



REGIONAL SEAS

UNITED NATIONS ENVIRONMENT PROGRAMME

Coastal erosion in West and Central Africa

UNEP Regional Seas Reports and Studies No. 67

Prepared in co-operation with



Nations

UNESCO

UNEP 1985

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P R E F A C E

The United Nations Conference on the Human Environment, which took place in Stockholm, 5-16 June, 1972, adopted the Action Plan for the Human Environment, including the General Principles for Assessment and Control of Marine Pollution. In the light of the results of the Stockholm Conference, the United Nations General Assembly decided to establish the United Nations Environment Programme (UNEP) to "serve as a focal point for environmental action and co-ordination within the United Nations system" (General Assembly resolution (XXVII) of 15 December 1972). The organizations of the United Nations system were invited "to adopt the measures that may be required to undertake concerted and co-ordinated programmes with regard to international environmental problems", and the "intergovernmental and non-governmental organizations that have an interest in the field of the environment" were also invited "to lend their full support and collaboration to the United Nations with a view to achieving the largest possible degree of co-operation and co-ordination". Subsequently, the Governing Council of UNEP chose "Oceans" as one of the priority areas in which it would focus efforts to fulfil its catalytic and co-ordinating role.

The Regional Seas Programme was initiated by UNEP in 1974. Since then, the Governing Council of UNEP has repeatedly endorsed a regional approach to the control of marine pollution and management of marine and coastal resources and has requested the development of regional action plans.

The Regional Seas Programme at present includes eleven regions (1) and has over 120 coastal States participating in it. It has been conceived as an action-oriented programme having concern not only for the consequences but also for the causes of environmental degradation and encompassing a comprehensive approach to combating environmental problems through better management of marine and coastal areas. Each regional action plan has been formulated according to the needs of the region as perceived by the Governments concerned. It is designed to link assessment of the environmental quality and the causes of its deterioration with activities for the management and development of the marine and coastal environment. The action plans promote parallel development of regional legal agreements and of action-oriented programme activities (2).

At the third session of UNEP's Governing Council (1975), a number of West and Central African States requested UNEP to study the problems of marine and coastal pollution of their region. Following that request, UNEP's exploratory mission visited fourteen States of the region during 1976. The mission's report identified major environmental problems of the region and recommended the development of a regional action plan for the protection and development of the marine environment and coastal areas.

-
- (1) Mediterranean, Kuwait Action Plan Region, West and Central Africa, Wider Caribbean, East Asian Seas, South-East Pacific, South Pacific, Red Sea and Gulf of Aden, East Africa, South-West Atlantic and South Asian Seas.
 - (2) UNEP : Achievements and planned development of UNEP's Regional Seas Programme and comparable programmes sponsored by other bodies. UNEP Regional Seas Reports and Studies n°. 1. UNEP, 1982.

After considering the report of the mission, the fifth session of the Governing Council (1977) decided that "steps should be undertaken for the development of an action plan and a regional agreement to prevent and abate pollution" in the West and Central African region.

Preparatory work on the development of the action plan and regional agreement included several expert group meetings, missions and surveys leading to the Conference of Plenipotentiaries on Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (UNEP/IG.22/7) convened by UNEP in Abidjan, 16-23 March 1981.

The Abidjan Conference adopted the Action Plan for the protection and development of the marine environment and coastal areas of the West and Central African Region (3), Convention for the Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (4), Protocol concerning co-operation in combating pollution in cases of emergency (4), and a set of conference resolutions.

Subsequent intergovernmental meetings (5, 6) identified coastal erosion control as a priority area for action. Consequently, it was decided to initiate a project (WACAF/3) which would study the causes, evolution and assessment of measures for the control of coastal erosion. The present report constitutes an outcome of that project. An additional publication resulting from the project (7) contains bibliography relevant to the coastal erosion problems of West and Central Africa.

-
- (3) UNEP : Action Plan for the protection and development of the marine environment and coastal areas of the West and Central African region. UNEP Regional Seas Reports and Studies N°. 27. UNEP, 1983.
 - (4) UNEP's Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region. Protocol concerning Co-operation in Combating Pollution in Cases of Emergency. UNEP, 1981.
 - (5) Meeting of the Steering Committee for the Marine Environment of West and Central Africa, Abidjan, 20-22 July 1981 (UNEP/WG.61/5).
 - (6) Meeting of the Steering Committee for the Marine Environment of West and Central Africa, Geneva, 22-23 April 1982 (UNEP/WG.72/3).
 - (7) UNEP/UNESCO/UN-DIESA : Bibliography on coastal erosion in West and Central Africa. UNEP Regional Seas, directories and bibliographies.

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I . I N T R O D U C T I O N

The joint UNESCO/UN-DIESA/UNEP Project "Control of Coastal Erosion in West and Central Africa (WACAF/3)" was initiated in January 1983.

The main objective of the project is to analyse the situation with regard to coastal erosion in West and Central Africa, in order to provide the concerned countries with necessary information and support their efforts in protecting coastal zone through environmentally sound management practices.

The project is being carried out within the approved framework of the Action Plan for Protection and Development of the Marine Environment and Coastal Areas of the West and Central African Region, adopted according to the priorities set out in the Preface. UNESCO and UN-DIESA have been recognized as executing agencies implementing the project under the overall supervision of UNEP. The project was carried out keeping in mind regional and local problems ; the collaboration and participation of various national institutes and organizations involved was therefore requested during various stages of the programme. As it was announced in the letter dated 27 June 1983 sent by UNESCO on behalf on the UN organizations involved (UNESCO/UN-DIESA/UNEP), the three principal phases of the project were :

- 1) collection of historical data available in Africa, Europe and North America on Coastal Erosion in West and Central Africa ;
- 2) field surveys of representative sites and training of local personnel;
- 3) analysis of the gathered data which the authorities can use for coastal erosion control and improved management of the coastal areas.

Thus the project has research, training and engineering/management components.

The following bodies participated in the project :

. 1st phase :

- Bureau de Recherches Géologiques et Minières (BRGM), Orléans, France,
- University College, Swansea, UK,
- University of Bordeaux I, France,
- ORSTOM, Paris, France,
- University of Perpignan, France,
- University of Angola,
- NEDECO, Netherlands,
- Research Planning Institute (RPI), USA,
- University of Dakar, Senegal,
- Nigerian Institute for Oceanography and Marine Research.

. 2nd phase :

- BRGM, France,
- RPI, USA,
- University College, Swansea, UK,
- Imperial College, London, UK,
- Nigerian Institute for Oceanography and Marine Research,
- University of Benin, Togo,
- Port of Lomé, Togo,

- Ministère de l'Équipement, des Mines, des Postes et Télécommunications (Direction du Cadastre et Direction de l'Hydraulique), Togo,
- CERES, Conakry, Guinea,
- University of Dakar, Senegal,
- University of Abidjan, Ivory Coast,
- National University of Benin, Benin,
- Port autonome de Cotonou, Benin,
- Direction de l'aménagement du Territoire et de l'Environnement, Benin,
- Direction de la Prévention des Pollutions et Nuisances, Congo.

. 3rd phase :

- BRGM,
- RPI.

The present report was prepared by BRGM on the basis of data provided by the above-mentioned organizations. The Marine Geology Department of the BRGM coordinated the writing of this report, using the contribution of, among others, Nicole LENOTRE*, Yves THISSE*, and Roger-Emmanuel QUELENNEC**, and relying particularly on :

- the report of M.B. COLLINS, G.L. ROWLANDS, and P.T. HARRIS, Department of Oceanography, University of Swansea, Wales : "Coastal erosion in West and Central Africa : literature review and data analysis (UK contribution), December 1983, UNESCO Project WACAF/3 - Phase 1" ;

- the compilation carried out by A. KLINGEBIEL, J.L. PAGLIARDINI, Département de Sédimentologie et Océanographie of Bordeaux I University, France, and by O. RUE, Laboratoire de Géomorphologie de l'Ecole Pratique des Hautes Etudes, Paris, and concerning following countries : Senegal, Ivory Coast, Cameroon, Gabon, Togo, Zaire and Angola ;

- the report entitled "Inventory of coastal problems based on Nedeco's project experience in the region" (March 1984, R 2030), related to Ghana, Togo, Benin, and Western Nigeria ;

- the report of J.P. BARUSSEAU, Laboratoire de Sédimentologie, Perpignan University, France, dealing with Mauritania ;

- the report of B. DENIAUX, Geology Department of Luanda University (Angola), on Angola ;

- the reports of M. MURDAY and B. SAVISTKY , Research Planning Institute, Inc. (RPI), Columbia, USA : "Inventory of North American sources for maps and charts" and "Inventory of North American sources for remote sensing" (1984) ;

* Département Géologie Marine of the Bureau de Recherches Géologiques et Minières, Orléans, France.

** "Atelier Sédimentologie Dynamique", Département Géologie Marine of BRGM, Marseille, France.

- data accumulated by the authors of this report ;
- field surveys carried out by N. LENOTRE in Togo, Benin, Cameroon, Gabon and Congo, and by R.E. QUELENNEC in Senegal, Gambia, Guinea, Ivory Coast, Togo and Benin.

The report was presented at the final workshop of the WACAF/3 project (11-18 March 1985, Dakar), discussed and amended by representatives of :

- National University of Benin, Benin,
- Ministère du Tourisme, Loisirs et Environnement, Congo,
- Centre de Recherches Océanographiques d'Abidjan, Ivory Coast,
- Ministère de l'Environnement, Gabon,
- Ministry of Water Resources and the Environment, Gambia,
- AESC, Ghana,
- Institut Central de Coordination de la Recherche et de la Documentation de Guinée, Guinea,
- Secretaria de Estado das Pescas, Guinea Bissau,
- Ministry of Lands, Mines and Energy, Liberia,
- Nigerian Institute of Oceanography and Marine Research, Nigeria,
- Ministère du Plan, Sao Tome and Principe,
- University of Dakar, Senegal,
- Ministère de la Protection de la Nature, Senegal,
- Ministère de l'Équipement, Senegal,
- Ministry of Mines, Sierra Leone,
- Ministère de l'Aménagement Rural, Togo,
- University of Benin, Togo.

Additional information on coastal erosion processes has been obtained from Laboratoire Central d'Hydraulique de France (LCHF, France) and Société Grenobloise d'Études et d'Applications Hydrauliques (SOGREAH, France).

The coasts of the West and Central African Region, purpose of this report, stretch between 23°N and 18°S latitudes and embrace 20 coastal countries. They face two-thirds of the Atlantic along the African continent, from Mauritania to Angola, making up 8,000 km of coasts (table I.1).

Entirely bracketed between the Tropics, this area is characterized both by desert zones (Sahara and Kalahari) and by a vast humid equatorial belt, where two of the biggest African rivers are debouching : the Niger and the Congo-Zaire.

These general climatic and structural trends endow our study area with very distinct features as compared to other main coastal areas of the world.

The littoral domain, acting as an interface between the continental and the submarine worlds, is a vital capital for mankind which has to be managed with the greatest care. It is a "living" feature, highly sensitive to minutest interactions with the natural environment, and is a permanent compromise between multivarious factors any slight alteration of which may generate effects which could no longer be labelled as unpredictable, owing to our present state of knowledge. Coastal areas represent a very strong centre of attraction and act as an economic factor of paramount importance because of their own resources (coastal agriculture, fisheries and related activities, tourism ...) and the exchanges with the outer world that they facilitate. The coastal zone, whose delicate equilibrium is nowadays constantly endangered by man's direct or indirect intervention, demands our full attention and, first and foremost, a background of interregional and international co-operation, since natural

Pays Country	Longueur de côte (km) Length of coastline (km)	Ports principaux Major ports	Ports secondaires Minor ports
Mauritanie ** Mauritania **	754	1	2
Sénégal Senegal	531	1	2
Iles du Cap Vert Cape Verde Islands			
Gambie Gambia	80	1	0
Guinée Bissau Guinea Bissau	274	1	2
Guinée Guinea	346	1	3
Sierra Leone Sierra Leone	402	1	2
Libéria Liberia	579	1	4
Côte d'Ivoire Ivory Coast	515	2	3
Ghana Ghana	539	2	4
Togo Togo	50	1	1
Bénin Benin	111	1	1
Nigéria Nigeria	853	2	10
Cameroun Cameroon	402	1	3
Sao Tome & Principe Sao Tome & Principe			
Gabon Gabon	800	3	2
Congo Congo	200	1	-
Zaïre Zaire	40	1	-
Angola Angola	1 500	3	15
<u>TOTAL</u>	<u>7 976</u>	<u>26</u>	<u>54</u>

** n'inclut pas l'ex "Sahara espagnol"

** not including southern part of Spanish Sahara

Tableau I.1. Longueur des côtes des pays d'Afrique de l'Ouest et du Centre et nombre de ports principaux et secondaires (d'après Williams, 1980)

Table I.1. Western and Central African coastline - Length of coastline and number of major and minor ports (after Williams, 1980)

phenomena are not concerned with political boundaries.

This report was conceived with a naturalistic approach, i.e. global and interregional, incorporating different parameters which shape the coastal zone. It is subdivided into 3 main parts. The first one takes into account factors influencing coastal morphogenesis : climate and general oceanography, as first order environmental parameters ; geological formations as substrate over which the former exert their action, and the nature of the vegetation cover and of the soils they generate ; sediments distribution on the continental shelf, sources of these sediments (not necessarily of a terrigenous origin), hydrodynamic factors which rework the sediments ; sea level variations (minute at human's scale, but globally important), and, last but not least, man's interaction with the coastal zone.

The second part deals with different types of coasts encountered along the Atlantic shores of Africa : it makes an inventory of shoreline variations during historical times, if documented, replaces the African coasts within the framework of the general classification of Inman and Nordstrom (1971), and argues the subdivision of this littoral into ten large natural areas.

Finally, the last part analyzes regional characteristics of these ten areas. Let us recall that among the twenty countries grouped under the general label of Western and Central Africa, two do not appear in this report : the Cape Verde archipelago and the islands of Principe and of Sao Tome.

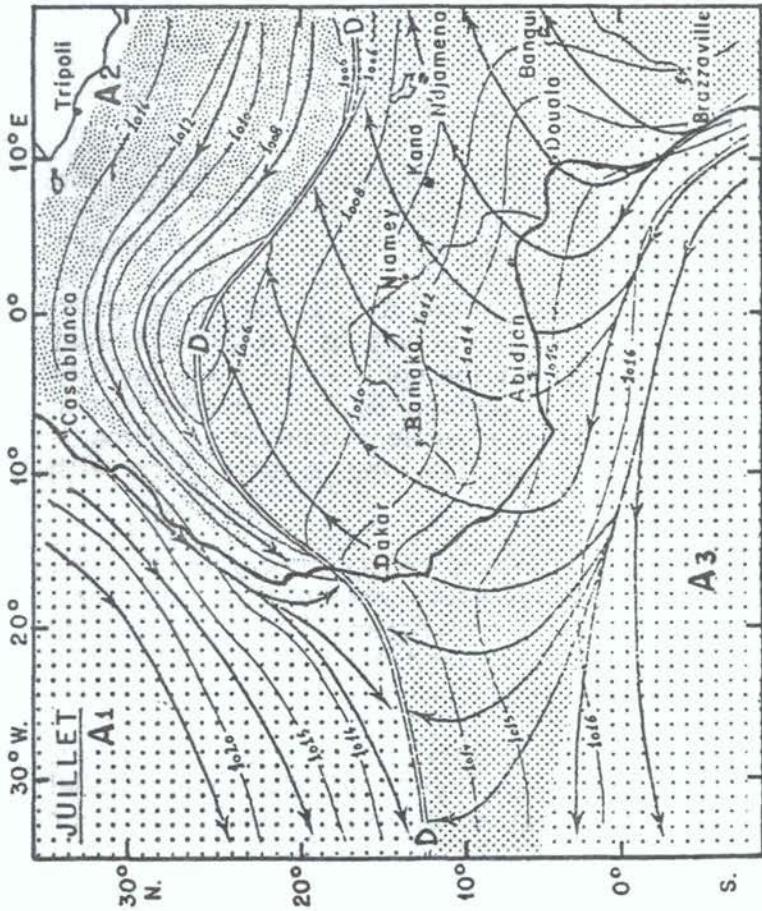
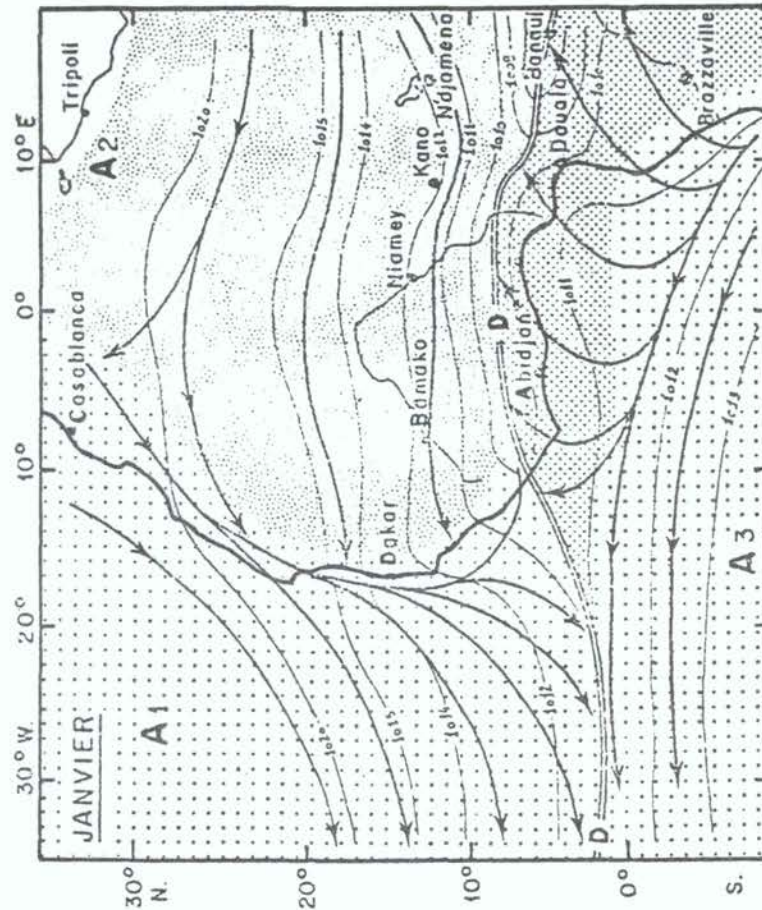
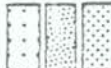





Fig. II.1 - Centres d'action et circulation en janvier et juillet
In Rebert (1977)

Fig. II.1 - General atmospheric pressure patterns in January (to the left) and in July (to the right)
In Rebert (1977)



	<u>MASSES D'AIR</u>	<u>AIR MASSES</u>
	Alizé maritime	Maritime trade wind
	" continental	Continental trade wind
	Mousson	Monsoon
	Traject. des masses d'air.	Air masses directions

-1015- Ligne isobare (pression en mb. au niveau de la mer)
 Tracé au sol de l'équateur météo. (F.I.T. sur le continent)
 D Axe des basses pressions intertropicales.
 A1 Cellule anticyclonique des Açores.
 A2 " " maghrébino.
 A3 " " de Ste. Hélène.

Isobarc line (in mb at sea level)
 Location, on the ground, of the meteor Equator (I.T.F., on the continent)
 Axis of intertropical low pressures
 Açores anticyclonic gyre
 Maghreb anticyclonic gyre
 St Helen anticyclonic gyre

II. FACTORS AFFECTING COASTAL MORPHOLOGY

The coast, or coastline, is usually considered as a limit between the inshore, or continental domain (supposed stable and passive), and the marine domain, whose water masses animated with various movements produce a more or less destructive action on the coastline. But the antagonism between these two environments is only apparent because "the coastal zone is, in fact, the zone uniting the land and the sea, and the coastline is only the present and temporary limit of the respective variations of these two domains" (Ottmann, 1965). Thus, coastal erosion is only one instance in the slow and continuous evolution of the moving border between land and sea.

The factors, governing this evolution, can be classified in two distinctly different groups :

- those related to the specific characteristics of the marine domain ;
- those related to the nature and evolution of the continental domain.

As regards the relief of the coastline, the characteristics of water masses (temperature, salinity, composition) are not as important as their general movements (currents, swells, tides), more or less immediately related to atmospheric movements, than long-term sea level changes (see chapter II.6).

II.1. METEOROLOGY AND OCEANOGRAPHY

The characteristics of ocean circulation in the African areas studied are related to the atmospheric circulation in the whole of Western Atlantic, the latter being subjected to the influence of the ocean due to ocean/atmosphere interactions.

The main factors of atmospheric circulation evolution will facilitate a better understanding of the basic characteristics of large oceanic movements, as well as marine and continental climates (see Dorot, 1972 and Leroux, 1972).

II.1.1. PRESSURE FIELDS AND ATMOSPHERIC CIRCULATION OVER WESTERN AFRICA

II.1.1.1. Pressure fields (Fig. A8 and A9)

In this African area, seasonal characteristics of the surface atmospheric circulation and those of ground wind systems are determined by the position and intensity of four major pressure fields. These four pressure fields can be classified as follows (Fig. II.1) :

- permanent maritime systems : anticyclones of the Azores and St Helen ;
- seasonal continental systems : Libyan or Maghrebian anticyclone and Saharan depression ;
- the two Atlantic anticyclonic systems which direct the northeasterly and southeasterly trade winds towards the Equator ;

- the Maghreb anticyclone, causing the cooling of the continent in winter, and generating the Harmattan, a dry easterly air flow which affects the Sahel ;
- the Saharan depression, caused by the heating of the continent, which appears at the beginning of the boreal spring and migrates progressively towards the north up to 20° - 25° N latitudes in summer. During this northern migration, the southern trade winds become humid above the sea and are transformed into a monsoon flow which generates abundant precipitations in tropical areas.

II.1.1.2. Intertropical front (ITF)

The intertropical front (ITF) is situated in the intertropical low pressure zone where the southern and boreal air masses converge. It is characterized by a threefold discontinuity : wind, temperature and humidity. It is known to migrate towards the north (20 to 25° latitude north) with the Sahara depression from January to August, to descend towards latitudes of 6 to 8° north above the Ivory Coast in December.

Along with this average seasonal movement, the front is subject, according to atmospheric disturbances, to average amplitude migrations on a several-day scale or even during the day. The daytime migrations of the front, linked to daytime temperature variations, can exceed a hundred kilometers (Leroux, 1972).

II.1.1.3. Schematic links between barometric distributions, continental climates and oceanic regimes

Seasonal variations of the position and importance of the pressure centres and of the intertropical front determine the occurrence and characteristics of climatic seasons and of rainfalls in Western Africa. These variations are also linked to periods of low rainfall or of persisting absence of rainfall which are currently accelerating the desertification process in the Sahel. Schematically, whenever the intertropical front moves insufficiently northwards from spring to summer, it reduces the probability of beneficial monsoon for the Sahel.

Inasmuch as it concerns oceanography, let us recall that the regime of surface winds over the ocean, affecting ocean circulation, as well as generation and propagation of the swell, depends :

- on the position of the main pressure centres and on the barometric distribution, as regards winds direction ;
- on the barometric gradients between these pressure centres, as regards winds intensity ;
- on the stability of barometric pressures, as regards winds duration.

That is why the northward movement of the intertropical front, during boreal spring, reinforces the north-northeasterly continental trade winds on the Mauritanian coast, and weakens them over the area, extending from Dakar to the Senegal river, by transforming them into westerly maritime trade winds.

II.1.2. GENERAL OCEANIC CIRCULATION

II.1.2.1. Major surface currents in the open sea

Schematically, the surface oceanic circulation off Western and Central Africa can be divided into two major (anticyclonic) circulations gyrating in two opposite directions (according to the Coriolis law), and originating one in the northern hemisphere, and the other in the southern hemisphere (Fig. II.2). Hence, the following currents are observed in the area :

- in the north (Fig. II.3), the southward cold current of Portugal and/or of Canary which flows along the coasts of Mauritania and Senegal and progressively warms up and splits into two opposite branches :

- . the westward North Equatorial Current ;
- . the Guinea Current which continues along the African coast, turning progressively eastward to join the Equatorial Counter Current, which transports eastward the saline and warm waters formed along the southern edge of the North Atlantic eddy.

Those principal currents are almost constantly oriented ; however, within the triangular domain they delimit, they are subjected to the influence of various migrating water masses. Consequently, they appear to generate seasonally rather unstable currents which often induce a northward movement of warm waters (Rebert, 1977).

- in the south (Fig. II.4) the cold current of Benguela, flowing northwards along the coasts of Angola and extending in the Gulf of Guinea through the westward South-Equatorial Current. This latter is bounded in the south by the South-Equatorial Counter Current which splits into two branches, the current of Angola flowing southward, where it interferes with the current of Benguela and the northward current of the "Trade Winds".

II.1.2.2. Seasonal dynamics of the principal oceanic currents

This general dynamics depends on the large-scale oceanic and climatic seasonal exchanges which occur in the oceans and remain but poorly known.

The characteristics of the water masses circulation in the vicinity of and on the continental shelf depend on the morphology of the shelf and on the orientation of the coast, as well as on seasonal variations of the barometric tendencies and the regime of the prevailing winds.

Off the coasts of Senegal, for example, where oceanic studies are carried out on behalf of the CRODT, the ITF movement towards the north in summer makes it possible for the Equatorial Counter Current to transport warm waters northward along Senegal coasts (Fig. II.5), while usually it is the cold coastal current of Canary that prevails in the area (Fig. II.6).

Fresh water inputs into the ocean by means of great coastal rivers of the equatorial and tropical zones have a great impact on the distribution, characteristics and dynamics of the water masses flowing over the continental margin. During monsoon periods, for example, salt-depleted water masses provided during the floods of the coastal rivers of Guinea-Bissau and Guinea, induce the development of a desalinated-water "fender" (Rebert, 1977), the slope of which favours the northward flow, increased by the local winds, of the fresh waters (Fig. II.7).

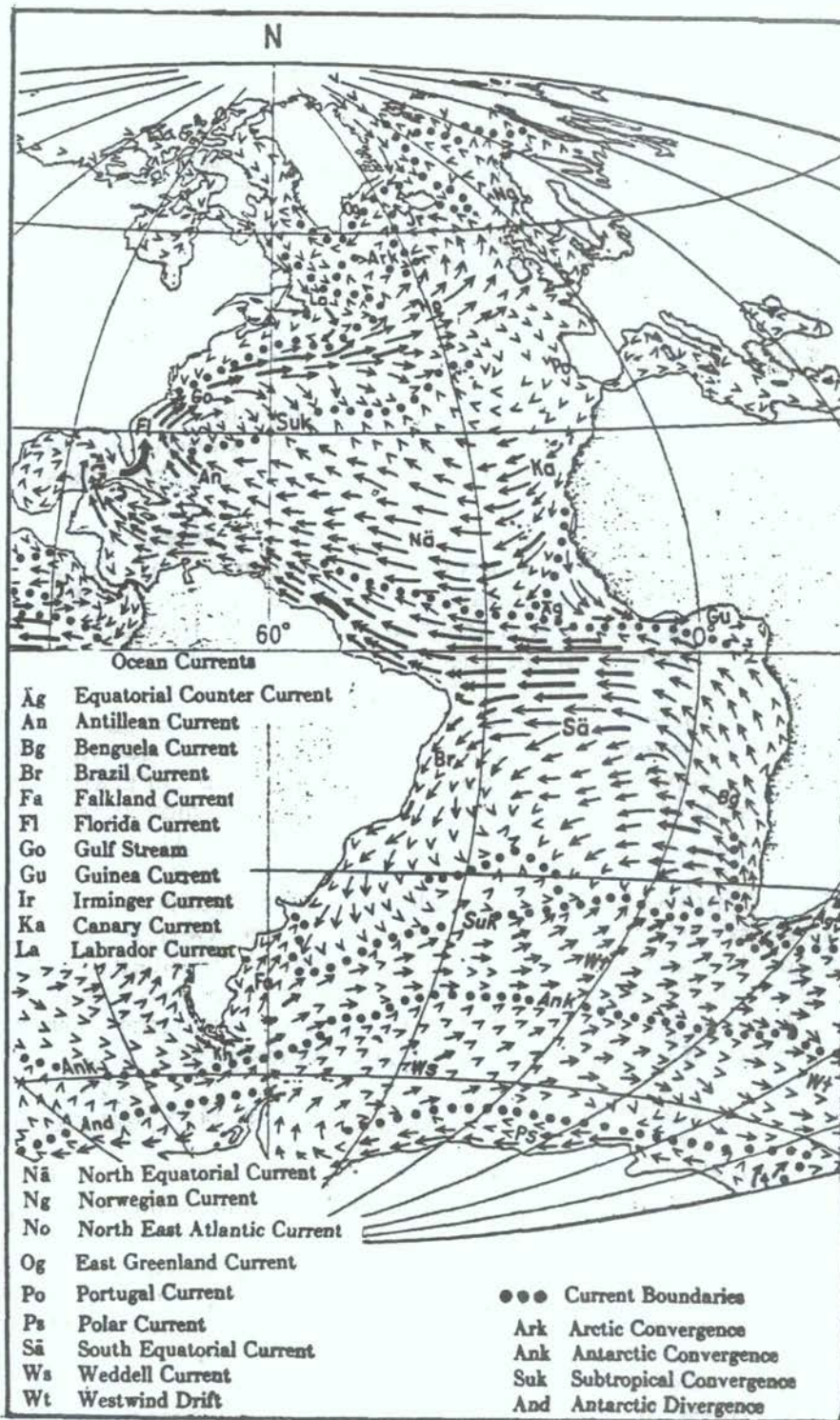


Fig. II.2 - Grands courants océaniques de l'Atlantique
In Fairbridge (1966)

Fig. II.2 - Principal currents of the Atlantic Ocean
In Fairbridge (1966)

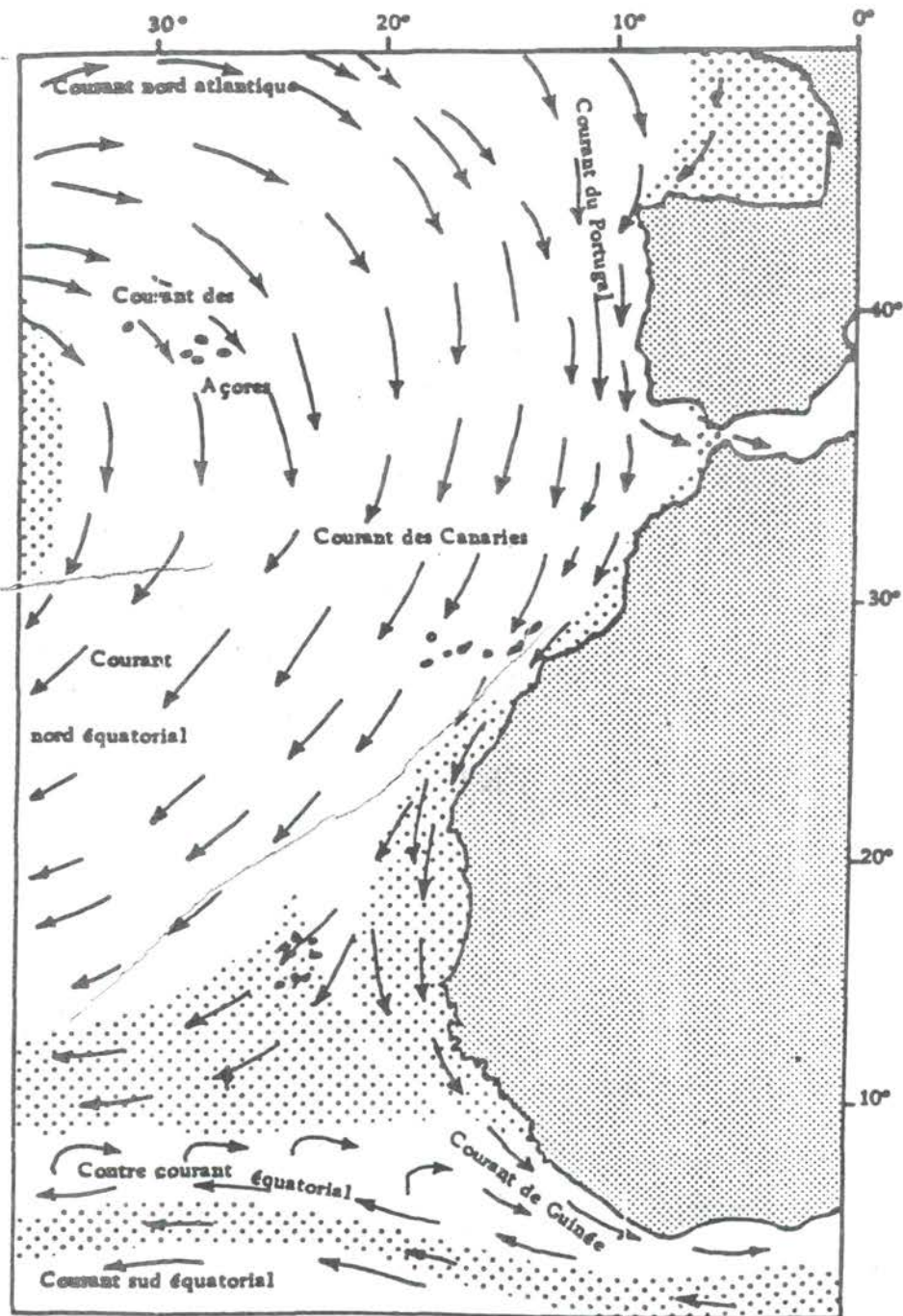


Fig. II.3 - Courants généraux de l'océan Atlantique nord
In Pinson-Mouillot (1980)

Fig. II.3 - Principal currents of the North Atlantic Ocean
In Pinson-Mouillot (1980)

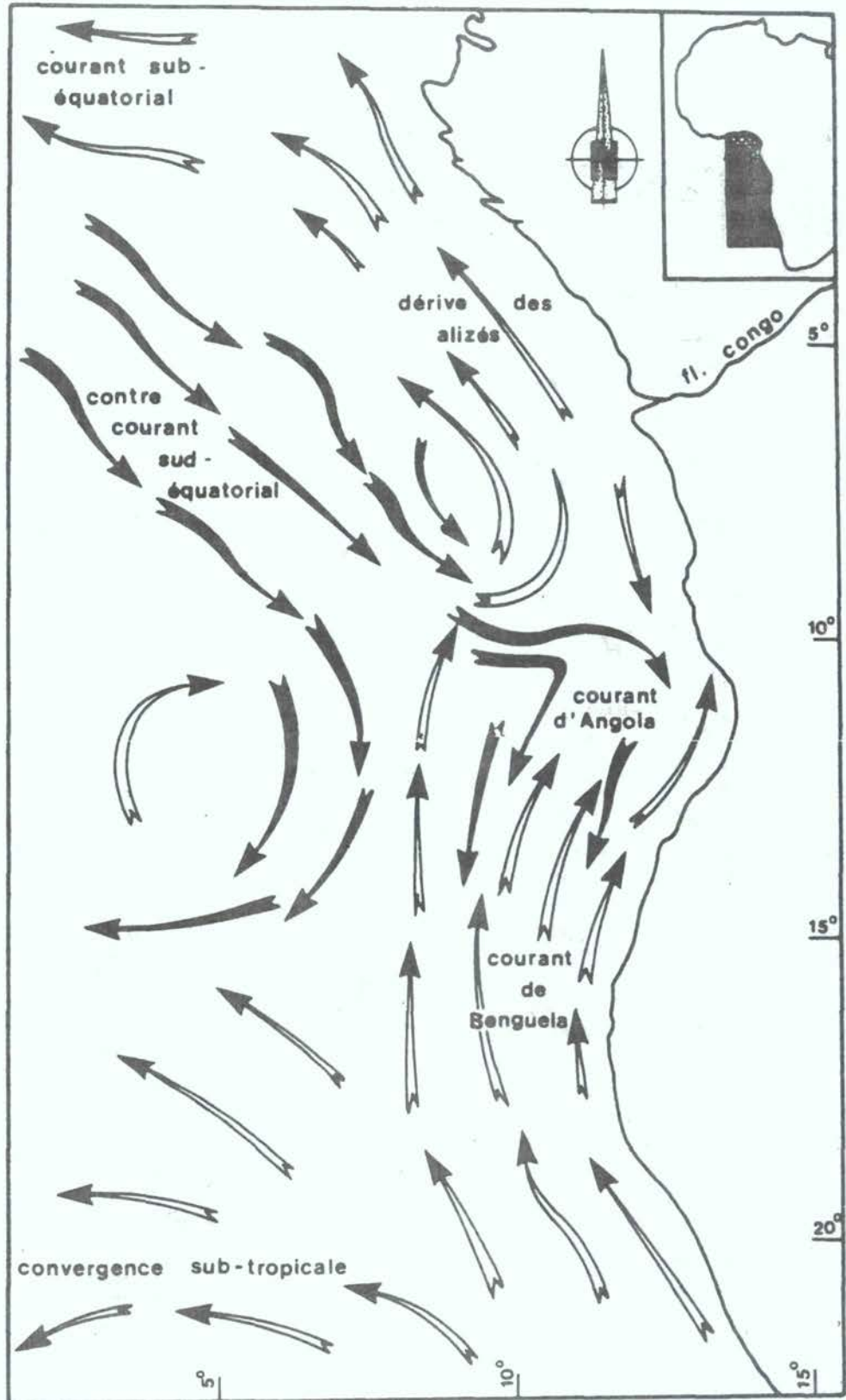


Fig. II.4 - Courants généraux de l'océan Atlantique sud (pendant l'été austral)

D'après Giresse et al., in Bongo-Passi (1984)

Flèches blanches : courants froids ; Flèches noires : courants chauds

Fig. II.4 - Principal currents of the South Atlantic Ocean (during austral summer)

After Giresse et al., in Bongo-Passi (1984)

White arrows : cold currents ; Black arrows : warm currents

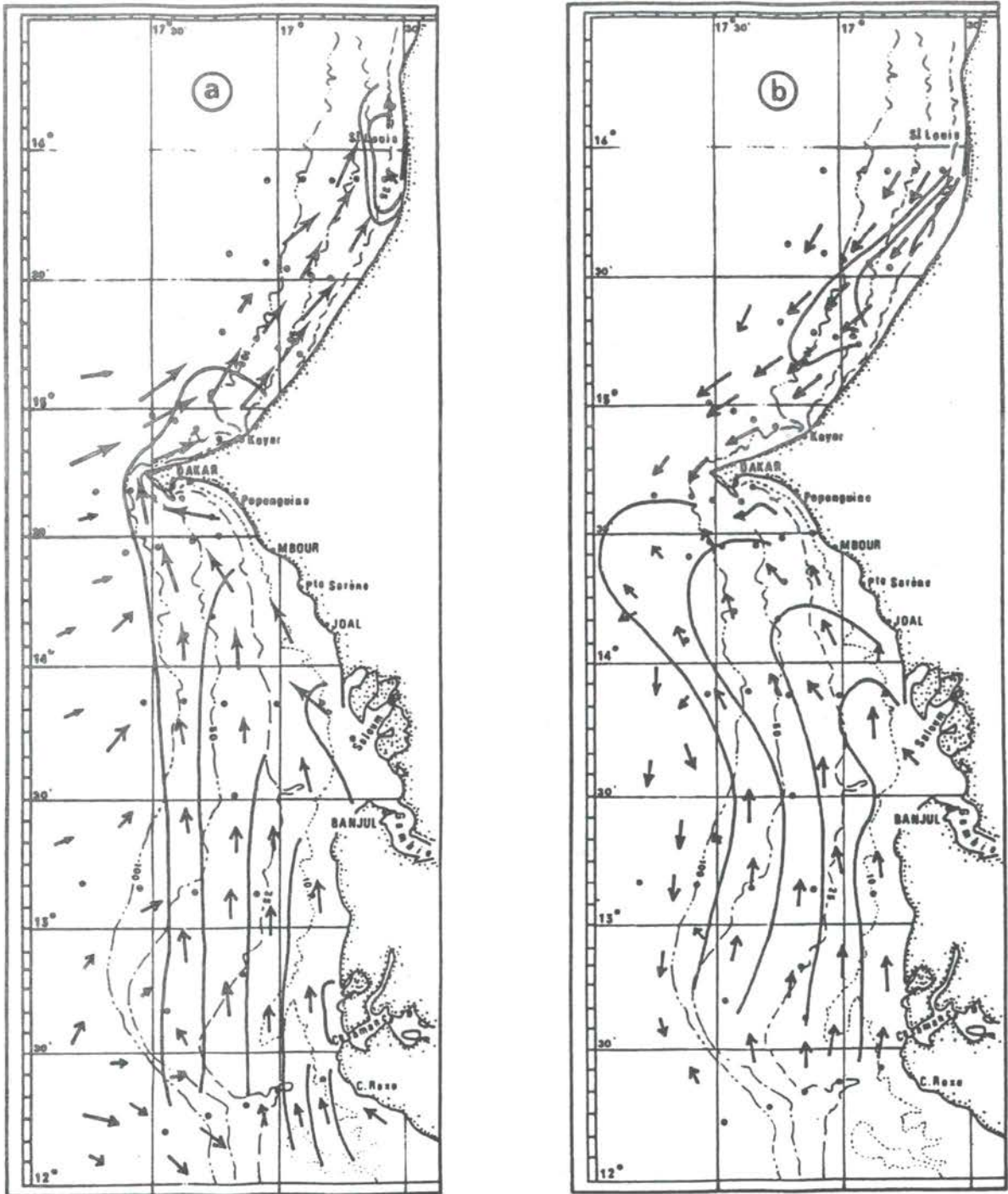


Fig. II.5 - Courants de surface et isohalines de surface en saison chaude
 a) stable (juillet-août) ; b) instable (septembre-octobre)
 In Rebert (1977)

Fig. II.5 - Surface currents and surface isohalines during the warm season
 a) stable (July-August) ; b) unstable (September-October)
 In Rebert (1977)

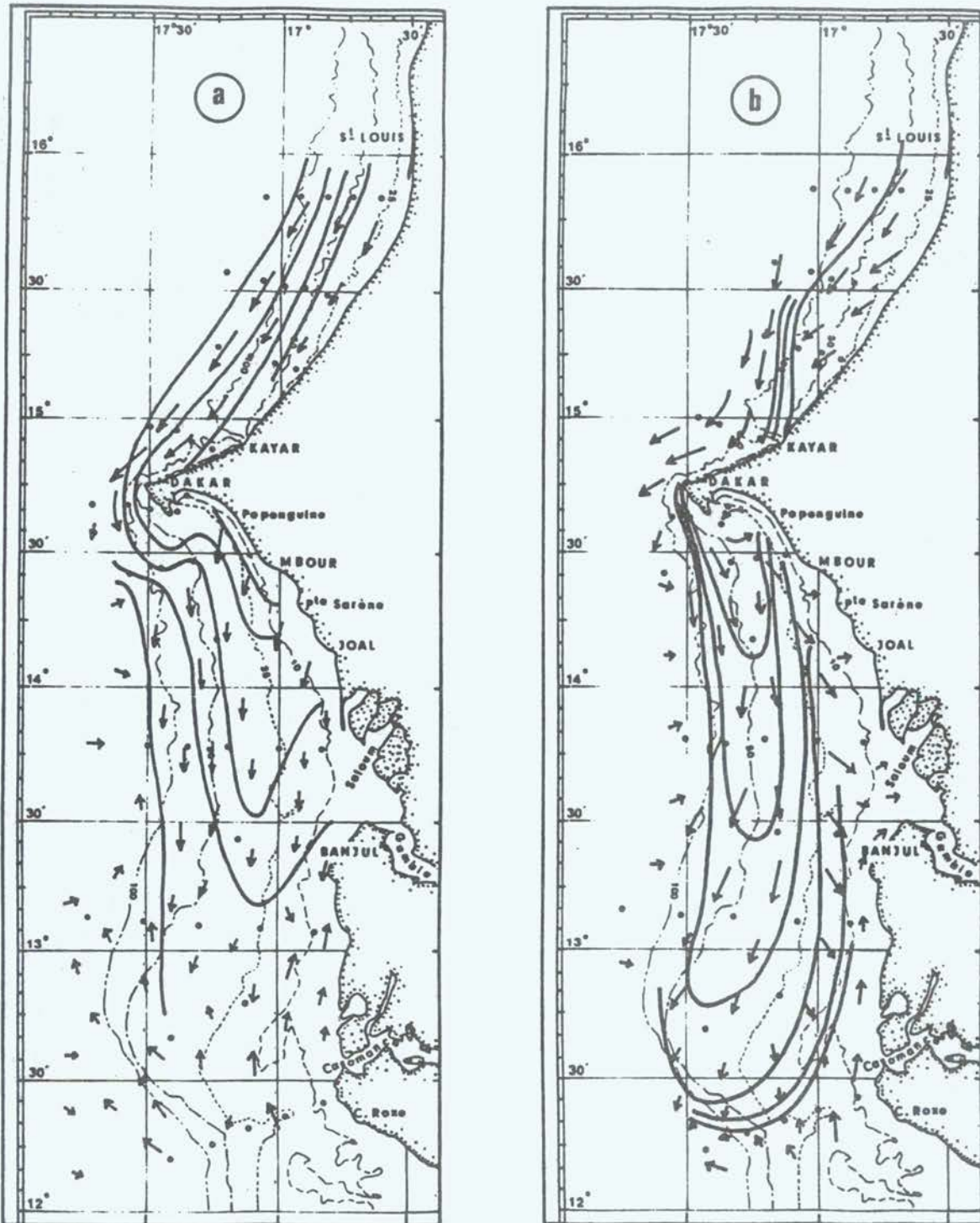


Fig. II.6 - Circulation superficielle et répartition des isothermes de surface en saison froide en période :
 a) d'upwelling faible (décembre-janvier) et d'advection ;
 b) d'upwelling fort (février-avril)

In Rebert (1977)

Fig. II.6 - Surface circulation and surficial isotherms distribution in the cold season during :
 a) weak upwelling (December-January) and advection period ;
 b) strong upwelling (February-April)

In Rebert (1977)



Fig. II.7 - Les catégories d'eaux de surface
In Rossignol (1973)

Fig. II.7 - Different types of surface waters
In Rossignol (1973)

II.1.3. DRIFT CURRENTS AND UPWELLINGS

Coastal upwelling results from a process combining atmospheric and oceanic factors and occurring off most of the Western coasts of the African continent.

Through the wind action, deep oceanic waters are moved upwards to the coast, while surface waters flow offwards as a drift current, due to the wind called the Ekman transport.

According to the studies made by Ekman (1905), Thorade (1909) and Mac Ewen (1933) of the theory of wind-induced current off a straight coast bounding an offshore sea water mass homogeneous in density and rather deep, the drift current flows perpendicularly and on the right to the wind direction in the northern hemisphere (Fig. II.8).

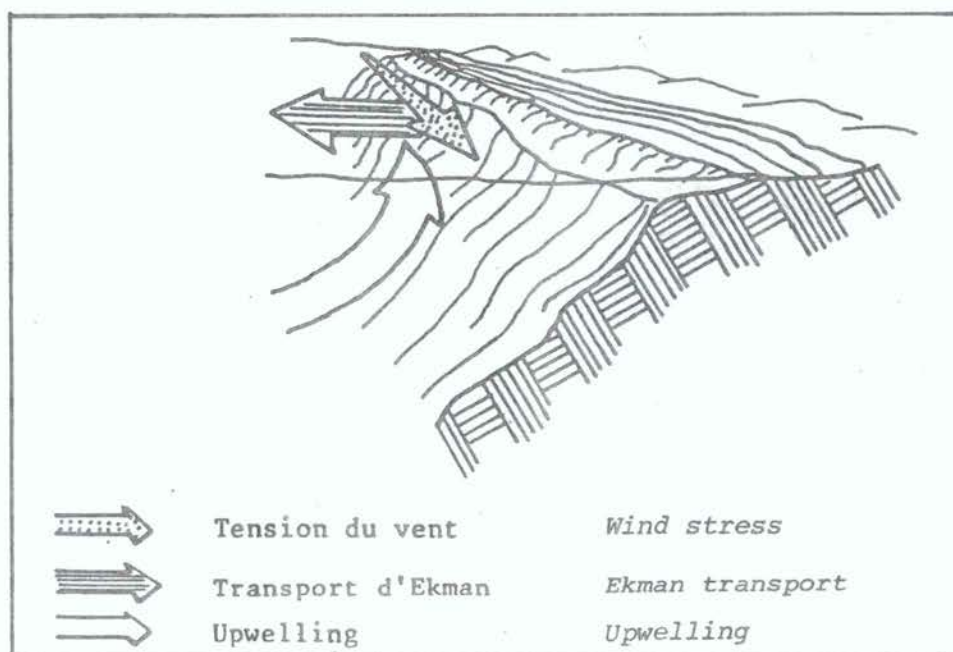


Fig. II.8 - Schéma d'upwelling
In Bakun (1977)

Fig. II.8 - Upwelling model
In Bakun (1977)

A regular wind regime, blowing from the right of an observer looking seaward, will induce in that hemisphere either a non-stratified ocean, the seaward outflow of the superficial littoral waters or, on the contrary, their piling-up, during a regime of inward blowing winds.

Piling-up situations correspond to inward flows, which are also accompanied by down-welling of the surface waters, while upwellings which bring up deep waters towards the coast, correspond to periods of outflows.

The most favourable conditions for coastal upwellings occur, in the area concerned by this study, off the coast of Mauritania and Senegal in the north, and off Angola, in the south, i.e. where winds blow (during continental regimes of trade winds) obliquely to the coast and towards the low latitudes, and where the general direction of the coast is north-south.

One has to mention specifically the northern continental margin of Senegal where big upwellings, effective over a 20 to 30 km-wide-part of the continental shelf, occur during the cold season (January to May) : at that time, the temperature of coastal waters is 4-4.5°C lower than the sea water 100 km offshore.

The upwelling processes reinforce the distribution and the dispersion over the continental shelf and even farther, the fine sediments being carried to the coastal zones by rivers. On the contrary, piling-up tends to trap fine fluvial sediments in the coastal zone and drift them over the shelf through the action of mass currents down-flowing type.

These processes which cause local surface wind-induced drift currents are counter-balanced or reduced, when the coastline direction changes ; this happens specifically off the Cape Vert peninsula (Senegal), that stretches almost normally during north-westerly (during the cold season, from January to May) trade winds ; such an orientation generates a piling-up (or convergence) situation characterized by a particular piling-up regime of the offshore waters between Cayar and Cape Vert (Rebert, 1977), the piled-up waters flowing then down through the Cayar canyon.

Thermohaline circulation may also disturb wind-induced mass water transports. This type of circulation is related to the warming-up of the waters along the wide and slightly sloped continental shelf edges (Southern Senegal and Guinea). It is comparable to piling-up type circulation (shoreward surface currents) within a concentration basin isolated from the offshore circulations by a thermohaline front which limits the transverse exchanges between the offshore and inshore zones.

II.1.4. TIDES AND TIDAL CURRENTS

The astronomical tide manifests itself as a periodical rising and subsiding of the sea level which results from the attracting forces of the celestial bodies, mainly those exercised by the sun and the moon on oceanic water masses.

Off the west and central African coasts, the tide is mainly of a semi-diurnal type, with two daily maximums and minimums.

The mean height of the tide (Table II.1), or mean tidal range, varies from one studied area to the other as follows :

<u>COUNTRY</u> - PAYS	<u>PORT</u>	<u>TIDAL RANGE</u> (m) MARNAGE
Mauritania	Bahia de Villa Cisneros	1.9
	Nouadhibou	1.8
Senegal	St. Louis	1.2
	Dakar	1.3
Gambia	Banjul	1.6
Guinea Bissau	Bissau	5.1
Guinea	Conakry	3.2
Sierra Leone	Pepal	2.9
	Freetown	2.6
Liberia	Monrovia	1.1
	Buchanan	1.0
Côte d'Ivoire Ivory Coast	Abidjan	1.0
Ghana	Takoradi	1.3
	Accra	1.3
Togo	Lome	1.4
Benin	Cotonou	1.2
Nigeria	Lagos (Bar)	1.0
	Forcados Bar	1.2
	Bonny Bar	1.8
	Calabar Bar	2.0
Cameroon - Cameroun	Douala	2.0
Equatorial Guinea	Bata	1.6
Gabon	Libreville	1.6
	Cap Lopez	2.0
Congo	Pointe Noire	1.3
Zaire	Banana	1.3
Angola	Cabinda	1.8
	Luanda	1.2
	Lobito	1.2
	Mocamedes	1.2

Tableau II.1 - Tableau des marées (vive-eau) dans les principaux ports de l'Afrique de l'Ouest et du Centre
In Collins et al. (1983)

Table II.1 - Western and Central African coastline tidal ranges
In Collins et al. (1983)

- decrease from Mauritania to Dakar (Senegal), where the mean height is 1.2 m ;
- significant increase southward to Guinea-Bissau where the mean height reaches 5 m ;
- significant decrease to the south, to the Ivory Coast where the tidal amplitude mounts to 1.0 m ;
- slight increase southward to Togo (1.4 m), followed by a stop and a progressive increase south to Cameroon (2.0 m of tidal range as off Gabon) ;
- decrease south to Zaire and Angola, where the tidal range does not exceed 1.2 - 1.3 m, with the exception of Cabinda, where it is 1.8 m.

As the mean tidal ranges observed along most of the reviewed African countries are insignificant, one may consider that tidal currents are generally weak, their maximum surface speed not exceeding 0.10 m/s.

The area extending from Guinea Bissau to Sierra Leone is the only one where tidal currents may run at significant speeds over the shelf, as their tidal range varies from 2.5 to 5.1 m.

The circulations induced by the tides on the continental shelf cannot be shown on a regional scale, as they interfere with coastal and submarine morphology, oceanic circulation and amplitude variations of the tides.

II.1.5. WAVES GENERATION AND SWELLS PROPAGATION

The generation of waves in the ocean is linked to the complex ocean-atmosphere exchanges and to the transfer of kinetic energy from surface winds to oceanic water masses. This energy transfer is all the more significant as the propagation speed of the waves is lower than the surface winds component in the propagation direction.

The most commonly applied, simplified models of waves generation (SMB), require the use of chronological serial meteorological maps, also called synoptic maps, which show the isobaric distribution of pressures above the ocean and which allow to :

- measure the intensity and direction of geostrophic and surface winds;
- delimit the "fetches", i.e. oceanic areas with a relatively constant wind, which are known to contribute to waves generation ;
- estimate the duration during which winds act on these fetches.

The velocity of the theoretical geostrophic wind, generally stronger (10 to 20 %) than the actual surface winds except in the vicinity of anticyclones, is estimated by taking into account the horizontal atmospheric gradient and, therefore, the distances between the isobaric curves on the synoptic maps. The geostrophic wind blows, theoretically, in a direction parallel to the isobars, rightwards to the low pressure fields in the northern hemisphere, and leftwards to them in the southern hemisphere. Winds then blow through the action of the friction and inertia forces across the isobars towards the low pressure centres ; that explains the presence of the harmattan in the north as well as a relatively constant winds regime, i.e. the southerly and southwesterly trade

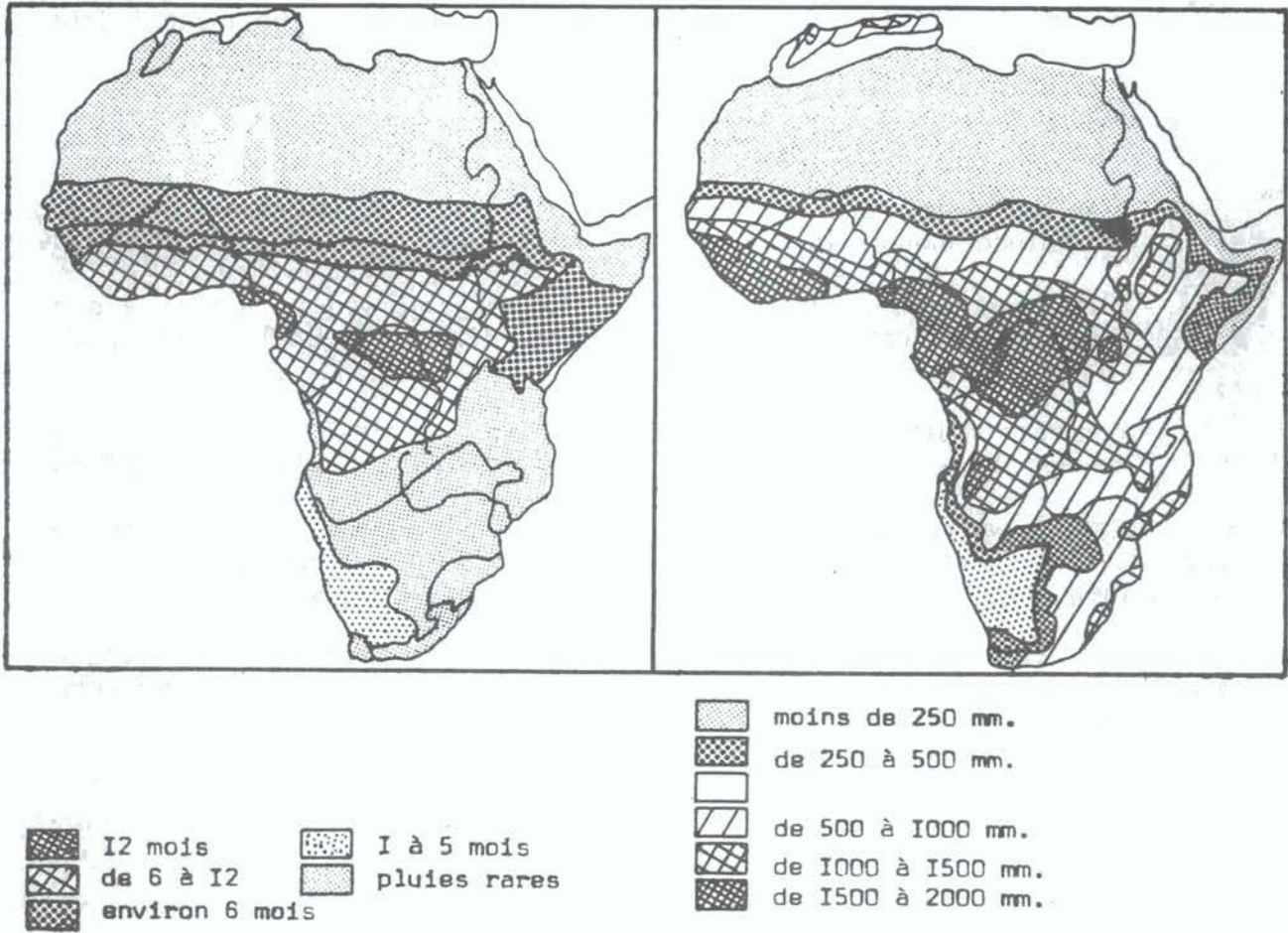


Fig. II.9 - Régime des pluies. In Furon (1968)

- a) répartition saisonnière des pluies
 b) précipitations annuelles

Fig. II.9 - Rain pattern. In Furon (1968)

- a) seasonal rain distribution
 b) annual precipitations

winds in the Gulf of Guinea.

When the wave trains, once formed, leave the fetch or "wind-sea", their amplitude tends to decrease while their apparent period increases and the waves profiles become regular : one may then call them swells (developed waves) which propagate towards the coasts, their period remaining constant, if favourable or opposite winds do not blow.

The above observations reveal our interest in the study of seasonal variations, location of pressure centres and barometric distribution above Africa and the Atlantic Ocean, to characterize the meteorological regimes, capable of generating waves trains strong enough to reach the West and Central African coasts.

It is possible, on the basis of the seasonal barometric distribution, to consider schematically that :

- the coasts of Mauritania and Senegal are exposed to mainly northerly to northwesterly swell regimes ;
- the coasts of Guinea Bissau and Guinea are rather more sheltered, although affected by south-southwesterly and west-northwesterly swells ;
- the coasts of the Gulf of Guinea and the bight of Benin are largely open to southwesterly to south-southeasterly long swells induced by fetches in the South Atlantic Ocean ;
- the coasts from Angola to Gabon are affected by southerly to west-southwesterly long swells from the South Atlantic.

II.1.6. RAINS AND TEMPERATURES

Climate has the greatest of impacts upon the hydrologic regimes of rivers to which it contributes through its action on the soils and conjugated effects of heat and humidity. Rivers play a role of transportation agent, carrying the sediments formed along the watershed through chemical weathering processes (the main continental erosion factor). Heat, humid air, vegetal cover, morphology,... determine erosion processes but water is, undoubtedly, the prevailing factor : "without water, no alteration". Continental inputs discharged into the ocean by rivers are mostly redistributed by currents in the coastal zone and, thus, condition coastal morphology (see chapter II.2.).

In the equatorial zone, it is not temperatures (almost constant between 25 and 30° C) which determine seasons, but rain (Fig. II.9) which tends to lag 200 to 300 km behind the ITF rather than follow its passage. The area located between 3° S and 8° N, always under the influence of wet equatorial air, is characterized by heavy rains all the year round (rainfalls totalling 2 - 3 m, with maximums of more than 4 m in the inner part of the Gulf of Guinea, permanently swept by the southwesterly monsoon) ; with short drought seasons occurring only at solstice. The subequatorial regions bounding the gulf of Guinea are thus affected by climatic variations during the 4 seasons : a long rainy season (March-April to July-August), a short drought season (August-September), a short rainy period from September to November and a long drought season from December to February-March.

Between 8° and 18° N and 3° to 15° S, the rainfall regime becomes tropical and divides the year into two main seasons (dry and wet).

The rainy season coincides with the passage of the ITF, and therefore occurs during summer in both hemispheres. It is eventually interrupted (Congo, Angola) by a short drought season in January-February. It grows increasingly as one moves away from the Equator and approaches the Tropics ; the rainfalls become respectively less heavy and more irregular. The disappearance of the rainy season marks the beginning of the desert.

It has to be noted however that even during the drought season, the relative average humidity due to the maritime trade-winds stays at 77 % ; that explains the observed high condensation levels and frequent dews and fogs.

The temperatures are high during the whole year, the annual averages never falling below 20° C ; the annual thermal amplitude is weak but increases with latitude, i.e. with the drought.

The proximity of the sea can naturally be a moderating agent as it levels temperatures. On the seashores warm marine currents augment tropical humidity ; on the other hand, cold currents aggravate the drought or desert conditions : the Canary Current off the coast of Mauritania or North Senegal, the Benguela Current off the coasts of Angola and Namibia.

II.2. CONTINENTAL FACTORS

Such factors as tectonics, lithology, hydroclimatology exercise a major influence upon the coastal morphology ; the predominant among them being the physical structure (structural tectonics), and the nature of the rocks (petrography, hardness, weathering stage, fracturing,...). In fact, it is these factors that interact to produce differential erosion and thus change the shape of the coastlines.

The main tectonic mechanisms to be considered for their immediate or secondary influence on the coastlines are, at a megascopic scale, the rift and associated transform faults areas. Similarly, the old or recent intracontinental rifts are graben-like structures which could create low zones as they reach the shore. On a larger scale, foldings, faults, shelf edges, warpings appear to control coastal morphology. Thus, the retrograding shoreline can abut against on an old inactive fault zone, or on the axis of a fold, and then either develop in a parallel direction, or stop when reaching that unevenness. Recurrent faulting located in a coastal zone may sometimes affect its orientation and significantly modify the evolution of the shoreline. Tectonic movements can also produce declines or rises of coastal compartments and cause local variations of the shoreline, independantly of the eustatic variations of the sea level. If physical and chemical characteristics can be said to regulate erosion sensitivity of a coastal rock, some of its parameters, such as its fracturing are directly or indirectly controlled by the regional tectonic history.

