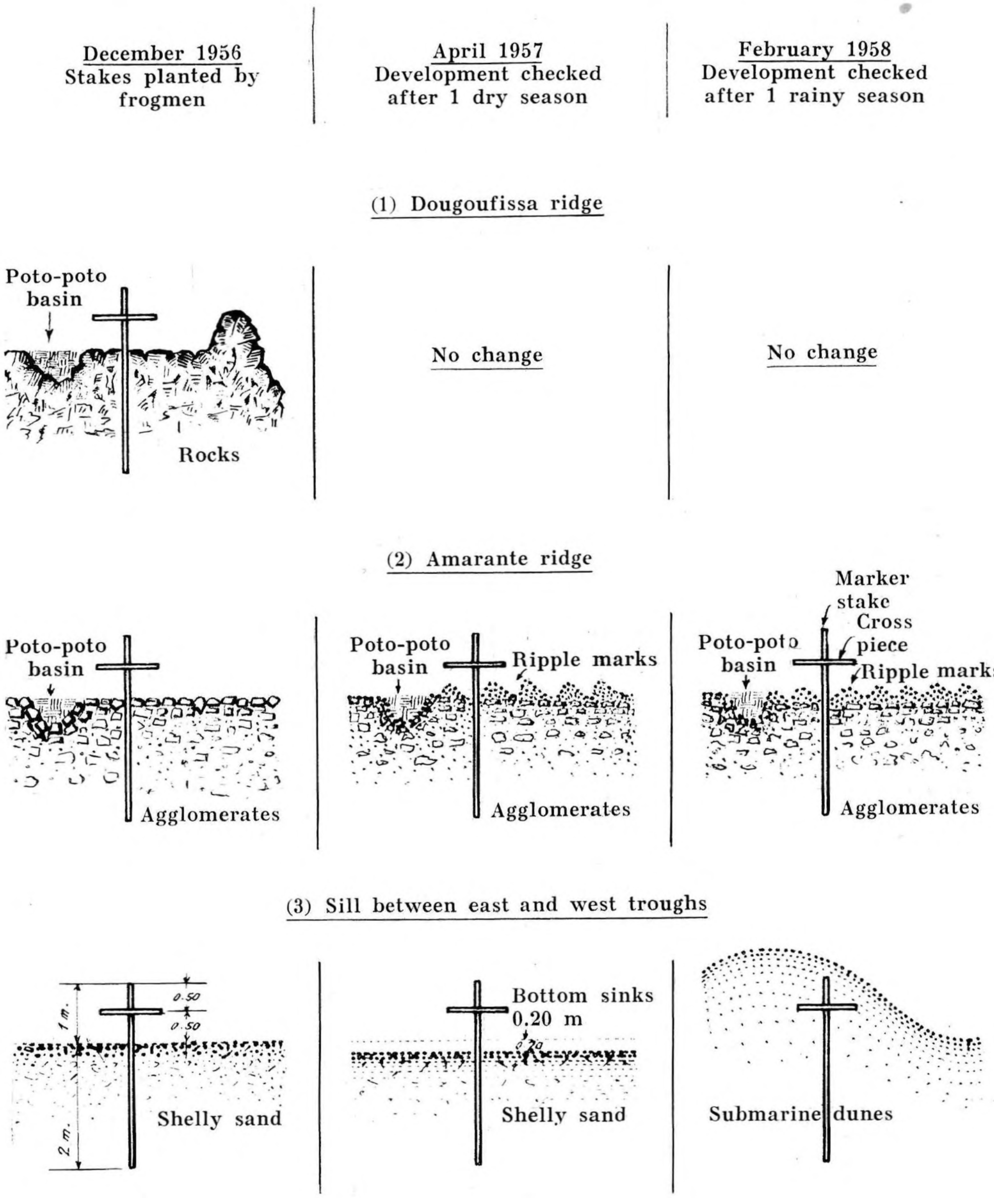
The sill between the east and west troughs, on the other hand, was composed of loose sediments, such as gravel, shells and sand.

C. Checking bottom stability

The ten marker stakes sited in December 1956 were examined in April 1957 and removed in February 1958 (see plate IV).

(1) Let us assume that the sill disappears, leaving a wide opening. Part of the Rio Nunez ebb which now flows in the east trough at approximately low tide would be diverted towards the west trough and would no longer contribute to depth maintenance in the entrance channel.