The generally rough morphology of crystalline basement coasts is, consequently, due to their complex nature (numerous foldings and faults of different orientation) which explains wide variability of their erosion potential. On the contrary, coasts based on sedimentary layers slightly tectonized are smoother, and erosion notches them more uniformly.

Generally speaking, the more oblique to the coastline are tectonic structures (faults, foldings,...), the more notched the coast is, and vice versa; that clearly indicates that coastal erosion is mainly affected by structural factors.

Another continental phenomenon, the weathering of the onshore zone, the decay of which is discharged into the ocean through the river pattern, can also notably influence coastal morphology.

II.2.1. GEOLOGY OF WESTERN AND CENTRAL AFRICA

Africa, extending over more than 30 millions square kilometers, looks like a massive continent. With the exception of its northwestern extremity (Maghrebian ridges) which belongs to the meseogean domain and was shaped during the Alpine orogeny, the continent is made up of an old, gently undulating basement, where large basins are closed by highlands overhanging a slightly notched shoreline (Fig. II.10). That large shield has structurally developed mainly around three cratons (made out of hard rocks : granites, gneiss,...) which give the evidence of a very old basement (4,500 Ma), indurated during successive orogenies. That large stable area was influenced by the Mesozoic (upper Jurassic - lower Cretaceous) opening of the Atlantic ocean and by different more recent tectonic phases, especially those linked to the Cenozoic structuration of the big East African rifts. On the margins, developed subsiding sedimentary basins, where marine and continental formations are deposited as alternating thick sequences currently outcropping along the coastline (Mauritania, Senegal, Nigeria, Gabon, Congo and Angola).

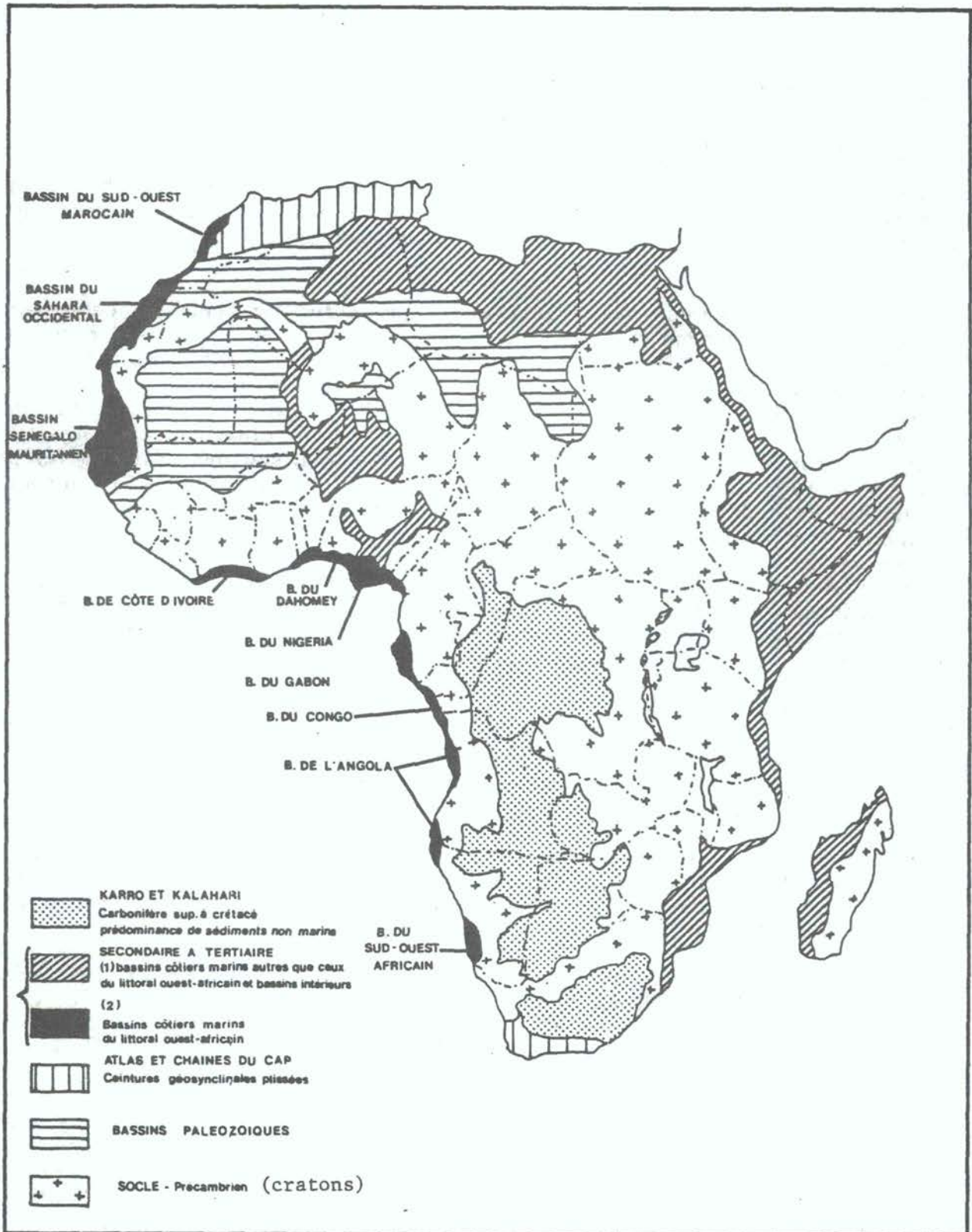


Fig. II.10 - Géologie générale de l'Afrique. In Reyre (1966)

Fig. II.10 - Geological sketch of Africa. In Reyre (1966)

II.2.1.1. Coastal cratons (Fig. II.11)

The West African craton represents the most important coastal outcrops (inducing coasts with cliffs) which extend from southern Guinea Bissau to the Sassandra river (Ivory Coast). It reappears along the Ghanaian shoreline, from Cape Three Points to Accra, alternating with sandy Quaternary deposits.

The Congo craton, separated from the Niger deltaic basin by the thick, neogene, volcanic formations of the Cameroon mounts, fringes the southern Cameroon shoreline down to the Ntem river (or the Campo river) at the Equatorial Guinea boundary. It appears again in a few places farther south, alternating with the numerous small coastal sedimentary basins of Congo and Angola.

Those cratonic coasts can be distinguished by their convex shape owing its origin to the resistance of the component rocks, but the details of their morphology are largely due to tectonic factors (faults, fracturing).

II.2.1.2. Coastal basins (cf. Reyre, 1966)

The West and Central African coastal basins are generally narrow fringes (5 to 20 km wide), either of small length (Ivory Coast) or extended over hundreds of kilometers. In some instances, those fringes can reach a width of 100, exceptionally 500 kilometers ; for example, the Ogooué, Senegal and, particularly, the Niger basin which extends inland to join with the huge Saharian zone to the north.

In all cases, their basement outlines are concave, just as their sedimentary terranes constitute a convex projection towards the ocean, the foremost parts being the most recent. Moreover, their main axis always coincides with the presence of a major river, whose valley extends on the continental platform either along submarine canyons, such as the Congo-Zaire, or the extreme narrowness of that shelf (Ogooué) or even induces the development of an enormous delta, with extensive rivers detritic inputs (Niger).

Four main units can be distinguished from north to south (Fig. II.10) :

- **the Senegalese-Mauritanian basin** : it extends over more than 2,000 km, reaching 500 km in its widest, and covers an area of about 500,000 sq. km.

This open-type basin is filled up by an important monoclinial series dipping west and pitching towards the ocean. The sedimentary layers are Upper Jurassic to Quaternary in age. From a tectonic point of view, the basin exhibits only normal faults without any important folding. On the other hand, volcanic stages occur during the Miocene and Pleistocene in the area of Dakar and Rufisque; Cape Vert is intruded by hardly erodible volcanic rocks. Close to the shoreline, most of the outcrops are made up of unconsolidated quaternary and pliocene sands. South of the basin Paleozoic non-erodible outcrops are evident in Guinea-Bissau and at Cape Verga (Guinea), whereas basic intrusions (dolerites and gabbros) form the Conakry and Freetown peninsulae.

- **the Ivory Coast basin** : this narrow sedimentary fringe does not exceed 30 km in width. It extends from Fresco in the west to Axim, in Ghana, in the east. Its area covers about 10,000 sq. km. Crescent-shaped, it follows a recess of the Gulf of Guinea on both sides of Abidjan. It is cut from west to east by an extremely important fault, called "the main tectonic feature of the Ivory Coast", which separates a northern zone with a slightly developed sedimentary cover from a southern zone corresponding to a deep basin filled

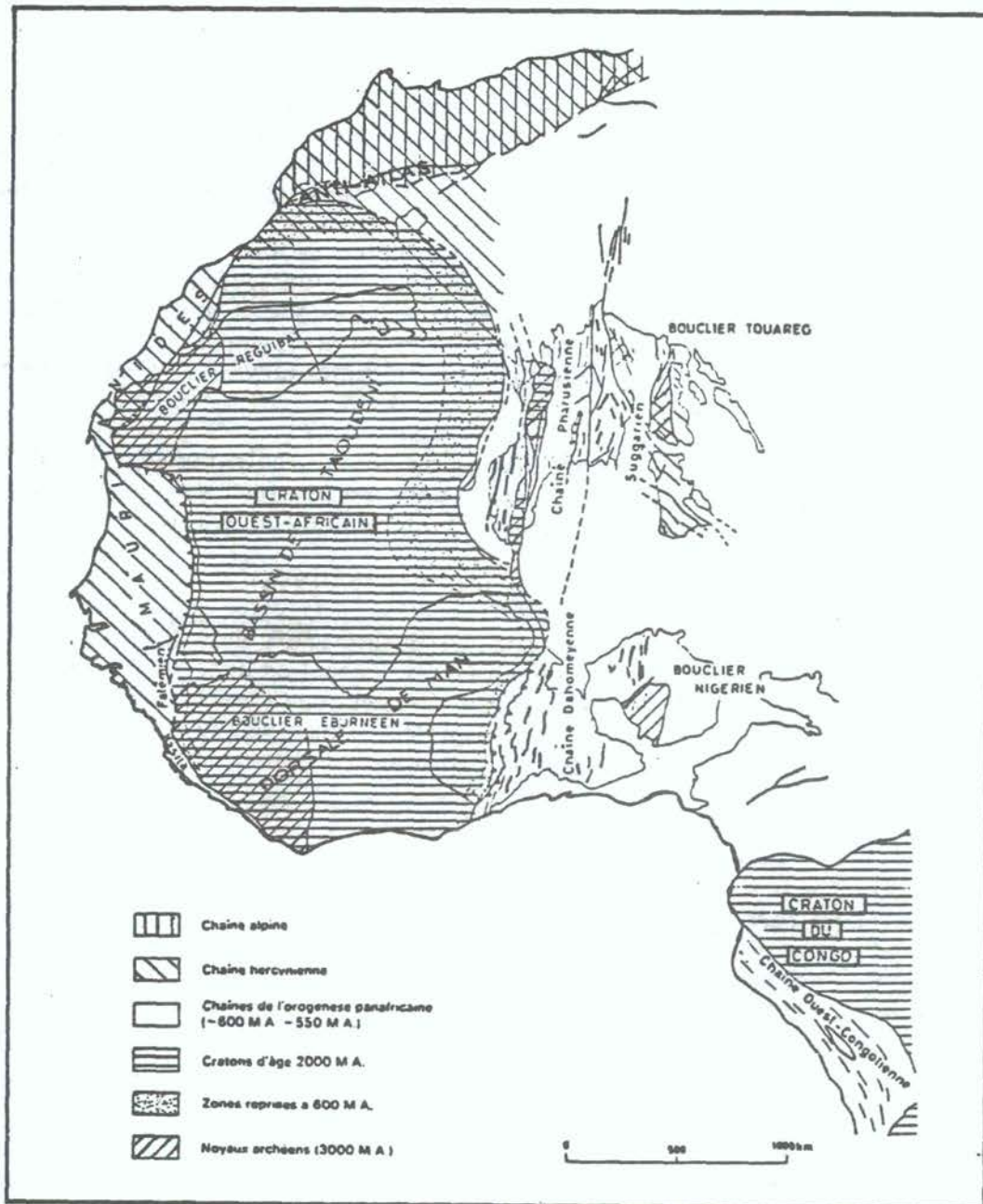


Fig. II.11 - Cratons de l'Afrique de l'Ouest et du Centre
In Furon (1968)

Fig. II.11 - Cratons of West and Central Africa
In Furon (1968)

up by 4 to 5, 000 m of sediments.

As for the shoreline, it can be divided into three parts according to the nature of the formations reaching the sea :

- . west of the basin, from Cape Palmas to Sassandra, the precambrian basement is separated from the sea by a small coastal plain made up of two coastal bars ;

- . between Sassandra and the Grand Lahou lagoon, the coastline is mainly characterized by the Continental Terminal, forming crusted plateaus separated from the sea by sandy bars. That part of the shoreline is located in the non-subsiding zone of the basin ; the lagoons are significantly less extended than eastwards of the basin, and are ancient valleys submerged during the last transgression ; the connection with the sea is more or less clogged up by the beach drift ;

- . the eastern part of the basin tends to subside ; the coast is low, formed of recent, quaternary deposits and bounded by lagoons.

- **the Niger basin** : it is, in fact, an extension of the Benoue rift, a major tectonic feature in the area. Contemporary of the south Atlantic opening during the Lower Cretaceous, it represents on the continent the equatorial oceanic fracture extension (transform faults) which transversally structures the mid-Atlantic ridge. This basin may prove to contain up to 10,000 m of Cenozoic and Cretaceous sediments below the present delta, but it becomes more shallow along its eastern and western borders, in Cameroon and Benin. Its corresponding coastline extends over 1,200 km ; it reaches its maximum width (500 km) off the Niger delta and its surface area is about 350,000 sq. km.

The coastal area, 60 to 70 km wide, is a plain covered by recent sediments and fluvial deposits. An important bar characterized by lagoons and sandy bays has developed off the shoreline. Over more than 350 km, the Niger delta (reinforced by its affluent : the Benoue) spreads out into a vast extent of swampy landscapes. That delta reached such dimensions during Quaternary rainy periods, that it now occupies an area of 30,000 sq. km, of which 10,000 are below the sea level.

Off the coast of Cameroon, the Fernando Poo, Sao Tome and Principe, and Annobon islands extend the Cameroon volcanic mounts. The major eruptive lineament, mainly Neogene-aged, corresponds to an important geotectonic feature extending southeasterly, parallel to the great Benoue rift, which it borders and on which develops the Niger delta.

- **the sedimentary basins of Gabon, Congo, Zaire and Angola (Fig. II.12)** : that unity is subdivided into three sedimentary basins : Gabon (60,000 km²), Congo (17,000 km²) and Cuenza (11,000 km²) which form an almost continuous sedimentary fringe from Campo (S. Cameroon) to Cape Santa Maria (Angola) (Hourcq, 1966). They have been made the object of intensive oil exploration studies. A fourth basin, the Moçamedes one, south of Angola, is related to the previous ones by its structural, stratigraphic and sedimentary characteristics. Their origin is linked to the opening of the South Atlantic during the Middle and Upper Jurassic periods. They are characterized by a series of sediments, at firstly continental, fluvial or lacustrine, later becoming deltaic or lagunal during marine transgressive stages. A warm climate and confined marine environment have led to the deposition of important evaporites and salt layers. The transgression having generalized, their history is similar to that of a platform subjected to sea level variations and to important subsiding phenomena.

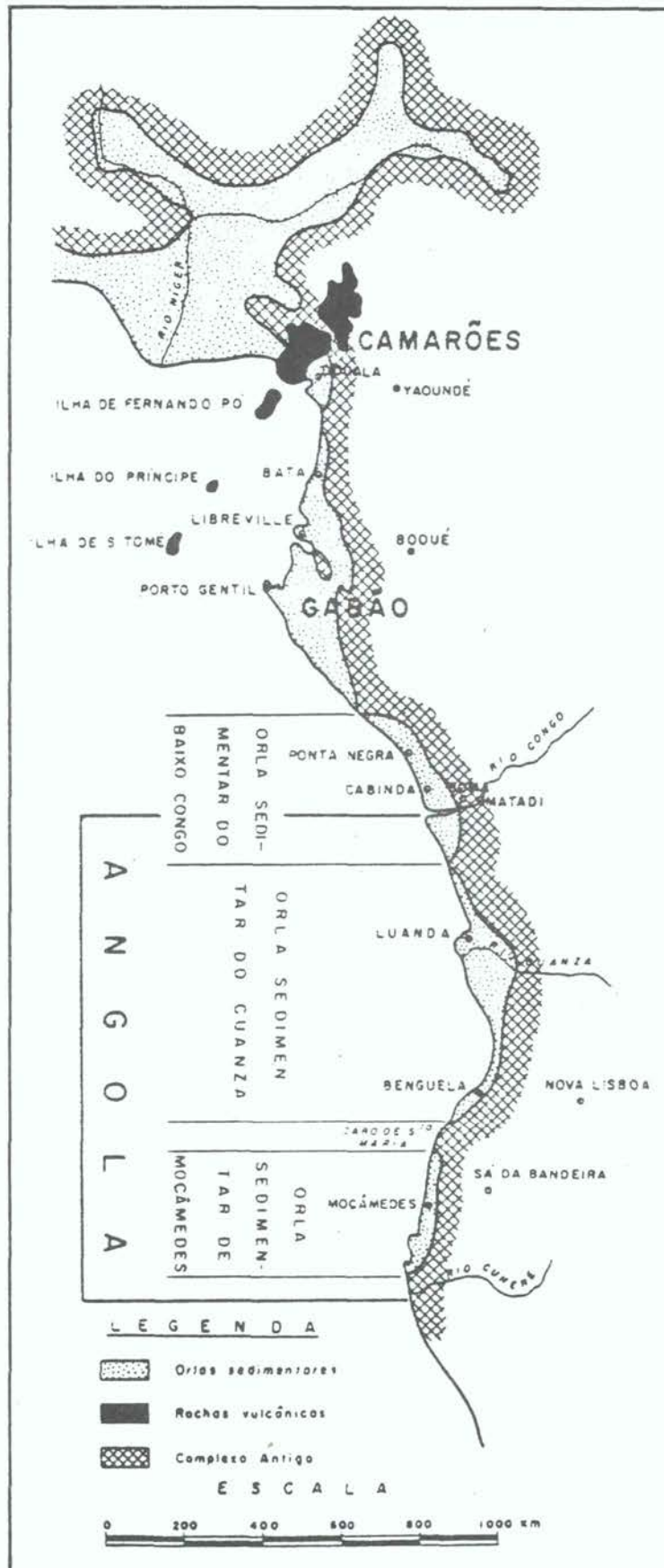


Fig. II.12 - Bassins sédimentaires côtiers de l'Afrique de l'Atlantique sud
In Carvalho (1961)

Fig. II.12 - Coastal sedimentary basins of South Atlantic Africa
In Carvalho (1961)

The coast is thus characterized by successive outcrops of various formations and its line emphasizes the lithology : the hard layers, corresponding to limestones or sandstones give rise to cliffs and headlands (Moanda, Diosso, Barra do Dande for example), the clayey and marly formations forming wide bays.

Along these low-coast shorelines, the beach drift is particularly active. It is responsible for the coastline shape and the building-up of littoral spits (Mayumba in Gabon, a series of spits in Congo, restinga de Luanda, de Lobito, de Baía dos Tigres in Angola). Backwards of the coastal bar, several lagoons are either open seawards (Gabon, Angola), or closed and comparable to pools (Congo-Angola).

II.2.2. VEGETATION

On the coastline and in the littoral zone, vegetation may contribute directly to reducing erosion rates by physically binding sediments and abating turbulence close to the surface. In areas where vegetation is dense (fixed dune, mangrove, reed-beds, sea-grass, algae), erosion and sediment transport are reduced. In some tropical lagoons and bays, mangrove may contribute to increasing silt and calcareous sediments. On the other hand, destruction of vegetation, due to drought or human activity, may in some cases favour erosion.

The vegetation zones (Fig. II.13) are distributed much as climatic zones, i.e. in strips more or less parallel to the Equator, but considerable damage, or weathering, are able to cause deviations from that theoretical pattern.

The equatorial domain is made up of dense forest (rainforest or ombrophile); it occupies areas where rainfalls amount to at least 1,000 mm/year and the rainy season lasts at least 8 months ; it disappears where rainfalls are below 1,200 mm. Its wider domain is located in the north of the Congolese basin and in areas south of Cameroon, southwest of Nigeria, south of the Ivory Coast, Liberia and Sierra Leone.

In some deltaic areas (Niger delta, in Nigeria) or lagunal areas (Ivory Coast, Nigeria, Sierra Leone,...) mangrove develops.

The tropical domain is made up of dry forest (xerophile) which is well adapted to a climate with alternating rainy and drought seasons, the latter lasting at least 5 months ; it develops exclusively in a strip extending from Guinea to the Great African Lakes. It also corresponds to the savanna. The typical savanna, a meadow of 1 to 3 m high perennial grasses, characterizes tropical areas where rainfalls come up to about 1 m/year ; it is invariably dotted with trees and bushes. Savanna is the most extensive zone along E-W strips north and south of the equatorial domain.

The Sahelian or sub-desert areas correspond to the thorny steppe. Vegetation is clearly xerophile and well adapted to the dry season lasting more than 9 months.

Vegetation plays an important role in characterizing human activities for cultivation, fixation of maritime plants and civil construction.

The role of the vegetal cover is minor whenever there are rocky substrates and gentle physiography ; it increases on humid plains where mangroves are fairly well developed and in coastal zones with rough physiography protecting them from gullyng.

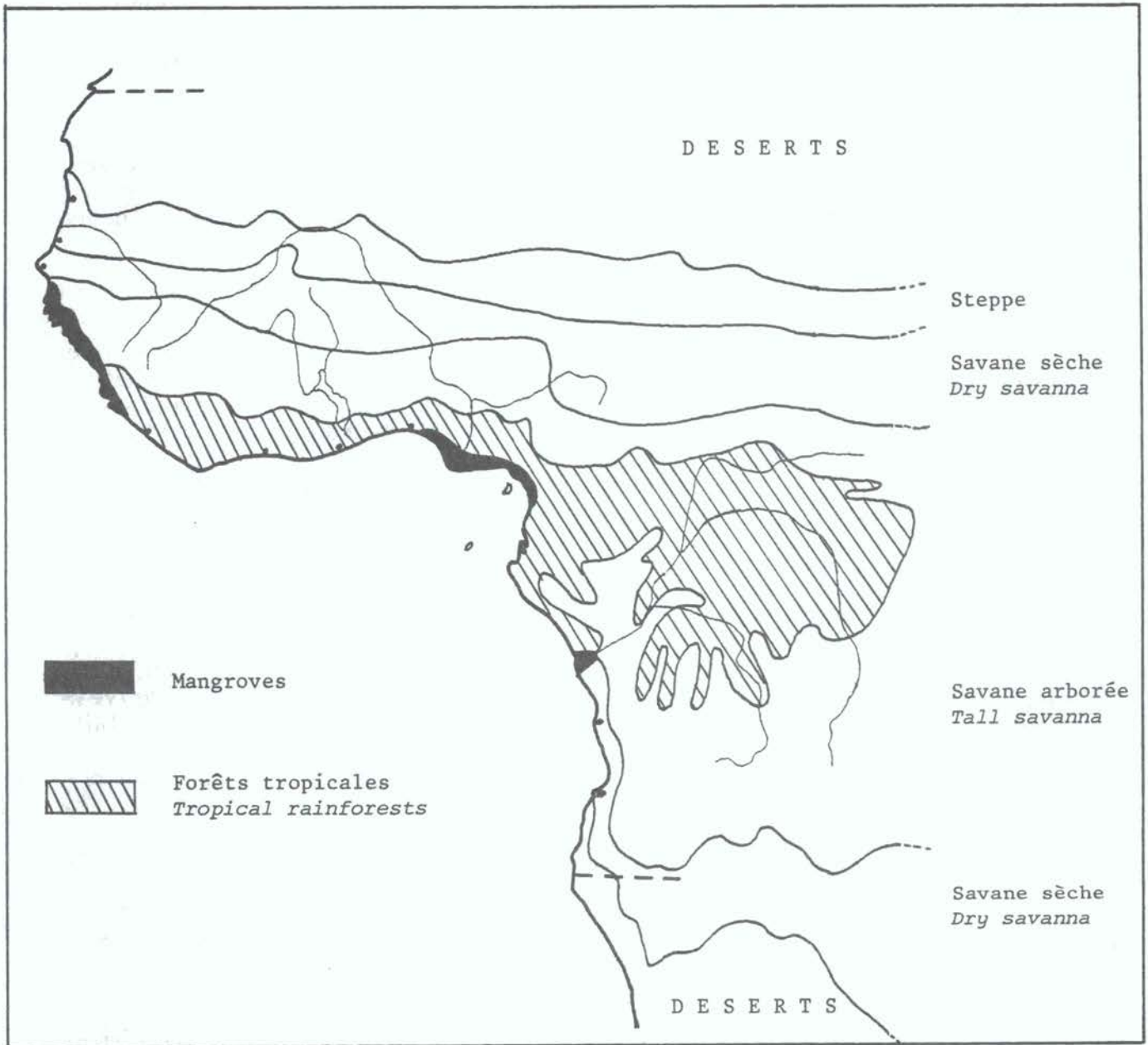


Fig. II.13 - Grandes zones de végétation de l'Afrique de l'Ouest et du Centre
D'après l'"Atlas Jeune Afrique" (1973)

Fig. II.13 - Vegetation zones of the West and Central Africa
After "Atlas Jeune Afrique" (1973)

Schematically, from Mauritania to Cape Vert the coast is characterized by relatively moderate temperatures and by a rather arid climate : vegetation in humid areas is limited to a few coastal basins, occupied by salt-marshes, while coastal dune sand bars are grown over with a scanty desert vegetation.

From Cape Vert to Angola, the warmer and more humid climate of the equatorial area favours the development of the vegetal cover and of the mangrove in humid plains. Coastal dunes are scanty and of moderate extension as the sandy littoral bars are protected from eolian action by vegetation which grows as they progress. In the same way, lagunal muddy grounds, estuaries and areas close to deltas are colonized and fixed by the mangrove.

Nevertheless, some of the factors which affect sediments mobility may notably reduce that. The mangrove grows in estuaries on muddy grounds affected by the saline tide ; during floods it is inundated by fresh fluvial waters. Water is trapped in between mangroves and that facilitates the decantation of silts. It is a preferential area of sediments deposition in lagoons and estuaries ("the comb" effect). These plants are well adapted to their environment ; they grow and multiply by layering. The deposited muds are not remobilized and are, therefore, more easily compacted. On the other hand, the banks, thus protected, are not undermined as it is usually the case on coastal bars. The mangrove favours the settling of sediments and, especially, of sandy, silty or clayey muds deposited during floods and high tides.

That settling action is somewhat restricted by the impact of burrowing organisms (especially by crabs) which by loosening sediments facilitate their subsequent transport by currents.

II.2.3. SOILS

Siliceous rocks (granites, gneiss, sandstones, sands,...) prevail on the African shield. Succession of highly humid periods and droughts, the solvent action of water in a warm climate, mechanical erosion due to rains aggravated their relative violence, all these factors contribute to explain the fragility and the barrenness of African soils.

The climatic belts which extend in a direction parallel to the Equator help in distinguishing the main pedologic units :

- in the equatorial area, where humidity and heat are constant, red-yellow ferrallitic soils are the most widespread. Chemical processes of weathering are extremely powerful and rapid ; when water flows down, elements are very rapidly lixiviated, iron or aluminium hydroxydes being concentrated in the soils ;

- in the tropical zones, dry and drought seasons alternate and that induces a maximum weathering (even silica being weathered). During the rain season, water percolates and dissolves the minerals ; during the drought season, high evaporation favours the development of a ferruginous crust which outcrops, once the superficial loose soil is removed by erosion. All soils of the tropical zones are, in fact, threatened with laterization owing to climatic impact as well as to destruction (intentional or unintentional) of the vegetal cover ;

- when reaching the Tropics, mechanical erosion begins to prevail over chemical erosion. Soils become then extremely depleted in humus and barren of vegetation.

Out of these arid areas, where large amounts of solids (even sand grain-sized) are brought into the ocean by the wind, the hyperaggressive conditions encountered; in between the two Tropics are so strong, that all minerals are partly dissolved ; the thus released ions, with the exception of iron and aluminium, are carried to the nearest rivers by a powerful water flow often aggravated by deforestation.

II.2.4. CONTINENTAL INPUTS

Rivers represent the main transporting agent of materials torn from continents carried to the sea. Winds are also capable, when they blow tempestuously over areas with a meagre vegetation cover, of carrying large quantities of sediments.

The erosion and transport capacities of these rivers are highly variable. They depend largely on the climate which determines weathering types, soils distribution and vegetation, and, especially, the pluviometric coefficient and thus the river network. The amount of sediments carried to the sea depends also on the nature of the bed-rocks in the catchments area, their alteration stage, density of the vegetal cover, and irregularity of the morphology. Such types of erosion may vary from less than 40 tons to 2,000 tons per square kilometer and per year.

Thus, climatic control helps to define two great units parallel to the Equator :

- the arid zones to the north and to the south : differentiated by the rocks which constitute them (mainly sedimentary in the north and cristalline in the south), they are characterized by water deficit. Hence, alteration is mainly mechanical and induces the formation of a thin eluvial layer. Water transport is in any way relatively reduced owing to the lack of permanent river network, apart from the Senegal river to the north and the Cunene river to the south. The prevailing winds over these areas (Mauritania and Southern Angola) which more or less correspond to desert zones, blow seawards ; they may carry to the rivers or directly to the ocean considerable amounts (through unestimated) of fine-grained or even sandy sediments. In the Sahelian or sub-desert marginal zones, where the vegetal cover is scanty and the climatic regime highly constraisted, the above mentioned rivers may have a high solid load with a big sands content ;

- the equatorial areas (*sensu lato*) are exposed to an intense chemical weathering responsible for an important crusting of the soils. Most products of that weathering effect are carried to the shore by various rivers draining these basins. The coarsest fractions are generally trapped by the developed roots of abundant and luxurious vegetation (sometimes damaged by bush fires or clearing up) ; the sediment inputs towards the shore range, therefore, from silty to clayey. In that area, the rivers solid load is lower than in the above one, but it has a higher content of fine-grained sediments (suspension) and of dissolved elements (alkalines, silica, iron).

When rivers cross different climatic zones (more or less sensitive to erosion), the upper stream may happen to have a high solid load which may be deposited entirely in the lower stream, which results in little sediments reaching the sea.

Evaluations of the dissolved and suspended loads of the main rivers of Atlantic Africa will be given in chapter II.4. It has however to be underlined that these data are often fragmentary and sometimes tentative (e.g. solid

transport evaluations do not take into account sands carried along river beds. Precise data are also lacking on the solid flow variations induced by the building of river dams. Recent increase (since the 50's) in the number of such works is certainly the cause of disturbances affecting coastal sedimentary systems located in the vicinity of river mouths, but their exact impact compared to that caused by other human activities (agriculture, destruction of the vegetal cover), or to natural changes cannot be precisely assessed.

II.3. CONTINENTAL SHELF

Continental shelf is the upper part of the continental margin, which is the seaward extension of the continent. This shelf varies in width and is limited on the seaward side by a shelf break ; beyond this break of the slope the continent is connected with the deep ocean. Off West and Central Africa, this break occurs at 100 or 120 m, or less often, at 160 m of water depth. The effect of the swell is directly linked with the width of the continental shelf. Hence, when the continental shelf is narrow -for example off Africa- the energy of the waves is higher, as they are deadened to a lesser degree. Moreover, this narrowness may also be responsible of the spreading of the coastal sediment toward the open sea and the deep seabed, when the hydrodynamic activity is high, or when the shelf slope is steep.

The 200 m isobath -usually considered as the limit of the continental shelf- is shown in Figure A7. Generally speaking, the width of the continental shelf off West and Central Africa is narrow in comparison with the other continental shelves of the world. This platform is rarely 50 km wide, mostly reaching a width of 30 to 40 km. The maximum extent (200 km) appears off Guinea Bissau. Widths of about 100 km are found off Mauritania, between Cape Blanc and Cape Timiris, off Casamance and Central Ghana. By contrast, the continental shelf is extremely reduced -being some 10 km wide- off the Cape Vert peninsula (Senegal) and off Cape Lopez (Gabon).

The continental slope is often notched with submarine valleys or canyons. It is only in exceptional cases that the heads of such canyons notch the continental shelf up to a proximity of the coast, thus playing an active role in trapping sediments transiting along the shore and towards the deep seabed. The western coasts of Africa offer three worldwide known examples of such exceptions : Cayar (Senegal), Trou-Sans-Fond (Ivory Coast) and Congo-Zaire canyons. The last example is unique, as the head of the canyon extends several dozen km inshore towards the inner part of the estuary.

Sedimentary cover

The bed-rock of the continental shelf is covered with surface sediments, of variable thickness. This sedimentary cover is occasionally missing giving rise to rock outcrops. A good knowledge of the nature and distribution of sediment on the continental shelf is important, as it can be mobilized by swells and currents in shallow waters, thus participating in littoral drift.

Two types of loose deposits can be identified :

- current deposits are kept in balance either with the dynamics of the water or its physico-chemistry. Such type of sedimentation occurs only along a coastal strip at a depth of 30 m and is posterior to the Nouakchottian (Holocene) transgression. Essentially, it is the result of recent or current river discharges ;

- relict deposits are dated from the last regression (Ogolian). These mainly sandy deposits were reworked during the last Nouakchottian transgression, which started 16,000 years B.P.

The nature of the surface sediments on the continental shelf is given in Figure A6 which summarizes all data published by Buchanan (1958), Allen (1964), Crosnier and Berrit (1966), McMaster et al. (1970), as well as by Martin (1973), Domain (1977) and Giresse (1969, 1980). Data coverage is very variable. Moreover, the results of several cruises conducted before 1974 off Angola remain

unpublished. On the basis of documentation available, one can assume that only four zones are covered by a sedimentological map at a 1:200,000 scale. They are respectively continental shelves of Mauritania and Senegal (3 sheets drawn by Domain, 1977), the Ivory Coast (3 sheets by Martin, 1974), of Ogooue (Giresse, 1969), and of the Southern Gabon to Zaire (Giresse, 1980).

Generally speaking the main sediment facies include :

- muddy deposits near river mouths and the continental edge as well as on the continental slope ;

- sandy deposits largely detrital, all along the shoreline and therefore subjected to the swells action ;

- sandy deposits, largely bioclastic in nature with a rather variable pelitic fraction, covering the outer continental shelf. These sediments are mainly relict, but are known to contain some authigenic grains (ferruginous, phosphatic or glauconitic faecal pellets).

This general trend has to be further specified depending on the impact of local factors : climatic zones, proximity of important river mouths, etc. Thus, the amount of muddy sediments is quite considerable on the continental shelf to the north of the Congo-Zaire river, where turbide inputs are great. On the contrary, off arid coasts (Mauritania, North Senegal, Angola), the percentage of sands is largely outstanding due to aeolian deposits.

Rocky bottoms

The loose sedimentary cover is discontinuous with some instances where sediments are lacking. Two types of rock formations are in evidence. the first one related to beach rocks -indurated sands- distributed in strips more or less parallel to the present coastline : they are the result of sea level changes during the Pleistocene (see III.1.). These are but surface deposits having no impact on the geological structure of the continental shelf. The second type of rocks concerns more consolidated outcrops, which constitute coastal sedimentary basins, and also volcanic intrusions more scarcely distributed and in most cases close to the shoreline (Cape Vert, Conakry, Cameroon Mounts).

A brief review of the zones covered by sedimentological maps is given below :

Mauritania - Senegal (Domain, 1977)

A succession of little rocky bars lie between the 15 and 20 m isobaths from the Cayar canyon to St Louis and beyond. A quite large and continuous rocky shoal, sedimentary in nature, but with no defined morphostructural signification, fringes, at shallow waters (below 8 m), the coastline from Mbour to Joal. From the head of Cape Vert to the Saloum river, two rocky "cuestas" are present corresponding to two breaks of slope towards the 35-45 m and 70 m isobaths. According to Domain, these steps made of sedimentary rocks (undated) have been shaped during the Quaternary stages of the sea level. The breaks of slope could be the result of erosion of layers of the sedimentary basin (to be confirmed).

Ivory Coast (Martin, 1980)

Two narrow and more or less continuous strips of rocks stretch over almost the entire length of the outer Ivorian continental shelf ; only two major interruptions are evident : east of the head of the "Trou-Sans-Fond" and east of the Grand Lahou lagoon. These interruptions are induced by locally greater coastal sedimentary inputs, carried out eastward by the littoral drift. These two banks are comprised between the 70 and 90 m isobaths. A third, more limited and less shallow (about 55 m depth) segment develops between Sassandra and Grand Lahou. According to Domain, it is composed of coarse shelly sandstone quite similar to beach rocks.

Togo

Three series of beach rocks are known just off the Togo coastline (Rossi, pers. comm., 1984) : on the lower part of the shoreline and seaward at depths of 14 and 50 m.

Southern Gabon - Congo - Cabinda (Giresse, 1980 ; Giresse et al., 1981)

In this relatively well studied area, the morphological control of the sedimentary basin of rocky outcrops distribution on the continental shelf is best illustrated. These outcrops, discontinuous according to the maps, are situated along lines, slightly aslant to the coastline, and become deep-seated in Cabinda. Roughly speaking, it is possible to characterize an outer strip of Miocene sandstones or limestones, with reduced reliefs known to the NW down to 120 m waterdepth, and an inner strip, with more indurated layers giving rise to stronger reliefs and extending down to 60 m of waterdepth. They are made of Upper Cretaceous sandstones and limestones, and towards the South of Eocene sandstones. As indicated above, the importance of the Congo-Zaire river discharge, completely masks the underlying formations in the southern part of this area.

II.4. SEDIMENTARY SUPPLY

Shoreline changes are mainly determined by the quantity of sediments supplied to the coast. Sufficient amount of sedimented material should be supplied to the sea to compensate for erosion. This chapter reviews different supply sources ; chapter II.5. describes how sediments are transported, distributed or reworked along the coast.

II.4.1. TERRIGENOUS SUPPLY

II.4.1.1. River discharge

Sediment, suspended matter and dissolved particles are mainly supplied by rivers (chap. II.2.4.). Before being transported by rivers sediments are taken out by weathering particularly active in West and Central Africa.

Discharges are controlled by climatic factors and depend on the river catchment area (Fig. A5). Two main climatic zones are defined in chapter II.2.4.:

- equatorial regions (*sensu lato*), where water discharge is especially great, (Congo-Zaire) and solid sediment load relatively low and mainly constituted by fine sediment (clay and silt) and dissolved material. Abundant vegetation traps most of the supply, mainly the coarsest fractions ;

- arid and subarid zones, where the Senegal river (in the north) and the Cunene river (in the south) are the only perennial rivers, and may have a significant bed load made up of more or less coarse sediments. Unfortunately, no published data are available to support these qualitative estimates.

There are essentially two modes of transporting sedimentary particles along river streams :

- suspended sediment transport concerning fine-sized sediments, constituting the stream bed or carried down to the rivers (wash load) following weathering and leaching of rocks and soils of the catchment area. The few data available are summarized in table II.2 ;

- bed load transport characterizing wash load sediment transport (on or near the stream bed). No estimate of that kind of transport has been made in West and Central African river mouths.

Sediment (suspended and bed load) of a river is not a simple function of the catchment area and discharge rates. It mainly depends on the capacity of the catchment basin to deliver sediments, on the presence and characteristics of those sediments and on the capacity of the river itself.

Owing to lack of data, it is now impossible to establish a balance of the river discharge to the West and Central African coast. Hence, with the few data available, one can say that the most important part of the river discharge is made of suspended sediment (silt and clay) ; such particles are discharged at sea and spread by swells and littoral currents over the continental shelf. They generally do not supply directly the shoreline adjacent to estuaries, except in tidal estuaries or in mangrove zones : coasts, extending from Southern Senegal to Sierra Leone and from Nigeria to Cameroon are the most typical examples. Coarser sediments (sand), are usually bed load transported, or, occasionally, as suspension during floods ("one day of flood carries more sediment than a whole summer" ; Ottmann, 1965). They usually settle on or near the shoreline and contribute directly to the supply of these areas, except

Fleuves <i>Rivers</i>	Longueur (km) <i>Length</i>	Bassin versant (10 ³ km ²) <i>Catchment area</i>	Débit liquide (km ³ /an) <i>Water discharge</i>	Débit solide (10 ⁶ t/an) <i>Suspended sediment load</i>	Références <i>References</i>
SENEGAL	1 430	441	-	0.2	Yemelyanov et Trimo- nis, 1977
		270			Rodier, 1964
	1 790	-	22 (8 à 39)	1.0	Pinson-Mouillot, 1980
VOLTA (à Akosombo)		292	37		Rodier, 1964
NIGER	4 160	2 092	192	67	Yemelyanov et Trimo- nis, 1977
	-	1 210	-	40	Milleman et Meade, 1983
CONGO- ZAIRE	4 700	3 690	-	64,7	Yemelyanov et Trimo- nis, 1977
	-	3 820	1 250	43	Milleman et Meade, 1983
	-	-	-	27	Giresse et al., 1981
OGOUE	1 200	220			<i>in</i> Klingebiel, 1984
CUANZA		123	1,7	1,5	Samento et Alfonso, 1962

Tableau II.2 - Caractéristiques hydrologiques de quelques fleuves de l'Afrique de l'Ouest et du Centre

Table II.2 - Main hydrological characteristics of principal rivers of the West and Central Africa

when sediments are trapped, i.e. when rivers flow into tidal estuaries (Senegal, Gambia,...), or into coastal lagoons (for instance the Ivory Coast).

Huge amounts of river-discharged sediments may therefore explain the existence of large deposits (mainly beach ones) along low shorelines. Moreover, these deposits can be supplied from previously existing fossil deposits of fluvial or continental origin.

The dams built since the 50's on the main rivers and tributaries appear to greatly affect sedimentary balance (cf. chapter II.2.7.). Except on the main rivers (the Volta, the Niger,...), the impact of dams has been neither assessed nor even compared to that caused by other human activities (agriculture, deforestation), or to natural changes.

II.4.1.2. Wind supply

Winds play an important role in sediment transportation towards oceanic environment, i.e., in the northern and southern parts of West and Central Africa. The Sahara desert, in the north, and the Kalahari desert, in the south, represent large reserves of loose sediments easily reworkable by the prevailing winds. They tend to accumulate onshore and contribute to the formation of extensive coastal dune fields. The areas where aeolian transport is effective are shown in Fig. A4.

Mauritania boasts more data on wind-transported sediments (Tooms et al., 1971 ; Milliman, 1977) than Angola. According to Lepple (1975), 60,000 to 250,000 m³ of aeolian dust of Saharian origin per km of northwest African coast are carried annually to the sea. Fig. II.14 indicates some aeolian dust concentrations in marine sediments off the coast of Mauritania, Senegal and Guinea.

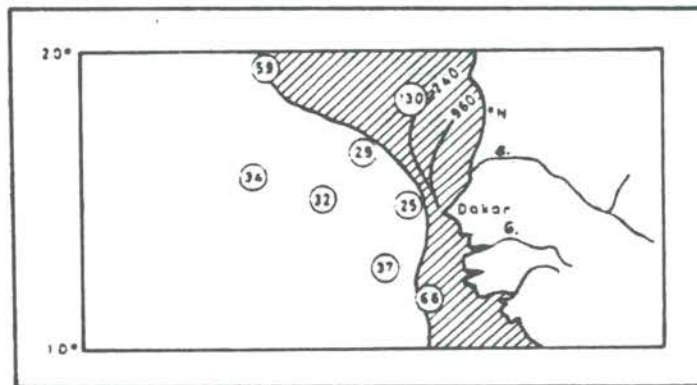


Fig. II.14 - Concentration de poussières éoliennes ($\mu\text{g}/\text{m}^3$) en suspension sur le plateau continental sénégalais
In Sall (1982)

Fig. II.14 - Eolian dust content ($\mu\text{g}/\text{m}^3$) over the Senegal continental platform
In Sall (1982)

In Angola, the desert with dunes occupies the southernmost part of the country, and its origin is related to the proximity of Namibian desert. Large sandy accumulations, concentrated southwards of the Cunene river, and on the Angola/Namibia border, are carried by the southwesterly and easterly prevailing local winds. The sediments, blown into the Cunene river, are rapidly transported to the sea, where they are remobilized by littoral drift and the Benguela Current. They are drifted 10 - 12 km northward and deposited on beaches by the wave action. The sands are then immediately recaptured by the prevailing winds (Garroas), blowing from the SSW towards the NNE to produce mobile dune fields extending as far as the Curoca river (Porto Alexandre area). The same process is observed along the Rio Curoca. North of this river, the coast is rocky and the dune fields are replaced by a rocky and stony desert. Eastwards, the dune development is limited by the easterly winds blowing offshore.

II.4.2. BIOGENIC SEDIMENTS

Bioclastic sediments are made up of fragments of marine organisms broken by hydrodynamic or biological factors. They are mainly remains of pelecypods, bryozoans, gastropods, echinoderms, crustaceans, corals,... or even of entire small-sized organisms : foraminifera, calcareous algae (maërl). They also include faecal pellets abundant on the outer and central shelf off Gabon and Congo. These elements mostly come from rocky outcropping areas where detrital supply is insufficient.

II.4.3. RELICT SEDIMENTS

Such sediments are no longer in equilibrium with the present environment. Corresponding to an older sedimentation, deposited during the low sea level stage, they are particularly widespread on the outer shelf (the Atlantic continental shelf of Africa being a good example) which is generally free from detrital input occurring by preference in the littoral zone. However, this pattern appears too simplistic. In fact, relict sediments can be reworked and carried towards the shore, as it is the case off the coasts from Guinea-Bissau to Sierra Leone (McMaster et al., 1970).

II.4.4. DISMANTLING OF COASTAL FORMATIONS

Sediments can also be supplied by coastal erosion processes. Those, eroded in one place, are transported by currents and deposited farther away in areas, where the transport capacity of the hydrodynamic agents decreases.

The intensity of erosion processes varies with the nature of the coast (rocky or sandy). Variability of littoral formations results from either present or past erosion processes, as well as from transportation and deposition rates. The deposits once accumulated can be eroded and vice-versa.

II.4.4.1 Cliffs and rocky coastlines

Sea cliff erosion is mainly induced by the mechanical action of the waves (wave impact and abrasion of the base of the cliff by rocky fragments brought by waves), by climatic factors (rain infiltration, pressure and dissolution), by biological ones (boring animals). Cliff recession due to erosion generates boulders and stones reworked by waves and transported as pebbles, gravels and then dispersed over the rocky flat bordering the cliffs.

Erosion of rocky coastlines depends, likewise, on the hardness, tectonics, structure of geological formations and on the power of the hydrodynamic agents causing it. Erosion of rocky coastlines is hardly noticeable at a human scale.

The hardest geological formations are shaped into salients (capets) separated by bights, or bays where erosion-derived sediments generate beaches.

Erosion of rocky coastlines and cliffs is commonly considered as a minor source of sediments.

In the area of our concern, i.e. the African coast, rocky coastlines are diagrammed in Fig. A7. One of the factors to take into account is the hardness of coast and cliff formations and, consequently, their relative erosion sensitivity.

The cliffs of Senegal (Capes of Biches, Naze and Fann), of Western Ivory Coast, of Ghana (Dei, 1975 ; Ly, 1980), of southern Cameroon and of Angola are all more or less eroded. Erosion rates have been evaluated as amounting to about 0.3 m/year for Senegal cliffs (Biches, Naze and Fann Capes ; Sall, 1982). These materials supply with sediments small embayments limited by the capes.

II.4.4.2. Erosion of sandy coastlines

A beach, or elemental unit of a sandy shoreline, can be schematically considered in equilibrium when sedimentary input equals output : this balance fits with the principle of mass conservation (or volume conservation) for the considered unit.

When the principle is not respected, there can be either a deficit or an excess of sediments, inducing respectively erosion or accretion (sedimentation or deposition).

Two kinds of natural sedimentary processes are known to modify the equilibrium of a coastal unit : inflation processes, or "sources", and deflation processes or "drains", which can be summarized as follows :

- "supplying" processes :
 - . sedimentary river discharge,
 - . wind supply from sand dunes towards the shore,
 - . erosion of adjacent beaches and cliffs,
 - . sediment transportation along the profile, offshore and onshore.
- "drain" processes :
 - . sediments trapped in estuaries and lagoons,
 - . wind deflation of beach sands favouring the development of littoral dunes,
 - . drainage of littoral sediments down to submarine canyons,
 - . submarine slumpings,
 - . sediment transfer from the beach, seawards.

The sedimentary budget can also be modified by littoral drift, when its intensity varies between the transverse end profiles of a single unit.

On a single littoral unit scale, the following hydrodynamic factors are known to modify the sedimentary budget :

- strong storms causing a rise of the mean sea level and thus favouring a direct attack of the highest part of the foreshore by uprush and the transfer of sediments down to the lowest part of the submarine beach and of the inner continental shelf (Fig. II.15) ; the case of Togo where an important beach retreat

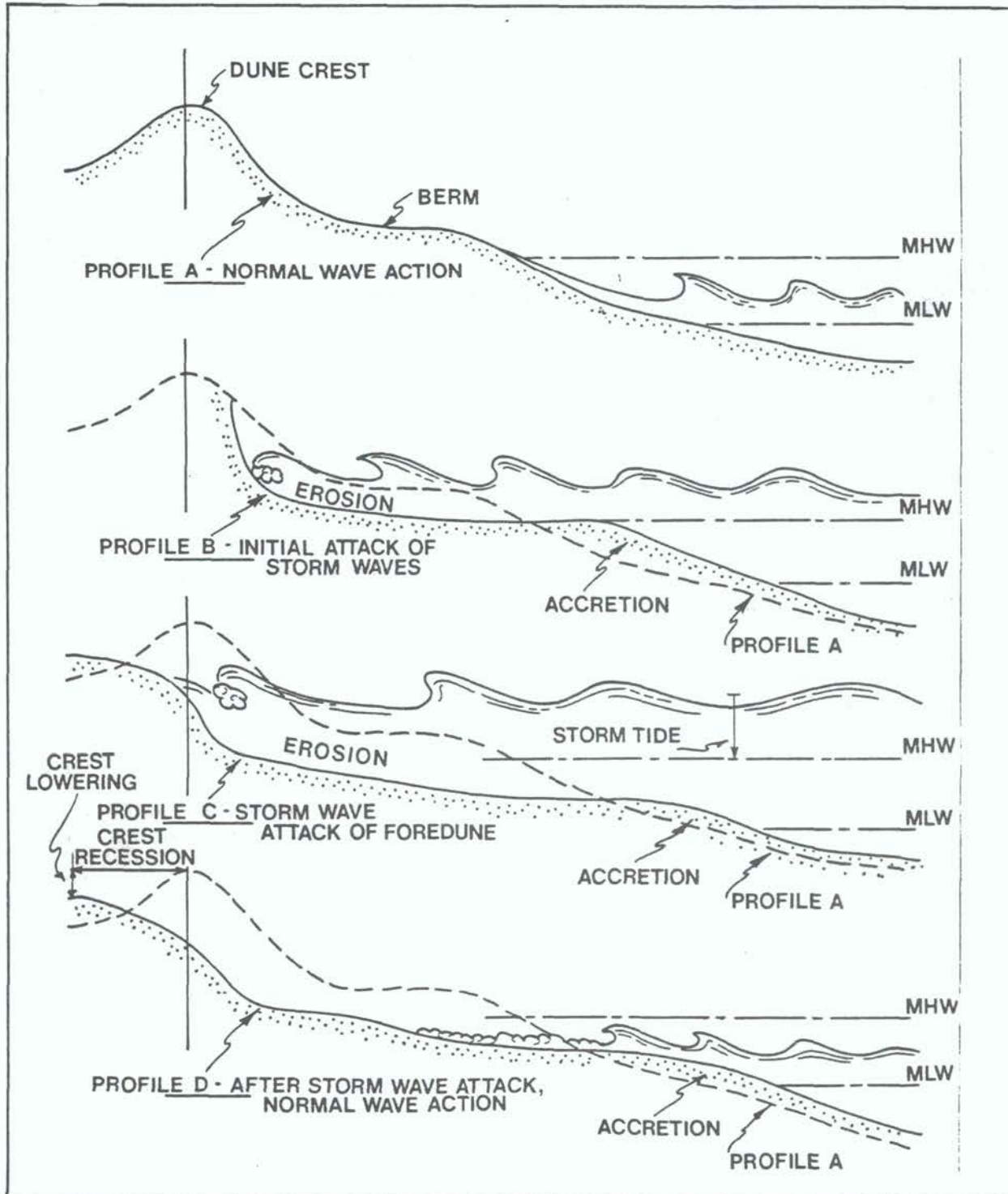


Fig. II.15 - Schéma d'attaque d'une côte par des vagues de tempêtes
 In United Nations (1983)

Fig. II.15 - Schematic diagram of storm wave attack on beaches
 In United Nations (1983)

is due to recent erosion (wharf of Kpémé), and of the Ivory Coast (Port Bouët shoreline) ;

- slumping of sediments accumulated on unstable slopes of submarine canyons : observed at Port Bouët in the Ivory Coast in 1905 and 1908 ;

- slow sea level rise at a rate of 10 to 12 cm since the beginning of this century also favouring wave attack on the high foreshore and causing progressive retreat of gently sloped sandy shorelines (a few dozen centimetres per year) (Fig. II.16).

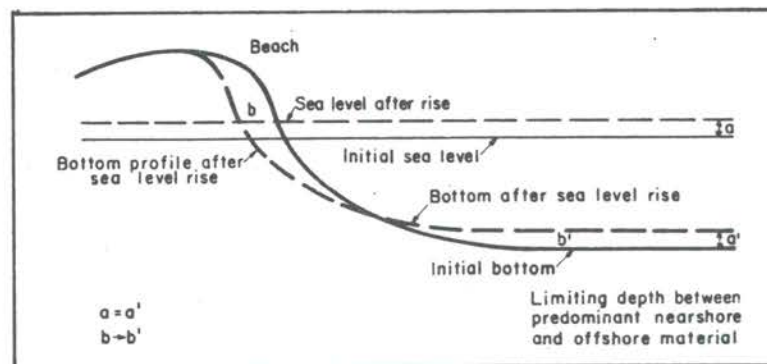


Fig. II.16 - Erosion d'une plage à la suite d'une élévation du niveau de la mer

In the Encyclopedia of Geomorphology (1968)

Fig. II.16 - Beach erosion due to sea level change

In the Encyclopedia of Geomorphology (1968)

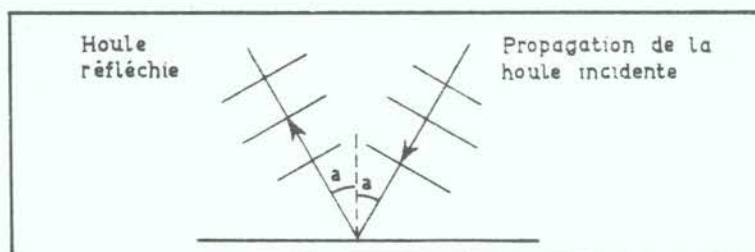


Fig. II.17 - Réflexion de la houle à la côte
In Ottmann (1965)

Fig. II.17 - Wave reflection to the coast
In Ottmann (1965)

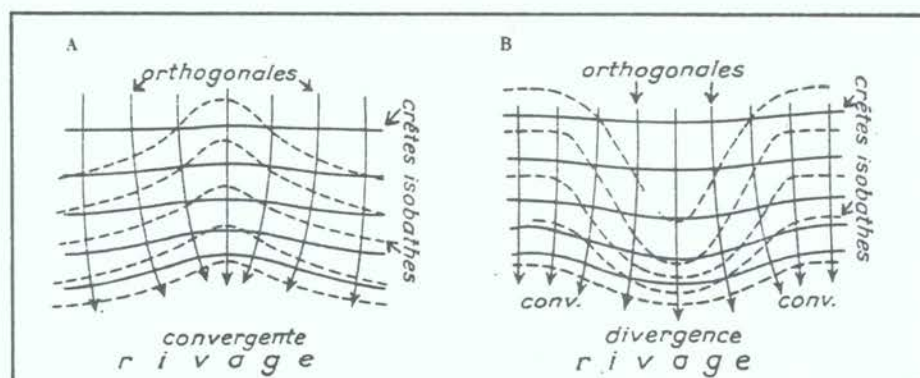


Fig. II.18 - Réfraction de la houle sur le fond
en fonction de la topographie
In Ottmann (1965)

A - Convergence sur une pointe
B - Divergence dans une baie

Fig. II.18 - Wave refraction on the shallow sea-
bottom due to topography
In Ottmann (1965)

A - Convergence due to a salient feature
B - Divergence in an embayment

II.5. COASTAL SEDIMENTARY TRANSPORT

Sources which may deliver sediments to the coast have been described in the previous chapter with special emphasis on the main river inputs. Those sediments may be deposited as soon as they reach the sea, or transported over a more or less long distance before being trapped in preferential areas. They may also be reworked and re-transported if the hydrodynamic conditions of the marine environment have been modified (Fig. II.16). Hence, transport and sedimentation rates and, consequently, coastal erosion rates depend on the impact of waves, currents and winds.

II.5.1. WAVES ACTION

There are several types of waves which are commonly classified according to their wave length (distance between two successive tops), their height (distance between top and trough), their period (time spent by 2 successive tops to cross the same line), their direction and propagation speed,... These characteristics are determined by the wind ; its force, speed and also its fetch, or the distance over which it is blowing. This undulatory wind-induced movement of the sea surface is called swell, generating what is commonly called "waves".

Swell characteristics, except its period, are modified, when the waterdepth decreases towards the shore and attains half the wave length, which affects the sediment transport.

. Direction change

The swell is generally reflected by obstacles with slopes exceeding 25 %, the reflection becoming more pronounced where slopes are steeper (cliffs, for example). When the swell reflection angle is equal to the incident angle (Fig. II.17), the interference between two undulatory systems intersecting obliquely produces a corrugated swell, while swash results from the reflection of waves perpendicular to the obstacle. Both can be responsible for intense erosion of the sea-bed.

The swell is refracted by the sea bottom when it obliquely intersects the isobathymetric lines or their tangents at a fixed point. That type of refraction, linked to the sea bottom morphology, favours swell convergence on headlands and divergences in bights (Fig. II.18).

The swell may also have to by-pass natural or artificial obstacles. Its crests turn around the edges of these obstacles and the swell propagates behind them (Fig. II.19).

. Changes of characteristics (Fig. II.20)

Waves deaden near gently sloped sea bottoms which do not induce reflection. Their height and speed progressively decrease, while their camber increases and swell hollows ; furthermore, it becomes dissymmetrical before changing to curl-over and, finally, to surf zone.

The particles trajectory follows an ellipse becoming more and more flattened with decreasing water depth and a reducing distance from the sea bed. These particles move backward and forward and that induces the formation of symmetrical ripple-marks on sandy bottoms. Nearshore, particles are moved towards the shore ; ripple-marks become dissymmetrical, their steep slopes being turned towards the beach. Sand grains are observed to be moving towards the beach which expands.

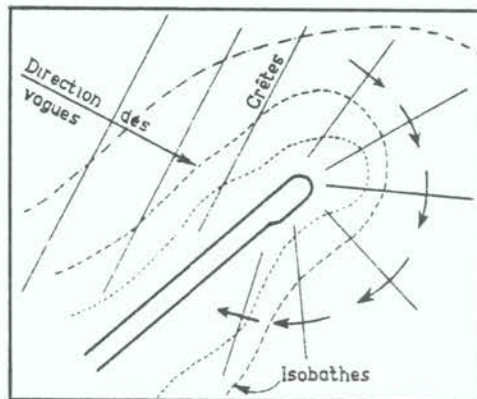


Fig. II.19 - Rotation de la houle sur un obstacle
In Ottmann (1965)

Fig. II.19 - Wave rotation (diffraction) due to
an obstruction
In Ottmann (1965)

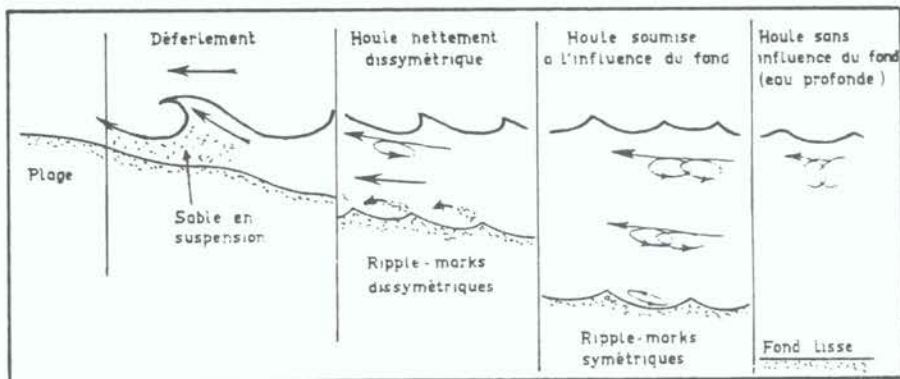


Fig. II.20 - Modification de la houle et des trajectoires
des particules avec la profondeur.
Conséquences sur le fond
In Ottmann (1965)

Fig. II.20 - Modification of the waves and of the orbital
motion of particles with depth.
Induced bottom morphology
In Ottmann (1965)

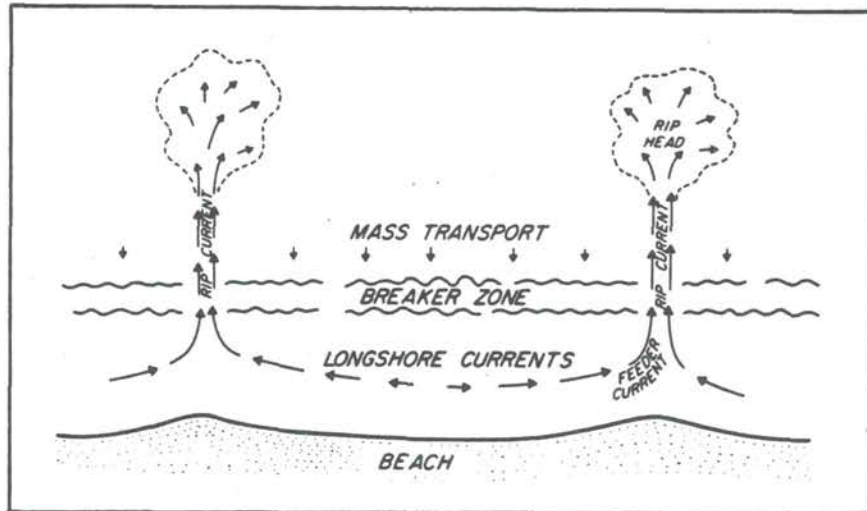


Fig. II.21 - Circulation cellulaire des courants littoraux
due à la présence de courants de retour
D'après Shepard et Inman (1950)

Fig. II.21 - Cell-like circulation of coastal currents
due to rip-currents
After Shepard and Inman (1950)

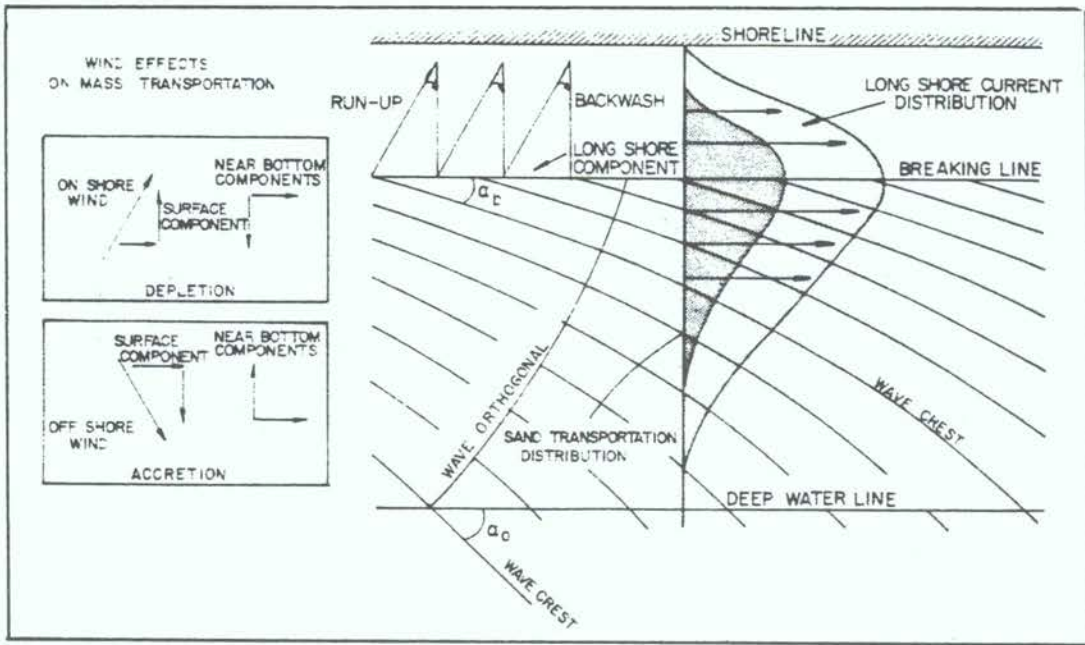


Fig. II.22 - Schéma explicatif du transport littoral
In the Encyclopedia of Geomorphology (1968)

Fig. II.22 - Longshore transport
In the Encyclopedia of Geomorphology (1968)

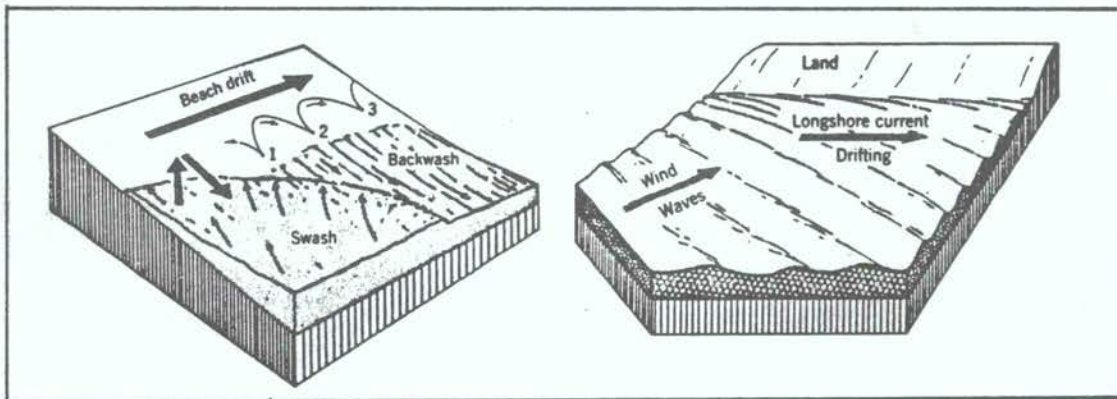


Fig. II.23 - Vagues arrivant obliquement au rivage :
a) instauration d'un courant de dérive littorale dans la zone de déferlement ;
b) jets de rive et de retour transportant les particules en un cheminement en dents de scie

In United Nations (1983)

Fig. II.23 - Waves reaching the shore at an angle :
a) inducing a longshore current in the breaking zone ;
b) swash and back-wash carrying particles according to a serrated pattern

In United Nations (1983)

. Depth of swell action

Swell action is effective in shallow waters, down to water depths which depend on the wavelength of the swell. Its action is negligible when the depth exceeds half of the wave length. However, during unusually strong storms or earthquakes-related tsunamis, this depth of influence may exceed 100 m.