(2) Local type of silt or mud.



Pl. IV. — Diagram showing bottom development of main ridges in Rio Nunez.
(Translation of legends in Pl. IV)

(a) *April 1957 check*

This initial check enabled the evaluation of bottom developments on all three ridges at the end of three dry-season months.

The cork floats which had previously marked the stake sites had been swept away (the strong current causes the lines to vibrate and finally to break), and the stakes had thus to be relocated, in spite of the complete lack of visibility.

The craft was anchored within a few metres of the stake position, determined by visual fix. The frogman then attached one end of a line to the anchor, and by holding on to the other end was able to describe a 20-metre circle around the anchor.

This was a particularly interesting operation to watch from the boat : as soon as the line encountered the stake, the circles described by the frogman (which could be traced on the surface by the air bubbles) rapidly decreased in diameter before the diver himself became aware of the successful outcome of his investigations.

Although this method sometimes met with immediate success, the drawbacks were considerable. The positioning of the boat by angles taken with a hydrographic sextant (that is to within one or two minutes of arc) presupposes a fair amount of angular sensitivity if the desired station is to be a few metres away from the stake. But as the distance from signals increases in a large estuary such as the Rio Nuñez, sensitivity rapidly decreases to one or two metres per minute of arc. Moreover, the arc must be followed against the current in order to avoid further headway and drift while the anchor is being dropped. This operation was facilitated, however, by the fact that the frogmen could only work effectively at or near times of slack water.

Before locating the stake markers, the frogmen were occasionally halted in their tracks, as on the Dougoufissa ridge, by large boulders projecting by as much as one metre from the bottom. The divers signalled by means of a line connecting them with the boat, using a special code (more or less rapid and repeated jerks of the line).

The April 1957 check uncovered nine out of ten stakes (RG 7 was missing, but was successfully recovered in February 1958, and consequently had not been displaced).

On the Dougoufissa ridge (stakes RG 1 to RG 3), no change in the depth figure was noted.

On the Amarante ridge, the crosspieces were still the same distance from the bottom, but ripple marks of broken shell from 0.10 to 0.25 metres high were encountered, indicating a certain amount of alternating shift of a thin layer of surface material. In places the ripple marks covered the sections of line which remained attached to the stakes. It was also noted that within the space of a few months the stakes had become covered with shells.

On the sill between the eastern and western troughs, a slight change was detected at the foot of stakes RG 4 and RG 5, where from 10 to 25 cm of material had been washed away. Shifts therefore occur on the sill.

(b) *February 1958 check and removal of stakes.*

The purpose of this second check was to evaluate the effect of the rainy season and resulting increased river outflow on the behavior of the ridges.

On the Dougoufissa ridge, only the two stakes marked RG 1 and RG 2 were recovered out of the three located in April 1957. But no change in the depths (incidentally covered with rocks) was noted in the vicinity.

On the Amarante ridge, four out of five stakes were found (RG 8 could not be recovered, in spite of repeated search). Examination showed no great depth change : stake RG 9 alone indicated that a local 15-cm rise in bottom level had occurred.

Finally, in reference to the sandy sill separating the east and west troughs, neither stake RG 4 nor stake RG 5 was recovered. Since a number of the signals used to locate them had been destroyed, possibly the boat failed to obtain a fix with the requisite accuracy. During their explorations, however, the frogmen reported the presence of giant ripples high enough to bury the stakes completely or interfere with their investigations. In any case, the ripples confirmed the shifting character of this sandy bottom stretch as previously noted in April 1957.

The frogman team was thus able over a period of thirteen months to ascertain the general stability of the Dougoufissa and Amarante ridges, which were directly tied to the port project. They found, however, that the Amarante ridge was traversed by sand and shell; and shifts of sandy material were also discovered opposite Dougoufissa during an attempt to recover a lost mooring : the chain was covered by ripple marks. As a result, a double series of bottom-transport measurements was undertaken.

DIRECT IDENTIFICATION AND ATTEMPTED MEASUREMENT OF TRANSPORT ALONG THE BOTTOM

The transportation of materials along the bottom in an estuary is difficult to measure for the following reasons :

(1) Motion is alternating, i.e. materials carried downstream at ebb tide are returned upstream at flood. The amount of solids transported consequently differs.