§ II.1.5. and figure A2 summarize the main characteristics of swells (direction, period,...) prevailing off the Atlantic coasts of Africa. Two main systems are observed :

- north of the area, from Morocco to Casamance, the swell is northerly to north-westerly ;
- in the central part and towards the south, from Guinea-Bissau to the Cape of Good Hope, the swell is south-southwesterly to south-southeasterly. These swell trains give rise to littoral drift currents (their orientation depends on that of the coast) responsible for the littoral transport, which is the primary factor in the evolution of African coasts.

II.5.2. ROLE OF CURRENTS

The main types of currents are the following : oceanic currents, tidal currents, wave-induced currents, these latter having the strongest impact on sediments reworking and transport.

As detailed above (§ II.1.2.1.) principal oceanic currents have usually no influence on the coast. They are capable of moving over great distances fine sediments and micro-organisms which they disperse over the continental shelf and deep sea beds, far away from their sources.

Tidal currents modify sediment transport in the vicinity of river mouths and thus play an important role, but they practically have no influence on the continuous and straight shorelines, except in areas with high tidal ranges (exceeding 4 m).

The most important wave-induced currents are shore drift currents ; they will be dealt with in the next chapter. Rip currents although localized cannot be ignored ; they are linked to the beach morphology which concentrates materials-enriched waters in neck-channels (Fig. II.21). The current then dissipates offwards as a cauliflower, depositing at the same time the sediments. They play an important role in coastal erosion processes and offshore sediment transport, but their localization restricts their action to particular points.

II.5.3. SEDIMENT TRANSPORT (Fig. II.22 and II.23)

About 90 % of this transport concentrates in the area extending from the shoreline to the breakers outer limit, and called the breakers zone, which may range from 10 m to several hundred metres.

This transport containing principally sand fraction takes place :

- either at the right angle to the shore, due to the wave friction on shoals and to swash and backwash induced by breakers : the so-called swash and backwash current ;

CREDIT	DEBIT	BALANCE
Transport littoral <i>Longshore transport into area</i>	Transport littoral <i>Longshore transport out of area</i>	Sédimentation ou érosion des plages <i>Beach deposition or erosion</i>
Transport par les fleuves <i>River transport</i>	<i>Wind transport out</i>	
Erosion des falaises <i>Sea cliff erosion</i>	Mise en solution et abrasion <i>Solution and abrasion</i>	
Transport vers le rivage <i>Onshore transport</i>	Transport vers le large <i>Offshore transport</i>	
Sédimentation biogénique <i>Biogenous deposition</i>	Exploitation de sable dans le lit de rivières ou sur les plages <i>Beach and river aggregates dredging</i>	
Depôts hydrogéniques <i>Hydrogenous deposition</i>	Dépôts de sédiments dans les canyons <i>Deposition in submarine canyons</i>	
Transport éolien <i>Wind transport onto beach</i>		
Engraissement des plages <i>Beach nourishment</i>		

Tableau II.3 - Budget sédimentaire d'un littoral
D'après Bowen et Inman (1966) ;
in Collins et al. (1983)

Table II.3 - *The budget of littoral sediments*
After Bowen and Inman (1966) ;
in Collins et al. (1983)

- or in the direction parallel to the shoreline, due mainly to swell-induced drift currents : the so-called longshore current.

II.5.3.1. Swash and backwash

This motion, perpendicular to the shoreline, is induced by several types of breakers which put sediments into suspension. Particles are thus carried up the beach to the swash limit and then backwards with the backwash.

High waves, steep sloped and of low frequency, are known to cause an offwards sand transport, while low waves, less sloped and of high frequency, transport sediments shorewards. Particle sizes and beach slope contribute largely to determining the resulting transported volume of sands.

II.5.3.2. Longshore current (Fig. II.22 and II.23)

The littoral, or longshore transport is induced by the longshore drift, or current parallel to the shoreline and occurring in the wave turbulence zone.

Where waves approach the beach diagonally, refraction reduces the angle of impact, though the swash is not quite normal to the slope of the beach, but the backwash is. This motion increases with the obliquity of the swell, being maximum for an angle of 65°. The result is a zig-zag motion of sand up and down the beach, leading to mass transport of sand in a longitudinal sense called beach drift.

The amount of transported material depends, among many other factors, on the beach slope, the angle made by the wave crestline with the coast as well as on height and period.

Unlike that of longshore drift the significance of the swash and backwash-induced transport depends on the wave type, its steepness, strength and orientation to the shoreline. A joint effect of these two factors generates a particles movement along the coast.

Schematically, the sedimentary budget can be summarized by the following three possibilities (table II.3) :

- if the amount of sediments carried up the beach is higher than that transported by the waves, the shoreline will benefit from that growth: **progradation** will occur ;
- if the input is lower than the seaward flow induced by the waves, the coast will be affected by **erosion** ;
- in case of approximate equilibrium between inputs and losses, the shoreline will remain relatively **constant (or stable)**.

External factors (exceptionally strong storms, coastal structures,...) or geomorphological particularities (canyons heads, evolution of river mouths,...) may significantly modify this equilibrium as described in Regional analysis (chapter IV).

ETAGES STAGES	AGES (années) AGES (years)	CYCLES MARINS MARINE CYCLES	QUATER- NAIRE EUROPEEN EUROPEAN QUATER- NARY
SUB-ACTUEL	1 700 ↑		
TAFOLIEN	2 000 ↑ 4 000	T	HOLOCENE
NOUAKCHOTTIEN	4 200 ↑ max: 5 500	T	Flandrien
TCHADIEN	6 800	R	
	6 000-7 300 ↑ 8 500	T	
OGOLIEN	11 000 ↑ Max: 17 000 ↑ 20 000	R	Würm récent
INCHIRIEN II	31 000 ↑ Max: 33 000	T	Inter- stade du
INCHIRIEN I	37 000 ↑ 40 000	T	Würm moyen
	↑ ↓	R	Würm ancien
AIOUJIIEN	85 000 ou 125 000 - 145 000 (BEAUDET et al., 1976)	T	RISS
	200 000 (HEBRARD, 1973)		MINDEL
TAFARITIEN	1 000 000	T	

Tableau II.4 - Cycles quaternaires de l'Afrique de l'Ouest. In Pinson-Mouillot (1980)
T = Transgression ; R = Régression

Table II.4 - West Quaternary transgressions (T) and regressions (R)
In Pinson-Mouillot (1980)

II.6. SEA LEVEL CHANGES

The mean sea level appears as a relatively constant point of reference at a human scale. The earth is, however, an active planet which is continuously changing at a geological scale (plates tectonics, large-scale climatic changes); oceans are also affected by continuous variations in their mean level induced by :

- variation of the volume of the oceanic basins which modifies the oceanic ridges activity ;
- variation of the volume of sea water trapped in the ice-caps or forced during ice melting ;
- changes of the continents morphology induced by tectonics or sedimentation.

The beginning of the Ice Age was initiated during Pliocene, 3 million years ago, or even earlier. The origins of this phenomenon are, probably, multiple :

- changes in the oceanic basins shape due to the sea floor expansion inducing a directional change of the principal oceanic currents and, as a consequence, drastic modifications of the earth climate ;
- increase in the volume of volcanic dusts due to a volcanic paroxysm modifying the earth thermal balance ;
- space factors (solar energy)...

During the last 2 billions years, our planet underwent at least 4 major glacial eras, separated by some hundreds of millions years during which the earth was free of ice caps (mean world temperature of 22°C vs its 14°C current value). The fourth glacial era is thought to be in progress or just about finishing. It appears, that in the course of the past million years there have been at least 9 ice ages, each one lasting for some 100,000 years, and separated by periods of relatively warmer ages of about 10,000 years duration (these figures are tentative and are supposed to give but a general idea of the magnitude of those phenomena).

The last glacial epoch appears to have started -as is commonly agreed upon- 80 to 75,000 years B.P. and ended about 10,000 years ago. The Würm (Würm III or Ogolian II in Africa) glacial maximum occurred at about 20,000 years B.P. inducing a critical drop in sea level (and may have been subjected to some retardation phenomenon) of about 110 to 130 m, compared to the present sea level mark. This synchronous event has left its mark along the entire continental margins the world over, except where tectonics modified them. Another low sea level stage dating to the Würm period, could also have reached - 100 m at 40,000 B.P. (Würm II or Ogolian I).

The steps of the last sea level rise are generally well known. The Holocene transgression starts at about 17,000 B.P. raising sea level to - 60 m, where it halted, as is testified by sea bottom morphology (flat surfaces, slope breaks, fossil bars traces, etc.). The sea level heaved up again around 10,000 years B.P., the point from which data become more abundant, particularly for the Atlantic coasts. This last rise was not gradual but is marked by positive and negative oscillations that could be broken into 7 peak periods since 8,200 years B.P. Their recurrence seems to be spaced by a thousand years, although their amplitude has been progressively diminishing and has not exceeded a few tenths

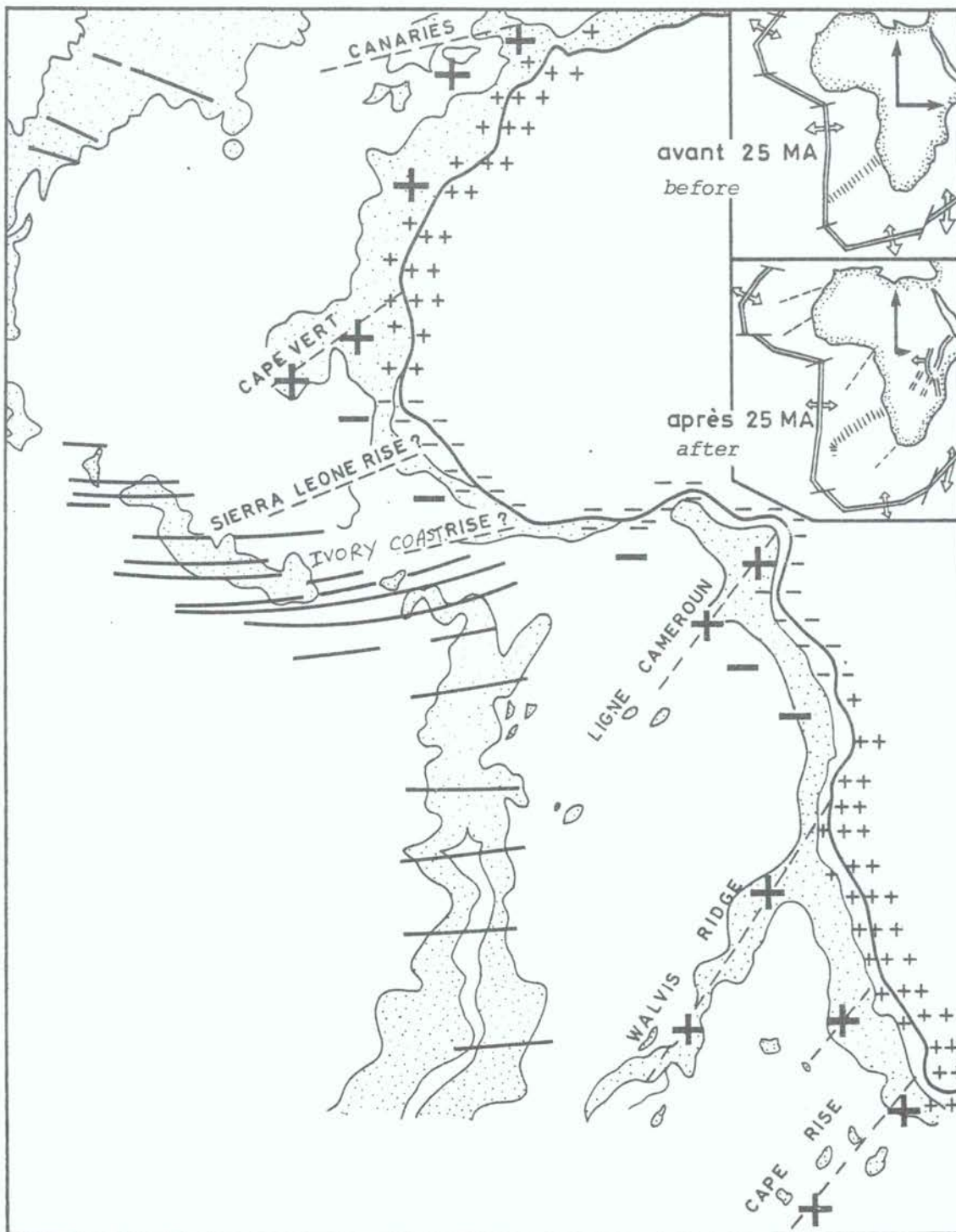


Fig. II.24 - Antéclises et synéclises océaniques et continentales et conséquences épirogéniques sur le littoral ; cinématique de la plaque africaine avant et après 25 Ma
 In Cornen et al. (1977)

Fig. II.24 - Oceanic and continental anteklises (+) and syneklises (-) and epirogenic implications on the coastal zone ; insets : Africa plate kinematics before and after 25 Ma
 In Cornen et al. (1977)

of cm for 1,700 years.

Although we find ourselves now in a relatively warm climatic period (postglacial), which started 10,000 years B.P., there is no evidence to suggest either the end of the glacial epoch, or of the advent of a warm intervening period which could be followed by a new glacial epoch. As regards the last warming-up (Holocene), commonly put at the end of the Würm glacial epoch, the combination of various analytical methods gives evidence of several minor oscillations during that time. The period of these oscillations varies significantly (from ten to hundred or thousand years) and, scientifically, it is impossible to infer from it a general trend for the future.

The present trend seems, however, to correspond to a slow sea level rise; its rate was estimated at about 12 to 20 cm per century (in United Nations, 1981). Measurements carried out over the past 48 years indicate that this rise attains about 2.5 mm/year (in Pomerol, *Géochronique*, n° 9, 1984).

Although planetary motions (precession, astronomic cycles,...) permitted glacial-interglacial oscillations, the enormous cold reserve of ice masses such as Antarctica and their high albedo, would call for such a vast heat supply to bring about melting that the Antarctic ice would not achieve more than 10 - 20 % of melting during the 50,000 - 10,000 year periods of warm interglacials. If a total melting of all present ice were to be observed, the sea level would rise to about 65 m, and that without taking into account any isostatic movement of the oceanic sea floor and of land masses, ice-capped or not, the effects of which are difficult to evaluate quantitatively but which may, as generally agreed upon, contribute to globally increasing the transgression.

This rise of the sea level at a rate of 1 to 2 mm/year may at first sight appear rather insignificant ; however, it plays a big role in explaining erosion processes affecting most sandy shores in Africa and in the world at large, especially off gently sloped beaches. According to P. Brunn's well-known model, a 1 to 2 mm/year rise of sea level may induce a beach retreat of several 10 mm/year.

The rise of the sea level -although frequently ignored- is one important factor responsible for coastal erosion ; a slow retreat of the coast may, however, be counterbalanced in some areas by big sediment inputs (in deltas, for example); it has two combined consequences : inward migration of spits, coastal bars, beaches and lagoons and trapping of fluvial deposits in estuaries and lagoons created by the flooding of low fluvial valleys. This last consequence intensifies erosion by stopping sand discharge.

The successive transgression-regression stages of the sea level, currently classified as local stages, shaped the African coasts where marine or continental sediments were deposited (see Table II.4).

The glacio-eustatic phenomena, although of a first order of magnitude, are not the only ones controlling sea level oscillations. A second order factor, tectonics, also interferes ; it is characterized in Africa by the movement of large warping flexures of the African shield. That problem was studied by Cornen et al. (1977) who demonstrated the dominant role played by the NE-SW perennial axes. Still active during the Quaternary, they produced regional coastal changes of Holocene shorelines. These authors (Fig. II.24) have also shown the uplifting trend of two areas of the West African coast (positive epeirogeny) which extend respectively from Angola to Cape Vert in the northern part, and from southern Angola to the Cape of Good Hope in the south. These

zones delimit an area centred on the Gulf of Guinea (*sensu lato*) which displays a present subsiding tendency (negative epeirogeny). Subsidence of that latter is disturbed by a high secondary axis constituted by the line of the islands of the mid-Guinea ridge (Sao Tome and Annobon) and subjected to an active positive epeirogeny. The intra-cratonic extension of that line inshore Cameroon (the Cameroon Mountains) could be stopped by stresses non existing in the oceanic bottom (coupling effect with this part of the African shield where those mountains are located ?).

The knowledge of the epeirogenic tendencies is of primary importance for any objective interpretation of sea level oscillations and inferred movement of the shoreline. A subsiding tendency of the continent corresponds to a marine transgressive tendency. Inversely, an upward movement of the continent induces a regression. The amplitude of these phenomena is closely linked to the mean slope of the continental margin (continental shelf and shelf edge) which has to be taken into account in any regional study of coastal erosion.

II.7. HUMAN ACTIVITIES

Coastal erosion does not only result from natural factors. It can also -and this tends to be the case more and more- be caused by often thoughtless man's intervention in natural environment and by the disturbances of the fragile balance it entails.

Factors influencing the stability of African shores will be examined hereunder.

II.7.1. DAMS

The sedimentary input of rivers is of primary importance for the sedimentary equilibrium of a coastal zone. If the hydrologic characteristics of a river are altered following the building of a dam, this can notably affect sediment quantities reaching the coast. In fact, dams regulate the river flow and act as "sediment traps". The liquid and solid loads discharged to the sea are, therefore, less important.

Nearly all major hydrographic networks of the Western and Central Africa are dammed (see table II.5). Some of them, such as the Congo-Zaire river, boast several dams along stream. At least 20 dams on this river and its tributaries are used as reservoirs and for electricity generation. Smaller dams used for water stocking in agriculture are not shown in this table.

A distinction can be drawn between upstream dams and those near a river mouth.

• Upstream dams

If a dam is built as a reservoir, the stream speed is reduced and that results in the deposition in the reservoir of nearly all the sediment carried by the river. The water discharged through the weir of the dam will then have a very low sediment content and a high erosion capacity. During the first years following the building of a dam, an undermining of the river bed downstream must be expected. Later on, a new balance will evolve, generally characterized by a much lower sedimentary transport since the reduction of the maximum flow decreases transport capacity.

To a lesser extent, similar effects will appear in case of a weir-dam used as a water reservoir. Because of the reduced stocking capacity planned for the sediments upstream such a dam, a discharge possibility is usually envisaged. In that case, downstream sedimentary input is temporarily diminished but there will be but few long-term effects on the coast.

In countries with a high annual precipitation level, such as those of the Gulf of Guinea, many small dams have been built for irrigation. This type of dam is usually found in the upper river stream. For instance, 129 small dams of this type were built in the north of Ghana between 1950 and 1965 (Hunter, 1981), as well as in Zaire, Nigeria, Benin, Togo and the Ivory Coast.

In arid zones (Mauritania, northern Senegal and Angola), a very short rain season reduces river input. Sediment transport occurs exclusively during the short rain season. It is at this particular moment that water is stocked in reservoirs to be used later during the dry period.

PAYS COUNTRY	N°	NOM NAME	ANNEE YEAR	FLEUVE RIVER	SOURCE REFERENCE
Angola	9	Cambambe	1962	Cuanze	A, Sarmiento and Alfonso (1962)
		Gove	1970	Cunene*	B
		Matala	1969	Cunene*	B
		Queve	1968	Queve	B
Cameroon <i>Cameroun</i>	4	Sangana	1965	Sangana*	B, Rubin (1968)
		Mbakaou	1971	Sangana	A
		Bamendjin	1971	Mbam	A
		Edea III	1971	Sangana	B
Congo	3	Inga I	1973	Congo	B
		Shongo	1970	Congo	B
			1983	Le Fini R	B
Eq. Guinea	0?				
Gabon	0				A
Ghana	9	Nauronga	1978	Tano*	B
		Hemang	1967	Pra*	B
		Akosombo	1961	Volta*	Mackintosh (1965), Ly (1980)
		Kpong	1981	Volta	Quartey and Allen (1981)
Guinea	2	Grandes Chito	1982	Konkoure	Rubin (1968)
Ivory Coast <i>Côte d'Ivoire</i>	11	Kolotali		Nzi (Bandama)	Rai (1974)
		Bouake		Kan*	Rai (1974)
		Ayame I	1959	Bia*	A
		Ayame II	1964	Bia*	A
		Kosson	1972	Bandama*	B
		Tabbo	1975	Bandama*	B
		Buyo		Sassandra*	A
		Soubre		Sassandra*	A
		Bandama	1972	Bandama	Chan (1973)
		Cavally	1965(?)	Cavally	Rubin (1968)
		Ticbisson		Kan*	Rai (1974)
Liberia	1	Mt. Coffee	1966	St. Paul.	A
Mauritania	1	Foum el Geita	198(?)	Gorgol	B
Nigeria	18	Bakolori	1975	Niger*	A, B Sargent (1979)
		Ejigb		Aro	A
		Gusau		Sokoto	A
		Ikere		Ogan	A

Nigeria (cont'd)	18	Igbaja	1968	Osin	A	
		Kishi		Soro		A
		Kainji		Niger*		McDowell et al. (1983)
		Shiroro		Kaluna		Baylis (1972), Rubin (1968)
		Kangimi		Kangimi		B
		Birnin Kuda				B
		Baganda				B
		Karage				B
		Keffin Guna				B
		Tiga				B
		Ikega				B
George		B				
Jebba	198(?)	Niger	B			
Dadin Kowa	1982	Gangola	B			
Senegal	4(?)	Bakel	1965	Senegal*	Rubin (1968)	
		Manantili	1980	Senegal*	B ; Sall (1982)	
		Diamas	1981	Senegal*	B	
		Kekriti(?)	1975		B	
Sierra Leone	4(?)	Mange	1961	Rokel Mano	A, Rubin (1968)	
		Bumbana	1960		Rubin (1968)	
		Guma	1966		B	
Togo	2	Kpime	1968	Koza	A, Rubin (1968)	
		Koza	1975		Sargent (1979)	
Zaire**	15	Inga I	1973	Congo*		
		Inga II	1982	Congo*		
		Kolwezi		Labudi		
		Lubumbashi		Lufira		
		Kinshasha		Congo*		
		Kisangani		Congo*		
		Ulindi		Ulindi		
		Lowa		Lowa		
		Luvua		Luvua		

A = World Register of Dams (1977)

B = Water Power (1966-1983)

** = Fleuves possédant plusieurs barrages
Depicts individual rivers with more than one dam construction

*** = Tous les barrages ne concernent que le fleuve Congo-Zaire et ses affluents
All of the dams concerned were constructed on the Zaire (Congo) and its tributaries

Tableau II.5 - Barrages de l'Afrique de l'Ouest et du Centre
In Collins et al. (1983)

Table II.5 - West and Central African dams
In Collins et al. (1983)

In Nigeria, the building of several dams in the seventies reduced the sedimentary deposit in the Niger delta, thus upsetting the balance between sediment inputs and outputs (McDowell and others, 1983). The dams built on the Niger river, more than 500 km away from its mouth and upstream the confluence with the Benoue river, brought about reduction in the sediment discharge to the sea and in the alteration of the natural prograding evolution of the delta, although its own solid inputs appear less significant than those of its main tributary (see IV.7.).

. Dam built in a river mouth

A dam built in a river mouth can, to a certain extent, be compared to a weir-dam upstream, as far as the trapping of the sedimentary load is concerned. Near the river mouth the slope of the river bed is very slight so that the stream speed is generally weaker than upstream. However, the main difference springs from the fact that a downstream dam can reduce the tide in the river mouth. During periods of low water level, this can cause a clogging-up of a sandy bar and/or an emergence of a spit in the estuary.

The Diama dam, under construction in the inner delta of the Senegal river, thus diminishes the sedimentary deposit on the coastline. In Mauritania, the reservoir-dam planned on the Foum el Geita site will partly prevent the sediments of the Gorgol river from reaching the sea (Water Power, 1981). The building of dams off arid coasts might eventually lead to a significant decrease in the sedimentary river inputs.

Intense erosion following the building of the Akosombo dam (Ghana) on the border of the Bight of Benin caused partial disappearance of the town of Keta (Ly, 1980 ; Nedeco, 1976a).

The ecological impact due to reduction in sedimentary input should be studied in detail before attempting the final phase of the Nangbeto project on the Mono river (Togo).

The problem of the Cotonou dam, also set up in a river mouth, is complex because of the situation downstream of Cotonou harbour. This dam appears to somewhat reduce the sedimentary deposit on the coast as it stops erosion of the Cotonou lagoon. In fact, this erosion was one of the motives for erecting the dam.

Not all dams set up across river mouths seem to be responsible for such profound changes in the sedimentary deposit on the coast.

To sum up, nearly all the main rivers of the Western and Central Africa have been dammed. The location of major dams, usually built for electricity generation, is shown in Figure A5. Most of these large dams constructed near river mouths are known to reduce the liquid and solid discharge to the coast.

II.7.2. MAN'S IMPACT ON VEGETATION

As stated in II.2., vegetation plays a very important part in the protection of soils from erosion. Intensive forestry (for hard wood species) and the increasing clearing for the expansion of single-crop farming, in low latitudes, as well as increased stripping of the Sahel and savannah soils represent a general evolving tendency of the African soils, owing to their vulnerability to running-off. Erosive action due to human activity can accelerate detrital input to the sea. However, part of this sedimentary input will be trapped by the increasingly numerous dams and may cause their clogging-up. The only

cultivated area of any significance is located between Senegal and Nigeria (Fig. A1). Within it, only Sierra Leone, Liberia and Togo have more than 30 % of their territory cultivated (Collins, Double Atlas, 1976 ; Davies, 1973). In the other countries of West and Central Africa, the cultivated area represents less than 4 %. Sall (1982) provides run-off values for Casamance : they are low in the forest (1 %), increase up to 16.6 % on fallow lands and up to 26.6 % on bare soils. This means that erosion is reduced in the forest (0.18 t/ha) and attains its maximum on bare soil (21.28 t/ha).

Open-pit mining also contributes to destroying vegetation, and tailings can often be subject to run-off. Although this activity is far from negligible in Africa (for instance Liberia, Mauritania and Angola, respectively, produce 18 million tonnes, 5 million tonnes and 3 million tonnes of iron ores per annum ; Price, 1980), it is only an artificial agent speeding up sedimentary deposit, and its impact is limited.

II.7.3. URBANIZATION

Urbanization can significantly influence coastline erosion where town development takes place in a coastal zone. As town begins to take shape, the land gains in value, making coastal protection less expensive compared to the advantages ensuing from land protection. Frequently, with the aim of protecting towns, protective installations are built along the coast. That intensifies erosion downstream of them as they partly or totally stop sediment inputs.

II.7.4. COASTAL STRUCTURES

Coastal management plans more often than not disturb the beach drift system and thus can affect the sedimentary balance of the coasts.

Structures perpendicular to the shoreline

84 ports -out of wharfs and ore terminals (e.g. the phosphate terminal of Kpémé in Togo)- have emerged along the West and Central Africa coast. They generally imply the building of a jetty or of an entrance channel which interrupts the beach drift and creates, in case of a jetty, a sedimentation area upstream the works, and an erosion zone downstream. Engineers in charge of construction have sometimes taken these effects into account as in Friendship harbour, Mauritania (Chen et al., 1981). But this is not often the case. Most of the old ports continue to interrupt the beach drift : for example in Lagos, Nigeria (Usoroh, 1971), or in Lomé, Togo (Nedeco, 1976 and 1978). In case of natural ports like Freetown, Sierra Leone, construction of jetties and dredging operations are not likely to change the beach drift to any considerable degree.

Structures parallel to the shoreline

The main function of protection structures, breakwaters, sea walls, etc., is to prevent the coast from damage induced by the swell. These structures are used when it is necessary to keep the shoreline in a forward position in respect to the adjacent shoreline. They appear to shield the immediate coast but not necessarily the adjacent shoreline.

Chapters III.2. and IV. described in detail coastal structures having a direct impact on the beach drift.

II.7.5. BEACH SAND AND SALT EXPLOITATION

Dredging of sands and gravels on beaches, for building purposes, is a common practice along many coasts.

There is no relevant data describing the impact of dredging and mining on the West and Central African coasts. The only available information concerns Sierra Leone and Togo. An impressive tonnage of sand dredged in Sierra Leone on the Freetown peninsula has induced destructive coastal erosion (James, pers. comm.). 200,000 m³ of sands (United Nations, 1981) are dredged on the beach west of the jetty of the Lomé harbour (Togo). The concerned area upstream of the harbour is a deposition zone, most of the sedimentary drift being blocked by the jetty. It is therefore quite unlikely that extraction of sand in that area will provoke erosion. This, however, delays the return of the system to natural balance.

Salt extraction in mangrove areas may also sensibly affect coastal processes as it results in a large-scale destruction of the vegetal cover. Salt mining started during the 17th century, and is still in progress in Eastern Ghana (Paradis, 1979). That kind of a salt-pan destroying large mangrove-covered areas which previously trapped sediments in their mixed roots.

II.7.6. DREDGING

Port entrances are frequently subjected to sanding up requiring consequent dredging of the entrance channel to maintain the navigation of a fixed maximum draught. Sediments dredged and discharged outside the port are reworked by the littoral drift. A dredging operation of the port of Lomé (500,000 m³, pers. comm.) during the spring 1984, has led to a temporary growth of the area upstream of the port. As early as September 1984, the area passed into a new erosion phase.

Dredging in river mouths does not only induce erosion in the proximity of the dredged area, but also disturbs its ecological balance (Banner, 1983). The Wouri estuary (Cameroon) is periodically dredged and although no mention is made of erosion in the literature, some areas are most likely being eroded.

II.7.7. POLLUTION

Pollution affects the growth of coral reefs, sources of biogenic sediments carried to the coastal zones. Coral reefs being scanty off the West and Central African coasts, the problem is not so vital as regards the sediments total transported toward the coast. It is, however, possible that the Bight of Biafra, where corals grow, may become affected by the development of oil exploitation in the Niger delta.

Tests of marine organisms constitute another source of biogenic sediments. Pollution has destroyed molluscan and crustacean populations in some ports of the world. Control of industrial and agricultural polluting wastes disposal was carried out in Western Africa by Middlebrooks et al. (1981, *in* Collins, 1983), but it does not follow that its impact on the biological productivity has been sufficiently studied.

III. DYNAMIC COASTAL MORPHOLOGY

III.1. COASTAL MORPHOLOGY AND NATURAL PROCESSES

INTRODUCTION

The change of a shoreline depends on its nature, whether rocky, sandy or muddy. This chapter introduces different types of shorelines encountered along the West and Central African coasts and their evolution and reactions to sea and climatic agents attacks (Fig.A7).

III.1.1. CLIFFS AND ROCKY COASTLINES

Cliffs and rocky coastlines are in evidence in different areas of West and Central Africa : Cape Verde in Senegal, in the south of Liberia and West of the Ivory Coast, in the southern part of Cameroon and in Angola.

Erosion of rocky coastlines depends, as described in chapter II.4., upon their petrophysical characteristics, structural and tectonic history of the geological formations as well as upon the attack by climatic and hydrodynamic agents. At a human scale erosion of rocky coastlines is hardly noticeable.

Sea cliff as rocky coastline erosion is not only related to their geological constitution, but results also from the mechanical action of waves, hydro-meteorological factors (i.e., rain infiltration, water pressure, dissolution) and biological ones (boring animals). Steep coasts are frequently straight. Erosion by seawater can be quite spectacular. For calcareous rocks, dissolution is an important phenomenon. Cliff destruction appears to be controlled by cyclic phenomena (Ottmann, 1965) : digging of the bottom, rockfall, removal of slipped products, digging (Fig. III.1).

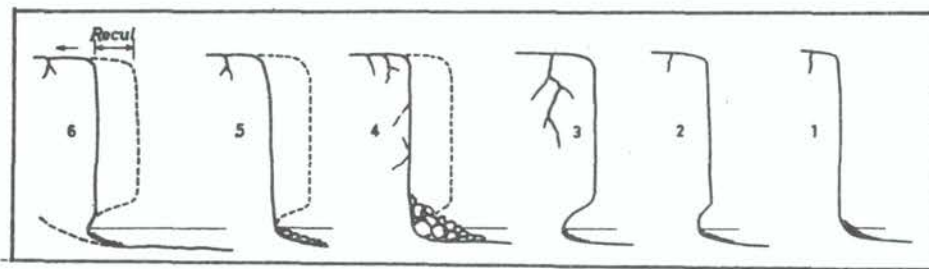


Fig. III.1 - Mécanisme du recul des falaises. In Ottmann (1965)

Fig. III.1 - Pattern of cliff retreat. In Ottmann (1965)

Retreat of cliffs creates an abrasion platform which extends progressively and tends to acquire an equilibrium profile protecting the cliff from further sea attacks : a stabilized cliff. If this process is followed by a regression, or by a massive supply of sediments from littoral rivers, sand or pebble barriers will accumulate at the cliff base : the cliff becomes an abandoned cliff (Fig. III.2).

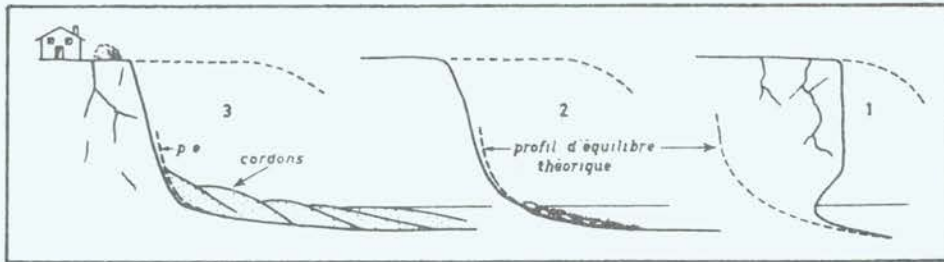


Fig. III.1 - Stades d'évolution d'une falaise
 1 - falaise avec fissures de dessiccation
 2 - falaise stabilisée
 3 - falaise morte
 In Ottmann (1965)

Fig. III.1 - Evolution stages of a cliff
 1 - retreating active cliff
 2 - stabilized cliff
 3 - abandoned cliff
 In Ottmann (1965)

This pattern can be illustrated by a cliff near Lobito (Angola). To the south of the city, there is an abandoned cliff with alluvial sediments covering its bottom. To the north, the cliff is active and the waves, though partially absorbed by the sand spit, continue digging its bottom. In this area several levels of fossil beaches and marine abrasion platforms have been identified.

Erosion is called selective, when a shore is alternatively made of hard rocks and soft, or weathered rocks. Erosion will obviously attack more rapidly softer rocks (Fig. III.3).

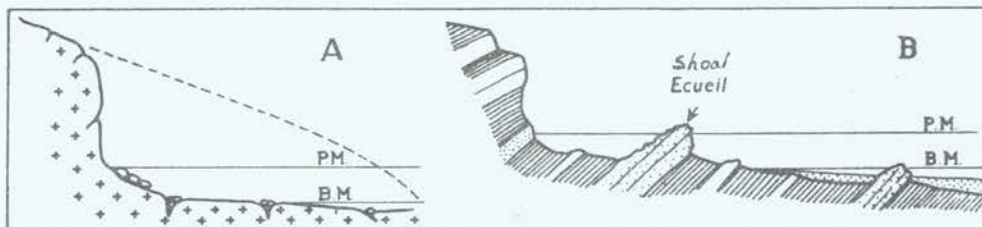


Fig. III.3 - Influences lithologiques sur le platier rocheux
 A - Granite
 B - Séries sédimentaires de dureté inégale
 In Ottmann (1965)

Fig. III.3 - Lithologic influence on rocky flat
 A - Granite
 B - Sedimentary rocks of unequal hardness
 In Ottmann (1965)

Fig. III.4 diagrams erosion of clayey cliffs. At the top of the cliff, dessication causes shrinkage cracks on the flat surface, inside which rain waters infiltrate deeply into the rocks. This causes the sliding of the layers and the drawing of a concave profile well known in soil mechanics (the Panamean fault). Erosion can be due also to saturation of the cliff base by seawater and to the flowing of the cliff top.

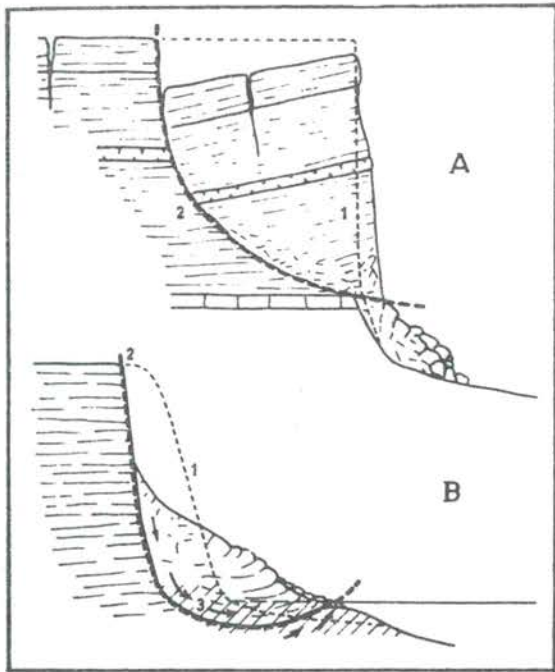


Fig. III.4 - Schéma montrant l'érosion des falaises d'argile
 A - par l'action des eaux de pluie (faïlle panamienne de J. Bourcart)
 B - par saturation de la base par l'eau de mer et fluage de la partie supérieure
 In Ottmann (1965)

Fig. III.4 - Erosion of clayey cliffs
 A - under rain water action (panamian fault of J. Bourcart)
 B - sea water saturation of the base and flowing of the top of the cliff
 In Ottmann (1965)

III.1.2. UNCONSOLIDATED COASTLINES

Sandy or silty coastlines are well represented along the coasts of West and Central Africa, from Mauritania to Angola. They are studied in detail since erosion processes, there, are very intensive.

III.1.2.1. Nomenclature of the theoretical beach profile

Fig. III.5 gives basic terminology used to describe geomorphology and hydrodynamics of subaerial and submarine beaches.

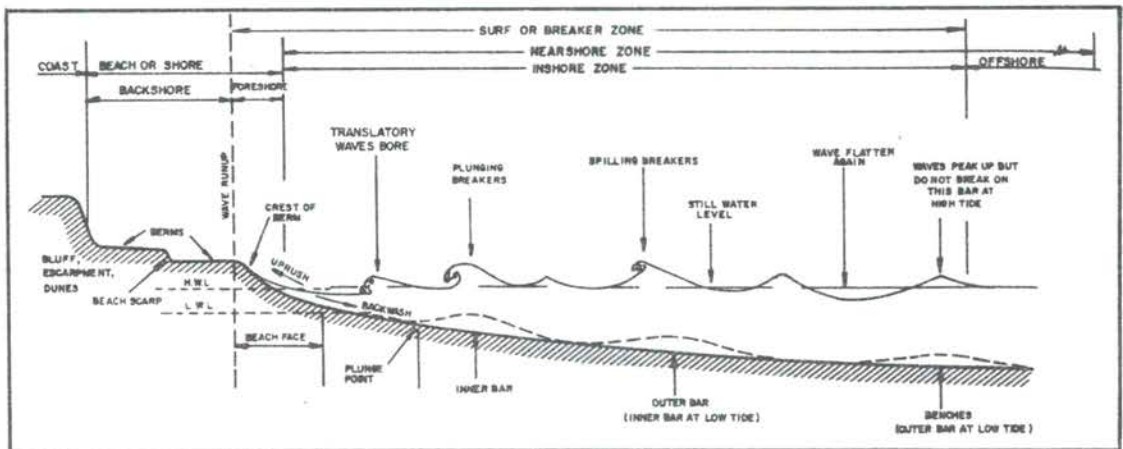


Fig. III.5 - Nomenclature de la plage théorique. In Quélenec (1984c)

Fig. III.5 - Nomenclature of the theoretical beach. In Quélenec (1984c)

Fig. III.6 schematically presents the main dynamic areas of the theoretical beach, subjected to the action of hydrodynamic agents.

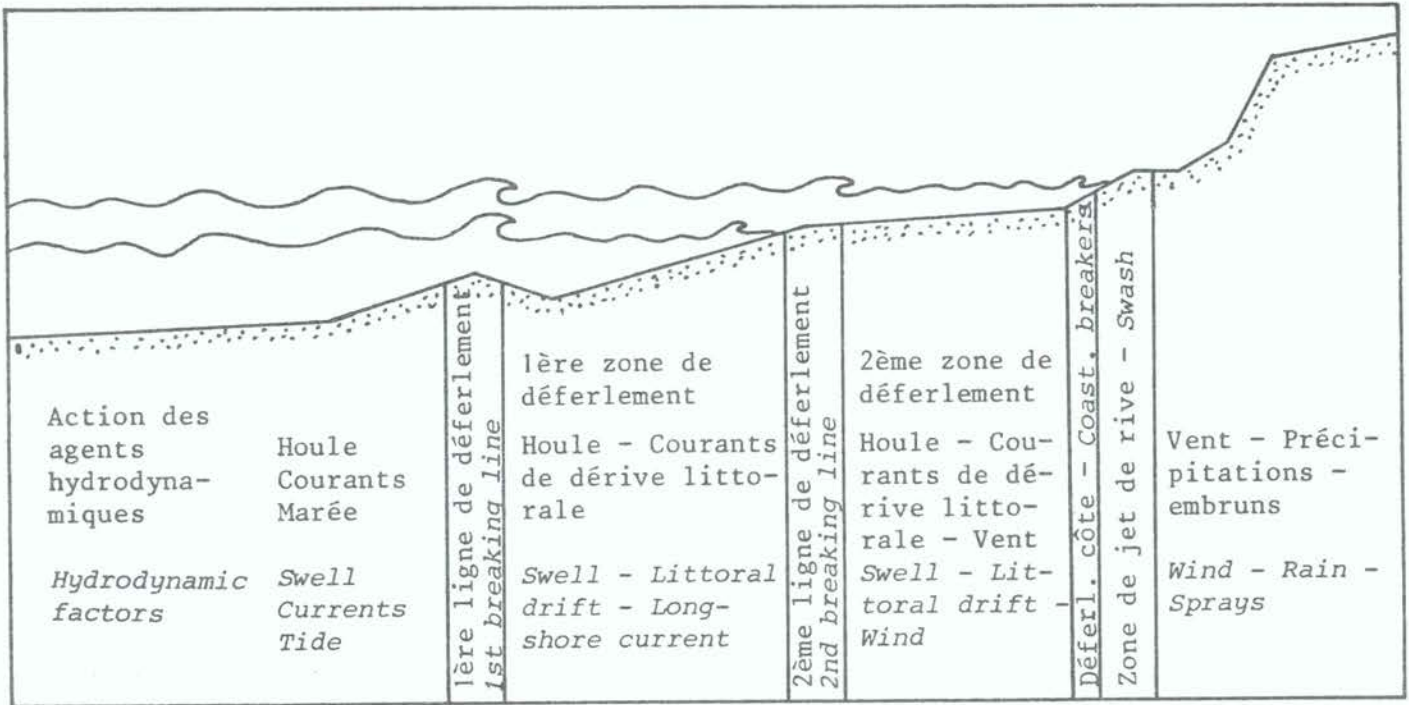


Fig. III.6 - Principales zones dynamiques de la plage théorique
In Quélenec (1984c)

Fig. III.6 - Main dynamic areas of the theoretical beach
In Quélenec (1984c)

III.1.2.2. Typology

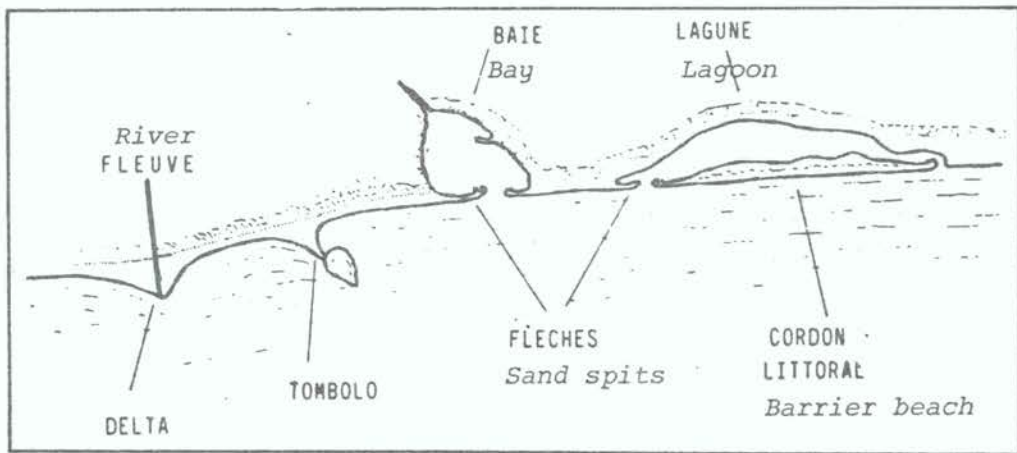


Fig. III.7 - Diverses formes d'accumulations littorales
In Quélenec (1984c)

Fig. III.7 - Different shapes of coastal deposition
In Quélenec (1984c)

Fig. III.7. summarizes the main morphological features created by coastal sedimentary accumulation processes.

III.1.2.2.1. Littoral dunes

Littoral dunes result from wind transportation of sand blown from the foreshore zone to areas with strong and regular winds. Dunes can exceed 10 meters in height. When located near the shoreline, they form a sedimentary buffer stock which can be reworked by storm swells and which determines the beach equilibrium. This type of formation is extensively represented in Mauritania, North-Senegal, and South-Angola.

III.1.2.2.2. Beach

Beach is a general term used for a littoral zone, an "interface", liable to accumulation and reworking of unconsolidated sediments (sand, gravel, pebble ...). The West and Central African coasts yield numerous beach types.

Beaches are frequently subject to alternating processes of erosion and deposition causing variations in their morphology.

Variations of beach profile morphology

- . Seasonal variations

It is easy to observe seasonal variations of beach profiles : during the calm season (summer of temperate regions) the profile is smooth with a large backshore (growth), whereas during the storm season (winter) the profile is excavated and the backshore narrows and subsequently disappears (retreats). This movement of the beach on both sides of the average profile across dynamically balanced shores, clearly indicates that sediments are transported in the profile direction with the average resultant onshore transport during the calm season and offshore transport during the storm season with a subsequent formation of submarine bars.

- . Abrupt variations caused by storms

They have already been described in chapter II.1.

- . Tide variations

Other variations of the beach profiles can be superimposed on those previously mentioned during tidal cycles (diurnal or seasonal) when the tide amplitude is high compared to the swell (which is not frequent on the western coasts of Africa). In such a case, foreshores have a smooth slope and are largely exposed at low tide ; inner berms and backshores have a steep slope and are made up of sediments significantly coarser and less well-sorted than those of the foreshore.

- . Wind variations

The winds blowing from the sea inland can contribute to the rise of the sea level, increasing the swell attack of the shore at ebb-tide. They create a surface current directed toward the shore and compensated by a bottom current in the direction of the offshore zone. This bottom current favours an offward fine sediment transport towards the continental shelf.

III.1.2.2.3. Sand spits

Sand spits are well developed along the coasts of West and Central Africa, the most important ones being the spits of Barbarie (Senegal estuary), Sangomar (Saloum estuary) and the spits of Mono at Grand Popo (Benin), Mayumba (Gabon) and the "restingas" of Angola. Sand spits are frequently associated with littoral morphological peculiarities, such as rocky headlands or capes, mouths of embayments or of rivers and they tend to level these features. Sand spits tend to grow in the direction of the littoral drift. They form a hook-like end pointed toward the inner part of the area sheltered from the swell.

III.1.2.2.4. Beach barriers

Beach barriers develop mainly along shores where the tides and swell energy are relatively low. They can be formed by various processes, which have been frequently discussed : emergence of submarine bars, uncovering of continental dunes after subsidence, extension of sand spits ... Beach barriers frequently separate lagoons and/or coastal marshes from the sea. Those located along the Ivory Coast section, such as the Ebrié lagoon are the best known.

III.1.2.2.5. Rythmic sedimentary formations of unconsolidated shores

These formations are frequent on the sandy shores off West and Central Africa, especially, along the coast of Togo and Benin. Beaches made of unconsolidated sediments usually do not develop linearly. Rythmic undulations are frequently observed on their foreshore. Curves or arcs are separated by small capes (accretion forms) oriented almost at the right angle to the shore (Fig. III.8).

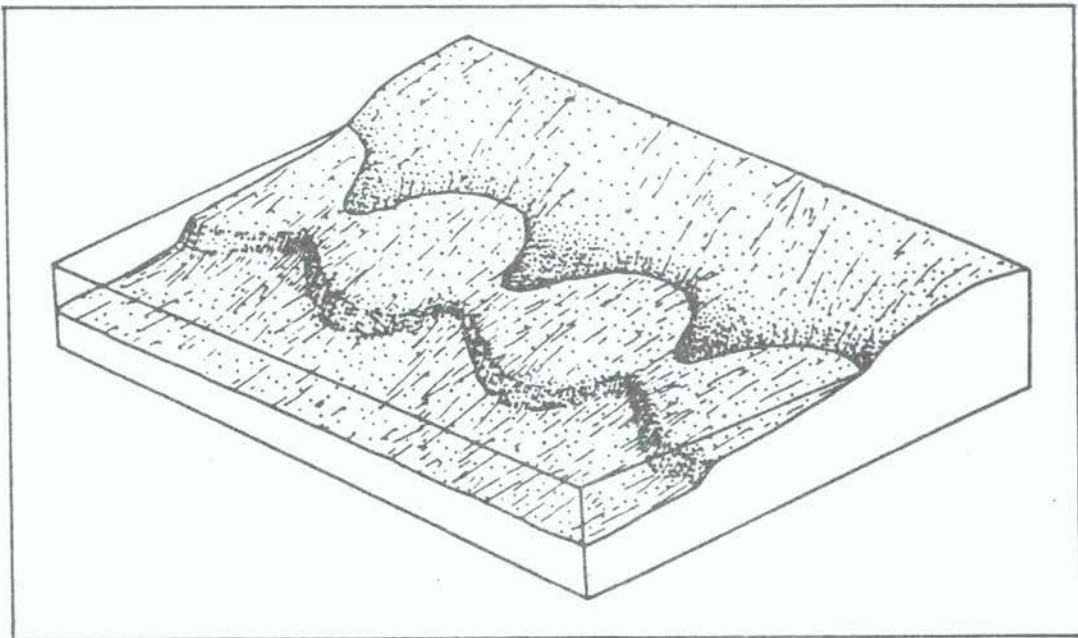


Fig. III.8 - Croissants de plage et "deltas" sous-marins associés
In Quélenec (1984c)

Fig. III.8 - Cusps and associated submarine "deltas"
In Quélenec (1984c)

These rhythmic littoral formations are commonly differentiated by their size :

- beach cusps : 0.2 to 100 m in amplitude ;
- undulations of the shoreline and submarine bars : 100 to 1,500 m in amplitude.

Cusps

Cusps are found on sea beaches and along lake -or pond- beaches, and do not depend on the nature of loose sediments (sand to pebble). Small capes which separate arcs (their amplitudes can reach 60 to 100 m), correspond to accumulations formed along foreshores and are made of coarser sediments than those of the arcs.

The theory of cusps formation is still being evolved and will not be detailed in this report (cf. Quélenec, 1984c).

Cusps are frequently present in bays and on regular shores where swells break on the shore at a slight angle (weak littoral drift). These cusps can disappear within a few hours under the impact of strong swells breaking obliquely to the shore ; they are generally more marked and stable on the shores affected by weak tides.

Undulations of the shoreline and submarine bars

These formations are well developed on rectilinear sandy shores with weak to medium tides. They are present on French shores, as well as on beaches of the Gulf of Benin, along North Africa and along the shores of the Nile delta. This kind of littoral rhythmic formation is not easily noticeable on subaerial beaches with great undulations amplitude. Submarine bars are arcs-like forms of large amplitude (100 to 1,500 m), their ends being pointed toward the subaerial beach, thus creating reflecting images of undulations of the shoreline (Fig. III.8). Cusps may be superposed on these formations complicating morphological interpretation.

The lateral migration of these large-amplitude formations is often the cause of rhythms in the shoreline morphological evolution, alternatively submitted to erosion and accretion phases. The longitudinal migration velocity of these undulations can be noticeable on a day, month or year-scale basis, depending on the coasts, strength and stability of the swell regime.

Shoreline undulations can sometimes be explained by a development of circulations, induced by cellular-type currents and accompanied by rip-currents (see chapter II.1.). Rip-currents known to cause occasional drowning off beaches, carry off-shore sediments brought by coastal currents as a result of mass transport due to the incident swell. This type of currents develops generally in areas marked by a weak swell convergence, or where sea level rises gently under the impact of incidence and reflected swells. The higher the swell amplitude, the larger the spacings between rip-currents.

The presence of curved submarine bars of great amplitude is not necessarily attributed to cellular circulation with rip-currents. Their formation is still considered controversial, obscured by occasional swell reflection patterns (i.e., choppiness, backwash), occurring on steep beaches or between capes.

III.1.2.2.6. Tombolos

Tombolos result from the diffraction of the swell on a small rocky islet or island close to the shore. The rotation of the waves crests along the end of the islet and progressive reduction in the swell amplitude in the sheltered area allow for the transport and accumulation of sediments between the rocky obstacle and the coast. The Cape Vert peninsula (Senegal) is a case in point.

III.1.2.2.7. Deltas

Deltas are complex sedimentary accumulating forms owing their origin to the inability of the hydrodynamic agents (swells, currents) to disperse the sedimentary river input discharged to the shore. Deltas are the final point in the evolution of fluvial valleys filling. The Niger delta, the most extensive of West Africa, represents a huge accumulation of sediments. The Ogooué delta (Gabon) and the Volta delta (Ghana) are also of consequence, the last one being currently at an erosive stage after the completion of the Akosombo dam (chapter IV.6.).

III.1.2.2.8. Muddy grounds

Muddy grounds are particularly well developed in Guinea, the Ivory Coast (Ebrie lagoon), Cameroon (Wouri estuary) and in Gabon (Ogooué). They are usually located in coastal sheltered zones such as lagoons, inner part of bays, edges of estuary. Sedimentation of fine particles of which cohesion increases progressively takes place in these areas sheltered from swell by islands and capes ; the result is formation of privileged tropical zones where mangroves develop. Fine particles are deposited which are made of colloids, powders and very fine-grained sands. The flocculation of the pelitic sediments results from the aggregation as flakes (0.1 to 2 mm) of microscopic elementary particles the size of a few microns. These particles, sticking together, can hardly be reworked even by the action of a strong current. Their fixation is further strengthened by the development of vegetation well adapted to this particular ecologic environment.

III.1.2.3. Side effects

After having described the main morphostructural features which shape the coastal area, we will recall the morphological effects which can have a local impact upon the coastal sedimentary balance.

III.1.2.3.1. Continental shelf effect

The shelf width may affect coastal hydrodynamics. As a matter of fact, when the continental terrace is narrow (20 to 30 km, i.e. off the Ivory Coast or Togo-Benin), the wave energy is less absorbed by the shelf bottom with the result that the waves have a stronger impact on the shore. In addition, very fine sediments may, occasionally, be dispersed more easily toward greater depths.

III.1.2.3.2. Submarine canyon effect

Submarine canyons may play an important role in coastal sedimentary drift, when their head arrives near or at the coast. Thus, they by-pass more or less completely the longshore sedimentary flow and divert it directly toward the deep ocean bottom, determining different contrasted sedimentary provinces. This case is exemplified by the Cayar (Senegal) and Congo-Zaire canyons, and to a lesser extent, by the Trou-Sans-Fond canyon (Ivory Coast).

III.1.2.3.3. Headland effect

Depending upon the protection from the swell provided by promontories, more or less well-defined bays may form.

Rocky headlands along the African coasts trigger off the build-up of sandy spits or bars downstream of the littoral drift. One can cite e.g. Cape St Paul to the east of the Volta mouth, Pointe-Noire and Mayumba bays. Within bays, the swell amplitude varies as the isobaths are not parallel. Consequently, beach profiles are steeper where the waves are stronger, and a grain-size sorting occurs, the coarsest sediments being drifted where the energy is maximum. Due to refraction, diffraction and reflection phenomena, sand movements are more complex in a bay than along a rectilinear coast. Refraction depends on the isobath gradient. A submarine valley or channel induces swell divergence and a decrease of the swell energy reaching the beach ; the opposite occurs with a shoal. Wave reflection may be considerably enhanced by rocky walls or by steep sloping structures.

The Lomé area is better protected from the SW swell by Cape St Paul, than the Cotonou area, as evidenced by observations. In the latter area, there is no damping effect of swell. However, between Cape St Paul and Lomé, in the Keta area, the incidence of wave crests generates a powerful erosion incidence of the shoreline. Along a coastal segment of 40 km, its rate is evaluated at 10 m per year.

III.1.2.3.4. River mouth effect

The debouchures either of estuaries or lagoons, allow a daily exchange of water masses related to tides and river outflow. These debouchures are generally unstable, migrating along the sand bar at a rate ranging from 1 metre to tens of metres per year. These rates depend on factors such as the littoral drift or the depth of the mouth.

The coastal zone near Grand Popo (Benin) was probably greatly influenced by the changes involving the position and the morphology of the Mono river mouth. It seems that the river, formerly debouched close to Grand Popo and that since then it has shifted to the east. Aerial photographs make it obvious that the river occupied successively several debouchures, during a relatively recent past. These migrations and fluctuations may have contributed to the instability of Grand Popo beach (United Nations, 1981).

III.1.2.3.5. Breaker bars (longshore bars)

Breaker bars encountered all along the coasts of West and Central Africa are associated with seas with no tides, or with areas where the average swell amplitude prevails over that of the tide. Their formation is due to the convergence, along a beach transect, of sedimentary transits from the beach and from offshore toward the breaker zone.

Permanent longshore bars are generally absent or ill-defined along shorelines where the tide prevails, whereas ridges and furrows shape the profile of the intertidal beach. They indicate that the breaker zone moves with the level of the tide which has an influence on the piezometric height and on the emptying of the coastal water-table by percolation through the sand of the beach. In calm weather and during the elevation of the mean tidal level, the storm-induced profiles are progressively smoothed and shift toward the shoreline. The longshore bars acting as a protection for the sandy beaches from the swell absorb a significant part of the swell energy whose amplitude,

therefore, decreases. These sedimentary and energy consuming structures are a locus where 50 to 80 % of the littoral sedimentary transport occurs.

III.1.2.3.6. Beach-rock

Beach-rock is made up of beach sands (of variable composition) cemented by calcium carbonate. This deposit is generally indicative of tropical seas and forms presently in the intertidal zone of warm seas beaches.

Genesis of beach rock is still the object of lively discussion in the literature ; several hypotheses of processes leading to its cementation have been proposed :

- seawater evaporation at low tide ;
- micro-organisms activity catalysing the calcium carbonate precipitation;
- lowering of hydrostatic pressure ;
- precipitation triggered off by the contact between fresh water (from the onshore water table) and the saline wedge.

The discussion is still open. Most of the authors suggest that the cementation occurs inside the sand mass, probably close to the top of the water saturated zone. This could explain why present-day beach-rocks are not to be seen in the open air unless they are located in areas under erosion. In this case, recent beach-rocks appear as large, discontinuous slabs of several metres or tens of metres (transverse extension) in width and of tens to hundreds of metres (parallel to the shore) in length. The slabs have the same slope as the beach, and when stripped off by erosion, they display micro-cuestas facing to the higher part of the beach.

Several superposed and distinct slabs can be observed, each of 10 to 60 cm thick, with a total thickness reaching and even exceeding one metre. The hardness of beach-rocks is generally high, but some are known to be less consolidated.