(2) Depths are uneven, and no reliable generalization can be made from the successful interception of the solid discharge in a limited area.

(3) The solid discharge, connected with the current velocity, varies during a given day with the time of the tide, and from one day to the next with the tidal coefficient. Allowance must also be made, especially during the rainy season, for discharge from the river proper, which distorts the tidal curve, increases maximum velocity of ebb, and decreases maximum velocity of flood.

We could consequently not expect to obtain complete data by testing a new method in the Rio Nuñez over a period of a few days during the dry season. We believe, however, that such investigations as were carried out shed light on the problem, and, provided facilities are made available, are capable of significant development.

At our request, SOGETRAM had ordered specially built plastic containers closed by a carefully fitted cover and equipped with a practical device for clamping onto the hoisting sling. The containers were designed to be set in the loose bottom during slack water, and to be removed — after fastening of the cover — at the next slack.

Before these experiments were undertaken, the divers themselves went down to inspect bottom conditions in the strongest part of the current.

A. Direct observation of bottom shift

These observations were made at the site of the projected structures and on the Amarante ridge.

(a) *opposite Dougoufissa, at flood*

At position A, i.e. in the middle of the —8-m trough, the divers by clinging to an anchor apeak located at the stern of the launch were able to observe the movement of materials in a 1-knot current, one to two hours before high water at springs.

Over a surface of fairly stable, gelatinous poto-poto, the current transported shell and gravel.

At position B, nearer the shore, sand discolored by poto-poto was displaced in the form of ripple marks.

(b) *opposite Dougoufissa, at ebb*

On the afternoon of the same day, three to four hours after HW, the diver noted at position A that round lumps of poto-poto 4 cm in diameter were being displaced instead of shells and gravel. These lumps, of which several were brought up as samples, were not unknown to us : the tide often deposits them on the beach, where they remain exposed as the tide recedes.

(c) *on the Amarante ridge*

While locating a rock on the Amarante ridge, a diver noted that fine sand ran in the crevices, where the current was slight.

B. Attempted measurement of solid discharge

The plastic traps were sunk in the loose bottom material, their length parallel to the course of the current, so that they would collect the sediment transported along the bottom over a sector corresponding to their width, i.e. 0.43 m.

Two measurement locations were chosen : one at position A, which was at the site of the projected structures, and the other at the middle stake marker (RG 8) on Amarante ridge.

(a) *Measurement at site of projected structures (position A)*

The total capacity of the traps was 64 cubic decimetres. It would have been of interest to lay several simultaneously and compare results, but this type of operation could rarely be performed owing to the brief slack water — the only period when work could be done on the bottom.

The material collected was poto-poto of a marked rounded shape, thus obviating the possibility of subsidence into the trap of adjacent, compacted poto-poto material.

(b) *Measurement on Amarante ridge (stake marker RG 8).*

Owing to the solid bottom on the Amarante ridge, the trap could only be sunk with difficulty, and had to be shored up with sand and non-compacted gravel.

Although no quantitative results could be retained, it was ascertained that the material collected differed completely from the type trapped at position A. Here it consisted of sand, shell and small gravel.

The accuracy of this type of measurement is largely dependent on the adequate sinking of the traps on a level with the bottom and their correct orientation, so that the paths followed by the small streams of water transporting materials along the bottom are subjected to a minimum of disturbance. Measurement should also take place in a constant sector.

Experiments have nevertheless established that an alternate, non-homogeneous type of transport exists in the sectors of the east trough which most closely affect the port project, and have supplied an order of magnitude for the amounts transported during the dry season in the vicinity of the port structures.

MEASUREMENT OF TRANSPORTATION IN SUSPENSION

A. General

(a) *Importance of mud deposits in Guinea*

Material transported in suspension can cause rapid, considerable silting whenever conditions are favorable for transition to sedimentation.

This possibility deserved special attention in the Rio Nuñez : the next river to the south, the Rio Kapachez, has recently silted up completely, even though allowance must be made for its slower current rate. In order to drain off the fresh water which accumulates in the upper part of the Kapachez basin, a canal connecting it to the Kassani, itself a tributary of the Nuñez, had to be built (see plate II).