The location of beach-rocks (of which some are in process of consolidation) with regard to the present shorelines, depends on the time of their formation, on phenomena such as sea level variations, tectonics, shoreline retreat, and on their ability to resist erosion or destruction by the swell or by biological agents. The occurrence of beach-rock lines cropping out at a few metres depth off the shore (i.e. off Togo-Benin) or on shelf, tends to modify, as for shoals or reefs, the swell propagation toward the coast (refraction), and may generate preferential accumulation or erosion on the beach. When located onshore, the beach-rocks are able to yield information concerning the position of the former shorelines and may also be used as a barrier from coastal erosion or as a firm substratum for protective or development installations. Chapter IV.6. presents the case-history of the Togo-Benin beach-rocks.

III.1.2.3.7. Coral reefs

Coral reefs are often rising up near the sea-surface and, hence, are able to absorb swell energy. They are built-up by corals, algae and other marine organisms secreting calcium carbonate (CaCO_3). Coral lagoons protected by the fringing reef generate near Pacific islands and in warm seas. They are of relative importance off the coasts of West and Central Africa.

III.2. HISTORICAL SHORELINE CHANGES

The study of old travel reports and of the attached maps has made it possible to trace coastal variations over the past 500 years. These documents, besides a purely historical value, can also provide relevant geographical data. However comparative review of different editions of coastal navigation maps (see Appendix I) remains to this day the main reliable information source. It is not uncommon that several editions (some of them limited to map corrections) cover the same coastal sector. They generally date back to the beginning of the XIXth century. The variations should, if possible, be considered against other available data (reports of local population, photographs, etc.) ; marine or hydrographic maps correct in terms of bathymetric data are known to contain a number of inaccuracies as regards coastline profiles. For comparison, one can resort to aerial photography, but this technique being fairly recent, many coastal sectors have not been photographed ; its application for the review of historical shoreline changes is, therefore, limited.

This chapter gives information which will be summarized in the regional analysis.

Example 1 : Mauritania : entrance to Nouadhibou (formerly Port Etienne) / Bay of Levrier

This study concerns the bay of Cansado in the inner part of which the port of Nouadhibou is built. This small bay is a secondary reentrant located on the west coast of the large bay of Levrier, itself delimited by the Cape Blanc peninsula. The evolution of this area can be deduced from US maps (1944 and 1976, scale : 1:39,400 ; in Murday et al.) and from French maps (French Hydrographic Office of the Navy, 1942 and 1976, n° 5915, scale : 1:37,500).

Fig. III.9 testifies that there has been no change in the shoreline of the western edge of Cape Blanc. On the other hand, in the Nouadhibou zone, thanks to a comparative study of various maps editions, a growth of the coast (1,200 m during a little more than 30 years) from Cape Chacal and Cape Flore can be observed. The areas, regained from the sea, either naturally or artificially during harbour sites development were mapped on the 1940 editions as more or less submerged sectors at high tides. It must be nevertheless underlined that the date of edition does not always correspond to that of the measurements : for example, in case of the French maps, the hydrographic surveys were carried out from 1909 to 1910, and from 1936 to 1938 for the 1942 edition ; then that map was updated in accordance with the survey by the Hydrographic Office from 1962 to 1963 and of MIFERMA in 1973, and edited in 1976.

Example 2 : Senegal : outfall migration of the river Senegal since 1850

The movement of the Senegal river mouth and the extension of the Barbarie spit since 1850 have been well documented (Gac et al., 1981-1982; Sall, 1982). In its lower stream, the Senegal river flows over several kilometers along the Atlantic coast, from which it is separated by the thin sandy bar of the Barbarie spit shaped over the years by the beach drift. Getting progressively longer, this fragile and unstable sandy spit induces the southward migration of the outfall. Upstream it becomes vulnerable. Either retreating under the swell pressure, or undermined by the river, this thin bar of active dunes breaks up and reduces in length. The outfall then raises towards the north, the bar reemerging, and the cycle seems to resume. An inlet towards the ocean near Saint Louis goes back to the middle of the XVIIth century. Old outfalls farther north can still be identified near the Maringouins and the

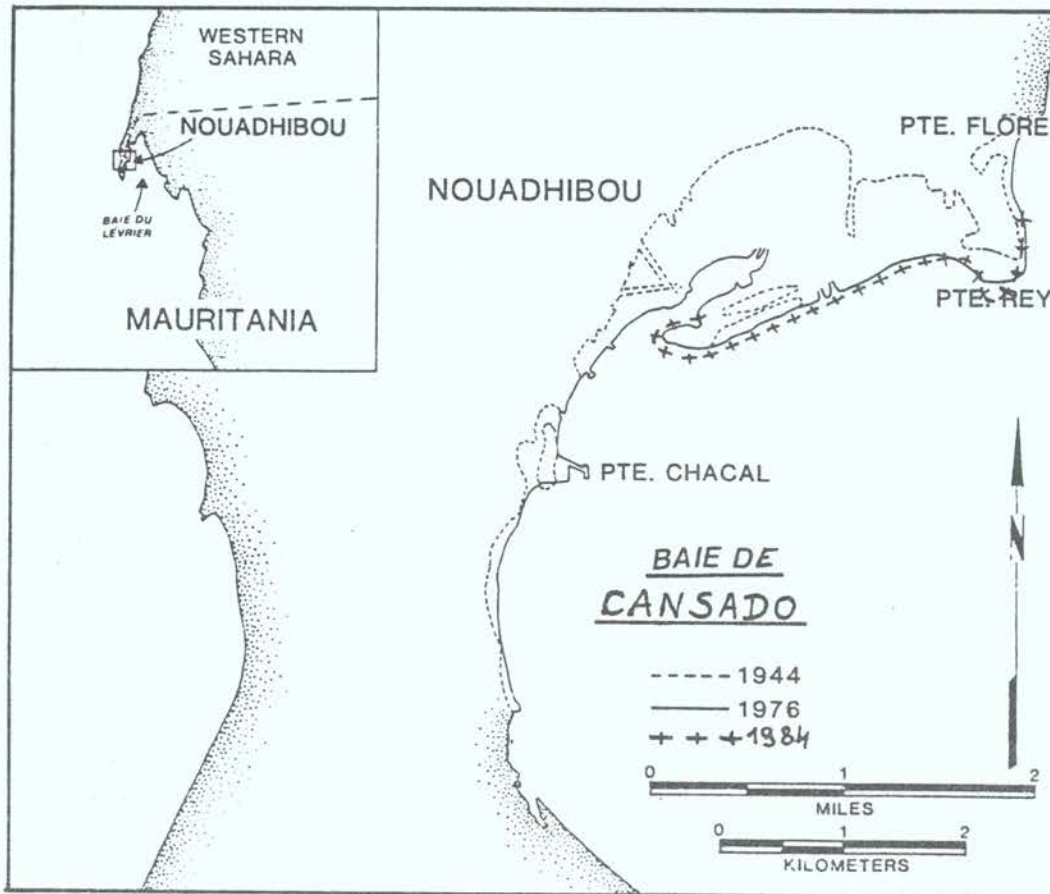


Fig. III.9 - Avancée du rivage (de près de 1 200 mètres) dans la zone de Nouadhibou, entre 1942/1944, 1976 et 1984

Fig. III.9 - Accretional changes of up to 1,200 m at Nouadhibou, between 1942/1944, 1976 and 1984

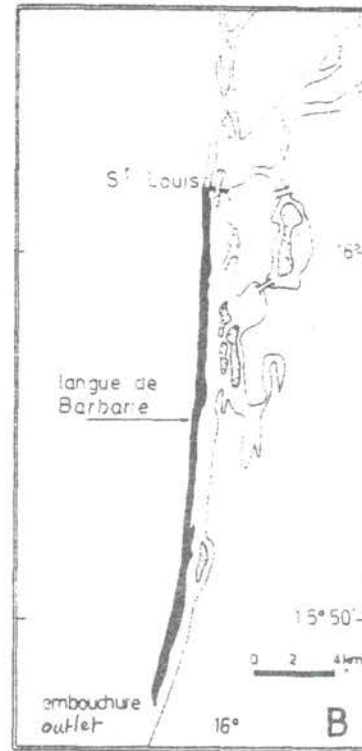
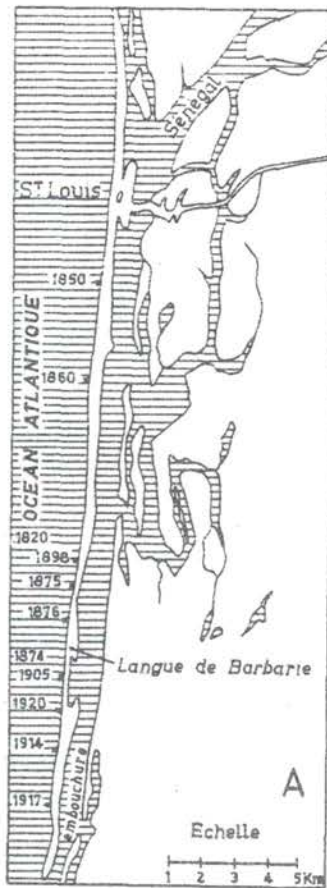


Fig. III.10 - Evolution de la Langue de Barbarie :
A, depuis 1850. In Ottmann, 1965 ;
B, extension maximale de 1959. In Gac
et al. (1981/1982)

Fig. III.10 - Historical "Langue de Barbarie" sand spit
changes : A, since 1850. In Ottman, 1965 ;
B, maximal length in 1959. In Gac and al.,
(1981/1982)

Date	Distance	Date	Distance	Date	Distance
1658	2,5	1884	18,3	1959	27,0
1726	10,0	1884	14,4	1959	16,5
1790	4,5	1887	12,1	1960	16,7
1801	27,5	1888	15,7	1960	18,9
1810	6,0	1894	14,3	1962	18,0
1825	14,4	1904	18,3	1963	17,7
1840	20,0	1906	15,7	1966	20,1
1850	3,4	1913	20,0	1967	21,3
1851	27,5	1921	16,0	1968	22,2
1854	4,5	1923	15,0	1969	22,5
1856	4,5	1928	24,2	1969	22,8
1861	10,9	1929	20,8	1970	20,0
1862	8,5	1932	23,4	1971	24,3
1864	6,0	1936	15,7	1973	15,0
1870	12,0	1945	23,9	1977	16,3
1872	12,4	1948	16,8	1978	19,5
1872	10,3	1950	25,5	1980	21,5
1874	11,5	1955	25,5	1981	21,8
1882	17,0	1958	28,0		
1883	14,0	1958	27,0		

Tableau III.1 - Variations de l'extension de la Langue de Barbarie depuis
1958 ; la distance (en km) est comptée entre l'île St Louis
et la tête de la flèche. In Gac et al., 1981/1982

Table III.1 - Variations in length of the "Langue de Barbarie" since 1958 ;
distance is computed between St Louis island and the tip of
of the sand spit. In Gac and al., 1981/1982

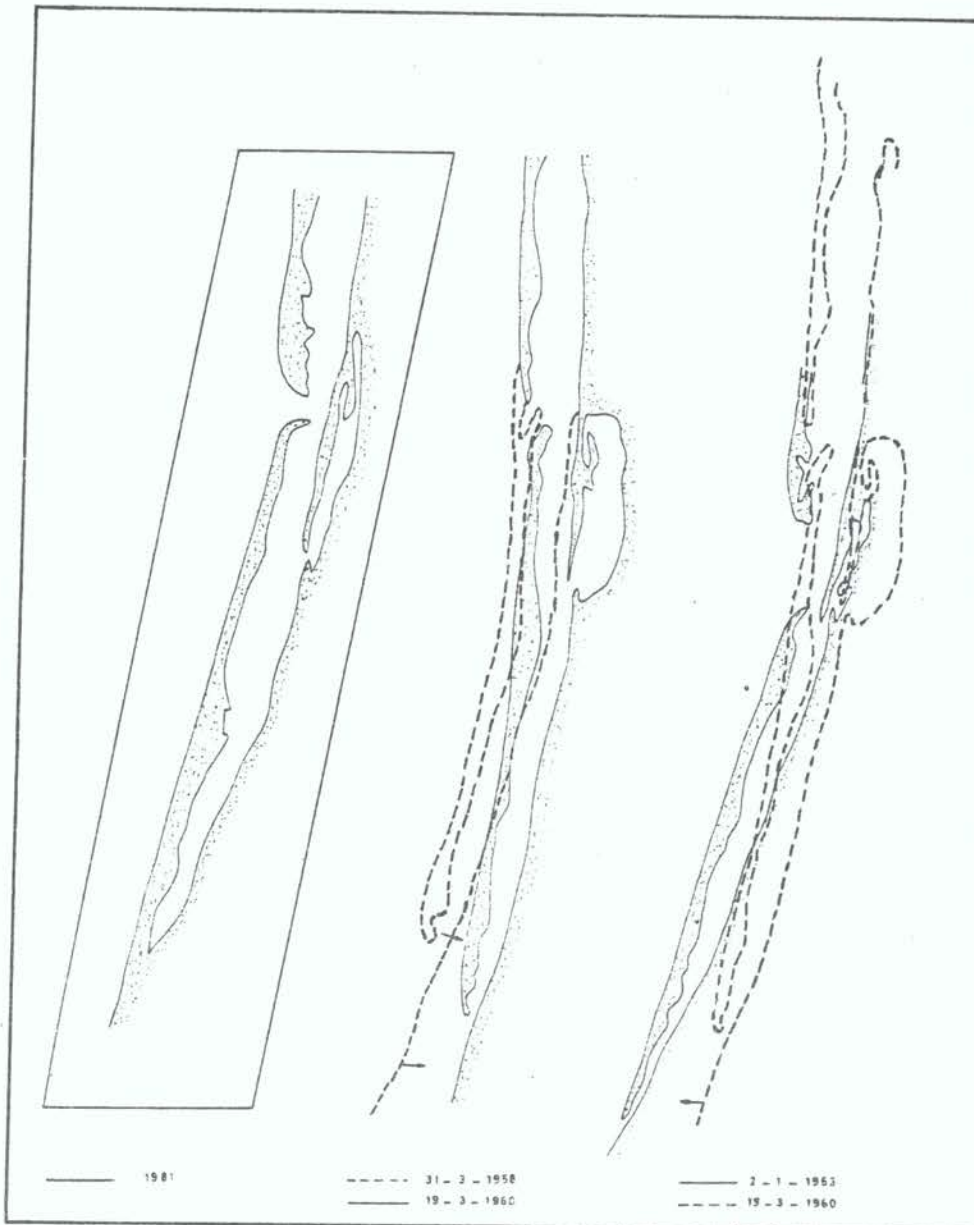


Fig. III.11 - Evolution du segment distal de la Langue de Barbarie, de 1958 (rupture et insularité) à 1981 (rattachement à la côte). In Sall (1982)

Fig. III.11 - Evolution of the distal segment of the "Langue de Barbarie" from 1958 (breaking and insularity) to 1981. In Sall (1982)

Boydét marsh. The outlet then clogged up and the river became subjected to the sand advance and to littoral stresses which induced its southwards movement. The data on the river mouth positions are summarized in table III.1 and figure II.10 and are provided by old cartographic documents, studies of harbour development projects and by aerial photography (in Gac et al., 1981-1982 ; in Ottmann, 1965). The history of the antagonism between the river and the ocean can thus be traced thanks to all these data and observations :

- From 1850 to 1900 natural processes contributed to the growth of the Barbarie spit. The river mouth progressed over about 11 km and was located in 1900 about 16 km south of the St Louis island. During that period seven cut-off phases of the spit were noticed, with the major one occurring in 1894 and provoking the dismantlement of the spit over about 4 km.

- Since the beginning of the century, stabilizing works (stakes, planting) have been undertaken, pushing the spit breaking zone 15 km inshore. A spectacular retreat of the spit was observed in March 1959 due to the combined action of storms and floods : the river mouth moved 11 km northwards. Further on, the spit reconstituted itself upstream and exceeded the downstream islet (part of the former bar) formerly clinging to the shore, thus creating the Mboumbaye lagoon which is currently clogging up (Sall, 1982) (Fig. III.11).

The bench-marks fixed on the Barbarie spit make the follow-up of the present evolution feasible : from 1972 to 1978 its end progressed by 912 m southwards. At the same time, its outer shoreline retreated by more than 6 m, while the arm of the Senegal river narrowed, its two banks growing as river sediments were deposited, its width decreasing from 365 m in 1749 to 93 m in 1978 (Sall, 1982).

With the main cuts-off taken into account, the littoral bar would weaken every 14 years. If so, the next cut-off would predictably occur in 1987 (?) (hypothesis proposed by Gac et al., 1981-1982). It also seems that the spit has presently reached its southernmost limit (Sall, 1982), but its evolution depends, above all, on the dynamics of the Senegal river and on its location on a coast with a high energy swell and an important sandy transport.

Example 3 : Senegal : from Saint-Louis to Cape Verde

In the past, the low and sandy coast north of Cape Verde did not have the monotonous aspect of today (Fig. III.12, map 5). Most probably, the entire area was interspersed with small coastal rivers and lakes debouching to the sea.

Barbey (1967), using ancient documents (maps, sailors accounts, travel reports, synthesis work, like the 5 volumes of Père Labat published in 1728 and stored in the IFAN library of Dakar), has made a critical study to trace the evolution of this littoral.

In the XVth century a lake named Budomel is reported, half way between the Senegal river and Cape Verde ; it communicated with the sea through a wide outlet. It reappears on the Portuguese charts of the XVIth century. On the other hand, in map n° 1 (Fig. III.12) of Père Labat (1728) only the debouchure is labelled as Guadomel. But if we refer to map n° 2 (Fig. III.12) of d'Anville (in Labat, 1728) we can note the presence of a river flowing to the south-west and passing along Embaul and Macaye. The outlet of the lake probably debouched near the present shore of Mboro where some legends speak of an estuary where ships could anchor, the littoral still bearing traces of a swamp interrupting the sand dunes ridge. This river, named Maka, is not the

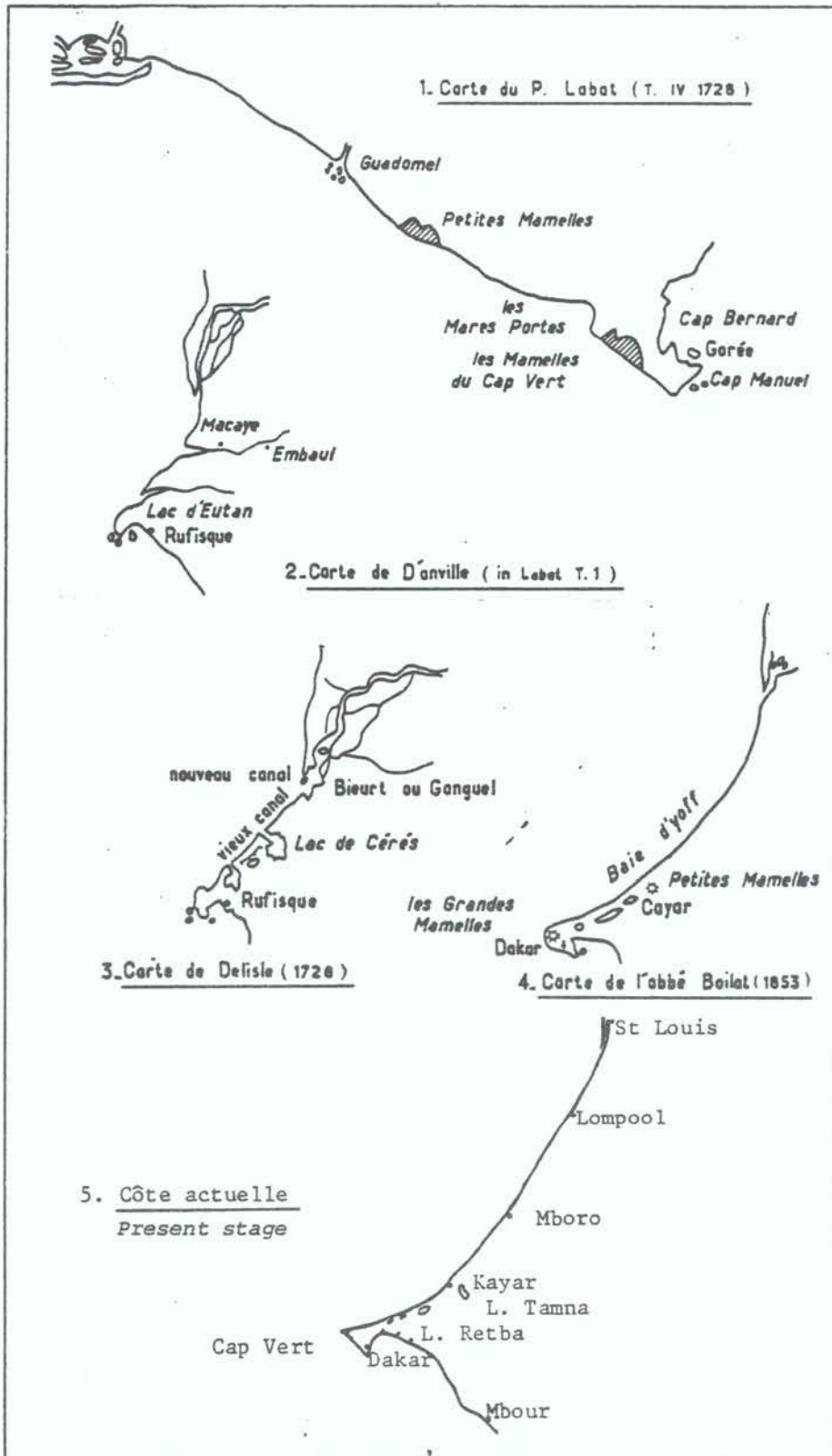


Fig. III.12 - Evolution historique de la zone côtière entre St Louis et le Cap Vert. Cartes 1, 2, 3 et 4 (in Barbey, 1967) ; carte 5, in Pinson-Mouillot (1980)

Fig. III.12 - Historical shoreline changes between St Louis and Cap Vert. Maps 1, 2, 3 and 4 (in Barbey, 1967) ; map 5, in Pinson-Mouillot (1980)

only one to have communicated recently with the sea ; map n° 3 (Fig. III.12) of Delisle (1728, no reference) mentions three lakes in the littoral area : lake Cerès, a large pond, and a lake located further southward and having a communication with the sea. Lake Cerès is designated by Père Labat as Entan lake, this name being still quoted in the Description of Africa of Dapper (1686). This lake might correspond to the present lakes of Retba (Joire, 1947) or of Tamna (Barbey, 1967). But these hypotheses are based on accounts and maps, sometimes conflicting and often lacking in accuracy. Nevertheless, the study of these documents show the persistence, until recent times, of small rivers and lakes, remnant of an older river network.

Example 4 : Senegal : Rufisque

Erosional processes are intense in the bay of Rufisque, south of Dakar, causing destruction of buildings and coastal structures. Sall (1982) recounted the historical evolution of the shore retreat, by correlating cadastral maps of 1933 and 1945 of Rufisque with aerial photographs of 1980. Figure III.13 shows a marked retreat of the shore, estimated at 1.30 m per year. According to Sall, this phenomenon is due to the NW swell, rotating around the Cape Vert peninsula, inverting the SE littoral drift, and generating a divergence zone off Rufisque. This induces, at certain points and, particularly, at Rufisque, a fairly vigorous coastal erosion, since terrigenous input is almost non-existent.

Example 5 : Senegal : evolution of Sangomar Point

This sand spit fringes the estuarian system of the Saloum for about 20 km and continues southwards (toward the Diombos mouths) with frequently reworked shoals. Its evolution can be traced owing to different maps published between 1895 and 1956 for navigation control, and to IGN aerial photographs, particularly those concerning the 1950-1978 period [Fig. III.14, after Tromeur (1955), completed by Diop (1984)]. Therefore, we have an idea of the successive emplacements of the coast and the movement of the spit tip. These data are corroborated by the accounts of the inhabitants and by the material evidence, such as ancient buildings now emerging at low tide. Sall (1982) draws a brief review of its evolution since the beginning of the century (Fig. III.14) : from 1905 to 1906, Sangomar spit extends some 300 m to the south ; from 1907 to 1912 this advance seems to have reached a 1,500 m mark but along a SE direction ; in 1914, the tip resumes its 1907 position, and it is only in 1925 that the tip goes 1,500 m downward after having risen by 1,000 m in the north (in 1916). The extremity of this configuration becomes an island, which is eroded and, finally, transformed in the "Douane" shallow, bisecting the Saloum channel.

Since 1930, a regular advance can be observed : first of 1,100 m within 20 years (till 1950) in the southerly direction, then of 350 m from 1950 to 1956. Starting from the latter dates, the trend begins to slow down and the direction changes from S to SE, inducing the movement of the sandbanks located further south of the Sangomar spit.

Simulated data from SPOT (1981), compared with the IGN aerial photographs (1954), show a southward spit extension of some 750 m, i.e., a mean annual advance of 44 m (Sall, 1982). This author is of the opinion that the tip may have reached its maximum southward extension : any further advance would be immediately attacked by the powerful NW swell.

The instability of the spit tip is associated with that of the coast (except point Jacksona, in replenishment). As a matter of fact, from Joal to Sangomar, the mean annual retreat of the coast is of 1.2 m (Sall, 1982). This retreat is linked to powerful storm swells, their frequency subject to wide interannual

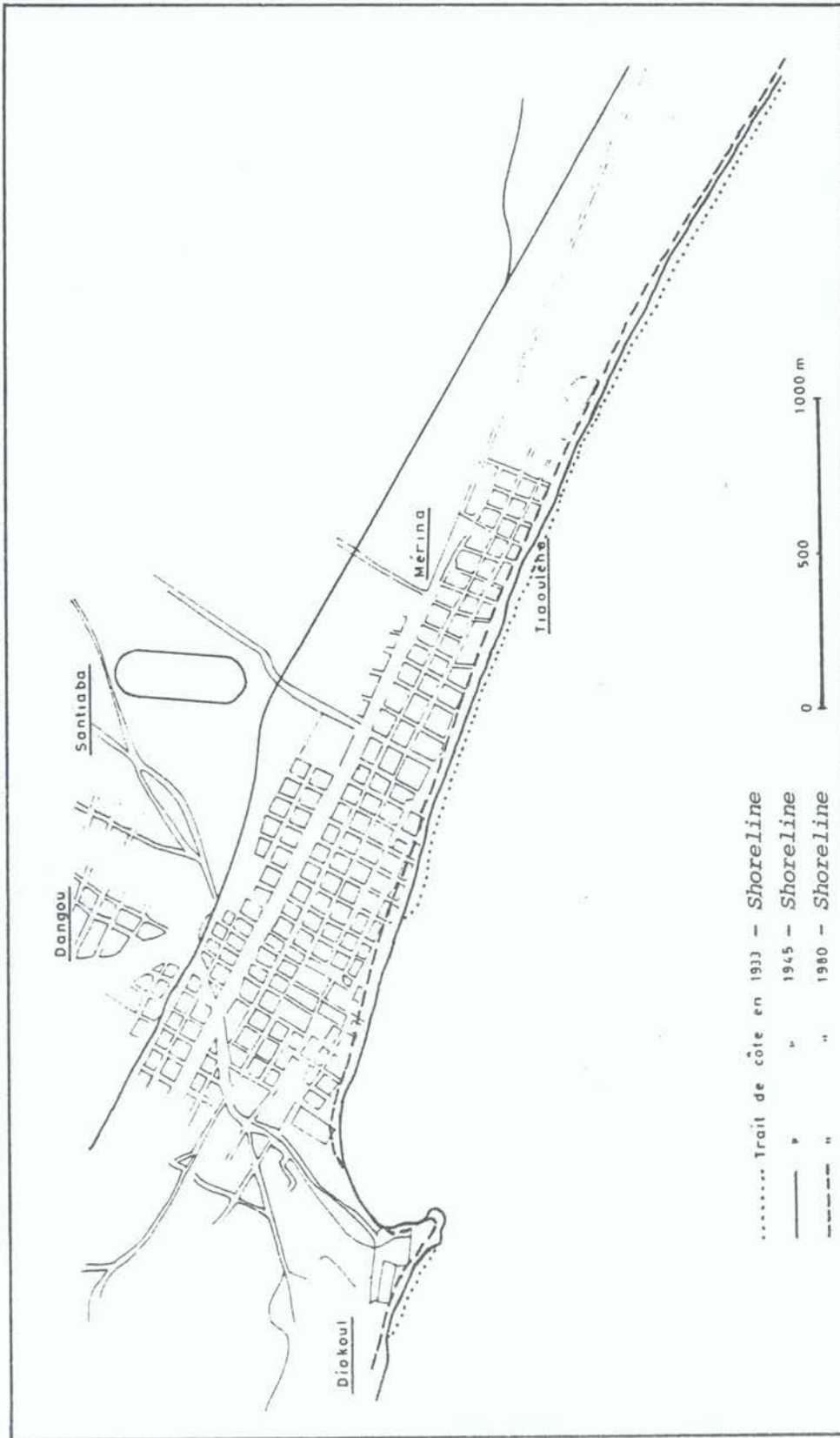


Fig. III.13 - Evolution du trait de côte, de 1933 à 1980, dans la région de Rufisque (d'après documents cadastraux). In Sall (1982)

Fig. III.13 - Evolution of the shoreline, from 1933 to 1980, in the Rufisque area (after cadastral data). In Sall (1982)

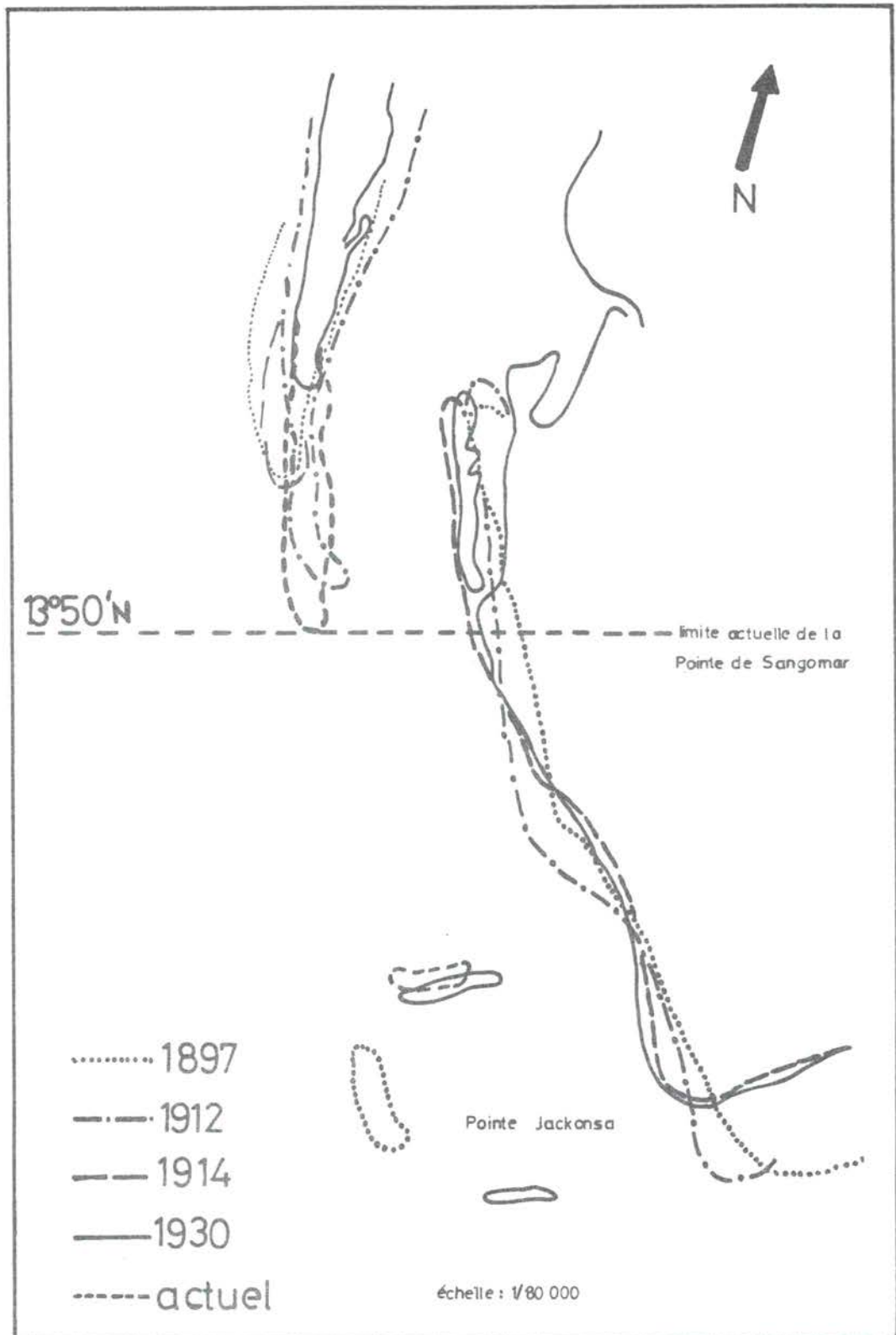


Fig. III.14 - Evolution de la pointe de la flèche de Sangomar et de la côte adjacente, depuis 1897. D'après Tromeur (1955), in Sall (1982) ; complétée par E.S. Diop (1984)

Fig. III.14 - Evolution of the tip of Sangomar spit and of the neighbouring coast, since 1897. After Tromeur (1955), in Sall (1982) ; completed by E.S. Diop (1984)

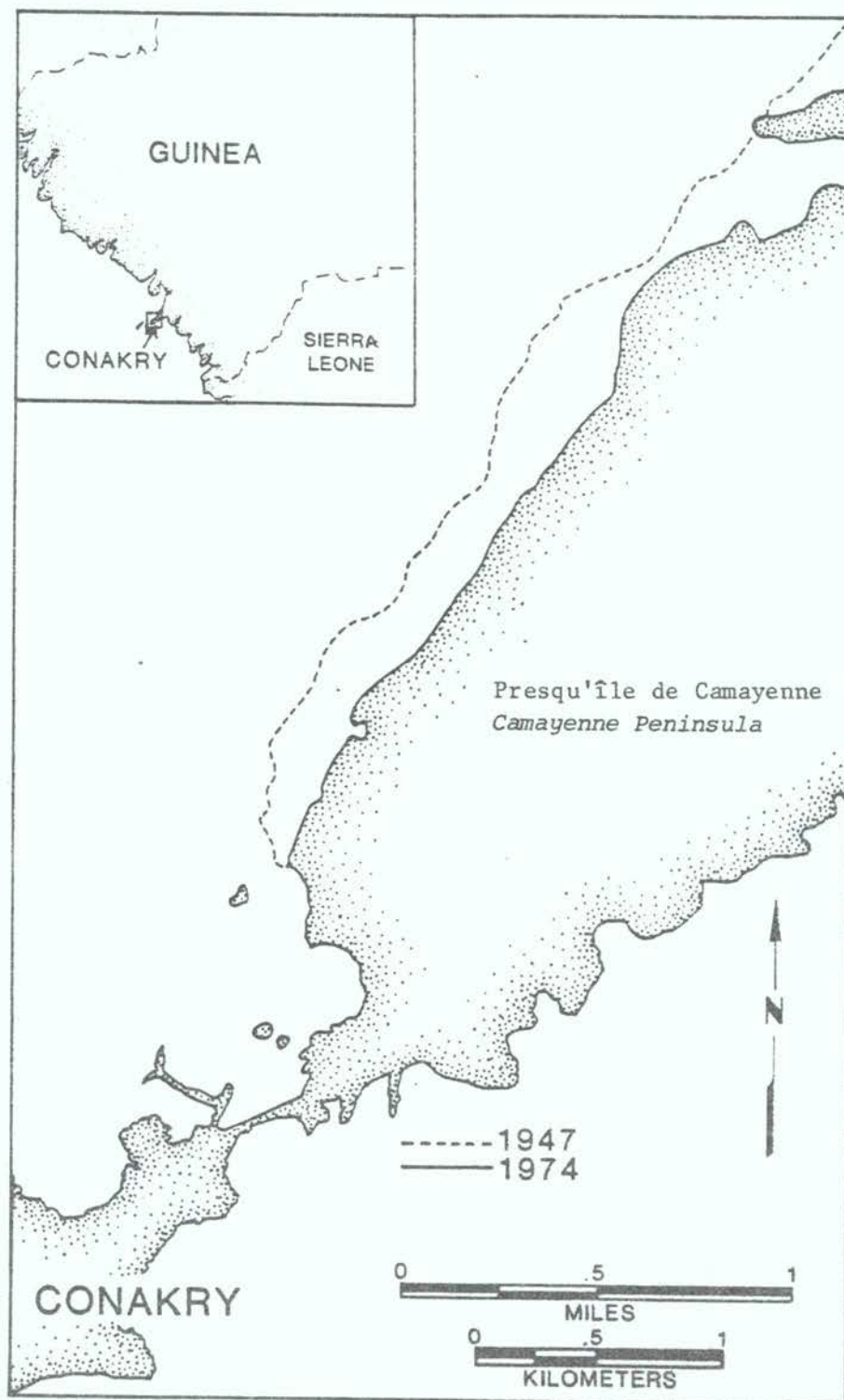


Fig. III.15 - Recul du trait de côte sur la façade ouest de la presqu'île de Camayenne, de 240 m environ, entre 1947 et 1974

Fig. III.15 - Shoreline retreat of approximately 240 m on the western part of Camayenne peninsula, between 1947 and 1974

variations.

The survey of archive documents and recent studies have revealed that a big part of the material contributing to the spit lengthening comes from the shoreline. "In 1915 double erosion of the sand bar is reported on its outer and inner sides. Nevertheless, it is the outer front that recorded greatest erosion rates : the distance between Diakhanor village and the shoreline shrank from 3 km to less than 80 m between 1925 and 1929 ; during this time, the spit lengthened by 400 m" (in Sall, 1982).

The shrinking of the spit may become dramatic in exceptional hydrodynamic conditions, such as storm waves or tsunamis, like the one of August 28, 1928. This was followed by a break-up of the sand bars (1860, 1890, 1909, 1928, 1960, 1970). However, all these breaks are transient ; since the co-existence of two neighbouring river mouths induces a time-lag between tidal currents impeding the flush out of the sea bottom which, therefore, is filled with sediments and eventually emerges.

Example 6 : Guinea : Conakry harbour area and Los Islands

The charts, studied and compared, come from American and French sources: 1947 and 1974 maps at 1:25,000 scale for the first (in Murday et al., 1984); 1944 and 1951 maps at the same scale for the second (SHOM n° 5935).

The shorelines tracings reveal an erosion process on the northern part of the Camayenne peninsula (Fig. III.15). Although the amount of beach loss was not linear, an average loss of 240 m was registered. In some areas, the difference was as much as 380 m.

If the coast retreat is identical on the two series of maps, the time interval varies significantly :

- 27 years for the American editions, with an average erosion rate of 9 m per year ;
- 7 years for the French editions, with the annual average of 34 m.

This ambiguity is difficult to understand ; one thing is certain, the new coastline was recorded on the French map as early as 1951 but it remains unchanged on the American map of 1974. Does it mean that there was no modification between 1951 and 1974 ? or, more probably, that it illustrates the danger of lending credence to such documents without critical analysis ? It is absolutely crucial to work on several documentary sources (photographs, field surveys, ...) to be able to reconstruct with a degree of certainty different evolutionary stages of the coast.

If we look back on the years of survey-making, it appears that the French edition of 1944 was published in 1907, with a supplement on topography and bathymetry appearing in 1938 and carried out by the Mission Hydrographique d'AOF. As for the 1951 edition, it is specified, that it was updated in 1947 by the above-mentioned Mission. Hence, the time lapse between the two surveys may consequently be either 9 years (1938-1947), or 40 years (1907-1947).

As for the Conakry harbour, numerous coastal installations (basins, piers, breakwater, roads) have significantly modified its western front.

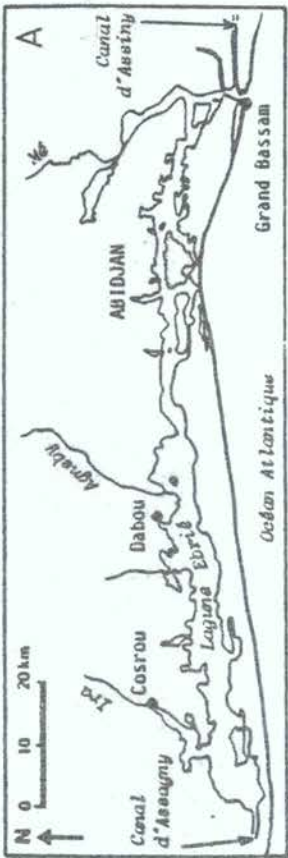


Fig. III.16 - Plan de situation de la lagune Ebrié (A) et plan de détail du port d'Abidjan (B). In Dufour (1984)

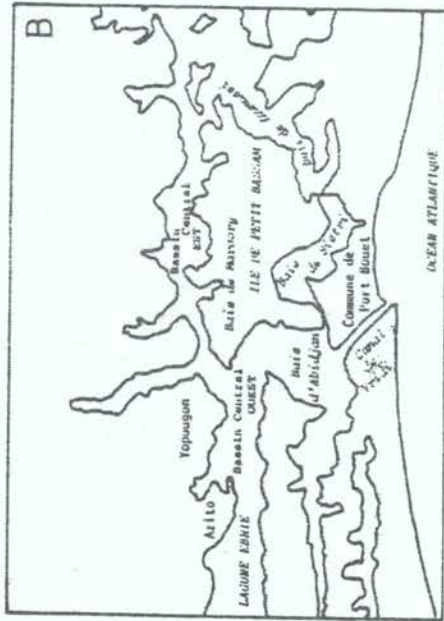


Fig. III.16 - Situation map of Ebrie Lagoon (A) and of Abidjan harbour (B). In Dufour (1984)

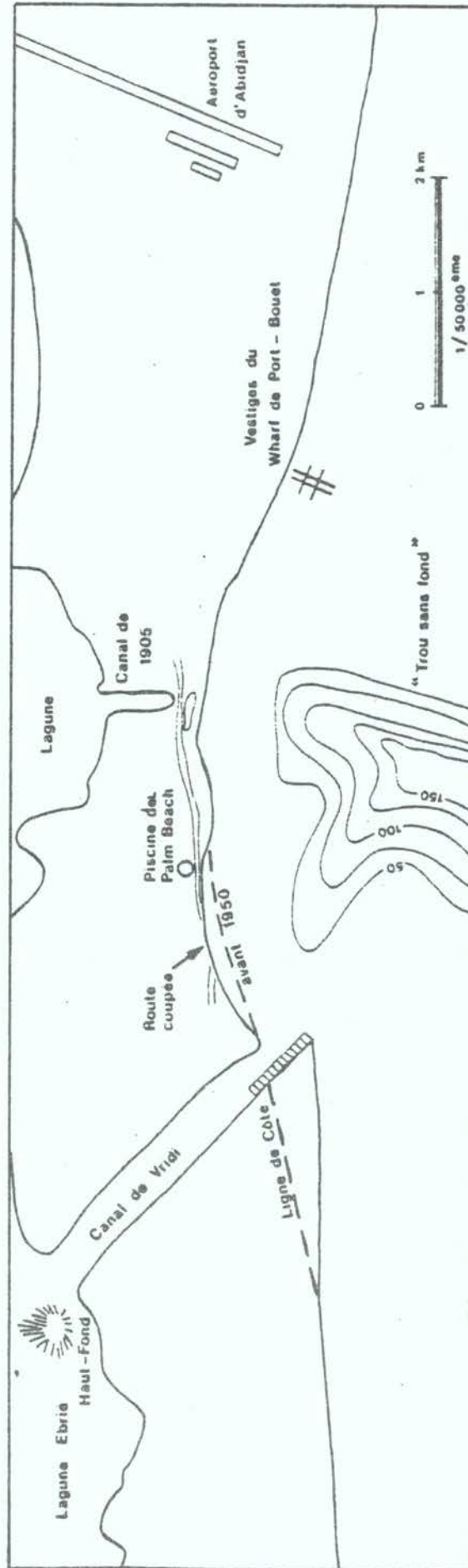


Fig. III.17 - Modifications du trait de côte, à l'embouchure du port d'Abidjan, depuis l'ouverture du canal de Vridi. In Hinschberger (1972) et d'après les cartes marines du SHOM (éditions de 1938 et 1978)

Fig. III.17 - Shoreline changes in the vicinity of Abidjan harbour entrance, after the opening of Vridi channel. In Hinschberger (1972) and after SHOM charts (1938 and 1978 editions)

Example 7 : Ivory Coast : Abidjan harbour area and Grand Bassam

The shores of the Ivory Coast are characterized by a great extension of lagoons. Ebrie lagoon (Hinschberger, 1972) (Fig. III.16) is the largest with an area of 532 km². At the beginning of the century its shores were not very much inhabited, but the choice of the Abidjan plateau in 1904 as a railway terminal bounding the Niger river to the Atlantic ocean, led to a spectacular development of this area.

The first attempt at digging a navigation channel was a failure and is an example of a necessity to study coastal dynamics before undertaking costly developments. Figure III.17 shows the remains of the first channel, opened at Port Bouët in 1905, and immediately closed by a sand spit generated by the eastward longshore transit. Despite everything, other similar attempts were persistent made between 1905 and 1911, equally unsuccessful. The wharf of Port Bouët was built in the 1930s and it remains only, but it led to development trade which in turn determined of an administrative centre and an ultra-rapid population growth which, now exceeds 2 million. The present Vridi channel was opened only in 1950. It is better designed : 2,700 m long, it is dug obliquely to the shore. On its western side it is protected by a 520 m long jetty, acting as a groin to stopping the sand transit ; above all, it was placed just in front of the head of the Trou-Sans-Fond canyon used as a "sediment trap". The consequences of the channel opening for coastal morphology as well as for lagoon hydrology, are worth mentioning. The western jetty stops the west to east sand transit inducing a rapid accumulation of sediments taking place on its western side ; whereas to the east, the coast is markedly retreating (Fig. III.17). Several rows of coconut trees have disappeared since 1950, and a road linking "Palm Beach" to "Lido" was cut. If one should rely on Varlet's assessment (1958, *in* Hinschberger, 1979), it would appear that 800,000 m³ of sand are annually passing in front of Vridi, and over 35 years about 30 million m³ of material has been diverted by the canyon, instead of continuing along the coast toward Port Bouët and beyond.

The impact on the lagoon hydrology is also important. The penetration of seawater killed the pre-existing freshwater species and a natural debouchure of the Comoé river, at Grand-Bassam, was blocked by a sand bar which needs to be periodically re-opened (Hinschberger, 1972). The tidal impact is apparent inside the lagoon at some distance from the channel ; it provokes a flush effect bringing about overdeepings. The sediment output carried along by the ebb current is probably absorbed by the Trou-Sans-Fond ; the sediments, thus carried inside this lagoon by the flow current, are deposited just to the north of the Vridi channel, where they form a shallow (Fig. III.17).

One of us (Quellenec, 1984) was able to observe, in October, damages, arising, after the storm of mid-July, to the shore of the Port Bouët community : in several spots, the shore retreat was of 10 to 20 m. This is a good example of the impact of strong swells which can be quite destructive, especially near the breaker zone. The effect is enhanced, when the storms coincide with exceptional tides (spring tides, plus atmospheric depressions) : the waves attack the upper part of the strand zone, and wash over the rather low coastal sand bars causing their erosion : e.g. Grand Lahou, Port Bouët, Grand Bassam, and Assouindé.

We shall briefly describe the creation of the San Pedro harbour (during the 70s) located on the western Ivory Coast, and planned for relieving pressure on the Abidjan harbour. It was decided on this zone after long studies, the context reminding the one of Abidjan. This harbour, set up in the estuary of the San Pedro river, had to be deepened by dredging ; the river bed was diverted

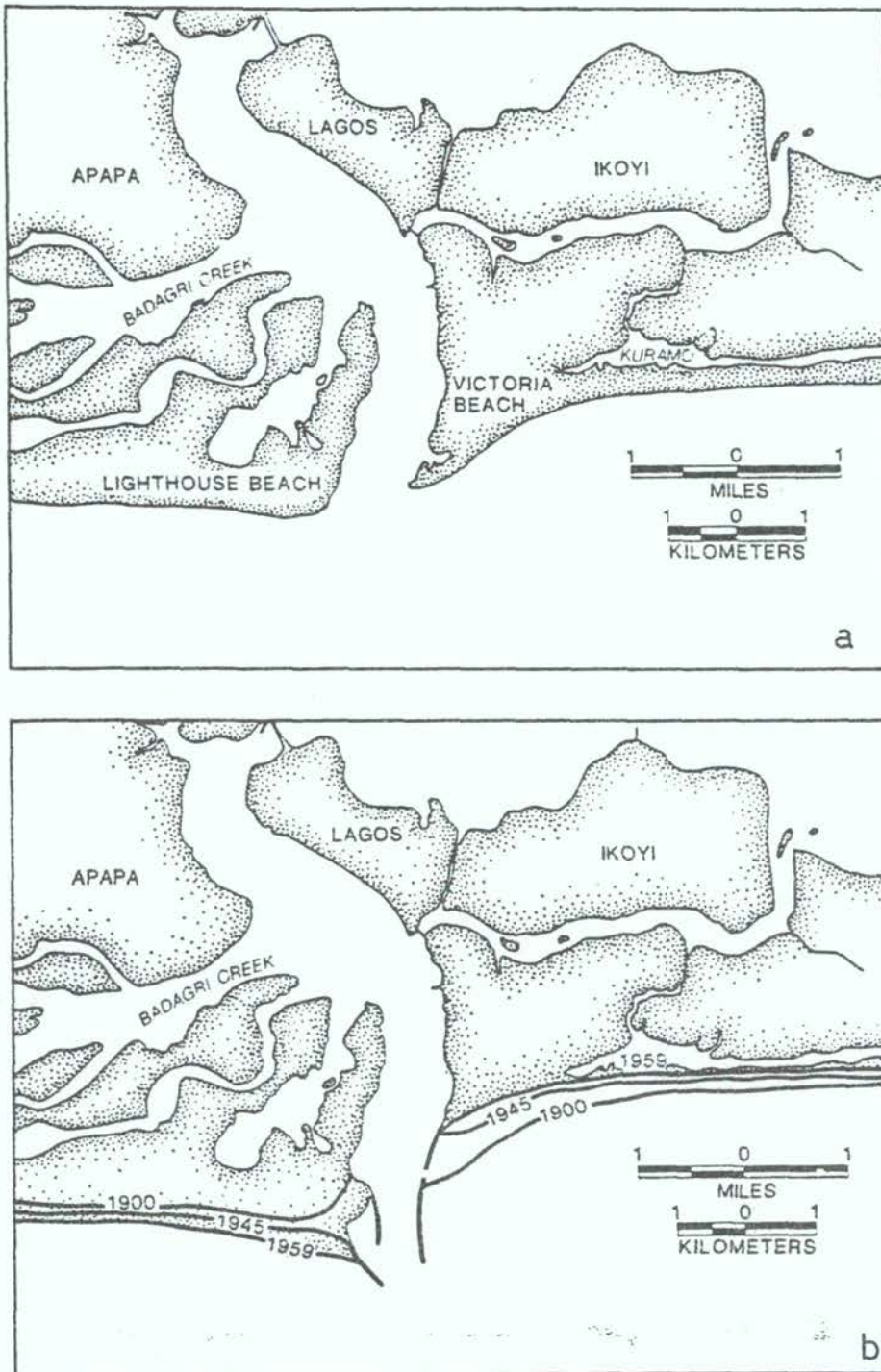


Fig. III.18 - a) Le port de Lagos en 1900 avant la construction des jetées.
 b) Après la construction des jetées, progradation à l'ouest (plage de Victoria) et érosion à l'est (plage du Phare).
 In Ibe et Antia, 1983 ; d'après Webb, 1960

Fig. III.18 - a) Lagos harbour in 1900 before the construction of the moles.
 b) Lagos harbour showing the progressive accretion of Lighthouse beach and the erosion of Victoria beach following the construction of the moles.
 In Ibe and Antia, 1983 ; after Webb, 1960

toward a more eastern outlet, thus preventing a silting up during floods. The access channel had to be protected from the littoral drift by a west located jetty perpendicular to the coast ; the latter acts as a "sediment trap", quite obvious on aerial photographs, and to its western side, the accumulated sand has led to an advance of the beach toward the sea of 100 m in 5 years.

Example 8 : Nigeria : Lagos harbour area

The Lagos harbour entrance was constantly subject to sediment accumulation. At the turn of the century, the harbour was repeatedly closed because of severe littoral drift clogging up the entrance channel (Fig. III.18a). The decision was then made to construct groynes to assure free navigation. The groynes were completed in 1907 and ensured a free access, but introduced new problems. Measurements and surveys carried out in this zone (Webb, 1960; Usoroh, 1977 ; Murday et al., 1984) have revealed that the shoreline retreat is general, except on Lighthouse Beach (the western beach), where a strong beach accretion is recorded. The annual erosion rates remain between 4 and 7 m on the western part of the shoreline as far as the Badagri old guardroom and between 20 and 30 m on Victoria beach (the eastern beach of Lagos). On the other hand, the annual prograding rate of the Lighthouse beach is 22 to 29 m ; Webb estimates that since 1900, this area has gained some 800 m whereas Victoria area has lost 500 m (Fig. III.18b) and III.19). This important stepback and very rapid progradation appear to have been caused by the eastward moving littoral drift generated by the S-SW swell (Guilcher, 1954): the sediments are piled up against the western jetty, and erosion occurs on the eastern side, as the sedimentary supply is interrupted.

Less evident to explain is the relatively moderate but generalized retreat of the western coast as far as the Benin boundary, since the sedimentary supply from Ghana should theoretically be sufficient for maintaining the equilibrium. But the littoral transit is probably affected by the increasing number of harbour jetties in this area and/or by the river sedimentary input cut down by the dams (mainly on the Volta river).

The sediments, removed from Victoria beach area are conveyed to the western corner of the Niger delta but do not seem to be going beyond. Guilcher (1978) suggests that this sand transit may be captured by the Avon submarine canyon, in a manner similar to the Cayar (Senegal) and Trou-Sans-Fond (Abidjan) canyons.

Usoroh (1977) provides beach retreat measurements for several locations of the Lagos lagoon shores. The loss for the western and northern shores (4 to 11 m per year) can be considered spectacular (trees with roots laid bare and washed away). This erosion case is almost classical : the shores of the lagoon made of less resistant sediments are eroded by the waves generated inside it ; the lagoon widens and its bottom rises due to the sediment set in suspension during the river attack.

In order to assess more accurately these variation rates (of erosion or accumulation) aerial photographs covering 3 periods (1947, 1959 and 1962) were used. After being brought to the same scale, they were compared with a British Admiralty chart (1968), which allowed to calculate these rates (table III.2) over a 15 year period (1947-1962) :

- mean erosion rate at Victoria beach : 6 m/year ;
- mean progression rate at Lighthouse beach : 8 m/year.

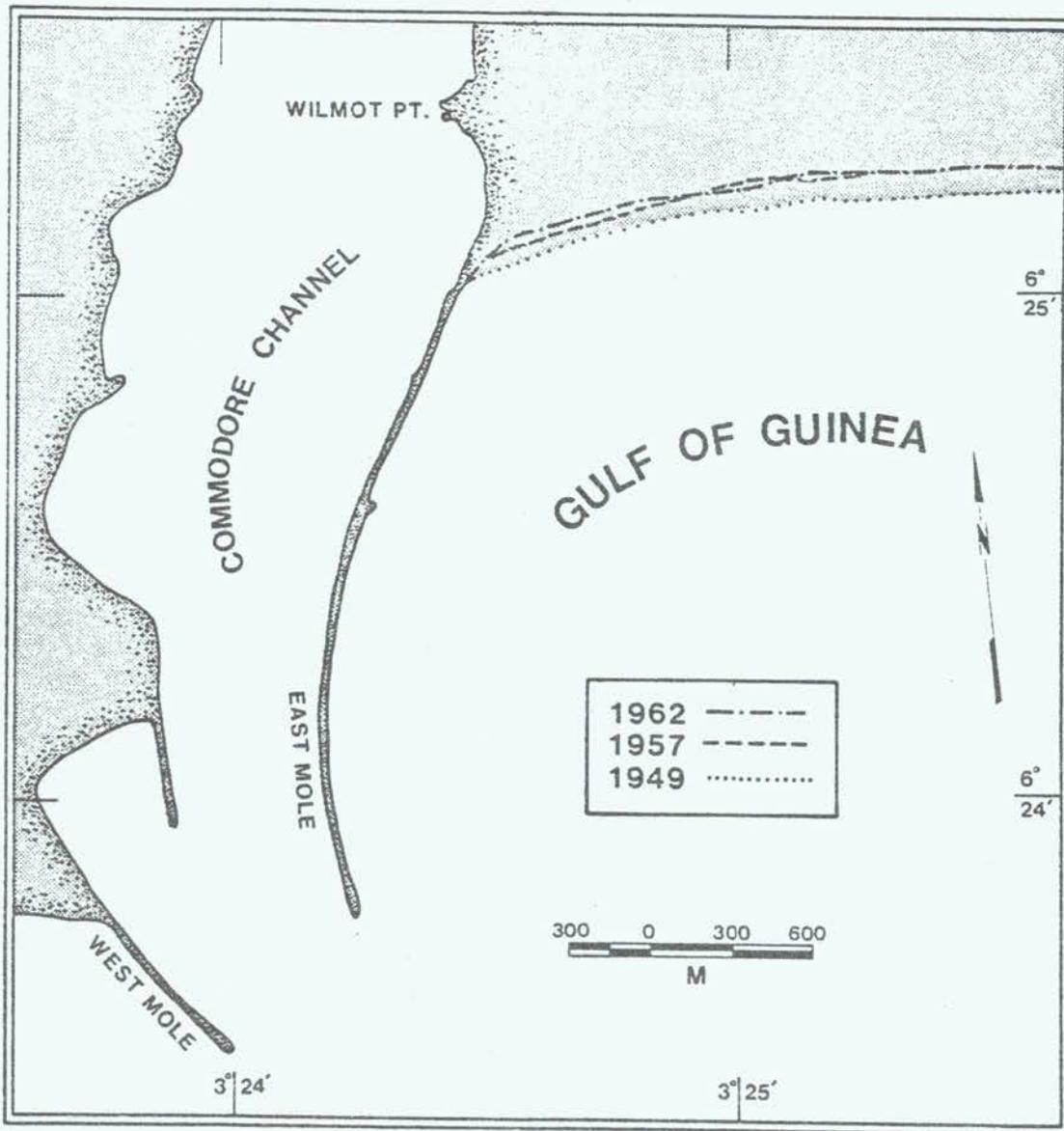


Fig. III.19 - Erosion de la plage de Victoria, à l'est de l'entrée du port de Lagos, due à la construction des jetées. Années 1949 à 1962 (d'après Webb, 1960 ; in Murday et al., 1984)

Fig. III.19 - Erosion of Victoria beach (Lagos harbour), due to the construction of moles, from 1949 to 1962 (after Webb, 1960 ; in Murday and al., 1984)

	Victoria Beach (erosional side)	Lighthouse Beach (accretional side)
1949-57	8.8	7.6
1957-62	4.0	8.2
1949-62	6.4	7.9

Tableau III.2 - Taux de variation du trait de côte de part et d'autre de l'entrée du chenal de Lagos (en m/an). In Murday et al., 1984

Table III.2 - Coastal change in meters per year (Murday and al., 1984) on both sides of the Lagos channel.

Similar values have been obtained by Fowora Renardet and Associates, Nigeria (1981) with direct measurements of the shore evolution between 1962 and 1970.

Over the past years, the nourishment of the beach east of the jetty has been undertaken to stop erosion.

Example 9 : Gabon : Cape Lopez bay, Port Gentil

Cape Lopez, located at 0°37'5 latitude south, was probably discovered in 1473 by the Portuguese, and is quoted for the first time on a nautical chart of the end of the XVth century, attributed to Christopher Columbus.

Bourgoin et al. (1963) have summed up historical and geographical data, permitting them to outline this coast's evolution. Figure III.20 displays some aspects of Cape Lopez since 1885. Plate A of the figure comes from a map established in 1885 by Lieutenant Heiman ; in 1893, Pobeguïn published an atlas of the coasts, where Cape Lopez (plate B on figure III.20) has at its side a sand bank. In 1911, Captain Audoin carries out a topographic survey between the lighthouse and the "pêcheries" (fishery) signal reported on plate C ; till this time, the Baleiniers lake seems not to have existed and the cape does not show the terminal outgrowth beyond the lake. Plate D of figure III.20 comes from a map established in 1937 by M.R. Lauraint ; Baleiniers lake is shown, encircled by a sandy strip partially settled by vegetation. And finally, plates E and F have been established from IGN aerial photographs taken in 1946 and 1957 respectively ; they testify to the shrinking of the sand bar over 11 years (100 to 150 m), at the level of the north-west tip of Baleiniers lake. "This retrospective points out to recent terminal outgrowth which probably did not exist before 1911" (in Bourgoin et al., 1963). On the other hand, the eastern front shows a growth trend.

We have been able to compare SHOM nautical charts n° 6446 published in December 1962 and in June 1969, at a 1:30,000 scale. The first edition corresponds to a survey carried out from 1958 to 1960 by the "Mission Hydrographique de la Côte Ouest d'Afrique", but it was that the topography derives from a map established by the "Société des Pétroles d'Afrique Equatoriale" and the "Service Topographique du Cadastre" without mention of dates. The second edition was updated after the surveys made between 1958 and 1964 by the "Service Hydrographique de la Marine" ; the topography comes from the same sources as above. These two editions, corresponding to surveys at a short interval (a few years only), show little if any coastline evolution (except in a small area -between Alcyon bank and Pointe Clairette, to the north of Port Gentil- where harbour development has taken place). Does it mean that no coastal modification occurred (at least, no significant one), or that the same topographic document was used for both editions (which seems prompted by the explanatory note of the maps) ? On the other hand, these two maps display a large extension of the "muddy sand bank, emerging only here and there, during low tide", located just in the middle of the debouchure of the Yombé river, at the far end of Cape Lopez bay (Fig. III.21).

Example 10 : Angola : the littoral spit of Luanda and its evolution

The "restinga" of Luanda is one of the two longest of the Angolan coast. It is located at about 20 km from the Rio Cuanza mouth and its southern part is deep-seated to Cape Palmeirinhas. At this point the coastline begins to stretch S.SW - N.NE whereas it is oriented S.SE - N.NW at the river mouth; it has developed as a long sandy beach bordered by sandy dunes which are stabilized by vegetation and limited by a 50-80 m hollowed-out high

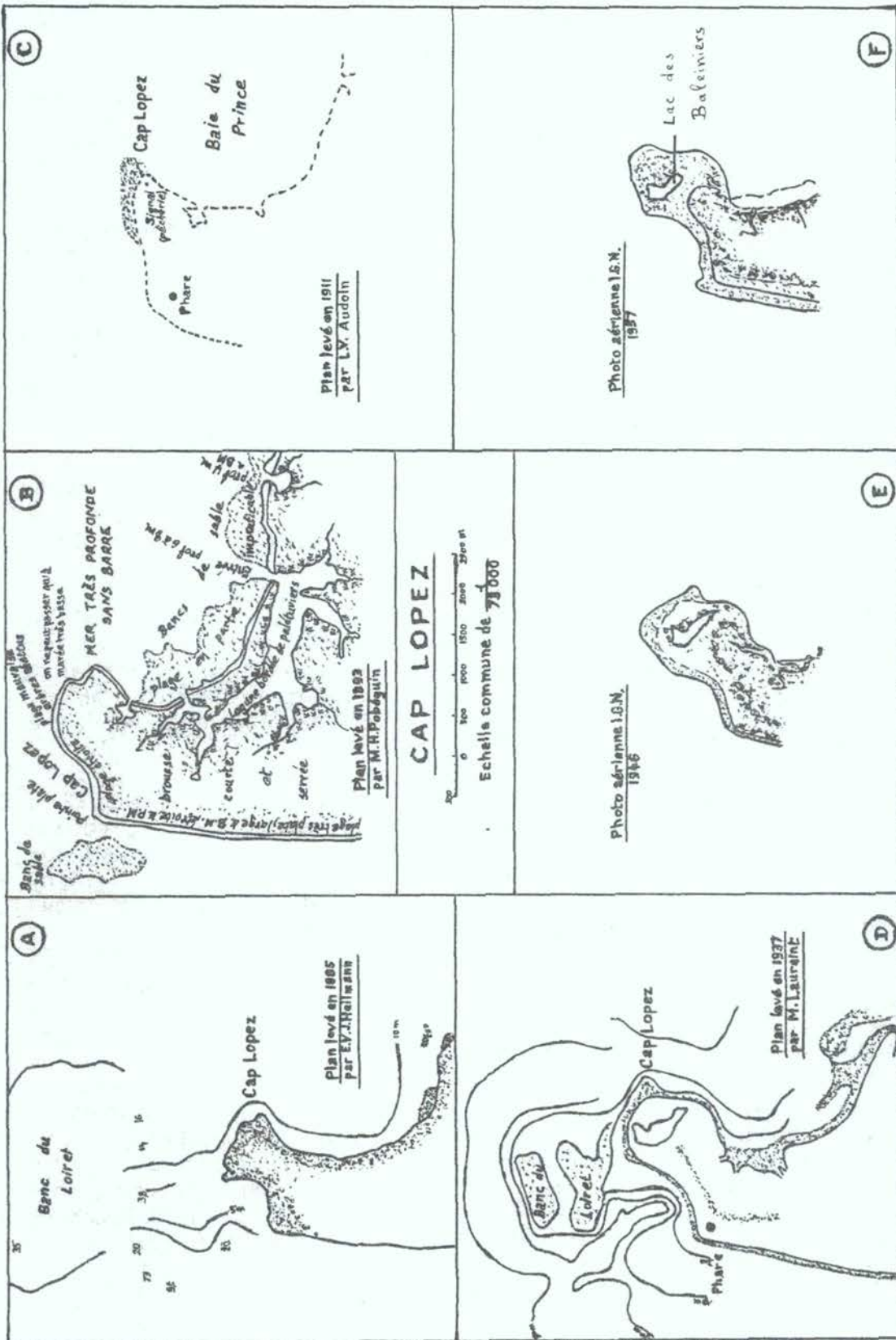


Fig. III.20 - Evolution historique du Cap Lopez, depuis 1885. In Bourgoïn et al., 1963

Fig. III.20 - Historical changes of Cape Lopez since 1885. In Bourgoïn and al., 1963

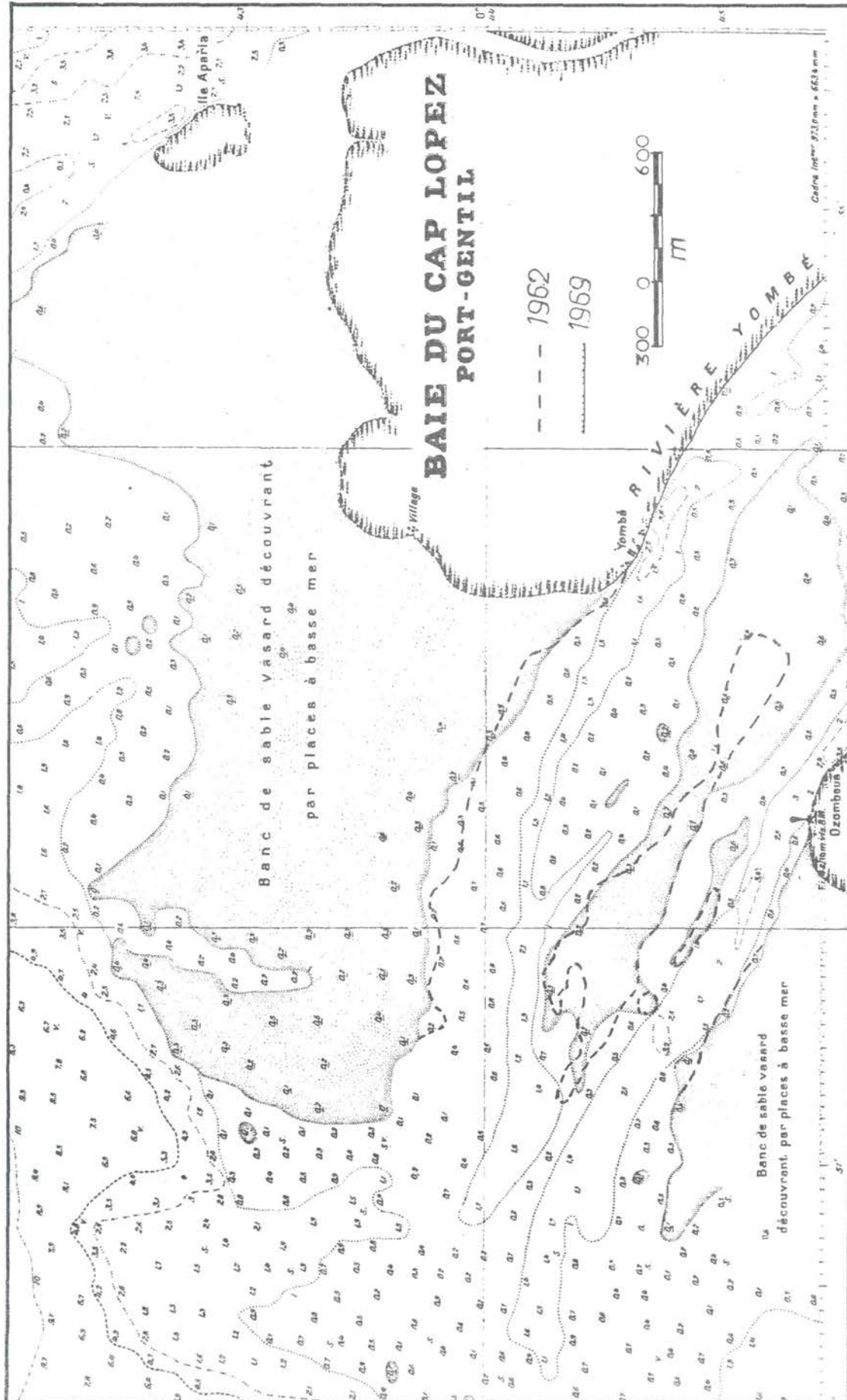


Fig. III.21 - Evolution du banc de sable situé à l'embouchure de la rivière Yombé (au fond de la baie du Cap Lopez), d'après les cartes n° 6446 du SHOM (1962-1969)

Fig. III.21 - Evolution of the sand bank in the mouth of Yombé river (at the far end of Cape Lopez bay) after SHOM charts n° 6446 (1962-1969)

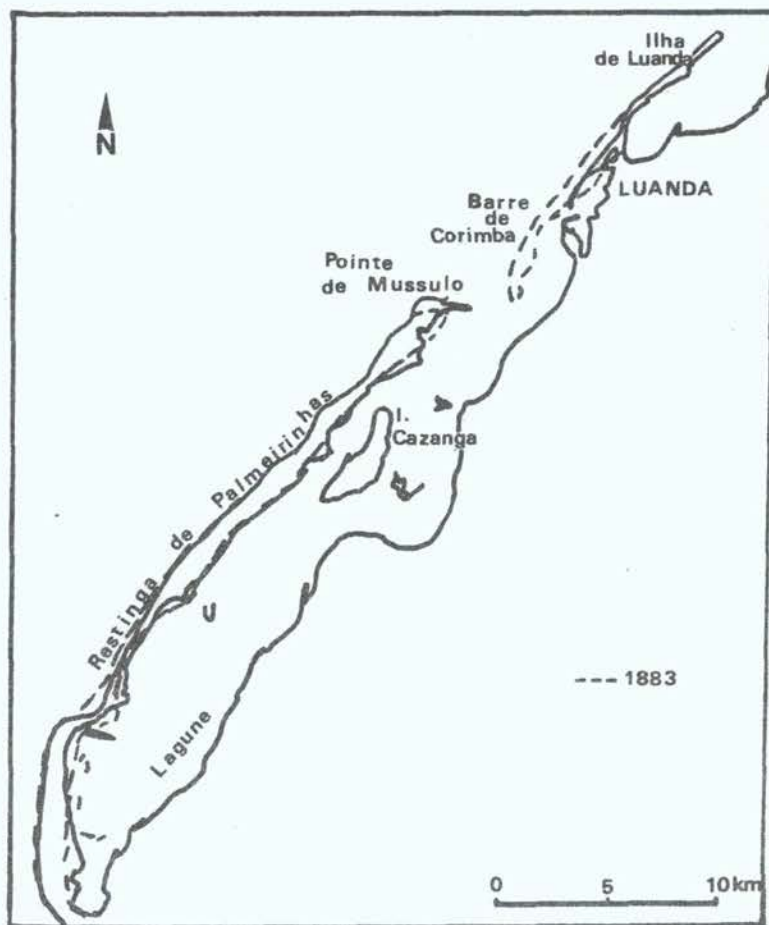


Fig. III.23 - Les restingas de Palmeirinhas et de Luanda.
 In Abecasis (1957) et Guilcher et al. (1974)

Fig. III.23 - The restingas of Palmeirinhas and Luanda.
 In Abecasis (1957) and Guilcher and al. (1974)

Plio-quadernary cliff. The littoral spit, probably started, developing as early as the Miocene (Cardoso, 1966 ; Brognon, 1972). The first Portuguese navigators marked it as early as the XVIth century (Fig. III.22).

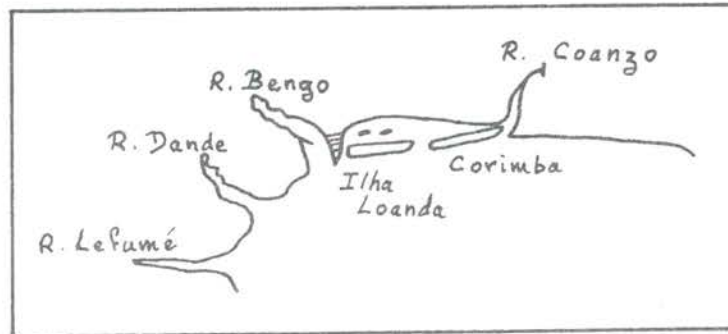


Fig. III.22 - Carte du Roteiro (1617), in Silveira (1953)

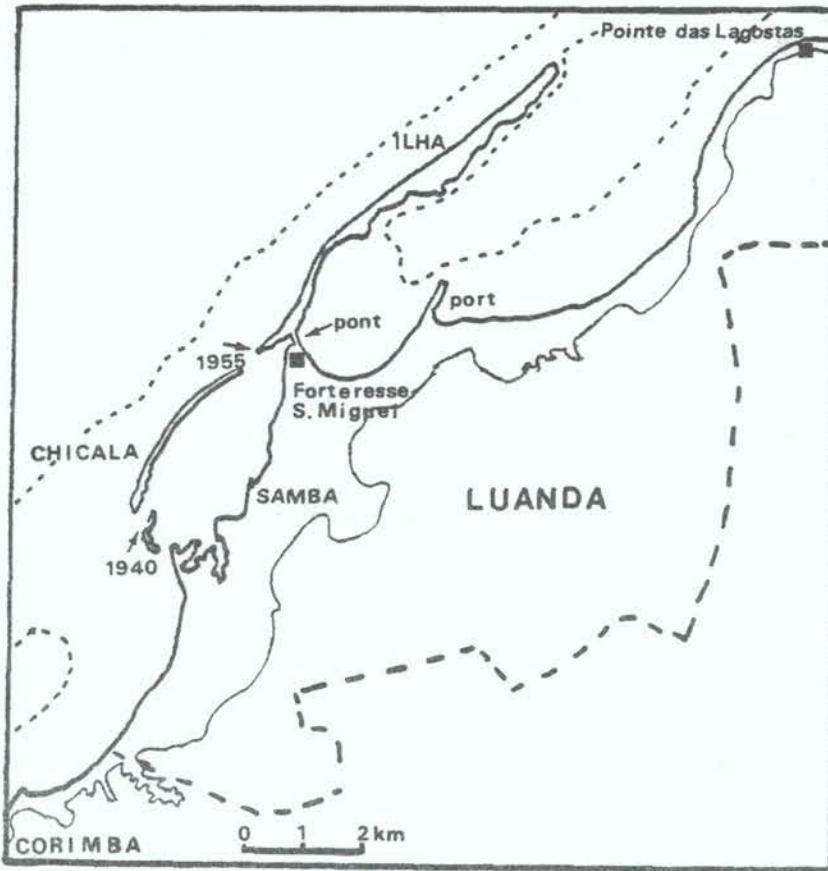
Fig. III.22 - Map of Roteiro (1617), in Silveira (1953)

This spit is split into two parts, their shape and extension being permanently modified : southward, the Palmeirinhas spit, also called Mussulo isthmus, is 34 km long and has a maximum width of 100 m to 2,200 km. In the inner part of the lagoon delimited by this spit, six islands are found, some of them inhabited. The largest one, the Cazanga island (or Sao Paulo of Cazanga) extends over a length of 5 km with a maximum width of 2,100 km. The islands shape is also undergoing changes. Northward, the "ilha of Luanda" is separated from Cape Mussolo by the Corimba spit, a passage currently 4,200 km wide, which constitutes a shallow sill. It has an overall length of 11 km and can be divided into a northern part, the "ilha" itself, which now is 7 km long and 400-500 m wide, and a southern part, the Samba isthmus (Cardoso, 1968) or Chicala (length : 4 km ; maximum width : 0.2 km). During the XIXth century the "ilha" of Luanda was tied to the shore by a bridge leading to the Sao Miguel fortress. Luanda bay is closed by another rocky cliff, the "Ponta das Lagostas".

Historical evolution

The first available scientific document concerning this "restinga" is the 1883 hydrographic survey (scale : 1:50,000) which can be correlated with the 1949 surveys (Abecasis, 1957) (fig. III.24). Many aerial photographic surveys (1947, 1956, 1960, 1973) have allowed to follow the changes of the spit shape.

The Palmeirinhas spit has not spectacular modifications. In its southern part it has, however, been affected by a temporary cut-off, which has not been precisely dated and is currently being rebuilt. Its end, Cape Mussolo, grew by 1,500 m at its northeastern end over a 100 year period. A massive sand accumulation occurred both in the spit and in the lagoon (Abecasis, 1957).



——— trait de côte - coastline

——— courbe de niveau (50 m) - isobath (50 m)

- - - - - ligne des 10 brasses (18,29 m) - 10 fathom contour

- . - . - limite urbaine de Luanda - urban limit of Luanda

Fig. III.24 - Evolution de l'ilha de Luanda. In Van Dongen (1960)

Fig. III.24 - Evolution of the ilha of Luanda. In Van Dongen (1960)

More important changes affected the northern part of the spit : at the end of the XVIIIth century it was about 15 km long and had lost nearly 4 km in length during a century and a half. In the XVIIth century, ships used to enter the harbour through the "Barra of Corimba" and to shelter in the two basins. One of them, in the north, corresponded to the present harbour zone whereas the south basin was sheltered by the south part of the "ilha", Samba isthmus. It is this part that has retreated notably and is represented by a 2 m deep shoal.

In 1940 an island developed due to the breaking of the south head of the spit. As the "ilha" was already connected to the shore by a bridge, a new lagoon has evolved, where sediment accumulation reduces the width of the passage between the Sao Miguel fortress and the "ilha". In 1955, strong storms caused a new break in the southern part insulating a 1.5 km long spit, which since then has been rapidly eroding (Fig. III.24). Finally, the north part of the "ilha" is still progressing toward the NE (Guilcher et al., 1974), its growth being accompanied by a retreat of its SW part. A sand bar along its northern part was already stretching along the "ilha" in the XIXth century (Perestrelo, 1945).

Dynamic interpretation

The origin of the littoral spit has been considered by Brognon (1970) as due to the Miocene shifting of the Rio Cuanza mouth, located in that period farther north, near Benfica. The tendency of the Rio Cuanza mouth to shift toward the south was first formulated as an hypothesis by Troquato and Rocha (1969) and supported by the sedimentological studies carried out by Ramalhal (1969). A relationship between the formation of the restinga and the position of the river mouth was already established by Abecasis (1957). Most of the material was probably delivered by the river and then longshore drifted (Van Dongen, 1960). According to Guilcher et al. (1974), the northern part, the "ilha" of Luanda, is Holocene in age, and the large island of Cazanga most probably corresponds to its old inner part. It could well have developed thanks to the Palmeirinhas spit which shelters it from the southwesterly swell. At present the restingas are thought to be developing under a joint impact of swell, currents and local tide :

- the refracted long swell reaches the shore and the outer part of the restingas, causing predominantly transverse sand movements from the outer slope of the littoral bar towards the coast and inducing its retreat and even disappearance. Plans for the protection of the outer part of Luanda island have been set up by management engineers as early as 1945 (Perestrelo, 1945). First wooden groynes were installed ; then an attempt was made to protect the exposed part of the spit by stone groynes (Van Dongen, 1960) ;

- in the lagoon, the transport induced by the ebb current is more important than that induced by the flood current. Consequently, the outlets opening the lagoon towards the south tend to clog up, whereas those opening towards the north become stabilized and more profound. This would explain (Abecasis, 1957) the erosion of the south head of the "ilha" of Luanda, which is no longer supplied by continental inputs (Guilcher et al., 1974) and the destruction of which feeds the northern part ;

- the local waves are generated by the southwesterly winds and shape smaller inner spits (Guilcher et al., 1974) ; in the outer part, they give rise to predominantly longitudinal movements on the foreshore (Abecasis, 1957).

RÉGION	MODIFICATIONS VOLUMÉTRIQUES CONSTATÉES					
	Atterrissement m ³		Erosion m ³		Total m ³	
	en 66 ans	annuel	en 66 ans	annuel	en 66 ans	annuel
I. — <i>Flèche et lagune des Palmeirinhas au nord de Benguela :</i>						
a) Cordon littoral	+ 86 × 10 ⁶	+ 1,3 × 10 ⁶	- 39 × 10 ⁶	- 0,6 × 10 ⁶	+ 47 × 10 ⁶	+ 0,7 × 10 ⁶
b) Lagune	+ 44 × 10 ⁶	+ 0,7 × 10 ⁶	- 7 × 10 ⁶	- 0,1 × 10 ⁶	+ 37 × 10 ⁶	+ 0,6 × 10 ⁶
II. — <i>« Barra da Corimba » :</i>						
a) Cordon littoral	+ 47 × 10 ⁶	+ 0,7 × 10 ⁶	- 27 × 10 ⁶	- 0,4 × 10 ⁶	+ 20 × 10 ⁶	+ 0,3 × 10 ⁶
b) Lagune	+ 13 × 10 ⁶	+ 0,2 × 10 ⁶	- 17 × 10 ⁶	- 0,3 × 10 ⁶	- 4 × 10 ⁶	- 0,1 × 10 ⁶
III. — <i>Partie sud de l'île de Luanda :</i>						
a) Cordon littoral	+ 17,5 × 10 ⁶	+ 0,3 × 10 ⁶	- 15,5 × 10 ⁶	- 0,2 × 10 ⁶	+ 2 × 10 ⁶	+ 0,1 × 10 ⁶
b) Lagune	+ 2 × 10 ⁶	+ 0,03 × 10 ⁶	- 0,5 × 10 ⁶	- 0,01 × 10 ⁶	+ 1,5 × 10 ⁶	+ 0,02 × 10 ⁶
IV. — <i>Partie nord de l'île de Luanda :</i>						
a) Cordon littoral	+ 39 × 10 ⁶	+ 0,6 × 10 ⁶	- 36,5 × 10 ⁶	- 0,53 × 10 ⁶	+ 2,5 × 10 ⁶	+ 0,07 × 10 ⁶
b) Baie	+ 19,5 × 10 ⁶	+ 0,3 × 10 ⁶	- 18 × 10 ⁶	- 0,27 × 10 ⁶	+ 1,5 × 10 ⁶	+ 0,03 × 10 ⁶

Tableau III.3 - Transits littoraux en différents points dans la région de Luanda (mesures réalisées entre 1883 et 1949). In Abecasis, 1957

Table III.3 - Coastal sand transport at different locations of the Luanda area (measurements carried out between 1883 and 1949). In Abecasis, 1957

The only statistical data currently available go back to 1957 (Abecasis), and they give an idea of the volumes involved in the littoral drift over a 70 year period (Table III.3).

Example 11 : Angola : Tigers Bay (16°35' S)

The most salient feature of the coast of Angola is the occurrence of littoral sand spits or "restingas", the largest being the Tigers spit. They are generated by the littoral sand drift, induced by a SW swell arriving obliquely to the coast.

F. Manzanares Abecasis (1956) describes the Tigers spit as follows : "rooted some fifty km to the north of Cunene river debouchure, it is more or less N.NW oriented and stretches along 35 km. Its width varies between 200 m, near its head, and 5 km at its tip" (Fig. III.25).

Guilcher et al., (1974), who studied this area in 1973, reviews the history of its discovery since 1486, and it appears, from ancient maps, that in the past one or more breaks might have occurred temporarily (some maps show two well-individualized islands).

At present, we should rather refer to the spit as "Tigers island" instead of "peninsula" ; as a matter of fact, the break in the southern end of the restinga occurred in March 1962 (Guilcher et al., 1974) (Fig. III.26). An hydrographic survey, carried out in November 1968, reveals a gap 2,600 m wide. In its southern third, there is a small 15 m deep depression (elsewhere the gap is from 3 to 5 m deep) maintained by tidal currents. The two tips bracketing the gap shifted 1,600 to 2,400 m eastwards (between 1962 and 1968) as compared to the older contours, curving with the refraction and diffraction of the swell. An aerial survey of 1970 shows, besides minor modifications, that the channel migrated (in 2 years) 200 - 300 m northwards ; this is due both to the advance of the new spit and the retreat of the older restinga in the same direction. The modification of the channel width was very insignificant.

Guilcher's survey of 1973 confirms this evolutionary trend and considers it unlikely that this gap should close up again under the impact of tidal currents.

Consequently, small restingas (Fig. III.25) of the eastern coast of the bay are threatened by the swell arriving from the open sea and passing through the channel. Indeed, the largest of these restingas, Joao do Pico, which is double, was significantly modified between 1953 and 1973 (some areas appear to have migrated several hundreds of metres).

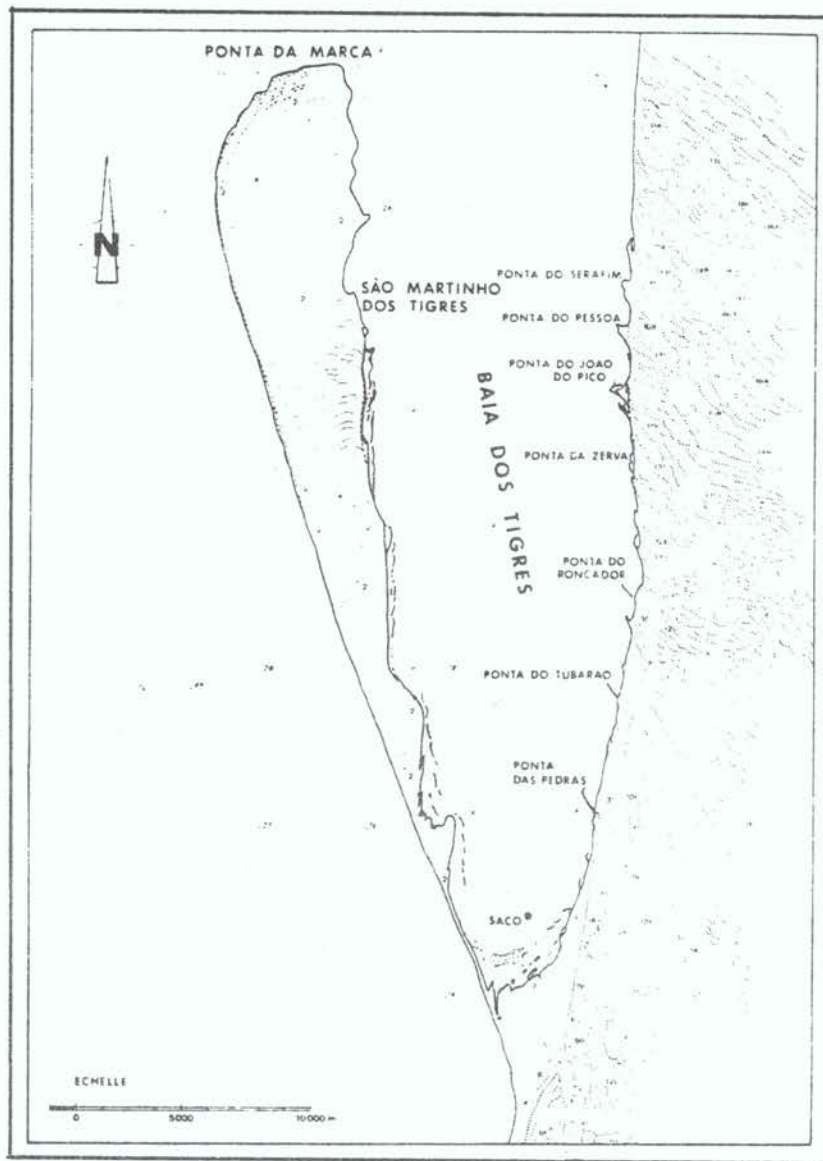


Fig. III.25 - Carte de la baie et de la presqu'île des Tigres avant la coupure de mars 1962. In Guilcher et al., 1974

Fig. III.25 - Map of Tigres bay and peninsula before the break of March 1962. In Guilcher and al., 1974

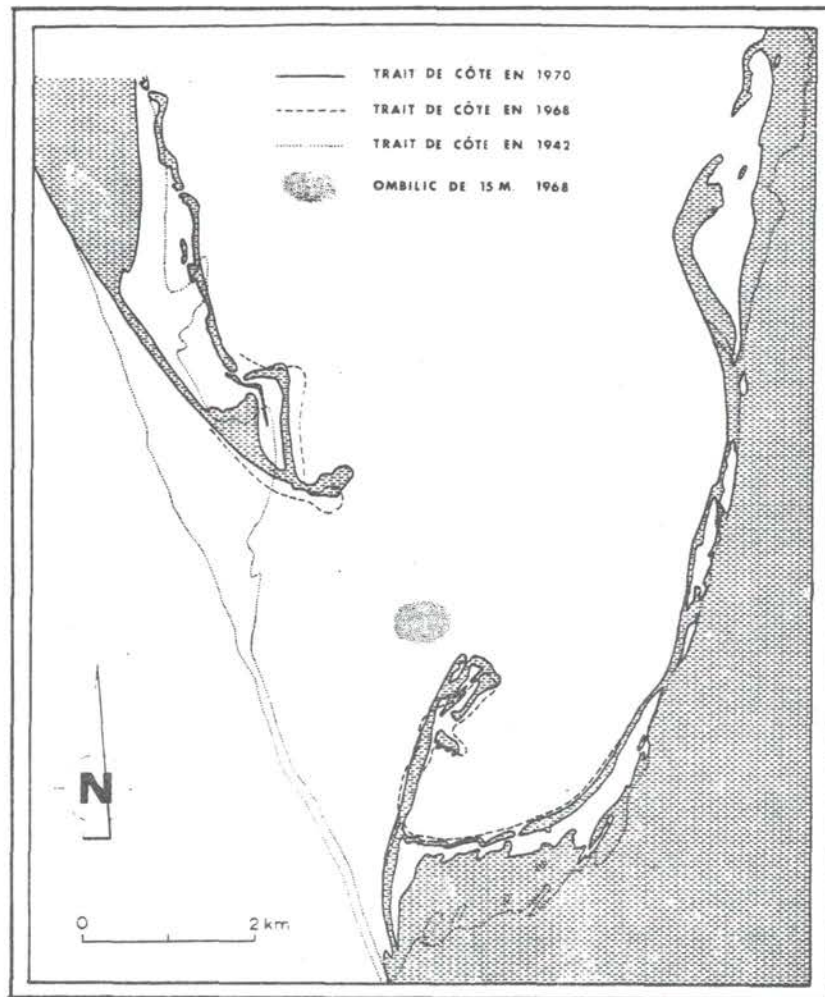


Fig. III.26 - Traits de côte successifs depuis la coupure de 1962. In Guilcher et al., 1974

Fig. III.26 - Successive coastlines since the 1962 break. In Guilcher and al., 1974

III.3. COAST CLASSIFICATION

III.3.1. INTRODUCTION

In this chapter, we will adhere to the general classification of the coasts proposed by Inman and Nordstrom (1971) and will attempt to apply it to the West and Central Africa coasts as proposed by Tastet (1972). In the second part, we will proceed to the subdivision of these coasts in ten geomorphological units.

III.3.2. HISTORY

Since the end of the last century, a number of coastal classifications have been proposed and successfully tried out. They were either genetic, or purely descriptive classifications, or a combination of both. For example, Gulliver (1899) distinguished two types of coasts : "the initial forms" due to continental factors, and "the sequential forms" attributed to oceanographical factors.

Previous coastal classifications were based upon two general criteria, (1) effect of recent changes in sea level, and (2) effect of erosional and depositional processes along the coastline. The classifications proposed by Johnson (1919) and Cotton (1952) are primarily based upon the apparently relative changes in recent sea level, and result in the development of the two principal classifications of "submergence" and "emergence" coasts. Johnson (1919) refers to coasts that do not show evidence of recent sea level change as "neutral coasts", and subclassifies them in accordance with the predominant active coastal process.

Guilcher (1954), like Gulliver (1899), characterize shorelines in accordance with the impact of oceanographical factors, and attempt to develop a classification taking into account their initial shapes :

- "ria coasts"
- "fjord coasts"
- "glacial plains coasts"
- "non-glacial coasts"
- "tectonic coasts".

The classifications of Shepard (1963), modified from Shepard (1948) and Prico (1953, 1955), are based upon a combination of the two criteria mentioned above. In general, Shepard points out that most of the coasts show the effects of both submergence and emergence, and that these terms, therefore, are not particularly relevant. Putnam and al. (1960) classified coasts into morphologic types, based on the dominant processes causing subaerial erosion or deposition. These two authors subclassify coasts as follows :

1) "primary coasts", shaped by terrestrial agencies, are subdivided into: (1) drowned land erosion coasts (ria, fjord, and drowned coasts) ; (2) subaerial deposition coasts (river deposition, deltaic, glacial and wind depositions and landslide coasts) ; (3) volcanic coasts ; and (4) those shaped by diastrophic movements (fault, fold, and sedimentary extrusions) ;

2) "secondary coasts", shaped primarily by marine agencies, are subdivided into : (1) wave erosion coasts (wave-straightened cliffs or those made irregular by wave erosion) ; (2) marine deposition coasts (barrier coasts, cusped forelands, beach plains, mud flats or salt marshes) ; and (3) biogenic coasts (coral, serpulid, and oyster reef coasts, mangrove coasts, swampy coasts).

Because of the complexity of coastal development, genetic classifications were found to be lacking in objectivity ; therefore, the Ottmann classification (1965) is morphologic, and it attempted to interpret interaction between coastal profiles and the adjacent sea floor.

The five morphologic types defined by Ottmann and subdivided further into units are based almost entirely on morphologic criteria and only incidentally on genetic ones. This classification is a precursor of the tectonic and morphologic classification of coasts by Inman and Nordstrom (1971).

III.3.3. CLASSIFICATION OF INMAN AND NORDSTROM

A classification can be considered uniform, if it is based on fundamental criteria capable of applying to phenomena of a similar scale. The authors suggest that there are three major scales associated with coasts. For convenience, they are thought to contain first-, second-, and third-order features, depending on the size of morphostructures they generate.

III.3.3.1. Tectonic classification

1) First-order features

These features are associated with the moving tectonic plates of the lithosphere and generate linear morphostructures of about 1,000 km, onshore-offshore morphostructures (including the continental shelves and the coastal plains) of about 100 km, and vertical morphostructures, rising from the ocean floor to the summits of coastal mountains on the order of 10 km.

In terms of the gross effects of plate tectonics, there appear to be three major classes and several subclasses of coasts :

First class : collision coasts

- continental collision coasts, that is, collision coasts involving continental margins, where a thick plate collides with a thin one (e.g. west coasts of the Americas) ;

- island arc collision coasts, that is, collision coasts along island arcs, where two thin plates come into collision (e.g. the Philippines, and the Indonesian and Aleutian island arcs).

Second class : trailing-edge coasts

- neo-trailing-edge coasts, that is, new trailing-edge coasts formed near beginning separation centers and rifts (e.g. Red Sea and Gulf of California);

- afro-trailing-edge coasts, i.e., those where the opposite coast of the continent is also trailing, with the effect that the potential for terrestrial erosion and deposition at the coast is low (e.g. Atlantic and Indian Ocean coasts of Africa) ;

- amero-trailing-edge coasts, i.e., those along the trailing-edge of a continent with a collision coast ; and, therefore "actively" modified by the depositional products and erosional effects from an extensive area of high interior mountains (e.g. East coasts of the Americas, except the Gulf of Mexico).

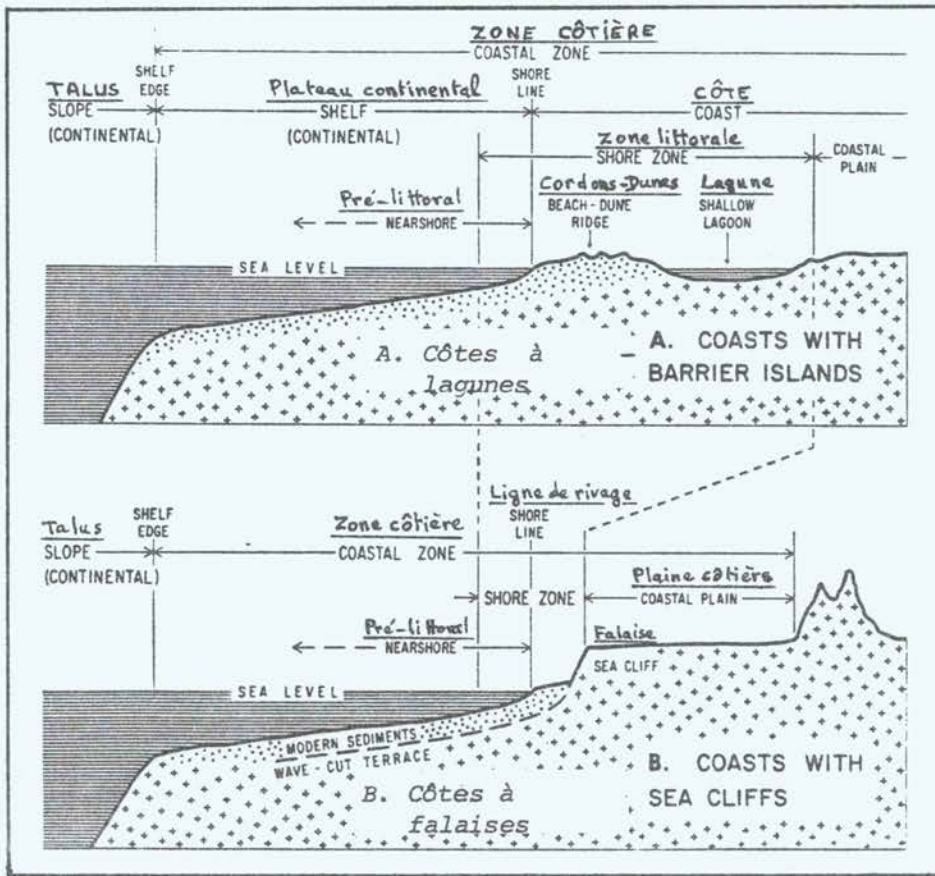


Fig. III.27 - Nomenclature de la zone côtière. In Inman et Nordstrom (1971).

Fig. III.27 - Definition sketch for coastal zone nomenclature. In Inman and Nordstrom (1971)

Third class : marginal sea coasts

That is, fronting marginal sea coasts protected from the ocean by island arcs (e.g. Southern China, and Korea). The shorelines are curved and modified by sediment inputs of big rivers, like the Nile, Huang Ho, Yantze.

2) Second-order features

A second-order scale is mainly associated with erosion and deposition processes that modify the first-order features, and which may attain 100 km, 10 km, and 1 km in length, width and height respectively.

Second-order features include erosional reliefs produced by glaciers, the deltas of major rivers, extensive fields of coastal sand dunes, and are often associated with the growth of organic reefs.

3) Third-order features

These features are those dependent upon wave action, type of material deposited, and sedimentary structures associated with the nearshore transport and depositional processes. They commonly have longshore dimensions of 1-100 km, and onshore-offshore dimensions within the range of 10 m to 1 km.

III.3.3.2. Coastal features

In considering the scale of coastal features, it seems appropriate to define two zones (Fig. III.27) :

- a "coastal zone", based on first- and second-order features ;
- a "shore zone", based on smaller, third- and higher-order features.

The "coastal zone" is defined in terms of large-scale coastal morpho-structures, including first-order features, such as the coastal plain, the continental shelf, and the waters covering the shelf ; and second-order features, such as large bays, estuaries, lagoons, coastal dune fields, river estuaries, and deltas.

The "shore zone" is a sedimentary and solid surface associated directly with the interaction of waves and wave-induced currents on the land and its run-off. The shore zone includes the beach, the surf zone, and the nearshore waters, where wave action is effective in moving bottom sediments.

III.3.3.3. Morphologic classification of coasts

For Inman and Nordstrom, the above considerations suggest that a more easily applicable classification would be one based on the width of the continental shelf and the relief of the coastal landform. A practical coastal classification, based, in part, on a synthesis of the statistics on coastal morphology developed for tectonic features (first- and second-order features), would be as follows :

- mountainous coasts : shelf width of less than 50 km ; coastal mountains 300 m high and above ; rocky cliffed shore zone with occasional pocket beaches;
- narrow-shelf coasts : shelf width narrower than 50 km :

. narrow-shelf hilly coast : coastal hills averaging 300 m and below, forming occasional headlands ; shore zone between headlands with beaches backed by cliffs or occasional barrier lagoons ;

. narrow-shelf plains coast : the shore zone deposits are less extensive, and there may be occasional low sea-cliffs and low headlands ;

- wide-shelf coasts : shelf width over 50 km :

. wide-shelf plains coast : low-lying coastal plains bordered by wide shore zone. This is typified by the amero-trailing-edge coastline ;

. wide-shelf hilly coast : headlands are usually wider spaced by large shore zones ;

- deltaic coast ;

- reef coast : shore zone of the coast consisting partially of resistant material or of organic origin ;

- glaciated coast : coastal features dominated by glacial erosion.

III.3.3.4. Conclusion

The tectonic and morphologic coastal classification of Inman and Nordstrom seems to be the most practical classification, showing fair coherence with the major tectonic features, as well as providing a more easily applicable description of the coast (e.g. at the scale of an individual country).

III.3.4. CLASSIFICATION AND SUBDIVISION OF THE WEST AND CENTRAL AFRICAN COASTS

If we apply the classification criteria of Inman and Nordstrom, the coasts of our study area will obviously belong to the "afro-trailing" type, since they have been selected by these authors as reference-type ; they are also characterized by a rather narrow shelf and by coastal plains, or plateaus.

The subdivision of the African coasts into main subunits takes into account :

- the main orientation of the coasts ; each province being generally bracketed between the main capes, this orientation controls the direction of the longshore drifts dependent on the incidence angle of the prevailing swell (the latter showing only slight variations throughout the year, unlike, for example, that of West European shores) ;

- the width of the continental shelf, whose variations match the subdivision of different coastal provinces ;

- the occurrence of large deltas ;

- the occurrence of submarine canyons notching the continental platform.

Regional subdivision, adopted for this report, will be the following :

1) From the Cape Blanc peninsula to the Cayar canyon (Mauritania to Northern Senegal) : sandy coast, desertic plain, with a generally rather narrow shelf, interrupted by and bounded to the south by the Cayar canyon.

2) From the Cayar canyon to Casamance (Southern Senegal to Gambia): coastal plain with a rather large shelf, progressively more humid and swampy to the south owing to the presence of Saloum, Gambia, and Casamance estuaries.

3) From Casamance to the Sherbro islands (Guinea-Bissau, Guinea and northern half of Sierra Leone) : humid, narrow tropical plain and large shelf.

4) From the Sherbro islands to Cape Palmas (southern half of Sierra Leone to Liberia) : humid tropical coast, narrow coastal plain, very narrow shelf.

5) From Cape Palmas to Cape Three Points (the Ivory Coast and the western end of Ghana) : humid equatorial coast, first rocky, then with a coastal plain, and again rocky, with a narrow shelf.

6) From Cape Three Points to the Lagos lagoon (Ghana, Togo, Benin, Western Nigeria) : humid equatorial coast, with a coastal plain, somewhat rocky to the west, and the shelf of a variable width. This segment is characterized by the presence of the vast Volta delta.

7) Niger delta (Nigeria) : quite well individualized, owing to the large sedimentary supply, shelf of an intermediate width.

8) From the Ria del Rey to Cape Lopez (Cameroon, Equatorial Guinea, North Gabon) : humid equatorial coast, with both rocky and coastal plain coasts, a relatively narrow shelf.

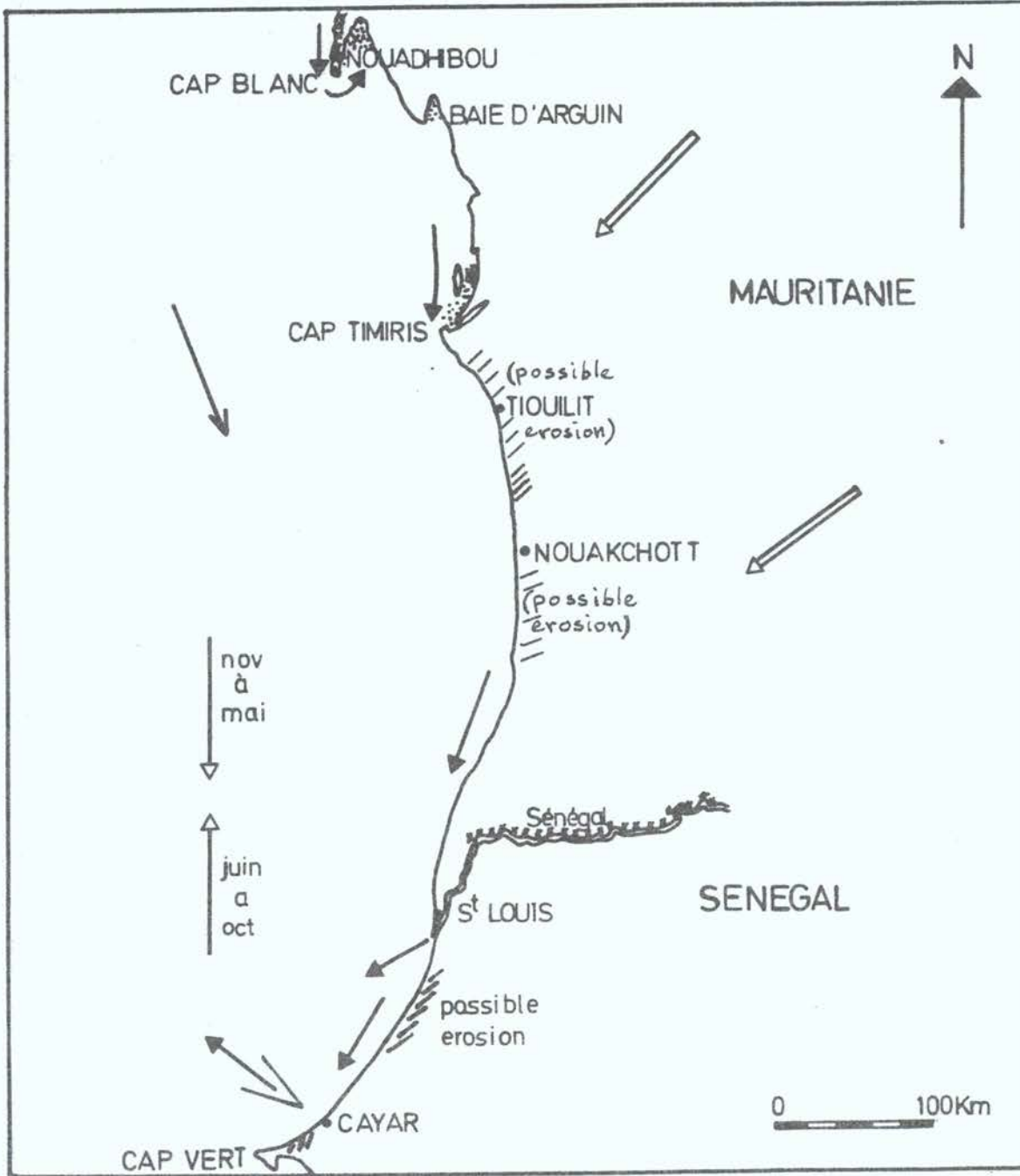
9) From Cape Lopez to the Congo-Zaire canyon (South Gabon, Congo, Cabinda, Zaire) : equatorial plain coast with a narrow shelf, abruptly bounded by the head of the Congo-Zaire canyon.

10) From the Congo-Zaire canyon to the Cunene river (Angola) : tropical coast, progressively arid toward the south, morphologically heterogeneous, with a narrow shelf.



In regional analysis, the object of the last section (IV) of this report, we will adhere to the proposed subdivision into 10 geomorphological provinces for the coasts of West and Central Africa.

Fig. IV.1 - Mauritanie - Nord Sénégal - Analyse régionale, d'après Collins et al., 1983

Fig. IV.1 - Mauritania - North Senegal - Regional analysis, after Collins et al., 1983



- ← transit sédimentaire - littoral drift
- ← courant - current
- ← houle - swell
- ← transport éolien - aeolian transport
- ∨ canyon

-  érosion - erosion
-  sédimentation - sedimentation

IV. REGIONAL ANALYSIS

IV.1. FROM MAURITANIA TO NORTH SENEGAL (Fig. IV.1)

The area extending from Cape Blanc (North of Mauritania), which shelters the harbour of Nouadhibou, to Cape Verde (in the middle of Senegal), constitutes a morphological unity about 790 km long, characterized by a low sandy coast with numerous dunes, spits and offshore bars. Its backland is arid, but irrigated southwards by the Senegal river.

From Cape Blanc to Cape Timiris, the coast makes a recess (north of which Levrier Bay is located), where the continental shelf is widest (120 km). Southwards, the continental terrace is 50 km wide, but reducing, until it becomes 10 km wide off Cape Vert. The continental slope is grooved by several canyons, but only the Cayar canyon (the southern most), can be said to affect littoral sedimentation, its head coming close to the shore.

Offshore, the general currents regime is shaped by the two main seasons: during the season of trade-winds (dry season from December to April), the Canary cold currents run south. The trade-winds also induce upwellings (upward motion of cold and nutrients-enriched waters).

The northwesterly swell greatly prevails (98 %) over the southwesterly one ; its period varies between 8 and 12 seconds, with a 300 m wave length. This swell is strongest during the dry season, the swell affecting the sea bottom at a depth of 30 m during storms. The swell is thus the main factor controlling regional sedimentation. It induces a southward sediment beach drift, owing to coast orientation. The southwesterly swell, noticeably weaker, can produce significant effects during the winter season.

The tidal range is low and favours the development of the observed limited tidal flat : 1.2 m at spring tides and 0.6 m at neap tides (in Pinson-Mouillot, 1980). Tidal currents are generally weak.

During the rainy season (from June to August), a branch of the Equatorial warm Counter-Current can run northwards up to Cape Timiris. The speeds of these two currents are relatively low, about 0.5 knot (Ruffman et al., 1977); they do not seem to be playing any noticeable role in sediment transport.

Off Mauritania, the continental shelf is generally blanketed by fine to medium-sized sands, with less than 20 % of muds (silt + clay). Offshore, on the outer shelf, these sands are mainly bioclastic : they are constituted by shelly remains, faecal pellets, quartz and "glaucconitic" grains (Ortlieb, 1975). Outside the littoral zone, sands have a carbonate content higher than 75 %, most probably the highest in the area from Gibraltar to Liberia. Considering the climatic and geomorphological conditions, terrigenous inputs are almost totally reduced to fine elements transported by northwesterly winds.

Southwards, the continental sedimentation of the Senegalese margin is better known (Domain, 1977 ; Pinson-Mouillot, 1980 ; Sall, 1982) ; sands cover about 40 % of the area and form a littoral strip from Mauritania to the Cayar canyon ; they acquire a slightly muddy component between the Senegal mouth and Fass-Boy. North of the Cayar canyon, muddy sands characterize mainly the middle part of the shelf, attaining their largest development off the Senegal mouth ; their importance decreases with the distance from the Cayar canyon. Muddiest facies and pure muds are concentrated mainly along the outer shelf and sometimes include an important calcareous fraction in front of the upwelling areas (Pinson-Mouillot, 1980). South of the Cayar canyon, the shelf is relatively

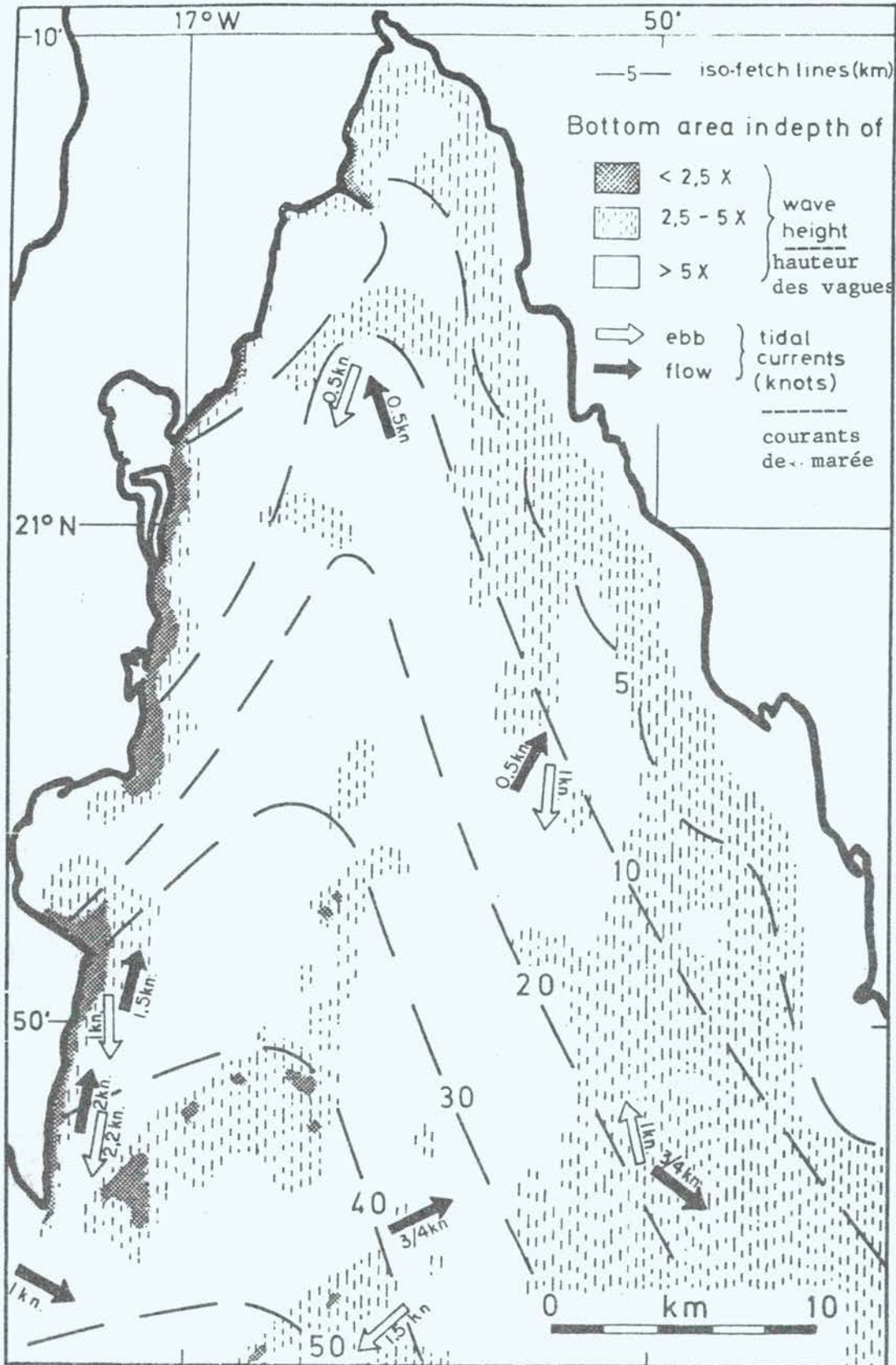


Fig. IV.2 - Baie du Lévrier ; vagues et courants de marée
In Koopman et al., 1979

Fig. IV.2 - Levrier Bay ; waves and tidal currents
In Koopman and al., 1979

narrow and covered essentially by muds (coastal areas), calcareous muds and muddy sands.

From North to South, the morphosedimentary aspects will be studied on a more local basis.

In spite of northern sedimentary inputs, the data in our possession do not allow us to affirm that the shape of the very elongated spit of the Cape Blanc peninsula (about 50 km) -armed with Quaternary argillaceous and gritty formations- has been modified since the maps were drawn (cf. III.3., example 1).

Levrier Bay (Fig. IV.2) (800 km², less than 20 m deep) is protected by that peninsula and a noticeable accretion induces an inshore sea retreat in Cansado Bay (Nouadhibou) (example 1, chap. III.2.).

Desert climate reduces the sedimentary inputs to a rather limited littoral fringe, where silty muds are mixed with dune sands and aeolian dust. Those inputs might be responsible for local erosion of the Pleistocene shore cliffs (Koopmann et al., 1979).

South of Levrier Bay, the large Arguin bank s.l. extends to Cape Timiris, covering about 15,000 km²; the main part of this shoal is less than 4 m in depth. It is covered mostly by bioclastic sands (Piessens and Chabot, 1977). Considering its extension and shallow waterdepth which makes it very sensitive to the swell action, this morphosedimentary structure must be playing an important part in the sedimentary supply process of the whole area to the south. This shoal constitutes a natural barrier to the water circulation between the shoal and the coast itself, particularly, in Arguin, Tanoudert and St Jean bights, and the channels separating southern islands (Tidra island,...). In these areas, a muddier sedimentation develops at shallow depths (Piessens and Chabot, 1977) with a trend to accretion (Collins et al., 1983).

In front of Cape Timiris, i.e., where the shelf narrows notably, the Tiouilit canyon may well drain toward the deep sea part of the southern sedimentary transit, because its canyon head(s) seem(s) to reach a waterdepth of 50 m close to the shore (Einsele et al., 1977). That could well be one of the causes of coastal erosion observed 30 km north of Nouakchott (Chen et al., 1981).

The coast limited by Nouakchott and the Senegal river represents a succession of offshore bars which isolate lagoons and swamps. Such type of coast may imply that the corresponding shoreline is not subject to erosion processes. However, Collins et al. (1983) suggest that the building of Nouakchott harbour could modify the coastline to the south. There is, however, no evidence at present to support that hypothesis.

The morphology of the whole Mauritania littoral fringe as far south as the Barbarie spit (on the border with Senegal) testifies to the importance of the littoral drift estimated at 2,700 m³ of sediments per day, in the vicinity of that spit, and totalling one million m³ per year (Pinson-Mouillot, 1980), or, on the basis of a conservative estimate, 200,000 - 450,000 m³/year (Barousseau, 1980). This drift is responsible for the shape of the large sandy "Langue de Barbarie", which drifts towards the South, the Senegal river mouth (cf. III.2., example 2). The significance of the drift is clearly indicated by the development of dune bars onshore, and of a submarine sand bar 100 m offshore, sometimes doubled by a second bar located slightly further (400 m).

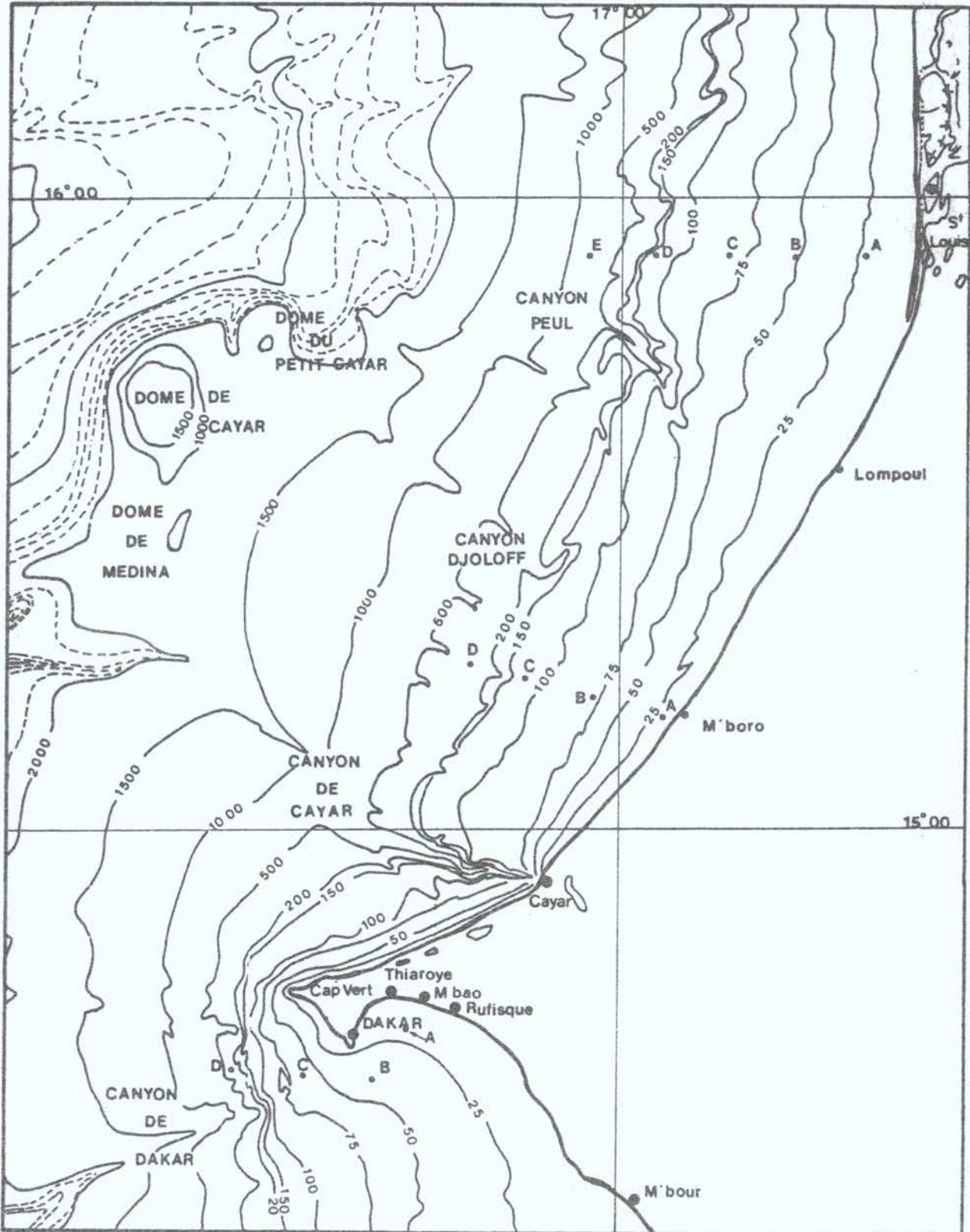


Fig. IV.3 - Carte bathymétrique du plateau continental du Nord-Sénégal (d'après Ruffman et al., in Baffin, 1977)

Fig. IV.3 - Bathymetric map of the North Senegal continental shelf (after Ruffman and al., in Baffin, 1977)

The lower course of the Senegal river faces true west, but its mouth is shifted to the South by the erection of the Barbarie spit which canalizes, towards the South, the mouth of this river over about 30 km. The characteristics of this river are as follows (Rochette, 1974 ; Domain, 1976 ; Pinsot-Mouillot, 1980):

- flowrate : 24 milliards m³/year ;
- average turbidity in the estuary between 50 and 58 mg/l ;
- solid discharge in the mouth (1976) : around 1 million tons/year ; this drift is, in fact, negligible when compared to the sedimentary littoral drift from Mauritania.

Two dams are being built on the river : at Diama 27 km upstream from St Louis, and at Manantali 1,200 km more upstream ; Sall (1982) anticipates a 500,000 t/year plugging at Manantali, and a more important one at Diama. These structures will most probably modify the river behaviour as well as the solid particles output in the marine environment, given the rate between the solid discharges, as estimated at the river mouth and at the "Barbarie Bar" level.

Moreover, the development of a waterway and an entrance channel are planned upstream of St Louis, to avoid navigation inside the Barbarie spit (Sall, 1982). Their construction will require the dredging of 200,000 m³ of rock and 175,000 m³ of sand ; one may expect that detailed studies have been carried out so as to avoid the filling of this channel by the major north-south sedimentary transit.

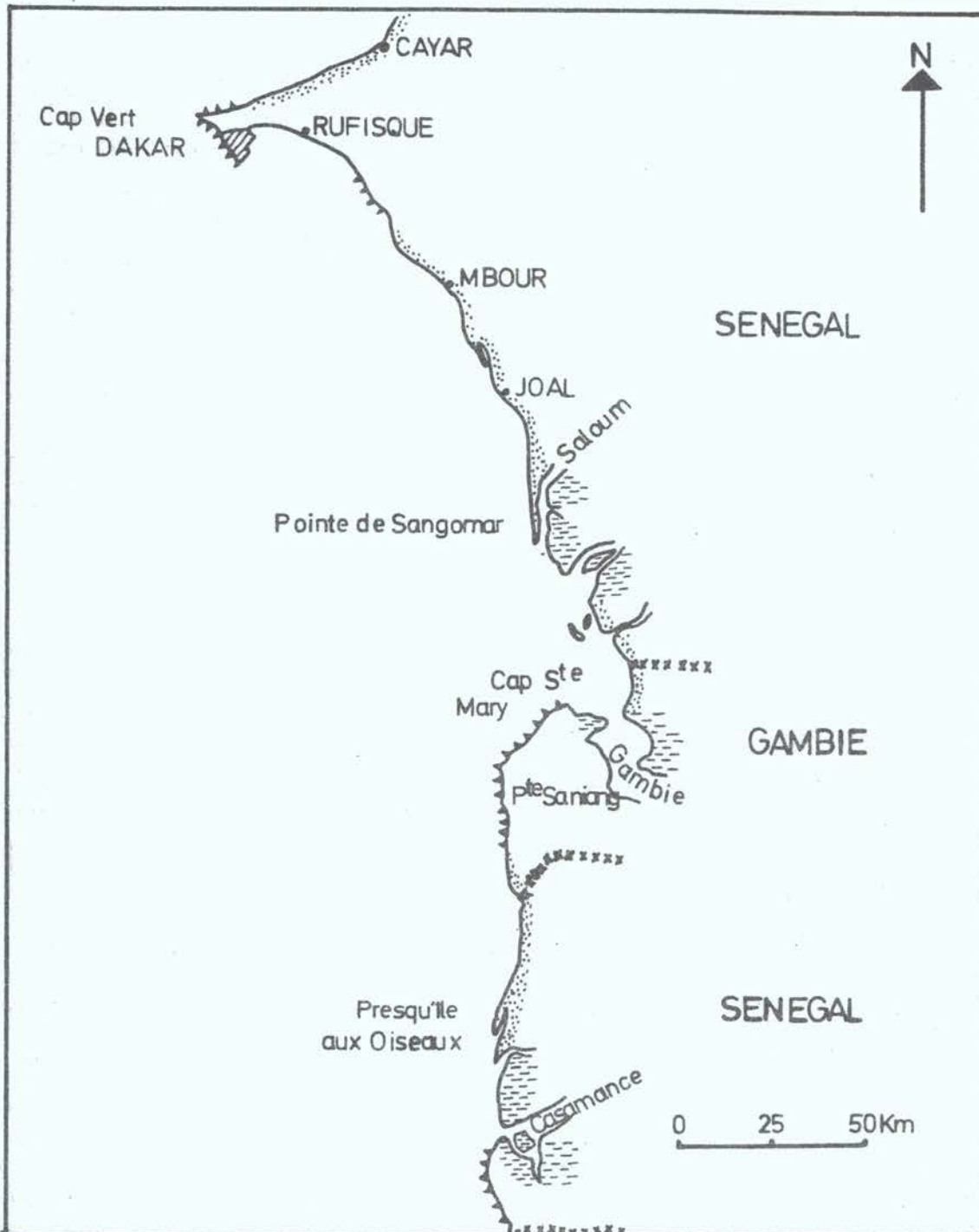
From the Barbarie spit to Cayar, the swell obliquity to the coast is still augmenting, reaching 56°, and thus strengthening the beach drift towards the South. One can find more detailed information on currents, swells, sediments, geomorphology,..., in the feasibility site study made in 1977 by BRGM, in view of the future development of Port Sedar, north of Cayar.