Moreover, the example set by Conakry (located nearby in the same geographical zone designated as the " southern river area ") indicates the type of danger involved, on the basis of actual figures. The roadstead, located at one extremity of Tumbo island (see plate II), has nevertheless been assimilated to a " maritime waterway, near its mouth in a tidal sea ", owing to the strong alternating tidal currents.

Recent additions to the port have resulted, however, in considerable sedimentation along the port installations. This has been attributed not to transport but to deposits caused by excessive amounts in suspension.

Within two years (1953-1955), 157 000 m^3 of silt were deposited along two quays and in the banana dock. Dredging costs for 1956 were estimated at 110 000 000 French francs (1 100 000 new francs).

(b) *Two types of turbidity in estuaries*

Discharge of solids from drainage basin :

In narrow estuaries, one may readily observe from a height (the Casbah of Mehdia for Oued Sébou, Moro Dos Conventos for Rio Ararangua, Cerro of Santo Domingo for Rio Maipo) the exit of turbid waters during the ebb, which likewise carries solids discharged from the drainage basin, usually after periods of heavy rainfall. The result is a mushroom pattern which spreads out in front of the river mouth, and which in falling back on either side towards the shore reflects the drift of the surface water under the joint influence of wind, swell and the coastal current.

During flood, on the other hand, clear waters may be observed travelling upstream, gaining first in depth then on the surface in the flood channel, while the loaded waters continue to flow in the ebb channel. This process is clearly apparent in air photographs of Oued Sébou.

Turbidity localized in seaward section of rivers :

In large estuaries such as the Gironde and the Loire, an oscillating mass of mud may be seen which travels down a portion of the estuary during ebb and up again during flood. As this alternating action results in material being deposited during slack water and swept up again as soon as the current and disturbance increase, the total effect is difficult to analyse.

B. Turbidity measurements and main observations

No elevated observation post overlooking the low-lying Rio Nuñez estuary unfortunately is available, and the cost of operating a helicopter is high.

A general survey of turbidity in the estuary during a complete tide of a given coefficient and marked by a specific degree of disturbance would moreover require numerous simultaneous stations. These would involve considerable expense (launches, personnel and instruments), and measurements would have to be repeated for various coefficients, and various degrees of disturbance for each of the coefficients.

In spite of the problem's extent and complexity, the measurements carried out from 1956 to 1958 in both the dry and rainy seasons and in various sectors of the river enabled the factors of the turbidity process to be established. Basic conclusions will be described without going into details of measurements and observations.

Turbidity in the Rio Nuñez estuary owes its origin to the renewed suspension of bottom and beach silt through the combined action of :

— tidal currents : it is a daily occurence for yellowish clouds to rise from the bottom to the surface as soon as the current freshens;
— wave disturbance, particularly breaking on the banks of muddy sand which form the greater part of the Ile de Sable.

It is consequently not surprising if the turbidity is always heavier at springs than at neaps, the currents being stronger and the muddy area covered more extensive.

During the rainy season, turbidity increases due to increased wave disturbance caused by the southwest monsoon and by the following two new phenomena :
— runoff of the lower course of the river and its connected marigots on mangroves and banks;
— reduction in salinity.

To sum up, the turbidity pattern in the Rio Nuñez is related, proportionately speaking, to the Loire pattern. Collecting in the estuary area, turbidity is translated as a mass of mud which oscillates with the tide. This subsides during the slack and revives at mid-tide through the action of strong currents. It is more marked in the rainy season, owing to recurrent wave disturbance and the effect of runoff, than during the dry season, yet remains closely related to the tide coefficient affecting the maximum velocity of flow and ebb.

GIANT RIPPLES AT RIVER MOUTH

The term *ridens* (giant ripple) has long been used to designate underwater accumulations in the Pas-de-Calais area. Later it was commonly used to describe the shifting sandy ridges in the Loire river bed. It has now been adopted by oceanographers to define sandy accumulations in deep water attributed to the action of turbidity currents.

Among the peculiarities of the Guinea seaboard, which is in direct contrast, as already described, with the two large coastal sectors at either extremity, is the presence of these giant ripples.