According to Pinson-Mouillot (1980), "the examination of aerial photographs reveals the presence of turbide convolutions, more or less connected to the shore, at the most salient points of the coastline. Those convection cells would reprocess a part of the longshore sedimentary drift by conveying it beyond the bar, in the opposite direction of the littoral drift, thus slowing down coastal erosion in that area".

The Cayar canyon (Fig. IV.3) represents one main feature among those characterizing sedimentation off West Africa, as it abruptly stops sedimentary processes on the Mauritania - North Senegal margin by trapping a major part of the sandy littoral drift (Dietz et al., 1968 ; Horn et al., 1974 ; Ruffman et al., 1977).

The negative sedimentary budget due to the trapping of the longshore sediment transport by canyons, is mostly balanced by northeasterly eolian inputs of dust and sand (chap. II.5.). Lepple (1975) evaluates the annual eolian input at 260,000 m³/km of coastline.

In conclusion, sedimentary processes in the northern part of the West African margin are controlled by a large longshore sediment drift, running N - S towards the Cayar canyon which carries most of it towards the deep sea bed. Any coastal structures will, therefore, have to be built with a view of that primordial factor, to avoid coastal erosion they are likely to induce downstream of their location.



 falaises - cliffs

 cordons sableux - sandy coastline

 mangrove - mangrove

Fig. IV.4 - Principales unités morphologiques du Sud-Sénégal et Gambie (Sall, 1982 ; complétée par les auteurs)

Fig. IV.4 - Main morphological units of Southern Senegal and Gambia (Sall, 1982 ; completed by the authors)

IV.2. SOUTH SENEGAL - GAMBIA (Fig. IV.4)

The southern half of Senegal and Gambia represents a unit characterized by two main features : the offset towards west of the Cape Vert peninsula and the important river network constituted the low zones of the Saloum, Gambia and Casamance estuaries.

The Cape Vert peninsula is shaped as an irregular triangle : its E-W, NW-SE and SW-NE sides correspond to major fractures responsible for the Mamelles Neogene volcanism, which induced the formation of the large tombolo connecting the mainland to the old volcanic island.

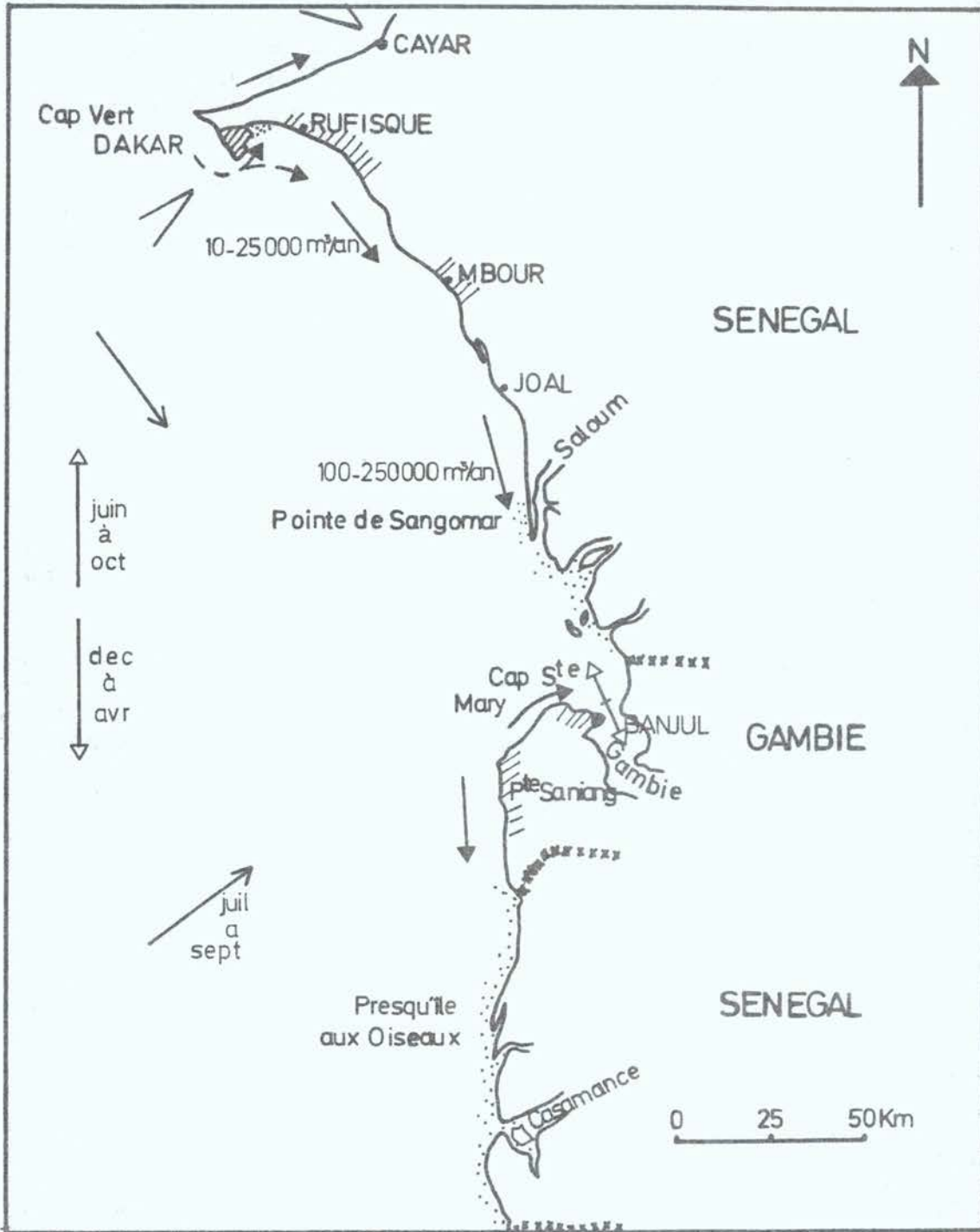
The whole backland is occupied by the Senegal sedimentary basin, where coastal fluvio-marine deposits outcrop together with, between Dakar and M'Bour, the clayey-arenitic deposits Maestrichtian on the N'Diass horst and Eocene to Oligocene of the "continental terminal" formation. South of the Cape Vert peninsula one may successively distinguish :

- Rufisque Bay which extends as far south as Popenguine and is part of the "Petite Côte" (small coast) south to Joal ;
- the low zones with swampy islands and mangrove vegetation of the Saloum, Gambia and Casamance estuaries.

From Rufisque to M'Bour, the coast displays, even if slightly marked, an echelon-like arrangement, which is obviously related not only to the tectonic, but also and mainly to differential erosion : the majority of the capes, although not salient, correspond to more resistant rocks (limestones, sandstones). From M'Bour to Casamance, the coastline trends approximately N-S. The grading of the coastline has to be considered as a consequence of the Nouakchott transgression (Holocene, cf. chap. II.6.) which favoured the formation of offshore sandy bars.

The continental shelf is narrow off the Cape Vert peninsula and almost non-existent west of the Almadies head. In front of that head, two canyons, the Sarakolle Deep and, particularly, the Dakar canyon (Fig. IV.5) cut through the continental slope ; as a result of the submeridian direction of the continental edge from the Cape Vert spit to the Casamance river and of the bending of the coastline, the continental terrace increases progressively, extending over about 100 km in front of Casamance.

As regards the general oceanic circulation, the winds and swells regime (Fig. IV.5.), the situation here is comparable to the one which prevails off the Mauritania - North Senegal area. It induces a general southwards sedimentary transit. Let us recall that, on the northern coast of the Cape Vert peninsula, the longshore drift creates a NE littoral transport towards the Cayar canyon (Riffault, 1980). However, the Cape Vert peninsula disturbs hydrodynamic processes (Fig. IV.6) as it obstructs the swell (mainly northwesterly) propagation; it brings on swell rotation accompanied by diffraction on the Almadies head and Cape Manuel, and then refraction due to the reducing waterdepth. That causes a decrease of the swell energy as it enters the sheltered area -north of the bay of Rufisque, which is the Bay of Gorée-, and is the reason, according to Riffault, for a local divergence of the drift in front of Rufisque. The tide is low and the tidal range reaches 1.60 m at spring tides ; tidal currents are weak compared to the swell-induced ones (Masse, 1968).




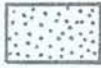
- ← transit sédimentaire - littoral drift
- ← courant - current
- ← houle - swell
- ∩ canyon
-  érosion - erosion
-  sédimentation - sedimentation

Fig. IV.5 - Sud Sénégal - Gambie - Analyse régionale d'après Collins et al., 1983

Fig. IV.5 - Southern Senegal - Gambia - Regional analysis after Collins et al., 1983

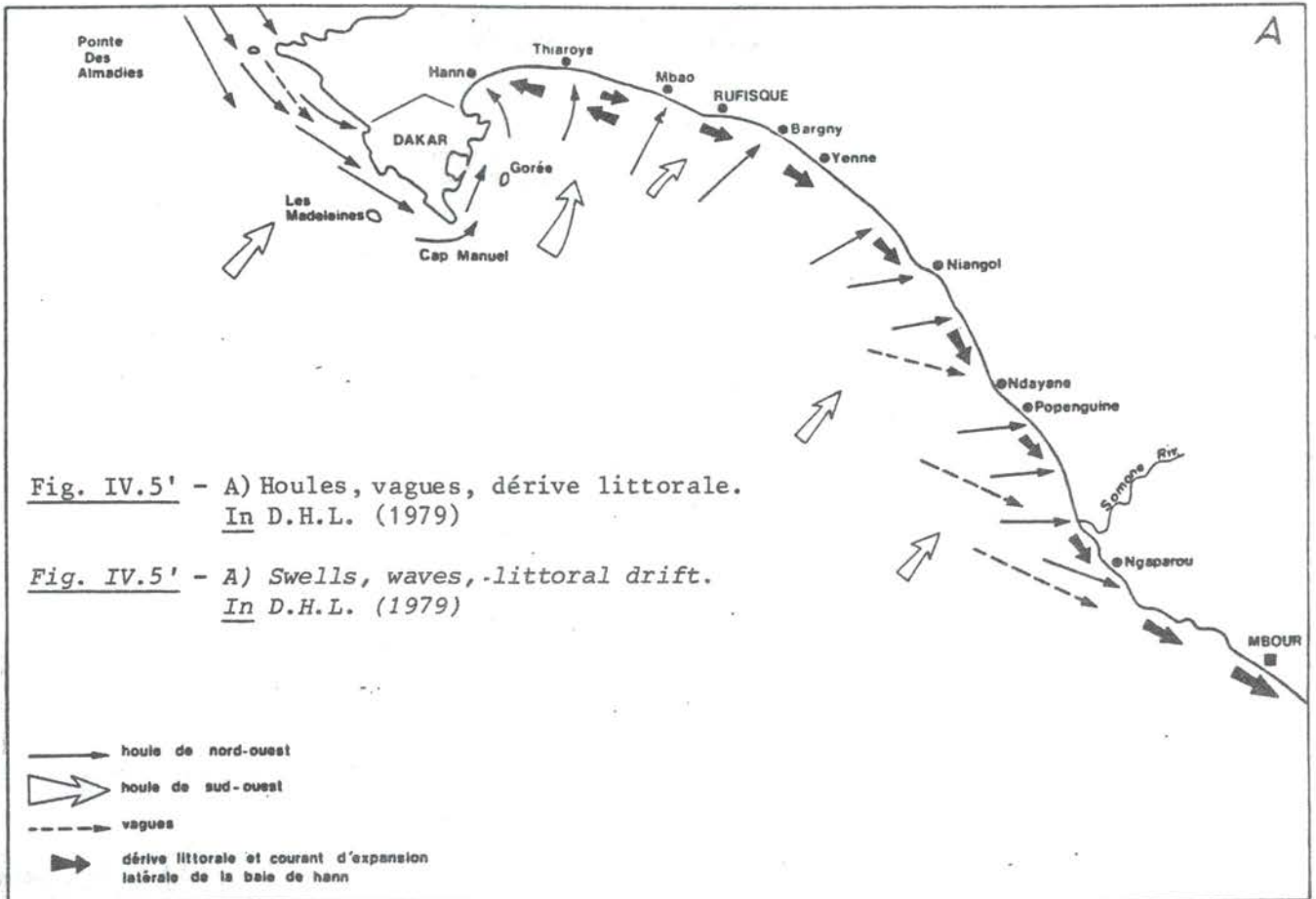
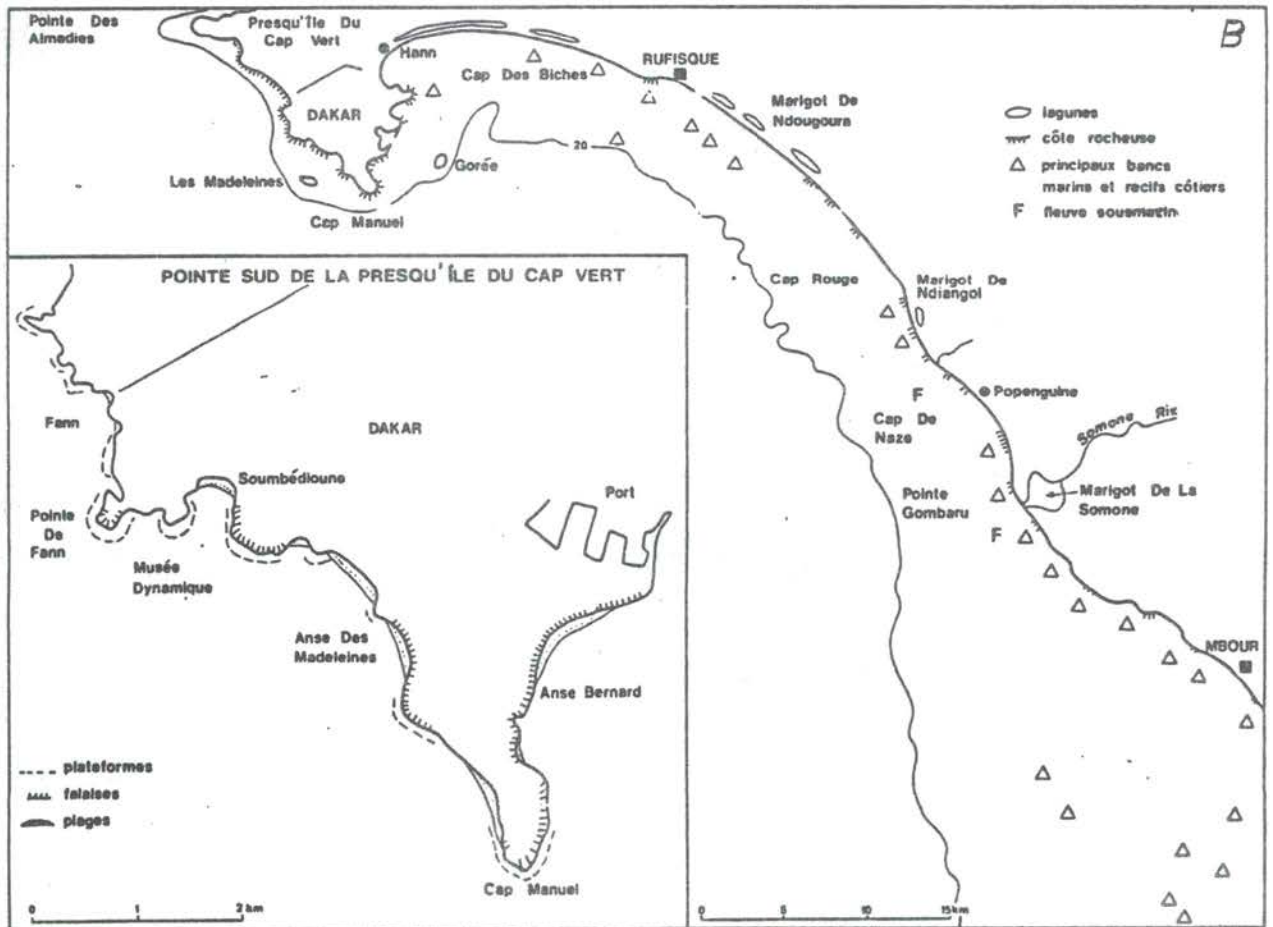


Fig. IV.5' - B) Configuration de la côte. In D.H.L. (1979)

Fig. IV.5' - B) Coastal morphology. In D.H.L. (1979)



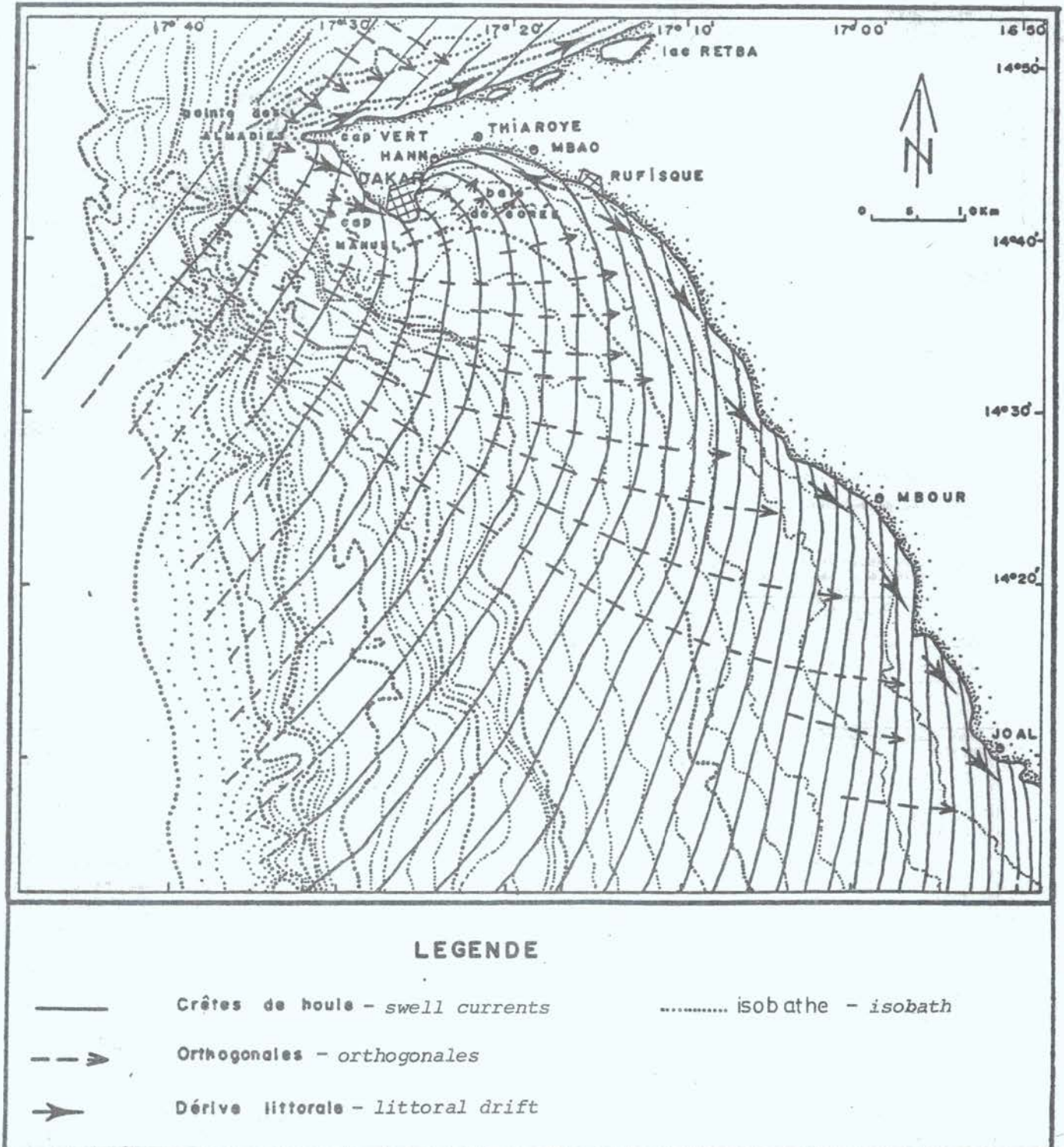


Fig. IV.6 - Plan de houle au large du Sénégal central, pour une houle du NW
In Riffault, 1980

Fig. IV.6 - Wave refraction diagram off Central Senegal, for a NW swell
In Riffault, 1980

Data on the nature of the loose sediments cover is given on a general map (Domain, 1977), and as for the area extending from the Cape Vert peninsula to Joal- one can refer to Riffault's work (1980). The most important part of the continental terrace of that area is covered by medium to gross-grained sands displaying a significant calcium carbonate content. This large sand belt extends as far south as Casamance with the exception of a few silty to muddy superficial deposits in front of the Saloum - Gambia system ; from the Casamance and further south, muddy sedimentation tends to prevail due to the river influence.

Some areas of the Cape Vert peninsula are eroded : erosion of some beaches and cliffs has been registered during field surveys (Quélenec, 1984) between the head of the Fann spit and Cape Manuel (Fig. IV.5' B).

Specific hydrodynamic conditions in Gorée Bay are supposed to be the factor favouring sedimentation. However, due to the rather limited sediments input, sedimentation rate remains low (Fig. IV.5' A).

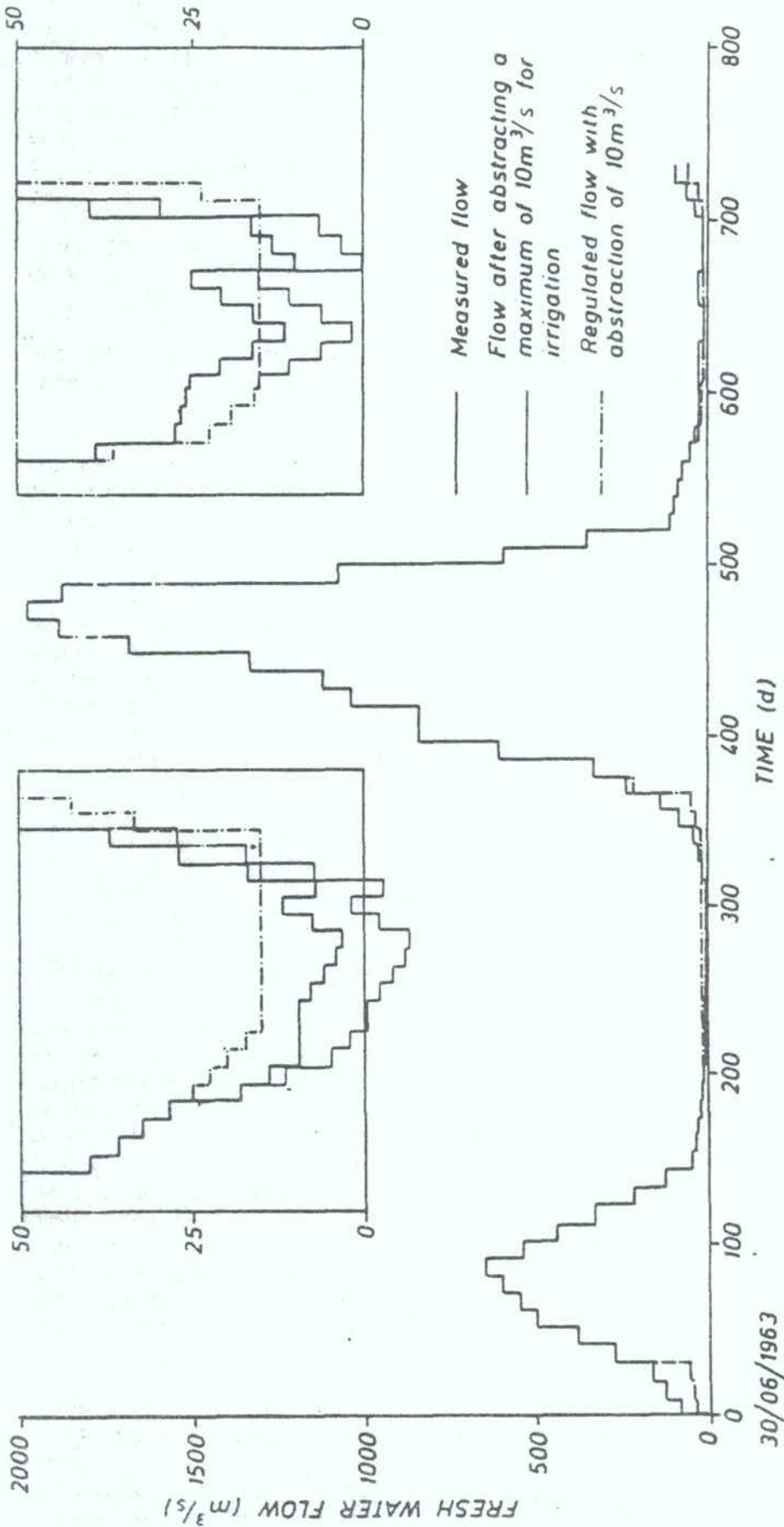
Further south, between "Cap des Biches" and Rufisque, the coast is subjected to erosion inducing an average annual coast retreat of 33 cm for the period 1969-1978 at the cliff of "Cap des Biches" (Sall, 1982). The coastline retreat at the latitude of Rufisque has already been detailed in chapter III (§ 2) : it is known to have totalled 1.30 m/year during 1933-1980.

The "Petite Côte" (Barusseau, 1980) represents a segmented zone, made up of compartments, each including an eroding northern part and a accumulating southern cell. For example, in front of Sarène, the coast is thought to retreat -according to an oral testimony- by 10 m during the last 5 years, while at the same time a spit is forming 10 km farther south. Still, according to Barusseau, 10 to 25,000 m³ of sediments are drifting yearly along the "Petite Côte".

A better understanding of erosion phenomena in that area was obtained during feasibility studies for the Bargny harbour project (BCEOM - BRGM, 1980). The "Petite Côte" is in a stage of unstable equilibrium and some areas, such as Bargny, "Cap de Naze", M'Bour and Joal are currently being eroded.

The Saloum and Casamance estuaries have been studied by Sall (1982). River inputs are low and the reversing tidal currents do not transport any significant amount of sand, except in the channels of the rivers mouths and in their offshore extensions represented by low tidal channels. Changes observed in the sandy bars off river mouths result from tidal currents and swells recycling, rather than from a true clogging up. The analysis of the sedimentary output indicates, however, that the ebb residual circulation prevails in tidal deltas, which extend offshore from the rivers mouths. The Saloum river outlet is shaped as a very narrow channel, limited westwards by the Sangomar spit, also exceedingly narrow and extending over 20 km. The approaches of that river mouth are characterized by shallow shoals (north, west and east banks), apparently sandy in nature and constituting a changing morphology according to the studies, carried out as early as 1895, of the entrance channel to Kaolack. The maintenance of that channel required the dredging of 150,000 m³ of sand between 1950 and 1956.

The evolution of the southern part of the Sangomar spit was also studied by Sall (1982) who took into account various profiles measured since 1895 (chapter III.2.). The sand spit was found to have progressed some kilometers southwards, the general trend, however, marked by stability and even regressive periods. From 1950 to the present time, the annual progression rate has varied

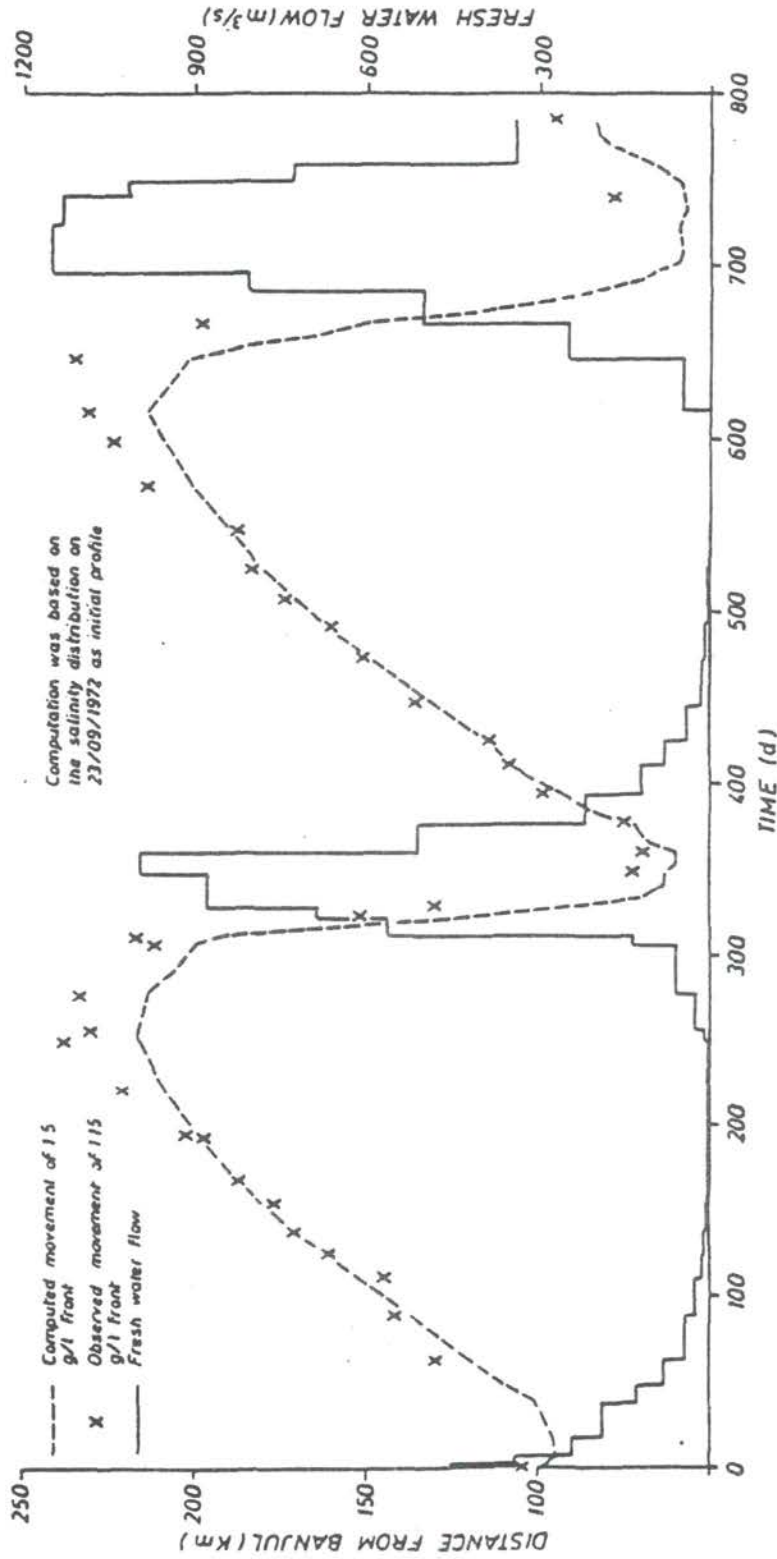


**THE GAMBIA ESTUARY
HYDROGRAPH AND ABSTRACTION RATES
1.7.1963 TO 30.6.1965**

(From the Hydraulics Research Institute, Wallingford).

Fig. IV.7 - Courants de marée dans l'estuaire de la Gambie. In Collins et al. (1983)

Fig. IV.7 - Tidal currents in the estuary of Gambia. In Collins and al. (1983)



THE GAMBIA ESTUARY - PREDICIED AND OBSERVED SALINITY ADVANCE

23 - 9 - 1972 TO 17 - 11 - 1974

(From the Hydraulics Research Institute, Wallingford).

Fig. IV.8 - Estuaire de la Gambie : avancée de la salinité prévue et observée. In Collins et al., 1983.

between 10 and 20 m. The volume of the sand drifted southwards along the spit averaged 100,000 to 250,000 m³/year (Minot, 1934 ; Sall, 1982). That spit may be affected by erosion both on its inner and outer sides : the Diakhanor village, for example, situated in the seaward northern third of the spit, was located 3 km inshore in 1895, while in 1925 it migrated to 80 m from the shoreline ; simultaneously, the southern extremity of the Sangomar spit extended by 400 m southwards. The erosional retreat of the spit may seem catastrophic during storms or tidal waves, but the induced cuts remain occasional, and calm weather conditions favour the re-building of the spit.

Apparently no significant study has been devoted to the Gambia mouth. According to Collins et al. (1983), strong tidal currents may have prevented the development of swamps in front of that estuary. Given the shape of the coast (notably between Cape-Ste-Marie and Solifor Head, or Bald Head, oriented SW-NE) and the seasonal hydrological regime of the river inputs, the mechanism of the sedimentary transports must be rather more complicated. The interpretation of aerial photographs indicates that littoral drift diverges between Cape Bald and Cape Saniang. Sand bars development is likely to occur during low river discharge, while during floods those bars might be destroyed.

The Casamance low tide delta, as well as the Saloum one, is constituted of numerous channels cut by subtidal channels used for navigation. However, unlike the above example, navigation is safer and that explains lack of hydrographic surveys. The relative stability (or reduced mobility) of the channels suggests, according to Sall (1982), that the coastal sedimentary transit, active north of the river mouth (and marked by a rapid growth of the existing Oiseaux island spits), is shifted off the Casamance mouth down to 5 m of waterdepth. That might be due to the prevailing ebb flow.

IV.3. FROM GUINEA-BISSAU, GUINEA, SIERRA LEONE TO THE SHERBRO ISLANDS

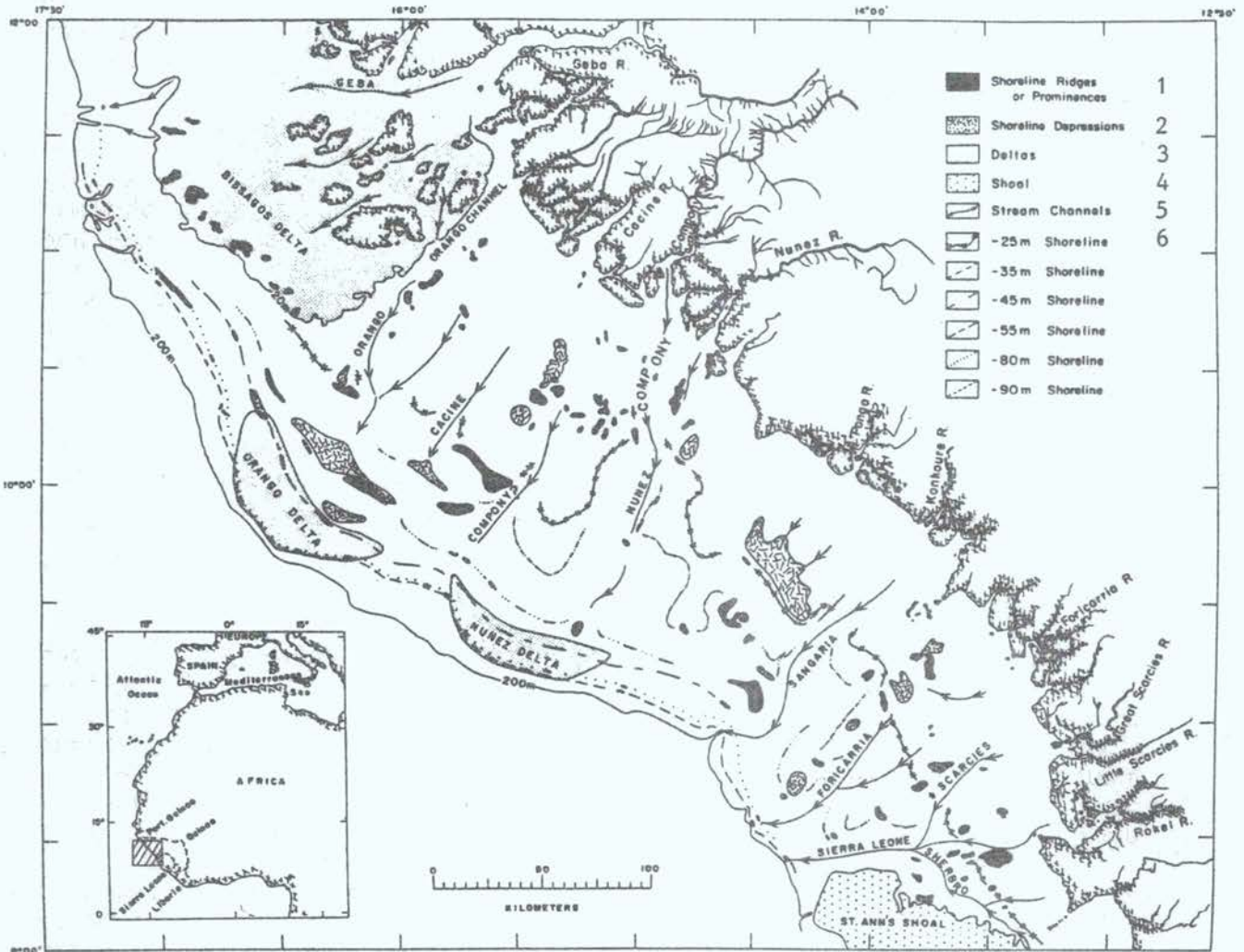
This well-distinct morphological unity stretches over 700 km from Casamance to the Sherbro Islands at the latitude of central Sierra Leone (south of Freetown). The continental shelf is narrow at its northern and southern extremities but considerably widens in its central part reaching 200 km, which is the highest value observed on the "WACAF/3" shelf sector.

The coastline running N.NW-S.SE is bounded in its northern half by a basin filled with Paleozoic sub-horizontal layers, and in its southern half by pre-Cambrian and Paleozoic igneous formations. The morphology of the platform is rather complex and characterized by the extensive delta of the Bijagos and its related network of valleys and submerged deltas, and farther south, by the great Ste Anne Bank located between Sherbro and Freetown. The valleys of the Bijagos system follow seawards the existing hydrographic network and extend towards the deep seabed as canyons (Fig. IV.9, and McMaster et al., 1970). The most remarkable structures are from north to south : the Geba plateau ; the still active Bijagos submarine delta limited by the 20 m isobath and extending far offshore and lineated by numerous low islands ; two smaller submarine deltas fringing the continental edge (Orango and Nunez deltas) ; many prominences and drowned channels from the Orango channel to the Sherbro-Sierra Leone channel ; and finally, the large Ste Anne shoal limited by the 20 m isobath and considered as the left bank of the old Sherbro-Sierra Leone river bed.

The loose sediments have been irregularly mapped ; according to McMaster et al. (1971) they are mainly medium to fine-grained sands whether terrigenous or not. The non-terrigenous stock predominates on the outer shelf and that might well indicate that during the pre-holocene regression, the terrigenous inputs were transported directly down to the deep seabed. Important detrital sandy deposits are however present in the Orango submarine delta, close to the continental edge. According to McGrail (1977), much finer sediments (silts and clays) have been formed exceptionally in the Bijagos delta. Results of a recent side scan sonar and sampling survey carried out by Kudrass and Newton (1984) show that fine sediments (muds and silts) may extend as far offshore as the continental edge ; this implies that substantial river inputs during the rainy season by-pass estuary zones. In the same area the authors noted the presence of sandy mega-ripples, especially on the Ste Anne Bank. The shape and orientation of these ripples lying below less than 30 m of water testify to the presence of a northeasterly sedimentary transport, probably induced by the prevailing NW swells.

One has to bear in mind that the rainfalls in this area amount to 2 to 4 m during summertime (from May to November). A big part of the fine detritic river inputs is probably trapped in the muddy estuaries where mangroves prevail. A significant area of these estuaries is mainly linked (Guilcher, 1954) to a rather high -when compared to the West African ranges- tidal range which characterizes that zone (it may attain 7 m in the Compony estuary, close to the boundary between Guinea-Bissau and Guinea) ; their development could be attributed to the large width of the continental terrace.

The shape of these coasts classified as "deltaic coasts with a wide continental shelf" indicates a NW littoral drift (Fig. IV.10) corresponding to the regime of the S to SW prevailing winds (Gorshkov, 1978). This is confirmed by the examination of aerial photographs displaying a generally NW stretching of the littoral bars ; it has to be born in mind that the northern border of Guinea-Bissau separates the two main swell regimes affecting the Atlantic



- 1 rides ou proéminence
- 2 dépression
- 3 delta
- 4 haut-fond
- 5 chenaux
- 6 ligne de rivage

Fig. IV.9 - Géomorphologie du plateau continental au large de la Guinée-Bissau, la Guinée et la Sierra Leone. In McMaster et al., 1980

Fig. IV.9 - Geomorphology of the continental shelf off Guinea Bissau, Guinea and Sierra Leone. In McMaster et al., 1980

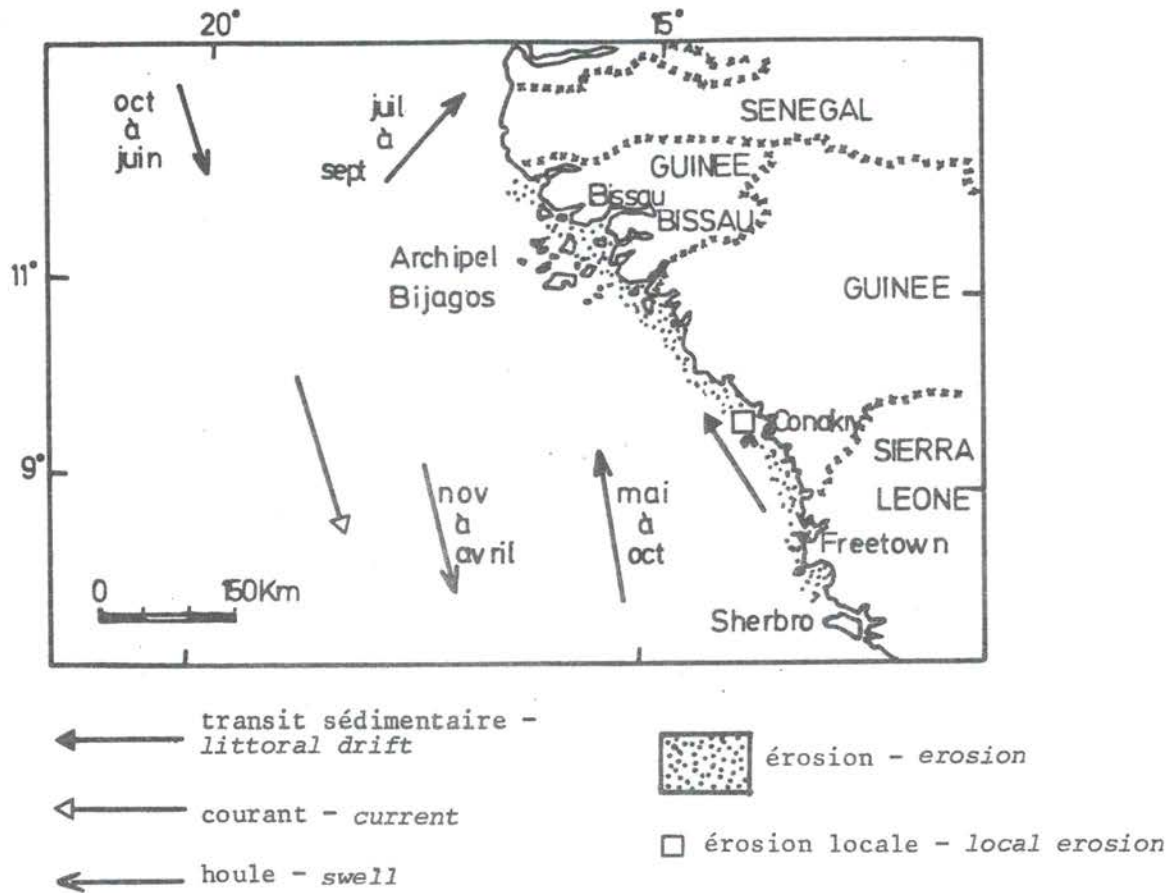


Fig. IV.10 - Guinée-Bissau, Guinée et Sierra Leone jusqu'aux îles Sherbro. Analyse régionale - D'après Collins et al., 1983

Fig. IV.10 - Guinea-Bissau, Guinea and Sierra Leone to Sherbro Islands. Regional analysis - After Collins et al., 1983

African coast (Guilcher, 1974). It is in that area that the southerly and northerly swells run into each other and the drift direction remains questionable ; crossed swell trains are often observed (Guilcher, 1954).

The general oceanic currents run SE off the coasts of Guinea-Bissau, Guinea and Sierra Leone ; they correspond to an extension of a part of the Canary current, reinforced by the Equatorial Counter-Current. Its surface velocities are on the order of 0.5 knot (McMaster and Lachance, 1969). Current measurements indicate speeds of 25 cm/s (0.5 knot), 3 m above the bottom off the Ste Anne bank, close to the continental edge. Tidal currents are much more pronounced close to the littoral : they are known to reach speeds of 75 to 150 cm/s (1.5 to 3 knots) in the Bijagos delta (McMaster et al., 1971).

The swampy deltaic coastal plains and numerous islands made of plio-Quaternary sands and clays -except at Cape Verga (Guinea), where Paleozoic formations outcrop, and on the Freetown (Sierra Leone) and Conakry (Guinea) peninsulae constituted of non-erodible basic intrusion. As explained in chapter II.6., this littoral is part of a still active major subsiding zone ; in spite of the resulting progressive submersion of the coastal valleys (leading to the emergence of the "rias coast", see Van Schlee and Bonnardel, 1973), the predicted retreat of the shoreline is nullified by large river inputs which are mainly trapped by the mangroves. Hence, that part of the African coast appears to be globally growing, although erosion processes can be observed in some instances. Such phenomena have been noticed in different locations (Lafond, 1967 ; Akpati, 1984) of the Kaloum-Tombo peninsula, where coastal villages had to be moved inshore several times during the century (see chapter III.2., example 6), and at Conakry, where remaining walls of the outlying boulevards are undermined in several points due to the retreat of the bordering beaches. Along the Sierra Leone coast, erosion affects Lumley beach and its structures between Sierra Leone Cape and Aberdeen, leading to the insularity of that cape. The tombolo, which joins Aberdeen Island to Lumley, has a slightly concave, sandy beach three miles long that faces the plunging south-westerly waves from the Atlantic ocean. On the other side is the mangrove infested, salty Aberdeen Creek that enters the estuary of the Sierra Leone river through the gap constructed at Cockle Bay. Observations show that the shoreline retreats by about 6 m per year (pers. communication of M. Agbadje, Ministry of Mines, Sierra Leone). Should erosion continue at the present rate, the ocean would eventually break through the narrow neck of the tombolo to join Aberdeen Creek, thus effectively cutting off Aberdeen Island and threatening tourist trade of this zone.

IV.4. FROM THE SHERBRO ISLANDS (SIERRA LEONE) TO CAPE PALMAS (LIBERIA)

This fourth area concerns the almost straight coast, 850 km long, extending from the Sherbro islands (Sierra Leone) to Cape Palmas (the border between Liberia and the Ivory Coast) ; the town of Monrovia is located in the center of that area.

The continental margin is extremely reduced, its width varying between 20 to 40 km. The littoral constitutes a coastal plain, 30 km wide, limited inland by hills, cut by short rivers running perpendicularly to the shoreline, active from a sedimentary point of view and contributing actively to fine sediment inputs on the continental margin (see McMaster et al., 1977). Those rivers are interrupted by rapids and have a high hydroelectric potential. Rocky areas and beaches alternate, beaches encountered more frequently to the north, i.e. south of Sierra Leone. The coastal sediments are derived from the granitic and metamorphic Precambrian formations. A silty-clayey belt covers the middle part of the narrow platform ; the outer part and the continental edge are covered by muddy sediments which contain a higher sandy fraction than the sediments of the central part of the shelf. Between the Sherbro Islands and the Liberia border, sediments are composed exclusively of shelly and silty-sandy muds.

The coastal plain is generally bordered by a linear sandy and lagoonal shoreline preceded by a well-marked bar, the only rocky points being the Capes Mount to the north, Mesurado near Monrovia, and Palmas. This plain is occupied by the savannah and mangrove zones in the swampy areas.

The area is characterized by a humid tropical climate marked by the alternation of a long rainy season (from May to November, sometimes interrupted during July and August) and a dry season from December to April. Annual rainfalls vary between 3 and 5 m on the shore.

The southern branch of the Canary current also runs SE along this area at a surface velocity of 50 cm/s (1 knot). At the level of the continental edge, off Cape Palmas, a Northwesterly Counter-Current was observed at a waterdepth of 60 m (*in* McMaster et al., 1977). Given the orientations of the coast and of the austral swell, the sediments are drifted NW (Guilcher, 1954) (Fig. IV.11).

According to Collins et al. (1983) many rivers of Sierra Leone have been dammed in the 60's, which brought about a significant reduction of the rivers discharge and enhanced erosion sensitivity of the Sierra Leone shorelines. There is, however, no significant proof that erosion is currently active ; As regards Liberia, rivers have fewer dams and their discharge into the open sea provides the shelf with a higher sediment input. Localized occurrences of beach erosion have been registered downstream (with regard to the longshore drift) of the Monrovia and Buchanan (Liberia) harbours moles (Fig. IV.11').

During the construction of the Buchanan ore terminal (the Nimba iron ore deposits) studies were carried out as early as 1956. These studies (Klingberg, 1956) have revealed that waves were constituted by the superposition of 2 swells trains : the first one corresponds to a 12 seconds-period-long swell, generated by South Atlantic storms, whereas the second is formed by the local winds. The maximum annual swell height reaches 48 m (16 feet) and 6 m for a 10 to 20 years periodicity. The most powerful swells occur during the July to September period, the most common direction being south to south-west. The tide, semi-diurnal in type, has a relatively low range, 1.3 m during spring tides and 0.5 m during neap tides. The general currents do not exceed 0.5 knot in velocity. During these surveys the coastal sands transport is directed northwest



- | | |
|---|---|
| ← transit sédimentaire - littoral drift | ← - - - courant subsuperficiel dominant - prevailing subsurface current |
| △ transit littoral faible weak littoral drift | ▨ érosion - erosion |
| ← houle dominante - prevailing swell | ■ sédimentation locale - local sedimentation |
| ← courant dominant - prevailing current | □ érosion locale - local erosion |

Fig. IV.11 - Des îles Sherbro (Sierra Leone) au Cap des Palmes (Libéria). Analyse régionale - D'après Collins et al., 1983

Fig. IV.11 - From Sherbro islands (Sierra Leone) to Cape Palmas (Liberia). Regional analysis - After Collins et al., 1983

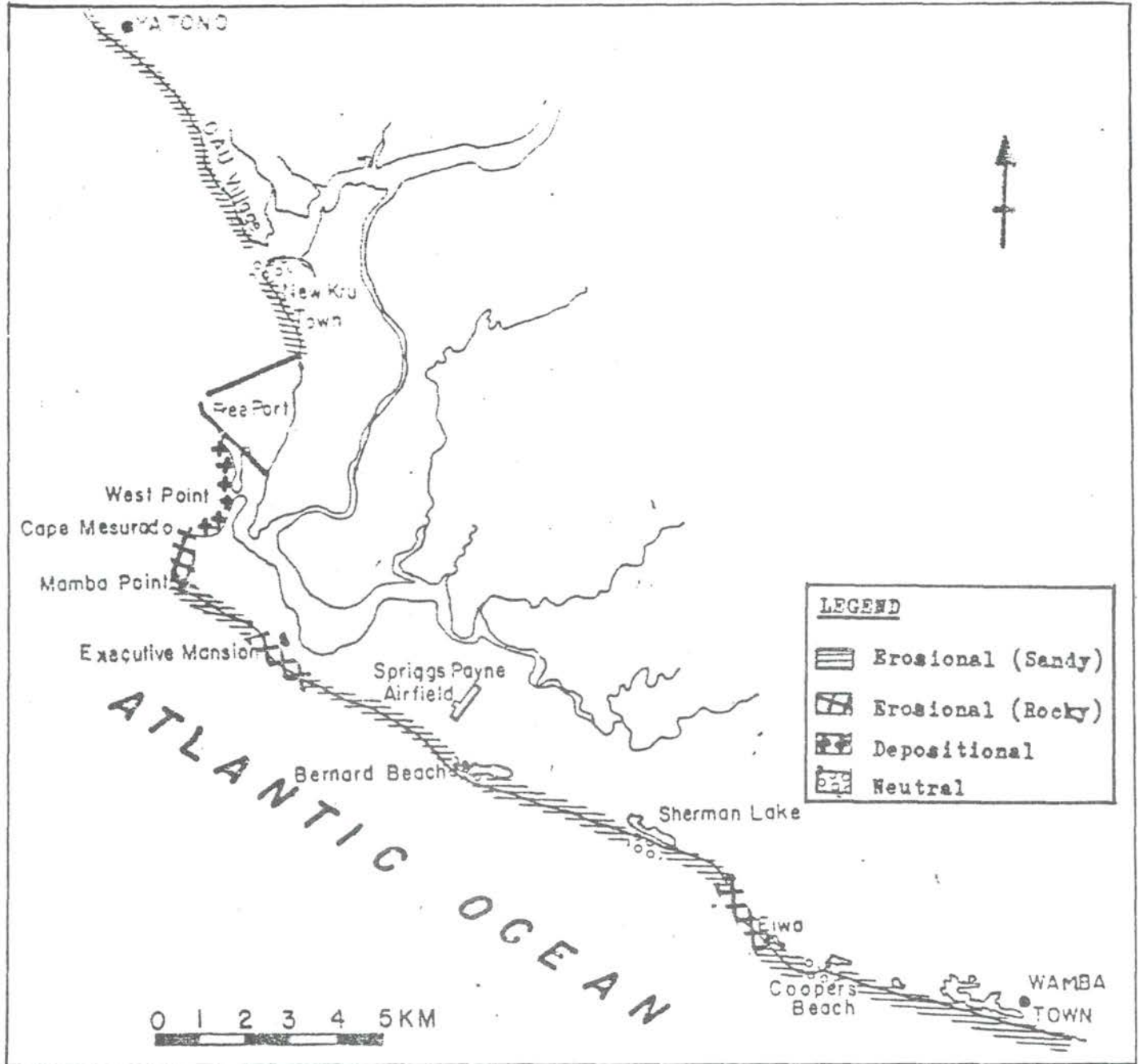


Fig. IV.11' - Morphologie ctiere de la rgion de Monrovia.
D'aprs Maasha, 1982.

Fig. IV.11' - Geomorphological classification of the Monrovia coastline.
After Maasha, 1982.

and accompanied locally by certain amount of beach erosion. The annual sands transport along the entire Liberia coast totals 380,000 m³.

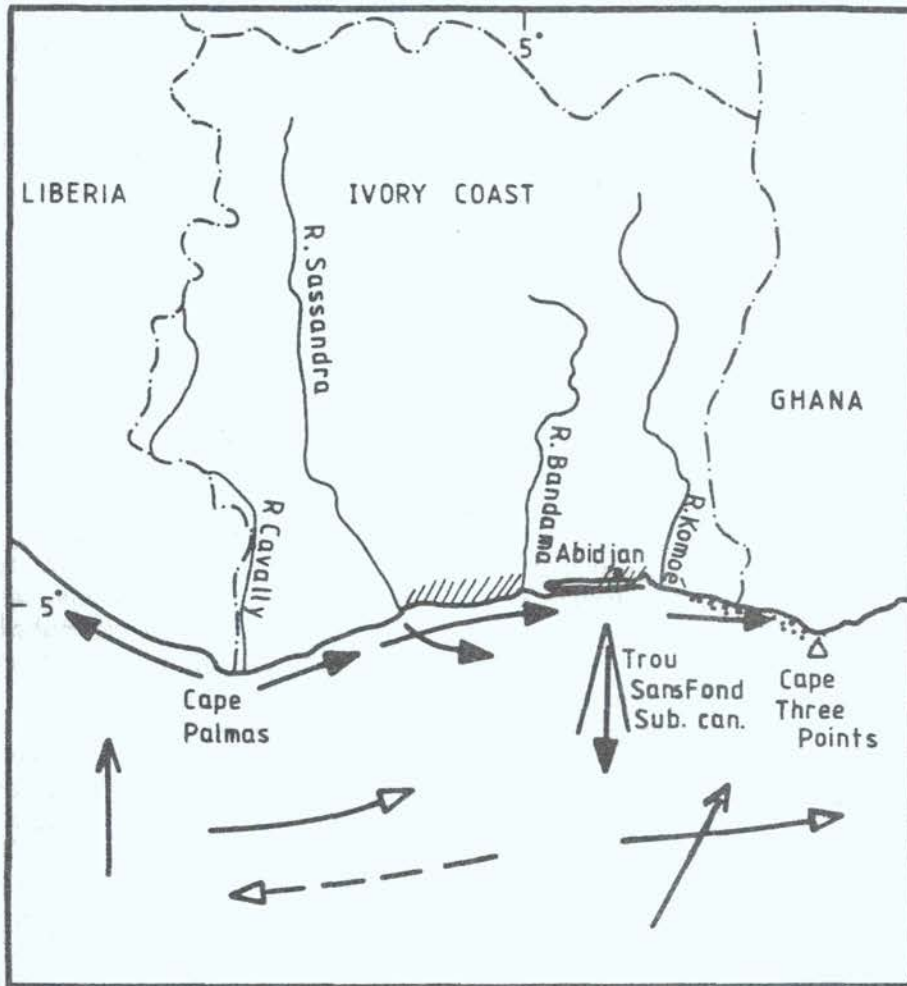
IV.5. FROM CAPE PALMAS TO CAPE THREE POINTS : IVORY COAST AND WESTERN END OF GHANA (Fig. IV.12)

The coastal unit extending from Cape Palmas to Cape Three Points represents a 640 km long coast with a gentle concavity deflected in the E-W direction. It can be divided into three parts (Martin, 1977 ; Ly, 1980) :

- to the west, from Cape Palmas to Sassandra, the coast trends W.SW-E.NE. From a geomorphological point of view, the Precambrian basement forms a coastal peneplain sometimes covered by a crust-cap and reaching the altitudes of 20 to 50 m between Cape Palmas and San Pedro, and of 50 to 100 m between San Pedro and Sassandra. The basement itself, except in a few places, does not reach the open sea, from which it is separated by a narrow Quaternary coastal plain ;
- from Sassandra to Fresco, where the Mio-Pliocene basin begins, the linear coast is bordered by clayey, more or less crusted hills, which form plateaus 20 to 50 m high (Fresco and Kosso), separated from the sea by sandy bars;
- from Fresco to Cape Three Points, the coast is low and bordered by lagoons (Grand Lahou, Ebrié, Aby).

The continental shelf (Martin, 1973, 1977) is not very large (about 20 km wide) but extends progressively reaching a maximum of 35 km in front of Sassandra. Further west, its width diminishes slightly westward as far as Abidjan before increasing again slightly to 35 km off Ghana. The morphology of that platform is rather regular, except in front of Abidjan, where it is affected by the major irregularity of the Trou-Sans-Fond (Fig. IV.13) (Dietz and Knebel, 1971). Martin's studies (1977) indicate that the continental shelf is mainly covered by very fine to medium-grain sands and, locally, by coarser sands ; muddy sands appear in the central part of the shelf, from the Liberian boundary to Sassandra, and on the central and outer part of the platform off the Grand Lahou Lagoon and the western end of the Ebrié Lagoon. They also cover both banks of the Trou-Sans-Fond head in front of Abidjan. In that last locality the muddy area, most probably related to the lagoonal fine sediments, is more extended eastwards than westwards and probably related to the direction of the drift. The many sandstone rocky banks, formed during the old marine regressive stage (Ogolian regression) outcrop in many locations of the continental shelf.

The general currents regime off the Ivory Coast is dominated by the Guinea surface current, running east at a speed of 0.3 to 1.1 m/s (Fig. IV.14). Below this surface current, a counter-current develops at 15 to 80 m of waterdepth. The swells, reaching the Ivorian coast, are mainly (more than 84 %) of S to SW origine. They are the strongest from March to July, attaining their maximum in May. The mean significant height is 0.80 m, the mean maximum height being 1.5 m, and the annual significant swell 3.3 m (in Quélenec, 1984). It follows that the sediments are transiting from west to east. It is in the area Tabou-Sassandra where the swell front makes the maximum angle with the coast (mean value 42°), that the drift should theoretically reach its highest volume; however, it appears that the sedimentary stock is relatively low. From Sassandra to Vridi the incidence angle is lower (27°) but littoral drift may affect a larger sedimentary stock provided by the continental terminal aged deposits and river discharges. At the eastern end of that area, littoral drift was estimated at about 800,000 m³/year during the construction of the western dike of the Vridi canal. The area is depleted in sediments since inputs amount to 200,000 m³/year, and outputs to 800,000 m³/year (Martin, 1973). This large deficit can only be compensated by coastal erosion, as the present river inputs are negligible, and



- | | |
|--|--|
| ← transit littoral -
littoral drift | ← courant dominant -
prevailing current |
| △ transit littoral faible -
weak littoral drift | ← - - - courant subsuperficiel dominant -
prevailing subsurface current |
| ∨ canyon | ▨ sédimentation - sedimentation |
| ← houle dominante -
prevailing swell | ▨ érosion - erosion |

Fig. IV.12 - Du Cap des Palmes au Cap des Trois Pointes. Analyse régionale. D'après Collins et al., 1983.

Fig. IV.12 - From Cape Palmas to Cape Three Points. Regional analysis. After Collins et al., 1983.