In addition to forming the tail sections of the Ile de Sable banks, others have been reported at the mouth of the Mellacorée River. Recently, while sounding south of the Conflict Reefs in an area marked « Tête de Roche », *Ingénieur Hydrographe Principal* PELUCHON, heading the West African Coast Survey, found instead of this rock a zone of evenly spaced giant ripples. The crests were oriented perpendicularly to the direction of the strong NE-SW alternating tidal currents prevailing in the area (see plate II). The ripple crests at the end of Ile de Sable (see photo 2), on the other hand, extend in a NNE-SSW direction approaching that of the tidal currents. Composed of medium-grade shelly sand, they are characterized by the fact that they rise in steps from the edge of the east trough to the crest of the bank forming the extremity of Ile de Sable.

During the time available we could but record the existence of the phenomenon, which would be well worth following up in detail on large-scale plans. Possible shifts in the ripples would thus be plotted, resulting in the detection of the simple or complex reason for their formation.

ZONE SELECTED FOR PORT SITE AND ADOPTION OF OPTIMUM COURSE FOR ENTRANCE CHANNEL

A. Siting of port

As soon as the survey was sufficiently developed, plans were drawn up of port installations capable of handling bauxite shipped to Dougoufissa by rail.

The installations essentially consist of a wharf and causeway (see plate III) raised on piles, so oriented as to allow maximum depth maintenance by the alternating currents. Hence the directions of these currents were measured at neaps and springs during both the dry and rainy seasons.

The wharf is to be built at the edge of the — 8-m trough, i.e. near the area of maximum natural depths, opposite Dougoufissa. To enable the ore carriers of the specialized fleet to remain afloat at low water, depths will have to be hollowed out down to about — 11.00 m.

This will probably involve some maintenance dredging. The — 8-m trough between the Amarante and Dougoufissa ridges is at present in a state of natural balance. Maintained at this figure by the ebb, which is reinforced by the action of the Dougoufissa ridge in its twofold capacity of guide and spillway, it will tend to revert to this depth. The dredged-out pit will gradually be filled in by the material alternately transported along the previously observed and measured bottom, and by deposits from the excess suspension during slack water.

It is nevertheless to be hoped that the churning action of the propellers and the movements of ships near the port structures will contribute to depth maintenance, as noted in similar cases, such as in the Mehdia channel at Port Lyautey.

B. Entrance channel course

The channel course is governed by the bottom topography, the necessity of maximum reduction of bends, and the presence of a giant-ripple area.

CONCLUSIONS

The Rio Nuñez is located in a favored sector of the West African coast, free from surf action and major littoral shifts. It is moreover unaffected by a phenomenon commonly found at the mouth of estuaries, consisting in the presence of a bar or loose sedimentary deposits which continuously reform in spite of repeated dredging.

These favorable features owe their origin primarily to the considerable oscillating volume of the tide, deriving from the exceptional tidal range and the extensive, suitably shaped estuary. Consequently the flushing capacity is high during springs. Channels are stable, due to the presence of laterite flush with the surface, firming the foreshore and consolidating the bottom; and there is a progressive decrease in the amount of sandy material at the river mouth.

Yet a number of obstacles remain. As indicated in the introduction, a natural balance is frequently a misleading factor, since it tends to recur. Bottom transportation, and the considerable weight of fine particles in suspension, are both ready sources which threaten to fill up dredged berths and artificial basins. The example of Conakry is too recent to be easily forgotten. Hence it will be well to adhere fairly closely to the natural depths and adopt port structures that will cause a minimum of interference with the tidal flow and discharge from the river.

At the river mouth, the development and possible shifting of the giant-ripple zone should be carefully watched, as well as eventual disturbances caused by deviation of the waters of the upper Kapachez towards the Rio Nuñez.

The foregoing considerations may appear to be remote from the field of standard hydrography. Actually they do no more than extend it. In dealing with a recently formed coast which is yet in the process of morphological development, or with an older, stabilized coast whose natural balance can be seriously upset by a minor structure, the engineer cannot confine his activity to a routine survey of the bottom topography. In analysing the main shifts of materials, with the aid of marine hydraulics and sedimentology, he ends up by practising a kind of " dynamic hydrography ", in conjunction with reduced-model tests, in order to draw up the port-installation plans.

Owing to the increase in ship tonnage and the consequently larger drafts (14 and 15 metres are now the figures indicated for giant tankers and ore carriers), the creation of port facilities requires considerable capital investment. To increase returns on such an investment, the natural conditions in the coastal area involved must be accurately determined beforehand by surveys conducted with absolute freedom of mind, over an adequate period of time, and with modern methods and equipment.

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