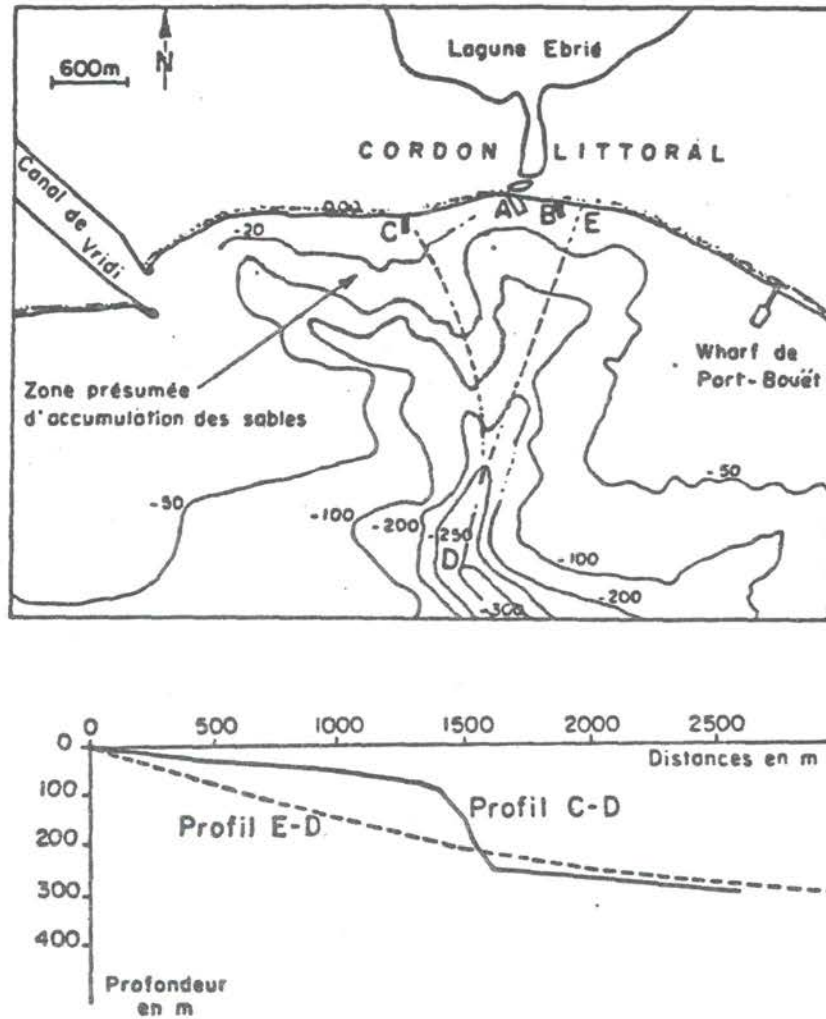


Fig. IV.13 - Implantation des anciens wharfs à Port Bouët et morphologie du Trou-Sans-Fond. In Quélenec, 1984

Fig. IV.13 - Setting of older wharfs at Port Bouët and morphology of the Trou-Sans-Fond. In Quélenec, 1984

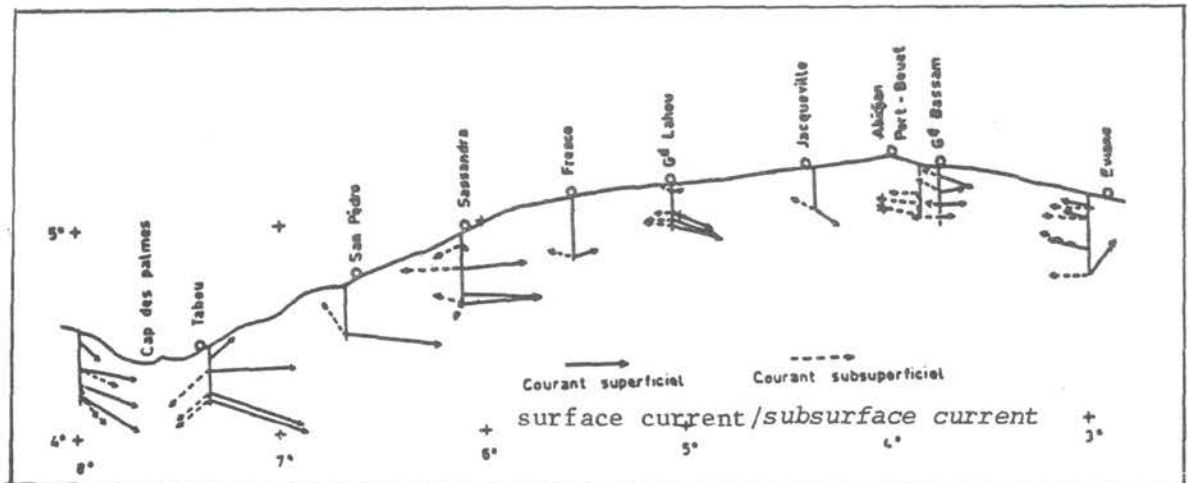


Fig. IV.14 - Les courants sur le plateau continental ivoirien. In Lemasson et Rebert, 1968

Fig. IV.14 - Currents over the Ivory Coast continental shelf. In Lemasson and Rebert, 1968

there is evidence confirming this hypothesis. An erosion cliff (2 m) can be observed along the entire shoreline. It cuts into the old sand bars, and the beach retreat is marked by numerous uprooted coconut palm trees. Some villages located along the sea front, had to be moved inland (Martin, 1973). According to Martin (1973) the area to the west of Vridi is characterized by an annual sedimentation rate of 400,000 m³ whereas inputs from the west amount to 800,000 m³/year; the difference flows through the Trou-Sans-Fond towards the deep sea bed. The 400,000 m³ build up littoral bars. However, since 1951 (the opening of the Vridi canal) that pattern has been modified. The main part of the 800,000 m³ transits are currently deposited in the Trou-Sans-Fond, and that enhances erosion processes along the coast from Vridi to Port Bouët (see chapter III.2.).

Major erosion occurrences of the Ivorian coastline, from Grand Lahou to Assinié, have been identified by Quélenec (1984).

Bandama Estuary to Grand Lahou

The Tagba (Grand Lahou) lagoon outlet which flows in the Bandama, displays, as many other coastal lagoons, the particularity of being presently the most frequently obstructed by a sandy spit. A large coastal sedimentary transit of about 700,000 m³/year, according to ancient evaluations, facilitates the spit build-out. Due to the rainfall decrease, since a few years ago, and to the regulating impact of the Kossou dam on the Bandama river, the obstruction of the lagoon pass (the so-called "grau" in French), just westwards of Grand Lahou, tends to persist, even during floods (summer-autumn). This can be explained by our previous observations and, equally, by the concomitance of the floods with extensive summer bars off the Ivorian shoreline.

The closing of the lagoon outlet has among several other consequences the following ones :

- increase of the lagoon water level and thus of the water tables ;
- decrease of the exchanges between the sea and fresh waters and, consequently, of the salinity level in the lagoon ; they may affect lagoonal primary productivity ;
- higher sedimentation rate of fluvial thin sediments in the lagoon ;
- difficulty of access by ship to the lagoon from the open sea.

In order to avoid some of these problems, the mouth of the lagoon has to be maintained mechanically, as it seems to have been done before the October 1984 survey.

The waters flowing out of the lagoon induces an offshore flow, moved eastwards by the incident south westerly swells. The flow acts as a barrier, or an hydraulic bar modifying the littoral drift and increasing the deposition of marine sands along the part of the shore westwards of the mouth. This could explain why the offshore bar at Grand Lahou is wider than on the eastern side of the lagoon outlet. The effect of such an hydraulic bar together with the swell refraction and its rotation on the shoals in front of the lagoon outlet, appears to enhance erosion rates and thus fragilization of the narrow coastal bar just to the east of the outlet.

Consequently, it seems that the development and maintenance of a permanent entrance channel (or exit) of the Tagba lagoon, east of Grand Lahou can not be planned without carefully considering socio-economical factors and the advantages ensuing from such a development (i.e., access to the lagoon, productivity, soils development ...) against any foreseeable disadvantages

(maintenance of the works and of the channel, erosion of the eastern littoral bar, increased salinity of the lagoonal waters, etc.).

From the Bandama river to Jacqueville

From Grand Lahou to Jacqueville, the coastline, stretching almost west-east, starts inclining strongly north-northwest at Toukouzou-Adessé, which in all likelihood, should induce a variation of the littoral drift intensity, with the probable resulting eastward drift and the proximity to the shore of a 30 m isobath. The coast is almost linear with a sandy foreshore fringed by a 20 m wide continuous vegetation belt : on October 8, 1984 numerous beach cusps 10 to 20 m in amplitude were clearly observed inside cells limited by 100 m spaced rip-currents.

These observations clearly imply the existence of circulation cells (Quélenec, 1984) frequently observed off linear sandy coasts in Africa and elsewhere.

From Noumouzou to Grand Jacques, the coastline is linear and bordered by vegetation ; it appears to be relatively stable although the present narrowness of the shelf enhances its vulnerability to swells and run-up currents : that is marked in the landscape by erosion micro-cliffs, particularly, around Toukouzou and Addah. These erosion land marks can probably be related to the effect of the July and September 1984 storms hitting the Ivorian shoreline. Similar erosion micro-cliffs are also present on the coast facing Jacksonville, where beach erosion is apparent east of the village probably due to beach sands dredging.

From Abredi to Vridi, the littoral which seems stable in the western part of this area, bulks out notably as one approaches Vridi, since a big part of the drift is trapped west of the western dike of the Vridi canal. That stocking assessed at about 500,000 m³ of sand for the period 1947-1952, following the construction of the Vridi canal, is most probably significantly lower now, as a large part of the littoral drift estimated between 700,000 m³ and 1,000,000 m³ is known to by-pass the western dike.

From Vridi to Port Bouët (Abidjan)

That area is detailed in chapter III.2. above. It is characterized by specific evolutive phenomena, very powerful and rapid, owing to the presence of the Vridi canal and the proximity to the shore of the Trou-sans-Fond canyon head. The digging of the Vridi channel and the construction of its western dike (in 1951), stretching 420 m offshore, caused a retreat of Lido beach, east of the canal, due to the trapping of the main part of the littoral drift west of the western dike. The role played by the Trou-sans-Fond was particularly spectacular, when small wharf B and small wharf C were swallowed up in October 1905 and May 1908, respectively, as a consequence of the submarine slumping of unstable sediments deposited at the canyon head (Fig. IV.13).

From Port Bouët to Grand Bassam

East of "La Vigie", the coastal uncontrolled residential areas of "Les Tourelles" and Adjifou with their sea-front shanty-towns, suffered damage during the summer 1984 storms as well as during the previous storms, which induced a several meters beach retreat accompanied by destruction of housing.

Large-scale sand mining on the coastal bar and on the beach for public works and construction purposes continued for several years in the Janfoli-Gonzagueville-Dieudonné area, where a significant beach retreat was observed. In 1982 the Ministry of Mines banned all extraction in the area, which might lead to progressive restoration of the equilibrium profile of the concerned beaches.

Further east, the narrow coastal bar separating the Ouladine lagoon from the sea in the Gbamblé-Azuretti-Grand Bassam area may be experiencing the effects of a cyclic evolution possibly linked, to the shifting of the cusps, or large shore undulations (Quélenec, 1984c) : it is subjected to submersion or temporary cuts during storms occurring at high water level (i.e., tide, low barometric pressure, onshore winds).

Such submersions and cuts were particularly marked at Grand Bassam during the summer 1965 storms, 1 to 3 km westwards of the "Taverne Bassamoise" restaurant as well as eastwards of the France District ; they were accompanied by a significant beach retreat (10 to 15 m), the destruction of habitation (Apatams) and of 7 coconut rows in the Taverne vicinity, as well as by the flooding of the Grand Bassam town-hall and south districts.

These phenomena reveal the sensitivity of this coastal sector to storm attacks at high sea level, although littoral urbanization is at present limited. This sensitivity may also concern the inhabited part of the coastal bar eastwards of Grand Bassam and bordering over about 50 km the Assinié channel.

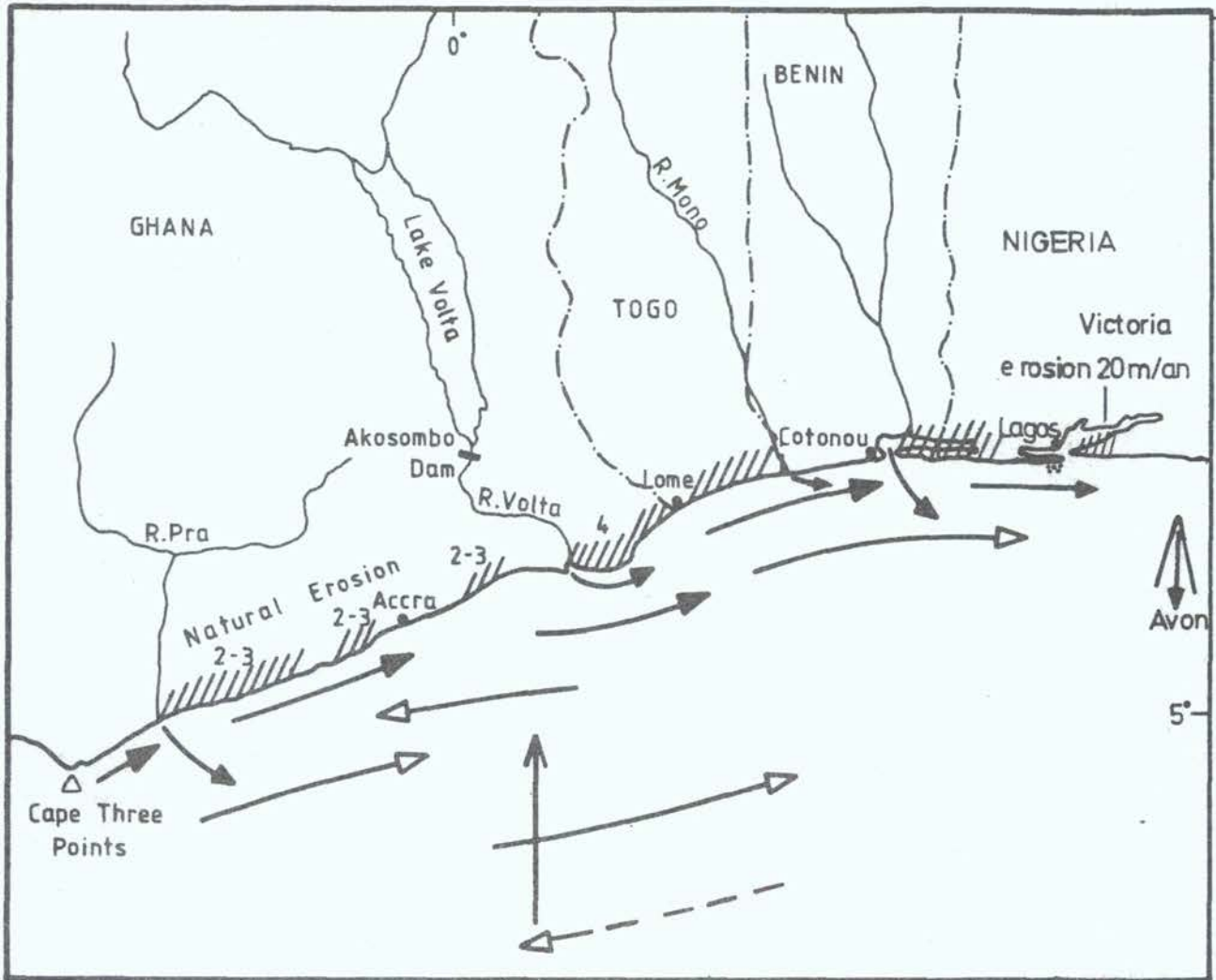
Coastal zone Assouindé-Assinié

The two major worldwide known tourist hotels of the Ivory Coast are located in that area :

- the Palétuviers village-hotel, built on the narrow and low (compared to the sea level) coastal bar which separates the open sea from the Assinié channel. Many facilities are built in the immediate proximity of the shoreline, below the coconuts trees. The coastline is now noticeably retreating as is evidenced by destroyed huts, felled or uprooted and erosion micro-cliffs all along the beach. According to locally collected reports, storms, occurring in conjunction with strong tides, are known to cause extensive damage to coastal structures and plantations, owing to the frequent submersion of the coastal bar, despite protective sand embankments made by hotel maintenance teams, a measure necessitating hotel closure from May to November ;

- one encounters on almost identical situation (felled trees, destroyed huts) in the neighbouring Assinié village-hotel a few kilometers eastwards, with the difference, that the buildings of the club are located more inshore (100 m) which helps to avoid a direct swell attack without evading, however, the submersion of the swimming-pool and of the gardens during strong storms. The low and linear coastal sector (Assouindé-Assinié), characterized by wide foreshores with gentle slopes and constituted by very fine-grained white sands, favours the progressive release of the swell energy in several series of swirl breakers before it reaches the shore. That alleviates the frontal attack of the storms swells more than in the Abidjan-Port Bouët sector. However, sediments mobilization and transport by the swell and induced currents remain active, which leads to cyclic longitudinal changes of the coastline marked by cusps and undulations, reaching sometimes 100 m or more and registered during the BRGM field surveys. The lateral migration of these undulations generates destabilizing or destructive erosional effects, particularly in the vegetation-bordered highest part of the tidal flat (Quélenec, 1984c).

It thus appears, that the main part of the sandy coastal zone of the Ivory Coast, as well as adjacent coasts of the neighbouring countries, where river sediments inputs are lacking, are going through a slow evolution. It induces a tendency of a beach retreat as a result of the cumulative action of the swells and of a slow sea level rise, playing a significant role in the progressive retreat of the gently sloped tidal flats.



- ← transit littoral-littoral drift ▨ érosion - erosion
- △ transit littoral faible - ▩ sédimentation - sedimentation
- weak littoral drift
- ← houle - swell
- ← courant - current
- ←--- courant subsuperficiel dominant - prevailing subsurface current
- canyon

Fig. IV.15 - Du Cap des Trois Pointes (Ghana) à Lagos (Nigeria).
Analyse régionale. D'après Collins et al., 1983.

Fig. IV.15 - From Cape Three Points (Ghana) to Lagos (Nigeria).
Regional analysis. After Collins et al., 1983.

IV.6. FROM CAPE THREE POINTS (GHANA) TO LAGOS (NIGERIA) (Fig. IV.15)

This sixth sector, fringing the Bight of Benin, includes the biggest part of Ghana, Togo, Benin and Nigeria up to the Niger delta. It is the best studied sector of the western African countries due to the extent of natural and anthropic erosion phenomena, and ensuing socio-economic changes. Generally speaking, three unities can be distinguished :

- west of Cape Three Points to Accra, a W.SW-E.NE coastline with a succession of rocky headlands surrounding sandy bars and small lagoons ;
- the extensive delta of the Volta, the principal water artery of the whole region, with sandy shores ;
- succession of sandy bars and large lagoons (Grand Popo lagoon, Nokoué lake, Cotonou lagoon, Porto Novo lagoon, Lagos lagoon ...) up to the Niger delta.

This last area have sustained the greatest damage resulting from erosion. "Beautiful beaches and arable soils have been lost, swallowed by the sea, plantations have been damaged, populations moved, several main and local roads have been eroded and costly tourist facilities are endangered" (United Nations report, 1981).

The continental shelf, which is 35 km wide in front of Cape Three Points, becomes still wider eastwards, off Sekondi, reaching 100 km ; it narrows further east up to Lagos, where its mean width is 20 to 30 km.

The southerly-westerly prevailing winds generate swells which reach the coast obliquely, inducing an eastwards beach drift, construction of spits in the same direction (Fig. IV.16), and also sands accumulation west of the harbour installations (Lomé, Cotonou). Unlike the Ghanaian coastal sector west of Cape Three Points, the waves height often exceeds 1 m in the surf zone (Ly, 1980). In the central part of Ghana, where the coast is partly rocky, beach drift and beach retreat are limited, as rocky promontories obstruct sedimentary drift (Ly, 1980). In the eastern part of Ghana, where the coast is uniformly sandy, the transportation and erosion rates should be more pronounced (Fig. IV.16). Currently, the rivers situated west of the Volta, discharging at sea a minute amount of arenitic sediments and pelitic sediments containing less than 3 % of fine to very fine-grained sand (Ly, 1981). According to this author, the drifted sands are probably originating from the eroded Quaternary littoral deposits.

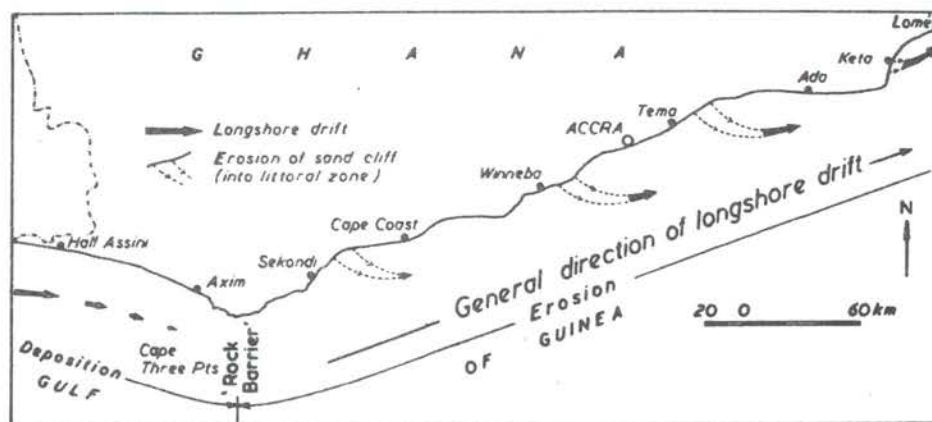


Fig. IV.16 - Transit littoral le long de la côte ghanéenne.
In Ly, 1980

Fig. IV.16 - Coastal drift along the Ghana coast. In Ly, 1980

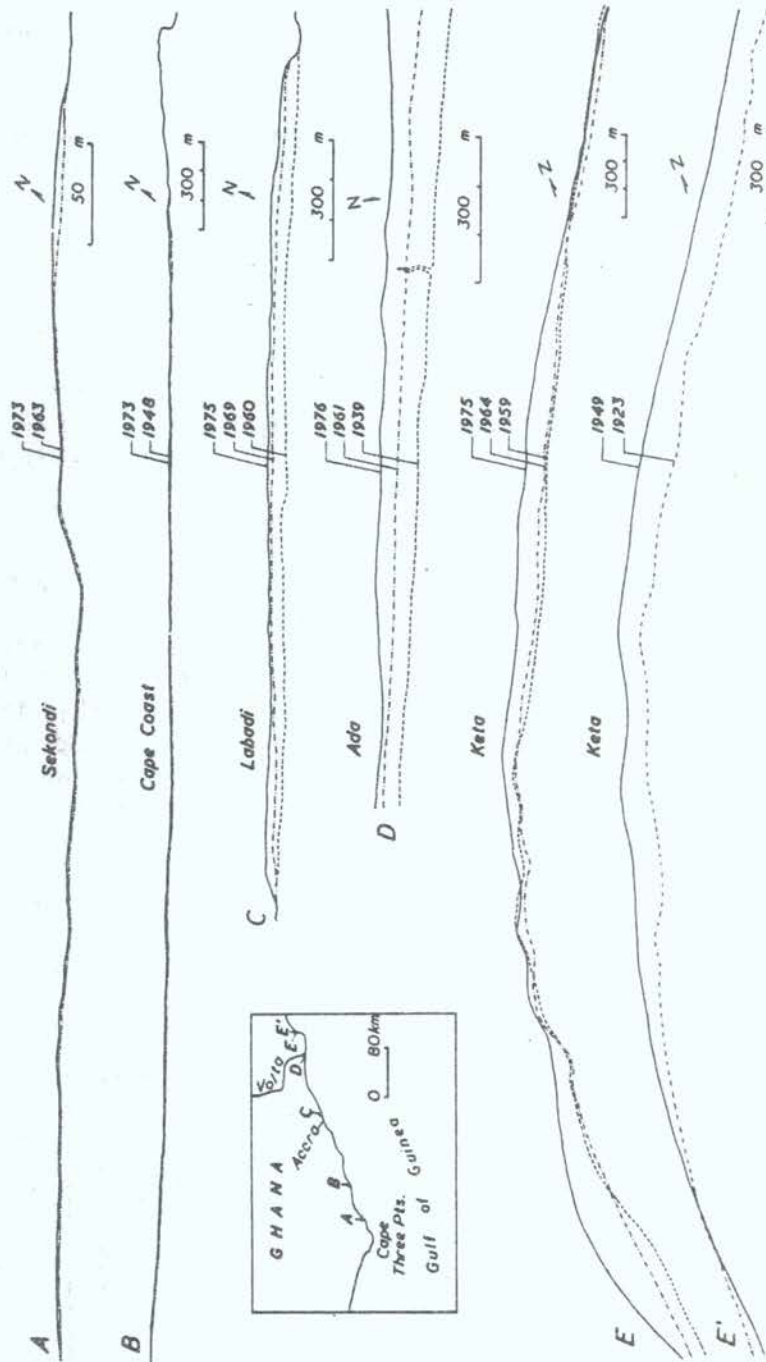


Fig. IV.17 - Evolution de la ligne de rivage dans la partie centrale et est du Ghana, d'après les photographies aériennes et les cartes produites entre 1923 et 1976. In Ly, 1980

Fig. IV.17 - Shoreline changes in Central and Eastern Ghana, from aerial photographs and maps produced between 1923 and 1976. In Ly, 1980

The predominant event affecting the sedimentary equilibrium of the whole sector was the building in 1961 of the Akosombo dam, downstream the Volta river ; this dam blocks 99.5 % of the Volta drainage basin (390,000 km²) and allows the delivery to the sea of only a minor quantity of sand derived from the low-lying areas of the coastal plains. Ly (1981) studied the dam impact on the shoreline evolution by comparing six beaches from Cape Three Points to the Togo border (Fig. IV.17). He has observed the following evolution instances, from west to east :

- west of Accra (Sekondi and Cape Coast profiles), the littoral is in an equilibrium stage ;
- at Labadi, east of Accra, a 3 m/year beach retreat was noted between 1960 and 1975 ;
- at Ada, near the Volta estuary, on the western side, the beach retreat amounted to 2.2 m/year between 1939 and 1961, and to 2.4 m/year between 1961 and 1976 ;
- at Keta, on the delta itself, east of the Volta estuary, the beach retreat was estimated at 4 m/year between 1923 and 1949, and at 6 m/year between 1959 and 1975, in some places it is known to have reached 8 to 10 m/year.

From Ly's analysis it follows that :

- the beach retreat west of the Volta river up to Accra was active prior to the dam construction and couldn't have been induced by it, as may be expected from the direction of the regional sedimentary drift ;

- prior to the dam construction, the Volta river was an important sedimentary carrier to the shoreline east of its mouth : part of the sandy sediments input to the sea was deposited in the delta, forming a succession of sand ripples. However, in the eastern Keta area (E' profile), i.e., in the eastern part of the delta, a shoreline retreat was observed before the dam construction ;

- the Akosombo dam caused a dramatic reduction of the river solid discharge, inducing or accelerating a general beach retreat tendency east of the river mouth.

The town of Keta, built on a littoral spit between the ocean and the lagoon, has been endangered due to marine erosion long time ago : as early as 1907, protective measures were taken to face this danger. In 1978, the Dutch company NEDECO was selected to find a solution to the worrying problems of roads and housing destruction. The measured hydrodynamic parameters were the following : significant waves height, 1.2 m during 50 % of the time ; swell period, 10-15 seconds ; speed of the eastward coastal current, 0.5-1.5 m/s. From Dzelukote to Blekusu the coastal current transportation capacity was estimated at about 100,000 to 250,000 m³/year. However, NEDECO considers that these estimates do not fit with the observations made on the part of the shoreline affected by a gross beach retreat ; one should take into account supplementary factors of transverse sedimentary transit between the emerged and submerged parts of the tidal flat. In the company's view, the building of breakwaters may be a solution of the encountered problems.

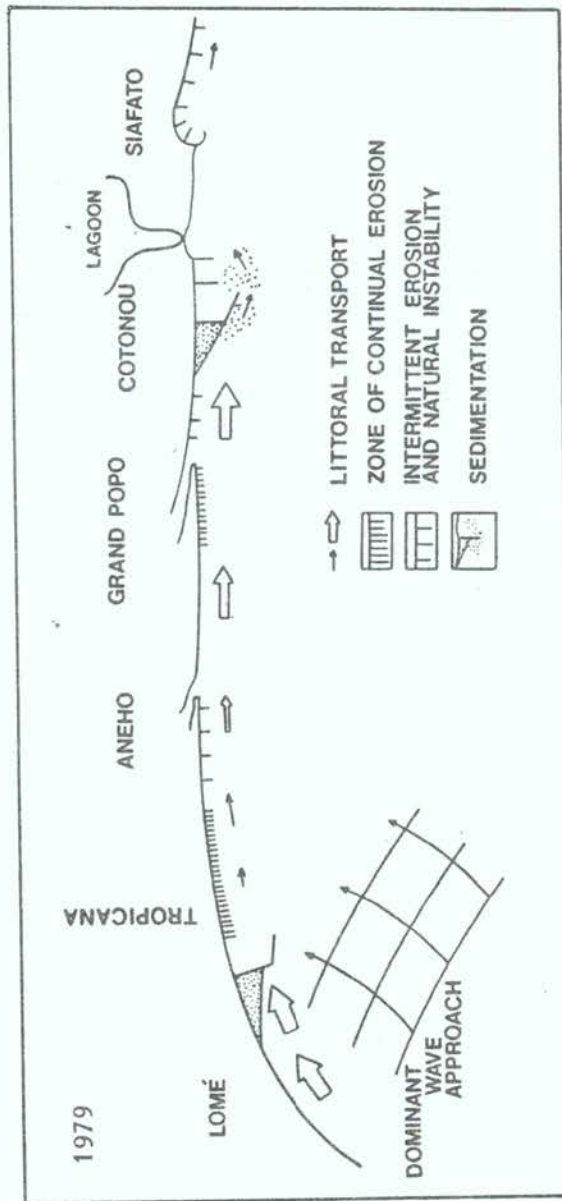


Fig. IV.18 - Problèmes d'érosion côtière au Togo et au Bénin. In United Nations, 1981.

Fig. IV.18 - Problems of coastal erosion of Togo and Benin. In United Nations, 1981.

Coastal erosion problems in Togo and Benin were the subject of a workshop held in Lomé in 1979 (United Nations, 1981). Many studies were also carried out by private companies, namely, by NEDECO in 1975, 1976 and 1978 for Togo, and from 1977 to 1983 for Benin. Due to the dramatic increase of erosional phenomena since 1980, the Togolese Government, with the assistance of the French Ministry of Cooperation, urged a multidisciplinary research team of the Benin University, led by Professor G. Rossi, to study and recommend suitable solutions for impeding the accelerating shore retreat. The main goal of this study (report of Benin University, 1984) was to understand, prior to any preventing action, the pattern of the Gulf of Guinea geo-systems. The main phenomena observed are described here below.

In 1967/1968 the building of the western jetty of Lomé harbour disturbed to a great extent the easterly sedimentary transit (Fig. IV.18). The measurements made by NEDECO in this area yielded the following characteristics : tidal range, 1.4-0.6 m ; maximum and minimum waves height 3.5 and 0.38 m, respectively, 75 % of the waves being lower than 1.5 m (the maximum heaving occurs from June to September) ; waves period, 5-19.5 seconds, with a 9.3 seconds average value ; main swell direction, S.SW during 51 % of the time, the other important directions are S (25 %) and SW (18 %) ; littoral sedimentary drift estimated at 1.2-1.5 million m³/year.

In front of the SCOA office (in the central part of the town of Lomé), i.e., 6-7 km westward of Lomé harbour, erosion occurring over a length of 800 m was reported in August 1976 ; it intensified during the month of December 1976. Given the direction of the sedimentary transport, it cannot be said to have resulted from the construction of the harbour jetty, but seems to be rather due to more or less local variations of the swell direction and intensity (United Nations, 1981). Erosion processes abruptly resumed during the summer 1984, when a sudden 15 m beach retreat was observed.

Off the western pier of Lomé harbour, the coast has advanced, as can be expected, by 380 m in 15 years. According to NEDECO, the shoreline progression rate, 2,000 m from the pier, amounted to 60 m/year during 1964-1969, 28 m/year from 1969 to 1973, 18 m/year from 1973 to 1975. NEDECO estimates that the westward by-passing of the 1,700 m long jetty will occur in 1992.

The entire eastern part of Lomé harbour is being eroded, erosion rates slowing down as the distance from the harbour increases. This phenomenon affected a 15 km wide littoral part in 1977, with the maximal scouring observed from 1973 to 1975. 5 km east of the harbour, the beach retreat averages 20 m/year near the Tropicana hotel. During the 1983-1984 field survey, it was noticed, that erosion seemed to have stabilized between the harbour and the Tropicana hotel (Kp 18), owing notably to the presence of a beach rock, parallel to the coast and situated at an altitude varying between +0.80 and -1.50 m (referring to the IGN zero). The beach rock outcrops due to sandy sediments erosion, and deepens towards Benin, which renders it ineffective as a breakwater beyond Kp 20 (Rossi, in : "Université du Bénin", 1984). Erosion seems presently to be accelerating while shifting eastward : a 25 m beach retreat was observed in 1983 within one week period, between Kp 29 and 31, the retreat amounting to 15 m in May 1984 within a 2 days period at Kp 37 (Kpémé wharf). This retreat occurred during a particularly strong storm, which laid partially bare the wharf piles. The eroded area extends to Aneho, where it affects the coastal road.

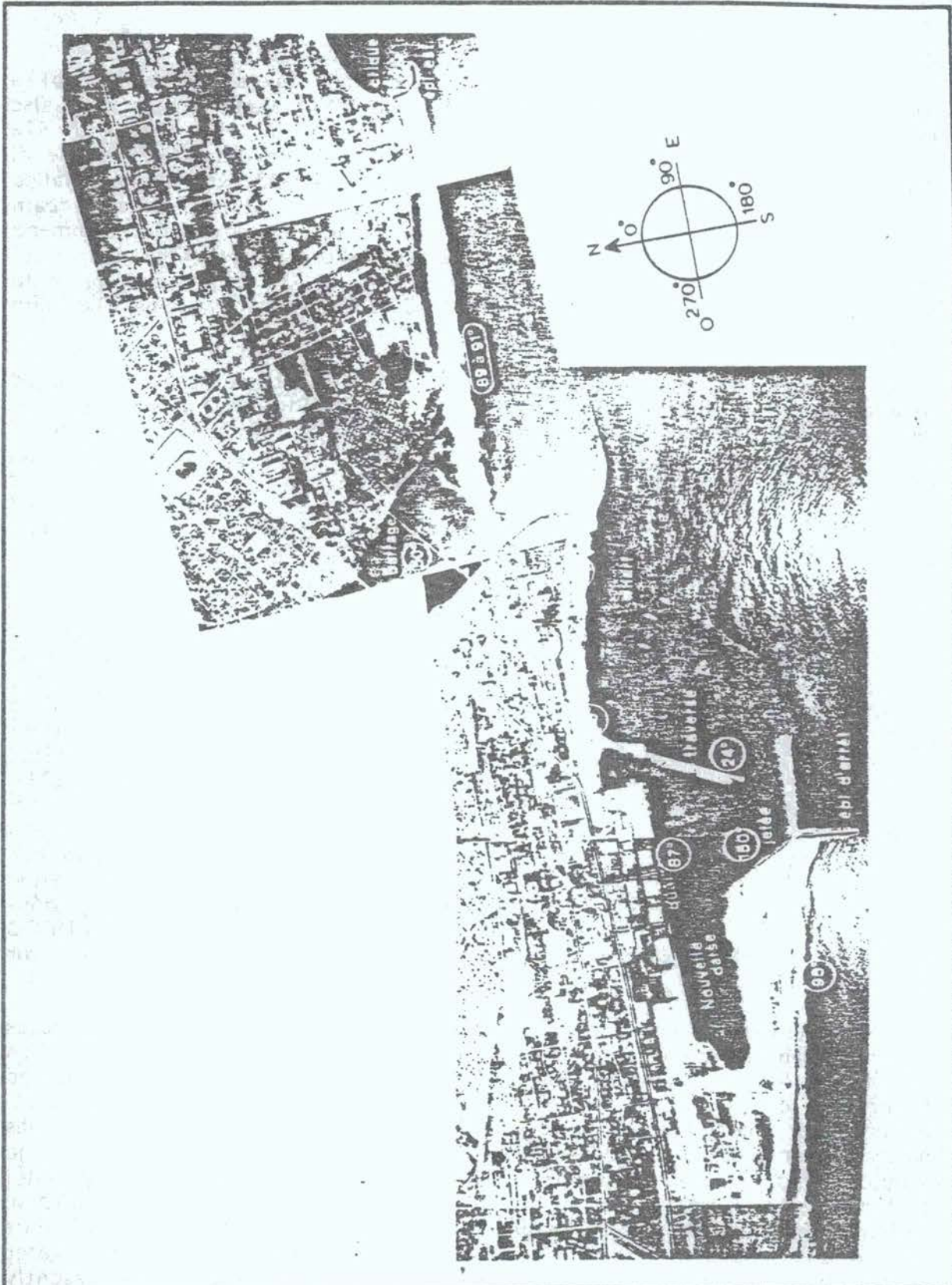


Fig. IV.19

VUE D'ENSEMBLE DU LITTORAL DE COTONOU

Fig. IV.19 - General view of the Cotonou coast.

échelle 1 : 25.000

NEDECO

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FIG. 10

Measurements carried out daily at the extremity of the Kpémé wharf by the "Office Togolais des Phosphates" indicate a prevailing westwards current (300 days/year) with an average speed of 0.7-0.8 m/s, and an eastwards current (2-3 days/month) with a speed of 0.4 m/s. This last current (locally known as "the Aneho current") has not been properly explained ; it flows during periods of harmattan and coincides with invariably easterly tornados. The Aneho current must be taken into account in predicting littoral evolution, as it may play an important role during tornados.

The town of Grand Popo (Benin) is situated on a low and very long sand bar, characterized by a total lack of vegetation. The town is wedged in between the sea and the lagoon, west of the Mono river mouth. It sustained severe sea attacks during storms, particularly, in August-September 1982, when it was partially flooded. A marked growth over a belt 30 m wide, 2 m thick and 10 km long was, however, registered at the end of 1983, these data remaining valid during our field trip in October 1984. A modification of the environment must also be expected as the outcome of the Nangbeto dam project on the Mono river, launched in September 1984. This dam is certain to affect the current hydrologic situation. It should be advisable to initiate studies to forecast the effects of this project for Grand Popo and the eastern part of the Mono river mouth.

Several studies have been undertaken by SOGREAH and NEDECO for the development of Cotonou harbour. East of the harbour, erosion problems are comparable to those of Lomé harbour. The harbour jetty, built in 1960, has stopped the eastward littoral transport. Thus we have a deposition zone west of the harbour (in 1976, the growth of the sedimentation zone amounted to 700 m, Sireyjol, 1977), and an erosion zone east of it (Fig. IV.19). To prevent the erosion of the Cotonou lagoon, the first jetty was built west, and the second one, curved, 1,500 m east of its mouth. The problem area was, therefore, shifted eastwards, where erosion is continuing : at Sémé, the beach retreat amounts presently to about 10 m/year (according to the reports of the SONICOG coconut plantation workers). In theory, erosion rates should slow down as soon as the sands, deposited along the western jetty, start to by-pass it. However, to avoid such a by-pass which would induce the sanding up of the harbour, another jetty was added in 1981 (Fig. IV.19). Prior to the harbour development, the Cotonou lagoon had been most of the time closed by a barrier beach which opened naturally during floods (July, September). Following the harbour development, sand inputs reduced and the lagoon remains permanently open, which has led to a significant change in the lagoon ecology. Sireyjol (1977) summarizes the hydrodynamic situation off Cotonou as follows :

- long swell, almost permanently south-southwesterly, the most frequent period being 12 s, the mean amplitude 1.4 m. NEDECO (1984) notices that waves are 20 % higher off Cotonou than off Lomé ;
- littoral transit ranging from 1,200,000 to 1,400,000 m³/year. East of the lagoon, a jetty was built (Fig. IV.19), and a shoreline retrogradation of about 250 m was measured in 1976 downstream of that jetty. This movement is still going on.

Coastal processes off the Lagos area seem to have been well studied (NEDECO, 1956-1966, 1975, 1979 and 1984 ; Longhurst, 1964 ; Usoroh, 1971 ; Guilcher, 1978 ; see chapter III.2., example 8). The building of the Lagos harbour jetties induced a sedimentation westwards of the harbour entrance channel (Victoria beach) (Fig. IV.20). The eastwards littoral transport is estimated at about 500,000 m³/year (NEDECO, 1984). Guilcher (1978) observed a 22-29 m/year growth of Lighthouse beach, and a 20-30 m/year recess of Victoria

beach. Usoroh (1971) pointed out a 1,350 m shoreline retrogradation for the period 1912-1970 at the eastern jetty level. Erosion appears to have grown less severe eastwards, amounting only to 750 m 1 mile further east during the same period (Fig. IV.20).

The flood currents tend to clog up Lagos harbour, whereas river inputs are negligible. NEDECO (1984) recommends, therefore, to periodically dredge the harbour approaches to avoid beach retreat, and to disperse the dredged materials in front of that beach to compensate for the desequilibrium created by the channel entrance jetties. According to NEDECO (1984), physical characteristics controlling the access to Lagos harbour are the following : significant waves height, 1.4 m ; period, 12 s ; swell direction, 10 m below sea level, S.SW ; mean diameter of sea bottom sediments, 0.2 mm (fine sands).

The eastern extremity of this sixth geographical unity is composed of east-west oriented beaches, bordering the Lagos lagoon ; further east, they correspond progressively to the western front of the extensive Niger delta, stretching NW-SE. Given the attack angle of the prevailing S.SW swell, one should expect a convergence of the littoral transits and, consequently, an accumulation of sands in the transitional area between these two sectors. According to Guilcher (1978), nothing of the kind has so far been observed. This author, therefore, suggests that sand is trapped by the Avon canyon, situated in front of the convergence area, acting as a "sediments trap" comparably with the Cayar canyon (Fig. IV.15).

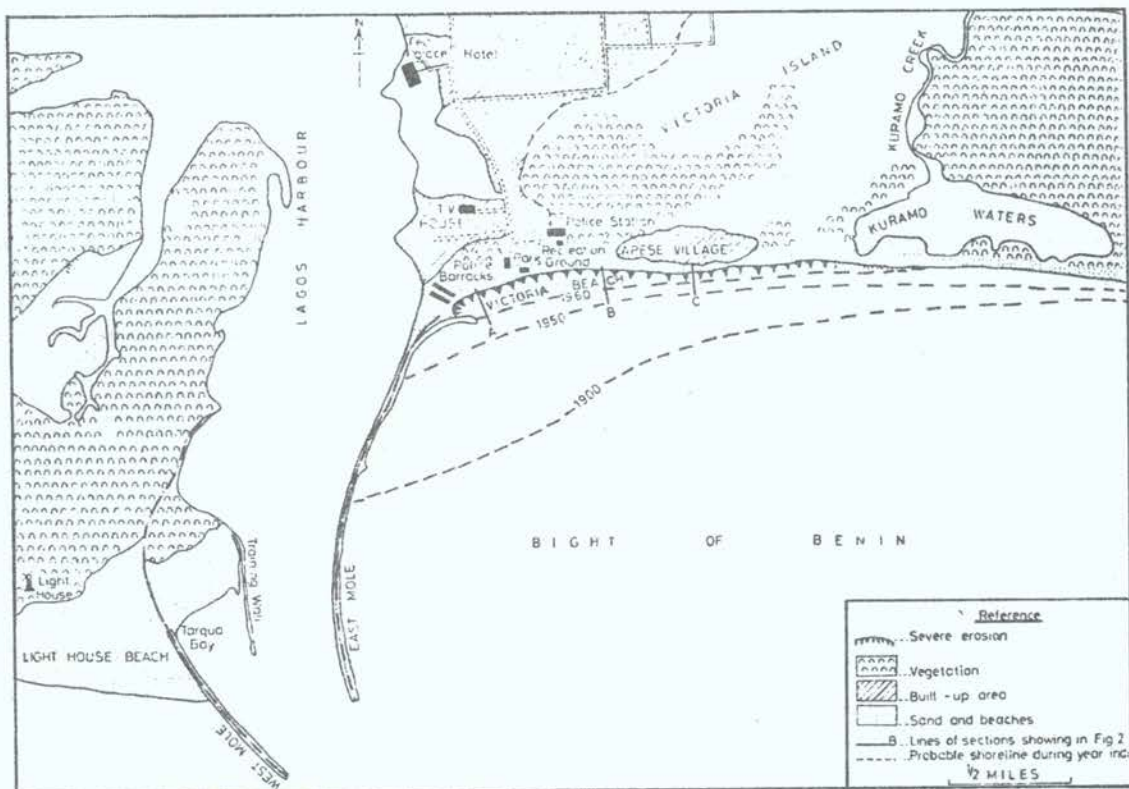


Fig. IV.20 - Erosion de la plage de Victoria (Nigeria). In Usoroh, 1971

Fig. IV.20 - Erosion of Victoria beach (Nigeria). In Usoroh, 1971

IV.7. NIGER DELTA (W-NIGERIA)

This seventh unit is entirely composed of the vast Niger delta, which represents a single geomorphological regional unity. The Niger is the third largest African river (4,200 km long), its lower stream flows in the Benoue trench, one of the main tectonic features of the African shield representing a rift which aborted at the time of the South Atlantic opening, and is composed in detail by pull-apart sedimentary basins (Benkhelil and Robineau, 1983).

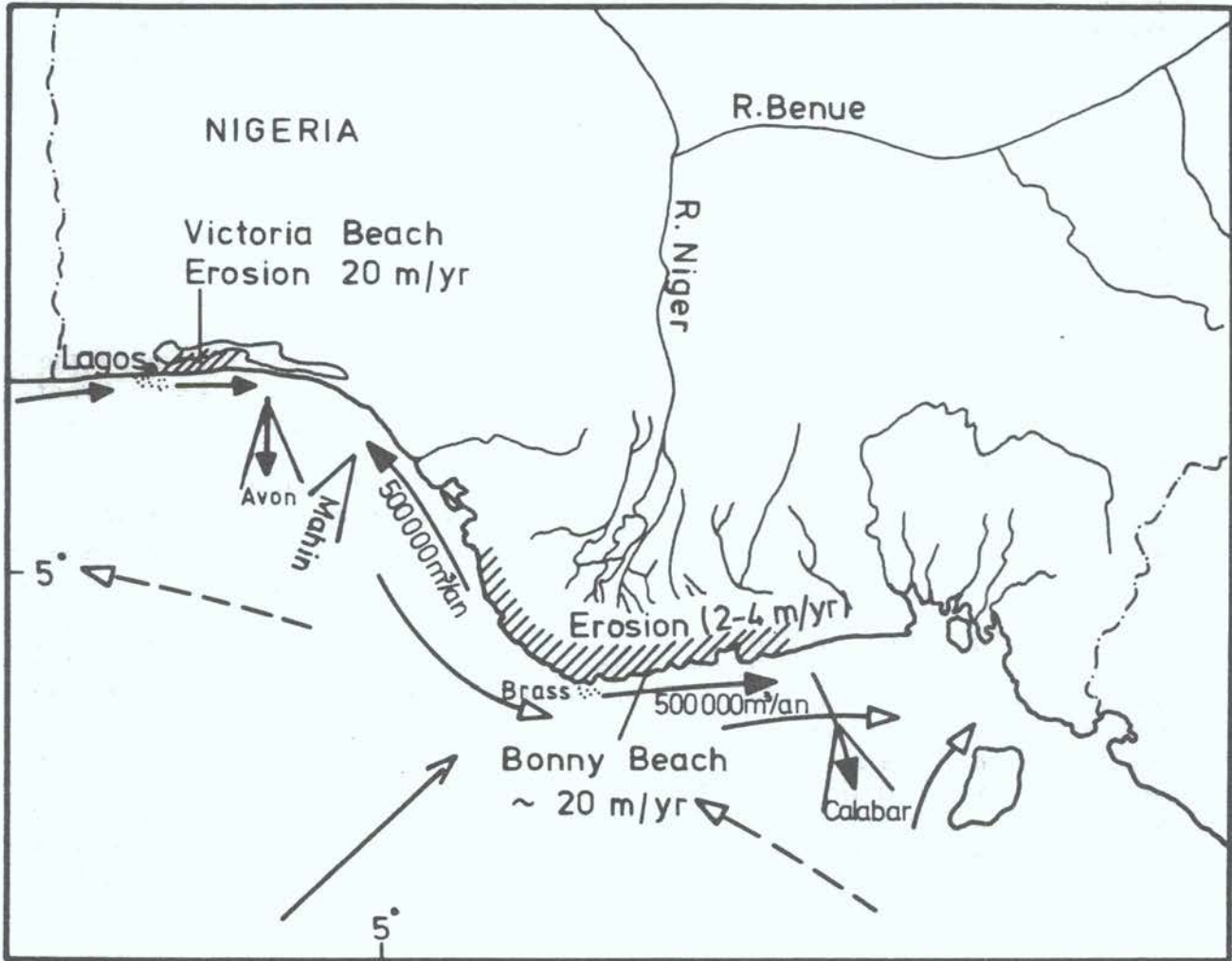
This main fault is bordered south-eastwards by a parallel line of the Cameroon volcanoes, which extends seawards with the Gulf of Guinea islands (from Fernando Poo to Annobon). The Niger delta is thus an unstable area, where subsidence is maximum along the symmetry-axis of the delta ; Allen and Wells (1962) indicate a piling rate of 1,400 km³ over a period of 4,000 years for the whole delta (offshore and inshore).

The continental shelf widens progressively from the west (35 km in the Lagos area) to the east (75 km offshore Calabar), reaching 64 km in front of Cape Formoso, on the delta axis. It is framed by the 2 canyons of Avon and Mahin westwards, and of Calabar eastwards (Fig. IV.21). The Niger delta shape is the result of the interaction of the river solids discharge radially disposed (goose-foot-shaped) at sea, and of the south-southwesterly prevailing swell direction, which distributes littoral drifts almost equally on both sides of the delta axis (Fig. IV.22).

The Niger, draining a major part of West Africa and crossing highly contrasted climatic zones, is the main source of sediments transport to the delta area ; just before its confluence with the Benoue river, its solid load totals 4.6 millions m³/year (0.3 million m³/year being sands). The Benoue, its main affluent, has a significantly smaller watershed, but carries a higher volume of sediments : 11 millions m³/year (of which 0.6 million m³/year are sands, Allen, 1965b). Sediments inputs drifted through the many channels are scattered by tidal currents which shape the mangrove swamps, and by waves-induced coastal currents. The largest sediments discharge occurs in September-October, the lesser one in December-May (Allen, 1965b).

NEDECO, which has repeatedly executed surveys of the region (1954, 1959, 1961) gives the following hydrodynamic parameters : the tidal range values increase from west to east (1.0 m at Lagos, 1.6 m at Opobo and 2.8 m at Calabar) ; the south-southwesterly waves are split into two systems : the first one composed of long waves, with a period of 12 s, the length 225 m and the mean height 1.5 m ; the second one composed of short waves, with a period of 5 s, the length 39 m and the height 0.9 m. The long waves energy is 7 times higher than that of the short waves. The incidence angle to the shoreline gives rise to a littoral transit in the following main directions (Fig. IV.22) : west of the delta axis, the sediments converge to the NW, towards the Mahin canyon and, particularly, the Avon canyon ; east of this axis, they drift towards Calabar, i.e., towards true east. NEDECO (1961) put the drift volume at 500,000 m³/year both in the west part (between Ramos and Forcados) and in the east part of the area (between the Kwa Ibo and the Cross rivers).

According to Udo (1971), the sediments originate either in the coastal fringe (during the rainy season) or from erosion of the drainage basin of the Niger upper course and its affluents ; but the inputs of these affluents are limited by the numerous dams built on the river (McDowell et al., 1983 ; Oygoke et al., 1983).



- transit littoral - littoral drift

 érosion - erosion
- canyon

 sédimentation - sedimentation
- houle dominante - prevailing swell
- courant dominant - prevailing current
- courant subsuperficiel dominant - prevailing subsurface current

Fig. IV.21 - Delta du Niger - Analyse régionale. D'après Collins et al., 1983.

Fig. IV.21 - Niger delta - Regional analysis. After Collins et al., 1983.

Collins et al. (1984) estimate that the erosion rate of the Niger delta shoreline has augmented by 2 to 4 m/year since the dams were built. A comparative survey of aerial photographs has led those authors to the conclusion that the shoreline grows locally at a rate of 20 m/year in the vicinity of Brass situated on the delta axis (where littoral drift diverges), and that it retreats at a speed of 20 m/year at Bonny beach, eastwards.

Sudden and large erosion fluctuations seem to be related to storms and to seasonal variations of river inputs (NEDECO, 1961). Oyegoke et al. (1983) assert that no large-scale erosion occurs in the entire basin of the delta head ; as for its extremities, the expected growth seems to be balanced by the "sediments traps", constituted by the Avon and Mahin canyons to the west, and by the Calabar canyon to the east.

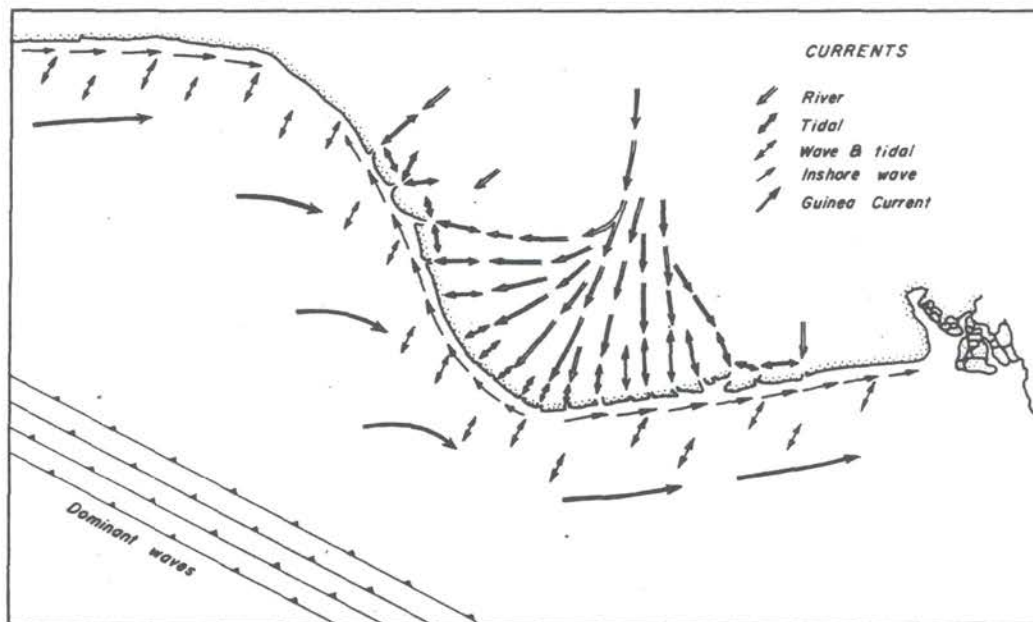
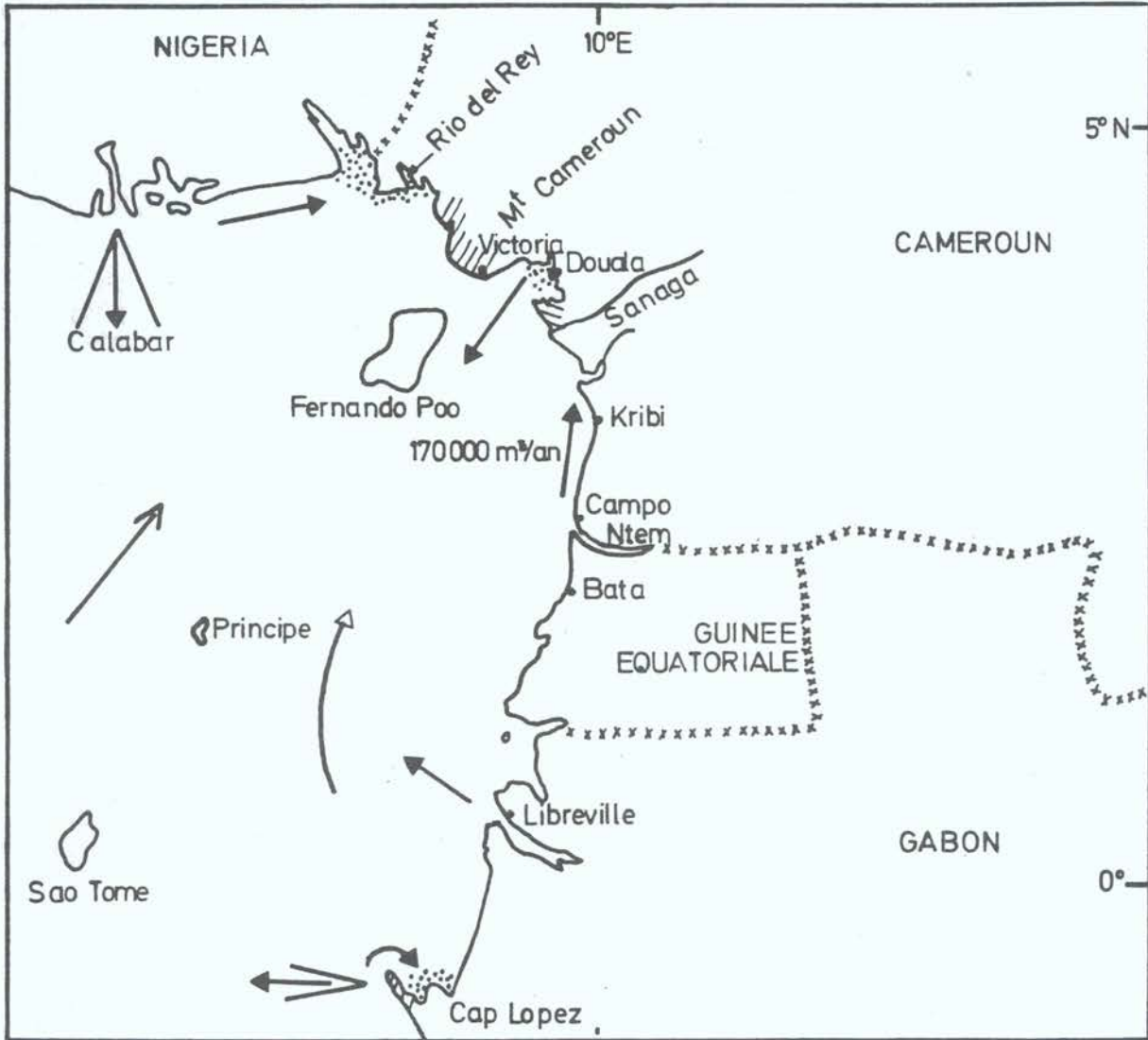


Fig. IV.22 - Nature et direction de forces modelant le delta du Niger. In Allen, 1965b

Fig. IV.22 - Nature and direction of forces shaping the Niger delta. In Allen, 1965b





- ← transit littoral - littoral drift
- ← courant dominant - prevailing current
- ← houle dominante - prevailing swell
- ∨ canyon
-  érosion - erosion
-  sédimentation - sedimentation

Fig. IV.23 - Du Rio del Rey au Cap Lopez : Cameroun, Guinée Equatoriale, Nord Gabon - Analyse régionale. D'après Collins et al., 1983.

Fig. IV.23 - From Rio del Rey to Cape Lopez : Cameroon, Equatorial Guinea, North Gabon - Regional analysis. After Collins et al., 1983.

IV.8. FROM RIO DEL REY TO CAPE LOPEZ : CAMEROON, EQUATORIAL GUINEA, N-GABON (Fig. IV.23)

This area has not apparently been studied in detail ; this seems to be especially justified in so far as Equatorial Guinea is concerned, on which data are almost non-existent.

This entire littoral sector has a sub-meridian orientation. As the prevailing swells are southwesterly, the beach drift will run globally from south to north. The coastal morphology is variable, and the following units can be distinguished, from north to south :

- the Rio del Rey area, on the border with Nigeria, can be considered as part of the eastern margin of the Niger delta ; its shore is low and very embayed, occupied by mangroves and numerous sand banks ;
- the coast, bordering the Cameroon Mountains from Bamusso to Cape Nachtigal, advances seawards owing to the huge Neogene volcanic intrusion which generates a rocky coast with pointed cliffs and slightly developed beaches ;
- the coast then borders the Douala basin as far as Kribi. Northward, up to the Sanaga river mouth, it is characterized by the estuary system, having a complex shape, called "the Cameroon estuary", into which the Wouri and Dibombo coastal rivers outflow. The coast is generally low, with slikkes with mangroves, and coastal drifts tend to progressively fill up this bay. The Sanaga delta stretches southwards of the Cameroon estuary and its arrangement clearly shows a northerly sediments drift ;
- the volcanic islands of Sao Tome and Principe present a ragged coast-line : the west coast being very steep and the east coast much flatter. There is not much evidence of marine erosion except during the season of heavy storms.

Southwards, between the Sanaga river and the Kribi approaches, the coast is low, straight, and constituted by coastal sand bars with swampy hollows behind them. From Kribi to the Equatorial Guinea border, the old basement comes into contact with the Atlantic Ocean, and the sandy beaches, exposed and with steep slopes (Klingebiel, 1984), are discontinuous, with an irregular series of rocky, only slightly prominent capes and wide bights. The Equatorial Guinea shoreline, between the Ntem river and the Cocobeach estuary, (on the border with Gabon), is fringed by a relatively narrow coastal plain, which extends inland in successive steps. The south part of Equatorial Guinea and the north part of Gabon, up to Pongara Head, are characterized by swampy mangrove coasts, deeply cut by the Mouni estuaries (Cocobeach), Mondah bay and the large Gabon estuary in the south (Weydert and Weydert, 1982). Except these two notches, i.e., those between Cape Esterias and Cape Santa Clara, the coast is rocky. The south end of the coastal sector is constituted by a low, sandy, relatively straight stretch which runs from Pongara head down to the bay of Cape Lopez.

Along this eighth coastal unit, the continental shelf is relatively narrow and its width does not exceed 50 km, except in front of the straits formed by Corisco bay (Cocobeach bay + Mondah bay) and the bay of Cape Lopez. It narrows to 30 km south of Cameroon and becomes extremely narrow in front of Cape Lopez (5 km). The tide, semi-diurnal in type, has a mean range of less than 2 m, which may be slightly higher in the inner part of the gulfs (a little over 2 m in the Bight of Biafra) or in the few estuaries (2.5 m at

Douala, 2.5 m at Owendo, in the Gabon estuary).

The Rio del Rey basin is thought to be an active sedimentation area.

Along the Cameroon Mountains coast, the sediments transport mechanisms are virtually unknown and most probably complex in nature. The Victoria region is being actively eroded and was studied specially by the Laboratoire Central d'Hydraulique de France (LCHF, 1977) when the Victoria refinery was being built at Limboh head, in front of Fernando Poo island. According to the data obtained in the course of these studies, the highest tidal ranges attain 2.4 m and the prevailing swells are south-southwesterly, the strongest ones being southerly.

The river Cameroon estuary, at the extremity of which stands the city of Douala, is progressively filled up by the coastal rivers solid inputs (the Wouri and Dibombo rivers) and by the small builders deltas with strong tidal currents (the Mongo river). The fine-grained sediments brought in by the Wouri river are silting up in Douala harbour ; according to Lafond (1967), this supply is estimated at 1 million tons/year of suspended material. SOGREAH carried out feasibility studies for the development of the Wouri lower course, where channels have been dug to facilitate the entrance of Douala. These channels, the sites of a sandy transit and the recycling of muds, have to be regularly dredged (Lafond, 1967). In the estuary tidal currents attain speed of 2.5 knots (125 cm/s) ; during the rainy season (from March to October), the ebb tide may persist as long as 8 hours, reaching 2.75 knots, while the flood flow lasts for only 4.5 hours and its highest rate does not exceed 2 knots (in Collins et al., 1983). The tidal currents may be generating a resulting sediment transport towards the continental edge 50 km away from the estuary entrance. In the south part of the Cameroon estuary, the NW end of the Sanaga delta is subjected to an erosion process (the Souellaba spit is, in fact, eroded by virtue of its location at the extreme end of the delta's outmost sandy bar). The erosion could be attributed to the construction of the Edea dam (1965) 70 km inshore of the Sanaga river mouth.

The only known study, concerning the rocky coast of the S-Cameroon, was attempted by the OCGR-INTER G, BCEOM and SOGREAH (1982) group, for a harbour project near Kribi. There is no general permanent current in front of Kribi, the currents sometimes running northwards, sometimes southwards, depending on the winds direction, and their maximum speeds are 0.33 m/s. Prevailing swells, south-southwesterly (the strongest ones being southwesterly), are weak and have an amplitude of less than 1 m. Beaches are composed of a series of compartments divided by rocky heads, and their appearance suggests a northward littoral drift, estimated at 170,000 m³/year (SOGREAH, 1981).

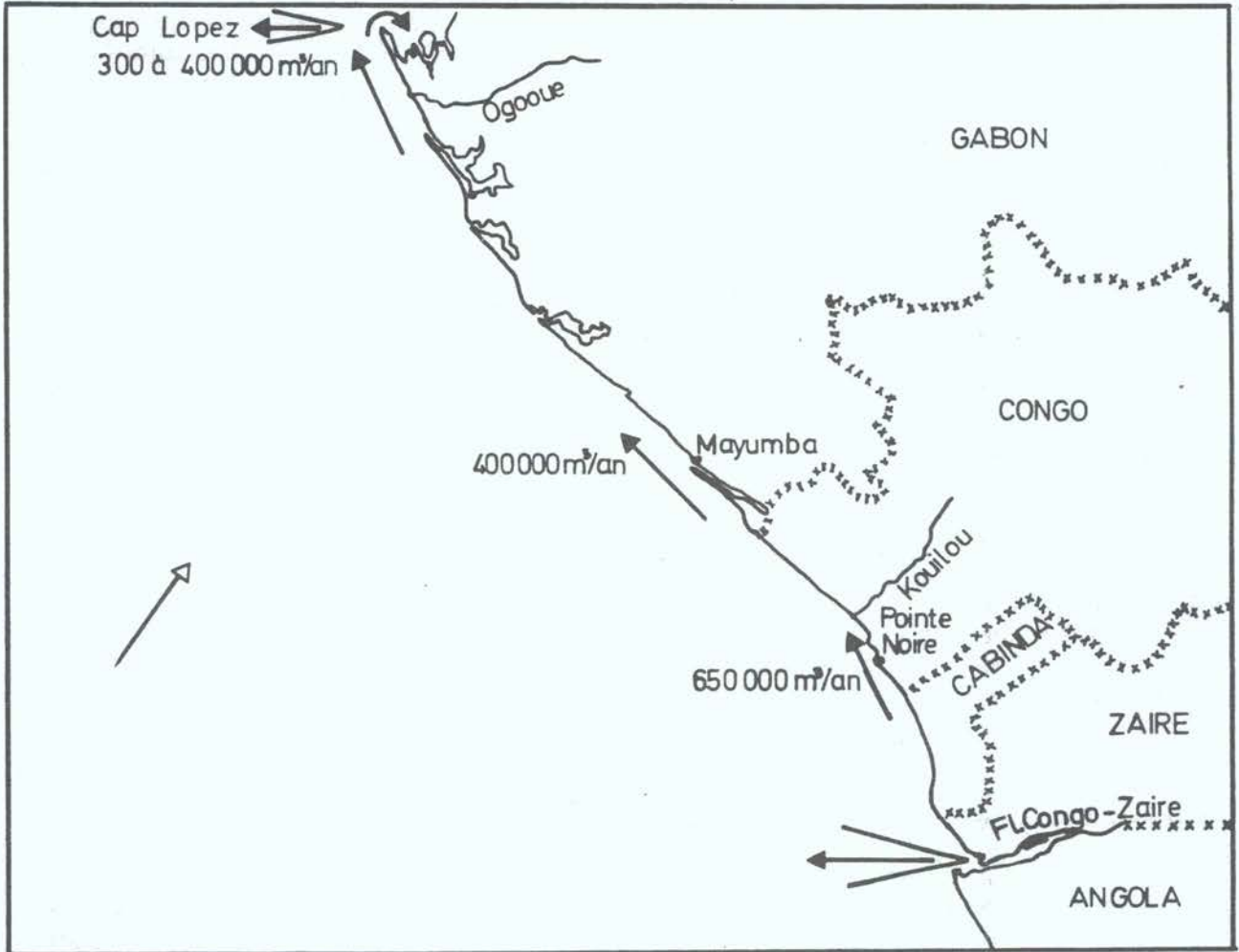
One can observe a slight erosive tendency of the coast in the Gabon estuary, immediately north of Libreville. Project studies for the Owendo harbour development have led to putting the maximum speeds of the tidal currents at 2-2.5 m/s. Illegal sand dredging has created seasonal erosion problems of the estuary shores. Regular southwesterly swells have built out the sandy extremity of Pongara head.

IV.9. FROM CAPE LOPEZ (GABON) TO THE CONGO-ZAIRE ESTUARY (ZAIRE-ANGOLA BOUNDARY) (Fig. IV.24)

The coast runs N.SW-S.SE over 800 km, extending from Cape Lopez to the Congo-Zaire river mouth. It is low, relatively straight, composed of coastal bars, back of which mangrove lagoons have developed ; the largest of them being the Conkouati, M'Banio and N'Dongo ones on the Gabon coast. Some of them are known to trap a greater part of the solid load of the rivers flowing from the Precambrian blocks closest to the coast. Many lagoons are completely isolated from the sea by coastal bars.

The two extremities of this province are limited by 2 unequally important fluvial systems, which have a major impact on the coastal morphology and represent two very contrasted morphotypes : to the north, the extensive Ogooué delta, to the south, the deep Congo-Zaire estuary. Between these two rivers, some minor rivers flow into the sea, the principal being the Kouilou one which outflows north of Pointe Noire. The province's shoreline is bordered by two coastal basins (containing well known oil reserves) : to the north, the Gabon basin, which deepens inlandward (its extension reaching its maximum at the latitude of Port Gentil), and to the south, the narrower Congo basin, which extends into Cabinda, Zaire and N-Angola. These two basins are separated at Mayumba by the Precambrian chain, which almost reaches the shoreline. The entire sector is dominated by the dual action of two opposite currents (Fig. IV.25), the Guinea current bringing from the north warm and salt-depleted waters, and the Benguela current carrying northwards cold and saline waters and upwelling, at the latitude of Cape Lopez, during the dry season (from June to August, i.e., austral winter). When these cold waters reach the Gabonese-Congolese shelf, they induce an upwelling which periodically brings to the surface nutrients-enriched waters. The south-southwesterly winds favour the development of a coastal swell regime which shapes the coast and is linked to a northward littoral drift, estimated at about 300,000-400,000 m³/year west of Port Gentil (Bourgoin et al., 1963), 400,000 m³/year in front of Mayumba (BCEOM, 1959), and at 650,000 m³/year south of Pointe Noire (comm. ELF GABON). Throughout the area, the maximum tidal range is 1.6 m.

The continental shelf width is 5 km at Cape Lopez and reaches 60 km in the southern part of Gabon. Further south, its width decreases to 50 km, but it is only at Tafe Point (Cabinda) that the shelf abruptly narrows to form the right wall of the submarine Congo canyon. North of this shelf, several canyons notch the continental slope near Cape Lopez (Bourgoin et al., 1963), the northern most and smaller of them coming very close to the cape. The Ogooué, which outflows in this area, has a watershed extending over 220,000 km², and its solid inputs have built the delta ; these deposits are prograding on the continental margin, in so far as they approach the continental edge, near Cape Lopez. The sediments discharged at sea are shifted northwards by the beach drift contributing to the formation of the Mandji island (the town of Port Gentil is built on it and Cape Lopez represents its extremity) and of the eastern part of the delta. The southern end of the province is characterized by the abrupt trench of the upper course of the Congo-Zaire canyon. The Congo-Zaire river is the only large river into the estuary of which enters a submarine canyon head (100 to 200 m of waterdepth) as far inland as 40 km (Fig. IV.26). This canyon is relatively well studied (Heezen et al., 1964 ; Donguy et al., 1965 ; Shepard and Emery, 1973 ; Eisma and Van Bennekom, 1978 ; Eisma and Van der Gaast, 1978 ; Peters, 1978). It acts as a trap for the arenitic sediments, eventually carried by the river, and for the northward littoral drift which starts forming off Angola. According to Giresse and Odin (1973), the actual Congo's solid discharge is mainly pelitic in nature ; it is shifted northwards and deposited in the most littoral part of the Congolese



← transit littoral - littoral drift
 ← courant dominant - prevailing current

▨ érosion - erosion
 ▩ sédimentation - sedimentation

Fig. IV.24 - Du Cap Lopez (Gabon) à l'estuaire du Congo-Zaire (frontière Zaire-Angola) - Analyse régionale

Fig. IV.24 - From Cape Lopez (Gabon) to Congo-Zaire estuary (Zaire-Angola border) - Regional analysis

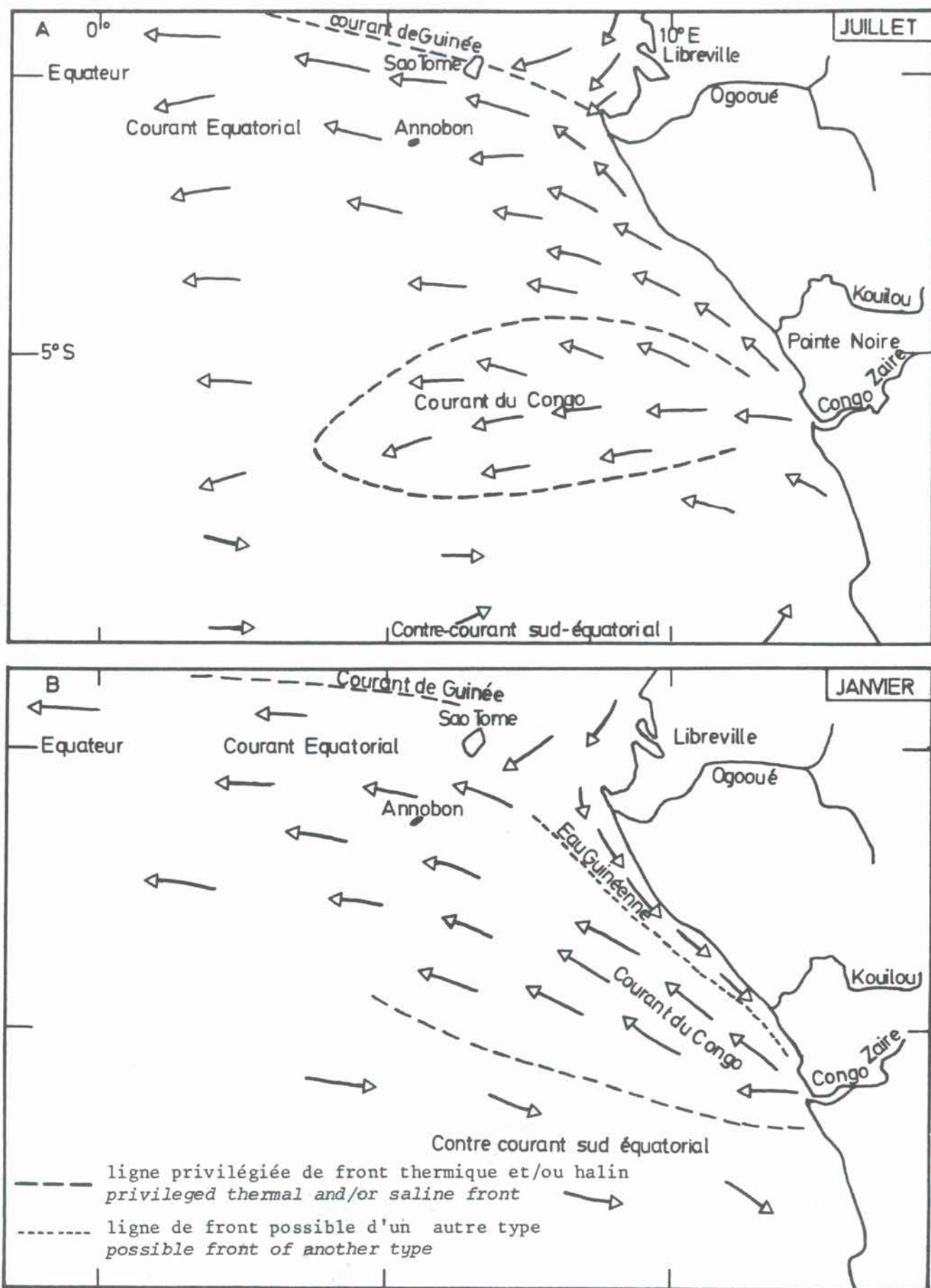


Fig. IV.25 - Courants généraux de surface dans le sud-est du golfe de Guinée en juillet (A) et en janvier (B). In Piton, 1977

Fig. IV.25 - Principal surface currents in the southeastern part of the Gulf of Guinea in July (A) and January (B). In Piton, 1977

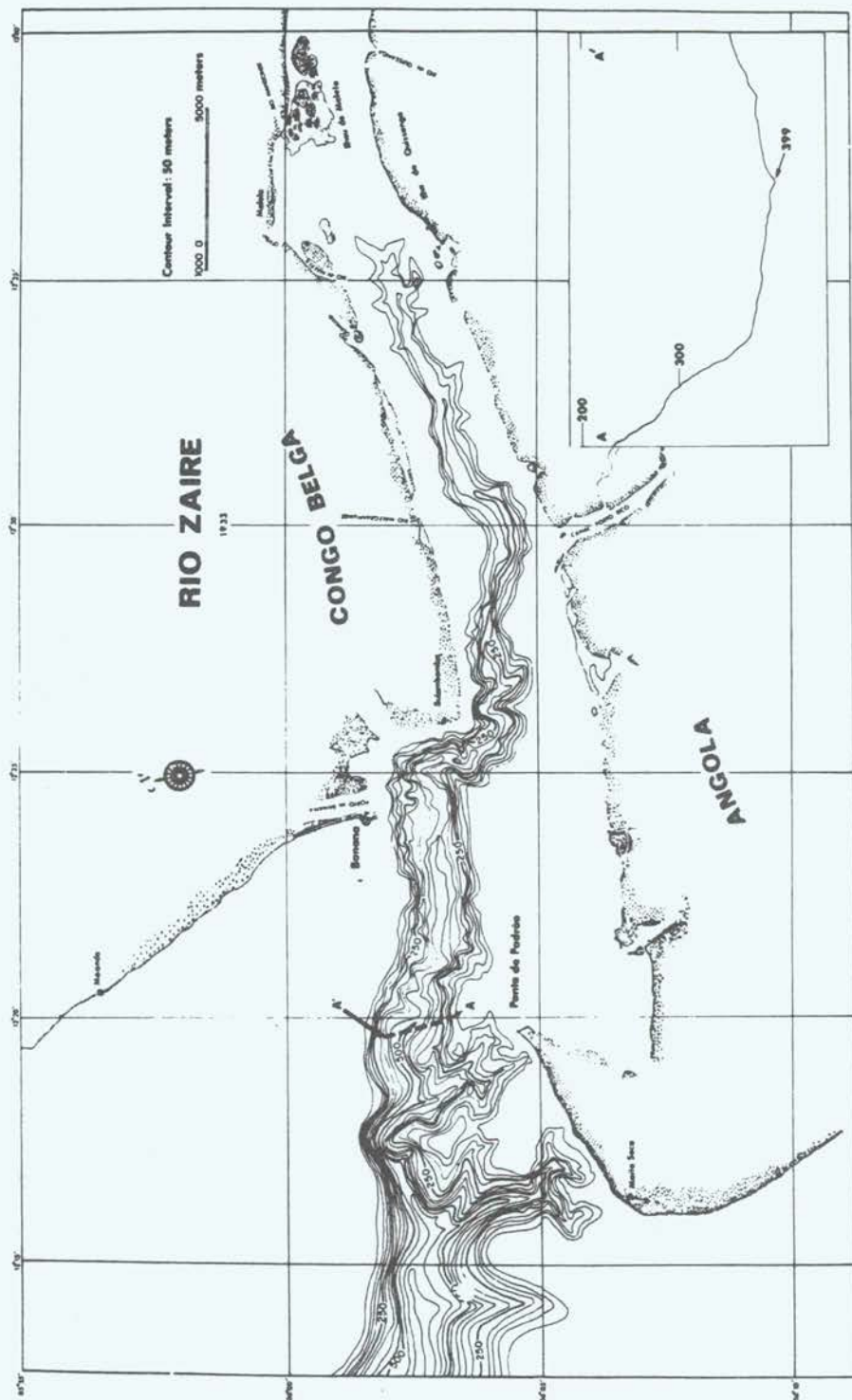


Fig. IV.26 - Morphologie de la tête du canyon du Congo-Zaire d'après la carte portugaise de 1933. In Shepard et Emery, 1973

Fig. IV.26 - Morphology of the head of the Congo-Zaire canyon based on a Portuguese chart of 1933. In Shepard and Emery, 1973

and Gabonese shelves. But the importance of this littoral muddy stretch decreases gradually, towards the north. In fact, the examination of the sedimentological maps of Giresse (1980) (scale of 1/200 000) has revealed that the true muddy ground does not pass over the Congo/Gabon border. The average flow rate of the Congo-Zaire river amounts to 45,000 m³/s, and is the second highest in the world after that of the Amazone. As for its discharge, the solid inputs are relatively low : less than 70 millions tonnes/year of suspended material, the mean turbidity being about 50 mg/l (Eisma and Van Bennekom, 1978), which places this river in the 21st rank of the world rivers. The ebb tide currents speeds reach 1.0-1.4 m/s in the estuary, between Boma and Mabela (where the canyon head is located). If one part of the sedimentary load reaches this canyon, another part contributes to the muddy grounds creation in the north. As far as we know, no study of the pelitic drifts distribution has so far been attempted.

As regards sediments characterizing the continental shelf (Giresse, 1969 ; Giresse and Kouyoumontzakis, 1973 ; Giresse and Odin, 1973) from Cape Lopez to the Congo-Zaire estuary, the pelitic inputs of this river are significant in the south, i.e., on the shelves of Zaire, Cabinda and southern Congo ; the turbid waters of the river start settling on the outer part of the shelf, to be brought back along the coast under the joint impact of the swell and the tidal currents reinforced by upwellings. The sedimentation rate is presently high and effective up to 250 km north of the river mouth. Traces of previous sedimentation are largely overlain by recent sediments, particularly, in the south of the area. The N-Congo shelf is covered by recent and relict deposits. The first ones, prevailing to a waterdepth of 80 m, are pelitic ; the second type, lying more offshore, are mainly composed of shelly sands. The quartzose fraction is reduced shorewards and completely lacking towards the outer shelf. The Gabon shelf, as far south as the Ogooue river mouth, is covered by poorly defineable sediments, where the present supplies are negligible, and where the sediments bearing a dominant quartzose fraction down to 80 m of waterdepth are provided by erosion which followed the pre-flandrian regression ; more offshore, the shelly facies, mostly relict, is widely developed. Besides a small area extending off the Tafe Point, 2 wide belts can be distinguished where rocky outcrops are more frequent (Giresse, 1980) :

- on the external edge, between -100 and -120 m, where Miocene and sometimes Pleistocene layers are almost outcropping ;
- on the inner shelf, from the coast to a depth of 40 m, rocky bottoms are less frequent, except near the surf zone ; being harder they have a rougher morphology, as they are formed by Upper Cretaceous sandstones and limestones or, sometimes, Eocene southwards.

The sedimentation in the Cape Lopez area depends upon the Ogooue river, of which the flow rate has 2 maximums corresponding to 2 rainy seasons (November-December and April-May). These flow rates are almost equivalent, and oscillate between 7,000 and 8,000 m³/s. The hydrology of the Ogooue river is characterized by the buffer phenomena due to the "sponge forest" and numerous wide effluent lakes : the overflow being stocked and redistributed during low water stages (Giresse, 1969). The Ogooue river is presently discharging at sea only very fine-grained materials. A growth of the eastern side of the Mandji island (marked by N-S oriented offshore bars), can be observed, however, its western coast is going through an erosion stage which endangers the oil production works. As early as 1959, SOGREAH was invited by the oil companies to study the possibility of Baleiniers lake (where crude oil products are stocked) being flooded by the sea. The threat was due to the thinning, exceeding 100 m in 10 years (1946-1957), of the coastal bar which

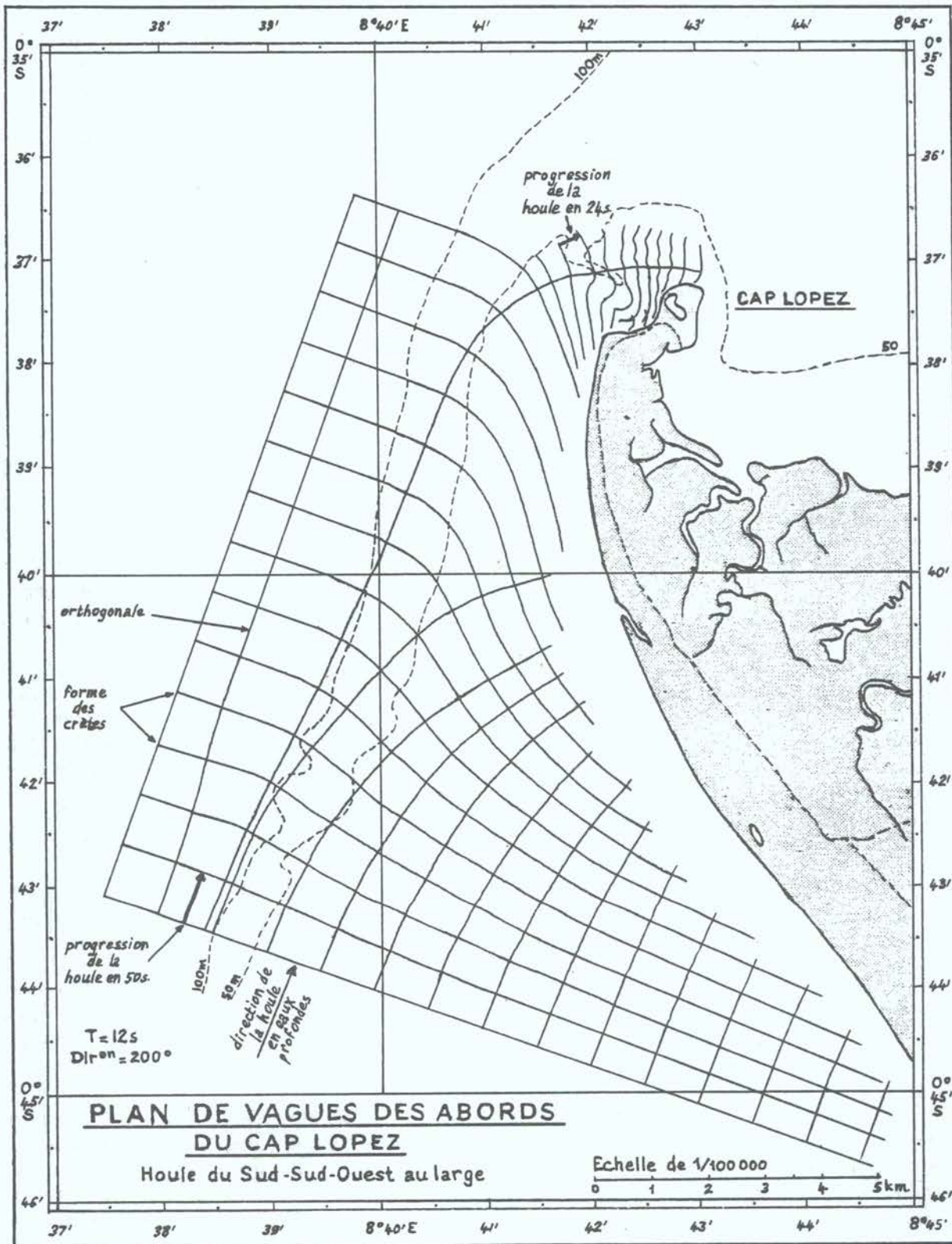
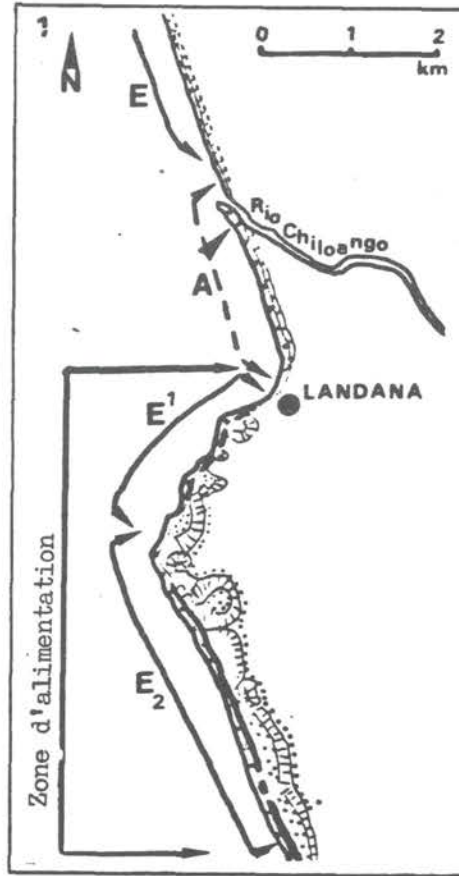
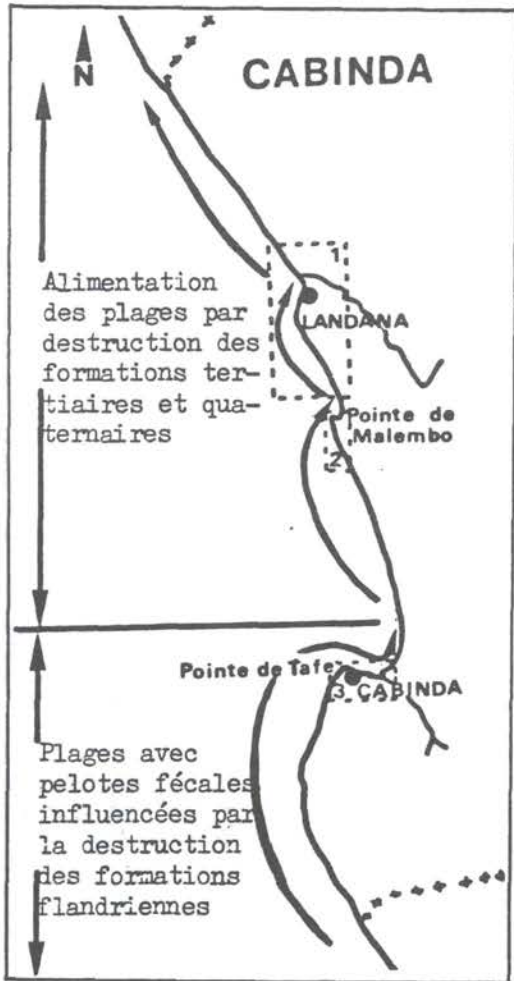


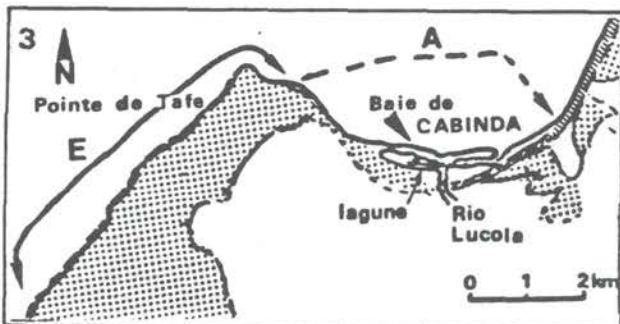
Fig. IV.27 - Plan de vagues aux abords du Cap Lopez. In Bourgoïn et al., 1963

Fig. IV.27 - Waves refraction diagram. In Bourgoïn and al., 1963



E¹ érosion dans les formations de falaises

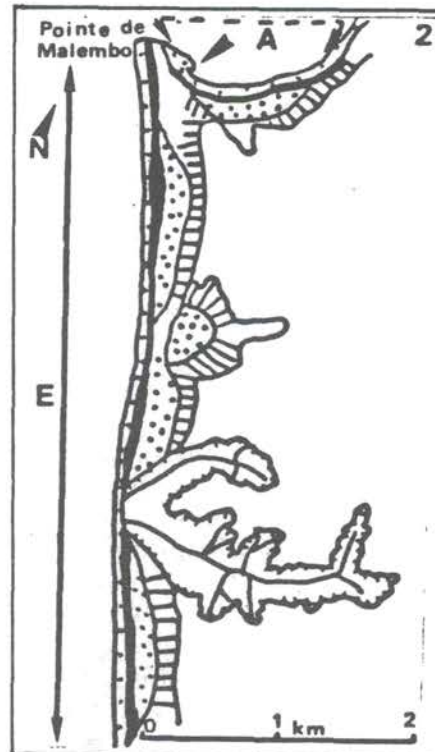
E₂ érosion des produits d'éboulement



Formations quaternaires : terrasses et falaises

Produits de démantèlement des falaises

Plage sableuse, avec pelotes fécales



E Zone d'érosion

A Zone d'accumulation

flèche littorale

niche d'ablation

a) fond de niche

b) talus de niche

Vallée au contour lobé, postérieure aux niches

Falaise dans les produits de destruction

Berge et avant-plage

Plage proprement dite

Fig. IV.28 - Evolution de la côte de Cabinda. D'après Carvalho, 1962

Fig. IV.28 - Evolution of the Cabinda coastline. After Carvalho, 1962

separated the lake from the sea (Bourgoin et al., 1963). In front of the Cape Lopez lighthouse, the characteristics of the swell, at a depth of 8 m, are as follows : most frequent period, 12 s ; most frequent significant amplitude, 0.6 m ; maximum significant amplitude, 1.5 m ; mean direction, 260°.

A waves diagram, for a 12 s period and a 200° direction, has been drawn by Bourgoin et al. (1963) (Fig. IV.27). Unlike what usually happens around heads, the swell energy seems to be scattered by Cape Lopez, due to the very oblique angle of the swell front. In spite of a rather low energy, an erosion is induced in front of Baleiniers lake.

The BCEOM (1959) study, south of Gabon along the Mayumba area, reveals characteristics of the swell identical to those observed near Port Gentil. Coastal currents run northwestwards during most of the time at speeds of 20 to 30 cm/s. However, occasionally a countercurrent flowing south can be observed ; its origin might be linked to tides. A sporadic erosion of the littoral spits, apparently related to the alternation of dry and wet seasons, is registered in this sector (S-Gabon and northern Congo).

In Congo, the only studies available concern Pointe Noire, and those were carried out for the harbour construction and maintenance. Otherwise, measurements are regularly carried out around oil platforms ; data may be obtained through the companies involved. The swell has a preferential SW to W-SW direction, a mean amplitude of 1.4 m, and a 12 s period (LCHF, 1959 and 1960). Sedimentary transit is estimated at about 650,000 m³/year south of Pointe Noire. While erosion does not represent a major problem on the Congo coast, it is nevertheless active in Loango bay (north of Pointe Noire), where coastline retrograd of 20 m was identified (in 1983) to the east of "Pointe Indienne".

Comparative analysis of aerial photographs and sedimentological study of beach sands samples helps to explain the geomorphology of the Cabinda coast and allows the follow-up of the present shoreline evolution (Carvalho, 1962). Knowledge of these phenomena are of primary importance for the planning of protective installations and harbour development. The Cabinda coast has a S-SE-N-NW trend, the general sands movement along it is SE-NW and coincides with the beach drift direction, which is itself linked to the incidence of swells on the coast (Fig. IV.28). Observed differences in the nature of inputs suggest the division of the zone into 2 areas, north and south of the town of Cabinda. Within the limits of those areas, supplying erosion and growth zones can be distinguished. In the northern area, the growth zone is located south of the Rio Chiloango, mouthed with a "restinga". The eroded materials come from the slide of the evolving southern cliffs, inducing a coarse-grained sediments input and thus modifying the mean diameter of the sand fraction. The sediments deposited in Cabinda bay appear to be arriving from the south, and, most probably, from deposits on the Zaire coast ; they originate from erosion of Flandrian loose formations. The presence of dark faecal pellets in those sediments should allow to trace their precise drift and determine their limit of dispersion in Cabinda bay.

Finally, LCHF (1975) studied the Banana Spit, on the northern shore of the Congo-Zaire river mouth ; but the results of these studies have not been made available.

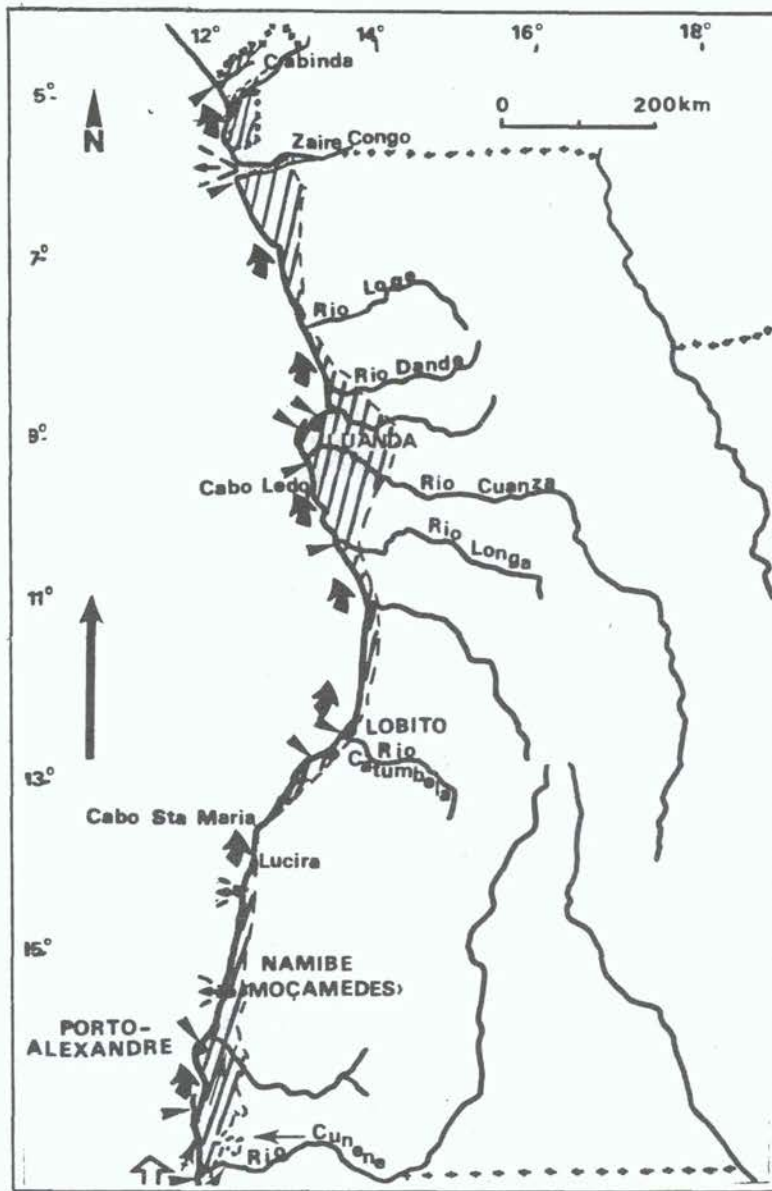
IV.10. ANGOLA (Fig. IV.29)

Except Cabinda, situated north of the Congo-Zaire river mouth and described here above, the Angola coast stretches out from 6° to 17°S, over about a length of 1,400 km. This coastal fringe is characterized by a series of cliffs, beaches and rocky escarpments. In low areas, the presence of spits with free headlands (restingas) constitutes the most outstanding geomorphologic feature. The N.NW-S.SE oriented coast turns N-S near Novo Redondo, then N.NE-S.SW at Lobito, and, lastly, almost N-S at Cape Santa Maria. Southerly, southeasterly and southwesterly, winds prevail throughout the area and tend to increase in the afternoon (Guilcher et al., 1974). The influence of the southerly swell on the beach drift is of primary importance : the swell reaches the coast with an oblique incidence and generates a northward beach drift. The climate is an important factor of differentiation : tropical, hot and wet in the north, it becomes desert in the south. In the north, the 2 seasons, rainy (from November to April-May, with a small dry season in January) and dry ("cacimbo" period, with almost no rainfall, but a low gradient of sunshine and a high relative humidity) are quite prominent. The rainfall maximum totals 800 to 1,000 mm/year on the coast and reduces southwards : 600 mm on the northern shoreline, 350 mm at Luanda, and 200 mm at Lobito. That underlines the evolutionary tendency from a semi-arid to a desert climatic pattern south of Moçâmedes (20 mm/year at Porto Alexandre). The mean annual temperature is higher in the northern (26°C) than in the southern part (17°C near the Cunene mouth) (Diniz, 1973).

The coastal fringe, except for 50 km between Cape Santa Maria and Lucira, around 14°S, is cut into the sedimentation layers of 3 basins constituted from north to south by the Congo, Cuanza and Moçâmedes basins. These sedimentary layers belong to the Congo basin which extends to Ambriz (Mussera) and extends to the Cuanza basin. The topography of the loose formations of Quelo (Pleistocene) is rather regular, but cliffs are still present in the consolidated formations or hard rock (limestones, sandstones) (dated Cretaceous and Cenozoic). The coast presents a series of rocky eroded cliffs and beaches, where pre-Quaternary deposits can be reworked and eroded too.

The coast of Angola, north of Luanda, has not been studied very extensively, because of the vegetal cover which makes the access difficult. Many small coastal rivers groove it. The continental shelf is 30-40 km wide. Oil companies locally carried out oceanographic and meteorologic measurements to anchor their drilling platforms and offshore derrieks. Results remain unfortunately unpublished. Throughout this area, just as in the eighth and ninth units, described in this paper, sediments are drifted northwards by longshore currents. This south to north drift induces the formation of small sandy spits deep-seated to the south at the level of the biggest rivers : Rios Chilango and Lucola, Congo-Zaire.

Between the Rio Loge and the Benguela area (Cape Santa Maria), the coast cuts again into the sedimentary sites of the Cuanza basin. The most outstanding morphological feature is the presence of the long deep-seated spit south of the town of Luanda, of which the northern part (ilha de Luanda) shelters the harbour (as described in chapter III.2.). It is situated at the level of a narrowing in the continental shelf (less than 10 km) which widens to 30, and further, to 20 km off Benguela. Similarly with the northern area, the shoreline and the hydrographic pattern accentuate the lithology : hard limestones and the sandstones give rise to cliffs and capes (Barra do Dande, Farol das Lagostas Point, Cabo Ledo, Cabo das Tres Pontas) which can extend as coastal escarpments (the ones of Barra do Dande to Seo Tiago, the escarpment which extends Cabo Ledo, and of Porto Ambouim). Those formations are undergoing




- | | | | |
|---------------|---|---|---|
| sand spit | ▶ flèche littorale | ← | transport éolien - aeolian transport |
| canyon | ↳ canyon | ← | houle dominante - prevailing swell |
| coastal drift | ↖ transit sédimentaire | ↖ | courant de surface - surface current |
| |  | | bassin sédimentaire - sedimentary basin |

Fig. IV.29 - La côte angolaise : caractéristiques morphologiques, processus de transport sédimentaire

Fig. IV.29 - Angolan coast : morphological trends, sediment transport processes.

very active erosion : marly layers lead to the formation of wide bays, sometimes limited inwards by a cliff, with sand dunes at its foot colonized by vegetation ; the old bars and weathered materials from these cliffs must be considered as sediment sources, on a par with solid river discharges. A survey carried out between Lobito and Tio Caporolo (Carvalho, 1963) indicates an unmistakably continental origin of sands deposited on the beaches. It is possible that the dams built on the main rivers (Cuanza, Catumbela) have led to a decrease of solid loads and thus of inputs to the restingas (Guilcher et al., 1974). On the spits of the Ilha de Luanda and of Lobito, some groynes had to be built to stop their erosion (Perestrelo, 1945 ; Van Dongen, 1960 ; Cardoso, 1966). Besides these 2 restingas, which are of major economic importance since they shelter the only 2 harbours of the country, small deep-seated littoral restingas are observed in the south, near the rivers mouths (Rio Dande, Cuanza, Longa).

The Precambrian lower group outcrops between Cape Santa Maria and Lucira. Thus, the coast is mainly rocky, with small bays. South of Benguela, the continental shelf grows narrower (2 km at Cape Santa Maria) and widens only in the south at Porto Alexandre, to reach 35 km in Tigers Bay (Rocha, 1973). A series of cliffs, escarpments and beaches reappear south of Lucira, where a sedimentary basin of Moçâmedes starts developing. The bays shelter fishing grounds which have contributed to coastal settlement in the XIXth century. These Cretaceous and Tertiary formations are notched by many small coastal rivers which have a very intermittent regime due to the insufficiency and irregularity of the rainfalls. 2 of them, the Rio Carunjamba and Rio Bero, flow seawards through canyons, may modify beach drift (but, to the best of our knowledge, no study has yet been made). It was in this area (from Lobito, notably) that different old marine abrasion platforms have been identified : they were found to correspond to the high levels of Quaternary seas. These elevated deposits speak of the intensity of the uplifts which affected the evolution of this area. The actual coastal geomorphology seems to have been inherited from these old processes, while erosion is perpetuated by the current evolutionary phenomena (Feio, 1960 ; Carvalho, 1961 ; Giresse, 1975 ; Kouyoumontzakis and Giresse, 1975 ; Giresse et al., 1984). The epirogenic tendency diminishes south of Moçâmedes.

The area from Porto Alexandre to Tigers Bay is characterized by the influence of the desert climate and thus, local winds have an appreciable effect (described in chapter II.1.). The most outstanding feature of this southern coast is the Tigers Bay restinga, which is well studied (Machado, 1923, 1936 ; Carvalho, 1961 ; Feio, 1966, 1970 ; Torquato, 1970, 1971 ; Guilcher et al., 1974 ; Guilcher, 1982). The evolution of this restinga is described in chapter III.2., example 11. Another restinga, smaller, deep-seated in the south and protected by Enfiado Point, serves as a shelter to the fishing port of Porto Alexandre.

To sum up, sedimentary transport phenomena along the Angolan coast are still poorly known. The swells action prevails and is reinforced by southerly winds inducing a northerly drift characterized by the implantation and development of spits. Erosion and deposition also depend on positive epirogenic changes well marked in the Benguela-Lobito area and slightly moderated in the south, whereas in the north there is a subsidence tendency. Mapping and hydrologic measurements of the continental shelf carried out by the Portuguese Hydrographic Office were stopped in 1974 ; to our knowledge, these data, if published, are not readily available.

V. CONCLUSION

The Western and Central African coasts facing the Atlantic ocean constitute a natural laboratory, particularly interesting from the point of view of coastal morphogenesis and erosion phenomena. Although they correspond to a common entity (western part of African continent), they display, from north to south, a wide variety of sub-units, controlled by a diversity of climatic, oceanological and geological factors, and by a variability of the continental shelf morphology (orientation, width, occurrence of submarine canyon heads). Some of these coasts are currently undergoing intense erosional processes, particularly rapid along the Bight of Benin, result of the Akosombo dam project on the Volta river (East-Ghana), and the presence of Lomé and Lagos harbours. Incidentally, we would like to emphasize that the dams are playing a major role in disturbing the equilibrium of sandy beaches by cutting off terrigenous river input to the sea, and thus causing impoverishment of sedimentary littoral transit. The construction of coastal installations at the right angle to the coast (e.g. jetties) appear to also disrupt, although to a much lesser extent and only sporadically, coastal circulation.

Although the available data are not uniform, they nevertheless represent a considerable amount of literature (about 900 references, see the separate volume) of which this report will provide only a general survey. However, it is but a first attempt at organizing and marshalling essential facts, and is intended to serve as a basis for a more elaborate synthesis.

Arriving at this final point, we deem it necessary to express our belief that the effort should be carried on and the paper perfected, so as to be of practical use for the countries involved in the WACAF/3 project, since they will become increasingly concerned with coastal erosion control, owing to expanded coastal development, or to human intervention with the shoreline shaping factors.

A P P E N D I X I

TOPOGRAPHICAL, SEDIMENTOLOGICAL, AND BATHYMETRIC MAPS

Map coverage

I. NORTH AMERICAN (United States and Canada) SOURCES

An inventory of North American sources for maps and charts of coastal areas was specified as one of the tasks for the UNEP/UN-DIESA/UNESCO project on coastal erosion in West and Central Africa (WACAF/3). The results of the survey carried out by Research Planning Institute, Inc. (RPI) are described in detail in the report of Murday and Savitsky (1984).

1) United States

Maps are available in the United States through both private firms and Government agencies :

- . Defense Mapping Agency (DMA) - Fig. 1 + Tables 1 and 2 ;
- . U.S. Geological Survey (USGS) - Table 3 ;
- . National Archives - Table 4 ;
- . the Library of Congress ;
- . the National Oceanic and Atmospheric Administration (NOAA) ;
- . private map distributors (see table, in Murday and Savitsky, 1984).

2) Canada

- . Canada International Development Agency ;
- . two private firms :
 - Gabriel Aerial Marine Instruments,
 - Mc Gill Maritime, Inc. ;
- . the data bank of maps and charts of the Department of Photogrammetry of Laval University in Quebec.

It is strongly recommended that European rather than North American sources be utilized, because of the lack of a central repository in the United States or Canada. And also, for purposes of collecting maps predating the 1900s or maps at a detailed scale, it is necessary to utilize the more complete French and British map collections.

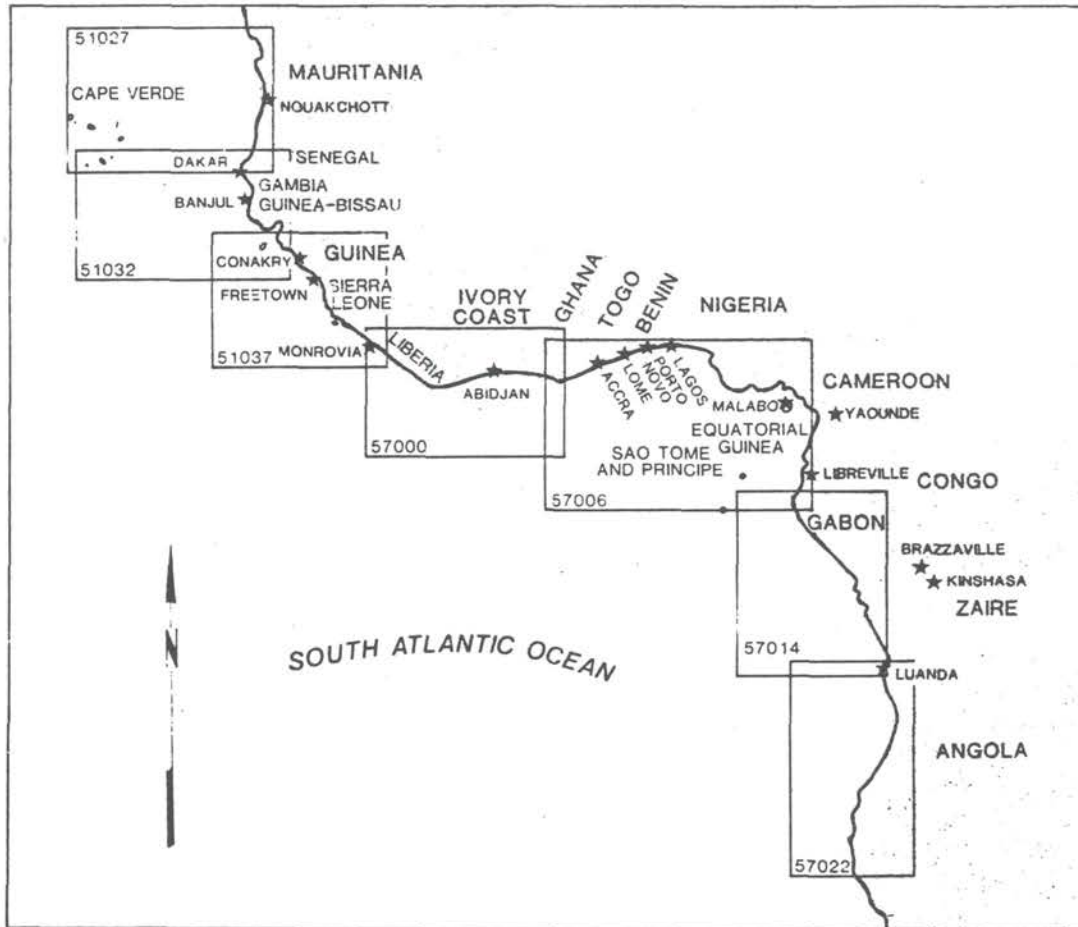


Fig. 1 - Assemblage des cartes marines de l'Afrique de l'Ouest et du Centre éditées par l'Agence Cartographique de l'U.S. Defence

Fig. 1 - Map coverage of West and Central Africa by the U.S. Defence Mapping Agency

Chart No.	Title	Scale (1:)
51460	Cap Blanc to Nouakchott (Africa-West Coast)	282,910
51461	Approaches to Port Etienne (Africa-West Coast)	39,400
51480	Coasts of Southern Mauritania & Northern Senegal (West Africa)	288,460
51481	St. Louis Anchorage Plan: Port of St. Louis	60,000 15,000
51500	Cape Verde Islands, Northwestern Group Plan: Porto Grande	250,000 20,000
51520	Cape Verde Islands, Eastern Group Plan: Porto de Santa Maria	250,000 15,000
51540	Cape Verde Islands, Southern Group Plan: Porto Da Praia	200,000 15,000
51560	Cap Vert to Ponta Caio	291,800
51561	Cap Vert (Cape Verde) to Cap De Noze Plan: Port de Dakar	49,910 7,500
51562	River Gambia Entrance Plan: Banjul	77,150 12,925
51580	Punta De Caio to Cap Verga including Arquipelago dos Bijagos (Africa-West Coast) Plans: A. Bissau B. Bolama	294,500 37,500 80,000
51600	Cap Verga to Cape Sierra (West Coast of Africa)	296,000
51601	Iles de Los & Approaches to Conakry (Guinea)	25,000
51620	Cape Sierra Leone to Cape Mount	297,500
51621	Entrance to Sierra Leone River (Africa-West Coast)	20,000
51640	Cape Mount to Cestos River (Africa-West Coast)	300,000
51641	Mano River to Junk River (Liberia-West Coast of Africa) Plan: Monrovia Bay	143,850 32,250
51642	Junk River to Cestos Bay (Liberia) Plan: Port Buchanan and Waterhouse Bay	145,250 24,460
51643	Cestos Bay to Sinu Bay (Liberia)	72,752
51644	Bays in Liberia Plans: A. Cestos Bay B. Port of Greenville C. Sinoe Bay D. Sehnkwehn River and Bafu Bay	24,320 10,000 24,640 24,320
51660	Cestos River to Cape Palmas	300,000
51663	Garraway to Tafu Point (Liberia) Plan: Cape Palmas Anchorage	72,690 12,554
57040	Cape Palmas to Grand-Lahou (West Coast of Africa) Plan: Port to San Pedro	300,000 20,000

Tableau 1 - Liste des cartes éditées par l'Agence de la Défense

Table 1 - Charts prepared by the Defence Mapping Agency

Chart No.	Title	Scale (1:)
57041	Plans on the West Coast of Africa A. Port of Abidjan B. Port of Lome C. Cotonou Roadstead	30,000 25,000 25,000
57060	Grand Lahou to Cape Three Points (Gulf of Guinea)	299,000
57061	Cape Three Points to Saltpond (West Coast of Africa)	100,000
57062	Takoradi & Sekondi Bays (Ghana) Plan: Takoradi Harbor	12,500 7,500
57080	Cape Three Points to Cape St. Paul	299,000
57081	Saltpond to Tema (West Coast of Africa)	100,000
57082	Approaches to Accra (West Coast of Africa) Plan: Accra Roads	25,000 12,500
57083	Port of Tema (Republic of Ghana)	10,000
57100	Cape St. Paul to Ikegu	299,000
57101	Lagos Harbor (Nigeria)	12,500
57120	Ikegu to Cape Formoso (Gulf of Guinea-Africa-West Coast) Plan: River Escravos Entrance	299,000 50,000
57140	Cape Formoso to Kwa Ibo River including Ilha do Principe (Gulf of Guinea)	299,600
57141	Bonny & New Calabar Rivers (Gulf of Guinea) (Nigeria)	50,000
57142	Wallis Point to Port Harcourt (Nigeria) Plans: A. Northern Port B. Southern Port C. Port Harcourt	25,000 25,000 5,000
57143	Plans in the Gulf of Guinea A. Baia de St. Antonio (Ilha do Principe) B. Ilha de Sao Tome C. Ilha de Principe D. Porto de Fernao Dias to Baia de Ana Chaves	25,000 200,000 200,000 20,000
57160	Kwa Ibo to Rio Benito including Fernando Poo	299,500
57161	Douala and Approaches Plan: Port of Douala	35,000 15,000
57162	Riviere Cameroun & Approaches	96,675
57180	Rio Benito to Pointe Ognore including Ilha do Principe and Ilha de Sao Tome (Africa-West Coast)	300,000
57181	Corisco Bay (Africa-West Coast)	100,000
57182	Riviere Gabon (West Coast of Africa) Plan: Libreville Anchorage	98,910 20,000
57200	Pointe Nyonie to Pointe Pardras (Gabon)	299,900
57201	Approaches to Port Gentil (Gabon)	30,000
57220	Pointe Pedras to Pointe Noire (West Coast of Africa)	299,400

Tableau 1 - Liste des cartes éditées par l'Agence de la Défense

Table 1 - Charts prepared by the Defence Mapping Agency

Chart No.	Title	Scale (1:)
57240	Pointe Noire to Cabeça da Cobra including Congo River Entrance	298,600
57241	Approaches to Pointe Noire (Africa-West Coast) Plans: A. Baie de Pointe Noire to Baie de Loango B. Port of Pointe Noire	50,000 10,000
57242	Congo River-The Entrance to Grande Ile Mateba	60,000
57244	Congo River-Grande Ile Matebo to Matadi Plans: A. Port de Boma B. Radi di Matadi	60,000 6,250 6,250
57260	Cabeça da Cobra to Cabo Ledo	297,000
57261	Baia do Dande to Port of Luanda (Angola)	60,000
57262	Port of Luanda	15,000
57280	Cabo Ledo to Ponta das Salinas (Africa-West Coast)	294,500
57282	Port of Lobito	10,000
57283	Ports on the Coast of Angola A. Baia de Banguela B. Porto do Cuio C. Porto da Baia dos Elefantes	30,000 20,000 20,000
57300	Ponta das Salinas to Ponta Albina	291,000
57301	Ports & Bays on the Coast of Angola A. Baia de Mocimoes B. Baia de Santa Maria C. Porto Alexandre D. Baia do Baba	30,000 15,000 30,000 15,000
57320	Ponta Albina to Rocky Point	286,000
57340	Rocky Point to Hogden Hafen	282,000

Tableau 1 - Liste des cartes éditées par l'Agence de la Défense

Table 1 - Charts prepared by the Defence Mapping Agency

Country	Date	Scale
Angola	-	1:3,250,000
Benin	1976	-
Cameroon	1970	1:2,525,000
Cape Verde	1977	1:1,700,000
Congo	1971	1:2,490,000
Cabon	-	1:1,690,000
Gambia (and Senegal)	-	-
Ghana	1971	1:1,500,000
Guinea	1977	1:1,716,000
Guinea-Bissau	-	-
Ivory Coast	1972	1:1,900,000
Liberia	-	-
Mauritania	1967	1:3,500,000
Nigeria	1979	-
Senegal (and Gambia)	-	-
Sierra Leone	1969	1:920,000
Togo	1983	-
Zaire	-	-

Tableau 2 - Cartes disponibles à la "Defence Mapping Agency"

Table 2 - Defence Mapping Agency maps

Date	Scale	Map Type
1949	1:500,000	Economic Planning Mission
1957	1:500,000	Geological Series
1970	1:500,000	Aeromagnetic
1973	1:250,000	Topographic Relief
1974	1:250,000	Aeromagnetic
1974	1:250,000	Total Count Gamma Radiation
1977	1:250,000	Geological Series

Tableau 3 - Cartes éditées conjointement par l'U.S. Geological Survey et le Liberian Geological Survey

Table 3 - Maps prepared jointly by U.S. Geological Survey and Liberian Geological Survey

REGIONAL		
Mauritania to Lagos, Nigeria	1945	1:500,000
Mauritania to Douala, Cameroon	1953	1:250,000
Sierra Leone	1943	1:250,000
Senegal	1953	1:200,000
Senegal & Gambia	1953	1:125,000
Mauritania, Senegal, & Gambia	1954	1:50,000
Cape Verde Islands	1953	1:100,000
PORTS		
St. Louis, Senegal	1946	1:5,000
St. Louis, Senegal	1949	1:5,000
Dakar, Senegal	1946	1:10,000
Bathurst, Gambia	1946	1:2,500
Conakry, Guinea	1947	1:5,000
Freetown, Sierra Leone	1946	1:63,360
Freetown, Sierra Leone	1947	1:6,250
Takoradi City, Ghana	1933	1:1,250
Accra, Ghana	1944	1:1,250
Accra, Ghana	1954	1:1,250
Volta Delta, Ghana	1949	1:5,000
Volta Delta Ghana	1952	1:5,000

Tableau 4 - Cartes éditées par le Service cartographique des Armées

Table 4 - Maps prepared by the Army Map Service

II. UNITED KINGDOM

All the charts available in order to identify coastal erosion problems come mainly from (in Collins et al., 1983) :

- . Directorate of Overseas Survey, Tolworth ;
- . Institute of Oceanographic Sciences, Taunton ;
- . the (UK) Admiralty Hydrographic Department, Taunton ;
- . Institute of Geological Sciences, Nottingham ;
- . Geology Department, Imperial College, London ;
- . the Geological Museum, London.

Documents purchased for the purpose of this investigation include : Hydrographic Charts (Table 5), and an African Resources Mapping and Development Chart (produced by Huntings Geology and Geophysics Ltd) (Table 6).

Region	Chart Ref. No.	Date of Initial Survey	Date of Latest Survey
Angola	627	1825-1826	1946
Angola to Gabon	604	1825-1826	1953
Gabon to Equatorial Guinea	1887	1954	-
Equatorial Guinea to Cameroon	1888	1954	-
Cameroon to Niger Delta	1357	1895	1979
Niger Delta to Ghana	595	1928	-
Ghana to Sierra Leone	3139	1826-1838	-
Sierra Leone to Senegal	1147	1900	-
Senegal to Mauritania	3247	1948	-

Tableau 5 - Cartes hydrographiques éditées par l'U.K. Admiralty

Table 5 - Hydrographic (U.K. Admiralty) charts purchased

Tableau 6 - Table 6 WACAF/3 : AFRICAN RESOURCES MAPPING AND DEVELOPMENT CHART

COUNTRY	AREA (APPROX.) km ²	POPULATION (MID 1980) x 10 ⁶	GNP ¹ 1980 US \$	GNP ¹ PER CAPITA 1980 US \$	PROPORTION OF EACH COUNTRY COVERED ²				GEOLOGICAL MAPPING ³				NUMBERS OF DIFFERENT MINERALS AND ENERGY RESOURCES IN PRODUCTION				COUNTRY		
					AIR PHOTO SURVEY	SAR	SLAN	616SAT	1:50,000 TO 1:250,000	1:50,000 TO 1:125,000	1:250,000 TO 1:500,000	1:500,000 TO 1:1,000,000	METALLIC ORES	ENERGY RESOURCES	INDUSTRIAL MINERALS	CONSTRUCTIVE MATERIALS		TOTAL	
NORTH AFRICA																			
MOROCCO	822,000	20.18	17,440	860										13	41	7	8	32	MOROCCO
ALGERIA	2,952,000	18.82	38,410	1,820										4	411	9	8	27	ALGERIA
TUNISIA	164,190	6.35	8,240	1,310										4	31	4	8	19	TUNISIA
LIBYA (S.P.A.J.)	1,789,000	2.88	28,730	8,840										4	211	1	7	10	LIBYA (S.P.A.J.)
EGYPT (A.R.E.)	1,000,260	88.77	23,140	880										4	31	13	11	30	EGYPT (A.R.E.)
A.C.P. COUNTRIES																			
MAURITANIA	1,088,000	1.83	830	320										2	1	1	2	5	MAURITANIA
MALI	1,240,000	6.84	1,340	180										2	1	2	5	10	MALI
UPPER VOLTA	274,000	6.73	1,110	180										1*	1	4	4	7	UPPER VOLTA
NIGER	1,287,000	5.32	1,780	330										2	3	2	4	11	NIGER
CAPE VERDE ISLANDS	4,000	0.32	100	(300)										1	1	1	1	6	CAPE VERDE ISLANDS
SENEGAL	201,400	6.86	2,560	450										1	1	1	2	8	SENEGAL
GAMBIA	11,000	0.80	150	250										2*	1	3	3	9	GAMBIA
GUINEA BISSAU	36,000	0.78	130	(150)										1	1	4	2	8	GUINEA BISSAU
GUINEA	246,000	5.42	1,590	760										1	1	1	2	7	GUINEA
BIERRA LEONE	73,000	3.47	950	270										1	1	1	1	5	BIERRA LEONE
LIBERIA	110,000	1.86	980	520										1	1	4	2	8	LIBERIA
IVORY COAST	323,000	8.64	8,920	1,160										1	21	1	2	9	IVORY COAST
GHANA	239,000	11.98	4,920	420										3	21	3	7	15	GHANA
TOGO	85,000	2.48	1,020	410										1	11	1	6	7	TOGO
BENIN	113,000	5.63	1,080	300										6	41	5	8	23	BENIN
NERGHERIA	924,000	64.73	86,610	1,010										2	31	2	6	13	NERGHERIA
CAMEROON	476,000	8.44	5,680	670										2	31	2	6	13	CAMEROON
EQUATORIAL GUINEA	28,000	0.36	N.A.	N.A.										2	411	1	1	1	EQUATORIAL GUINEA
GABON	287,000	0.86	2,420	3,680										4	31	1	4	11	GABON
SAO TOME PRINCIPE	840	0.11	80	(490)										1	1	1	1	4	SAO TOME PRINCIPE
CONGO	342,000	1.64	1,120	230										1	1	1	1	4	CONGO
CHAD	1,284,000	4.46	830	120										1	1	1	1	4	CHAD
CENTRAL AFRICAN REP.	623,000	2.29	680	(300)										1	1	1	1	4	CENTRAL AFRICAN REP.
SIUDAN	2,506,000	18.37	9,640	470										1	1	1	1	4	SIUDAN
ETHIOPIA	1,220,000	31.47	4,320	140										3	21	2	8	15	ETHIOPIA
DJIBOUTI	23,000	0.35	170	(480)										2	1	1	1	4	DJIBOUTI
SOMALIA	638,000	3.81	N.A.	N.A.										1	1*	1	1	2	SOMALIA
KENYA	683,000	15.98	6,620	420										2	14	10	29	KENYA	
UGANDA	236,000	13.20	3,750	(280)										4	2	1	3	8	UGANDA
RWANDA	28,340	6.08	1,040	200										2	2	1	3	8	RWANDA
BURUNDI	28,800	4.10	810	200										2	2	1	3	8	BURUNDI
TANZANIA	948,000	18.14	4,780	260										2	2	8	8	21	TANZANIA
MALAWI	118,000	6.95	1,390	230										1	1	1	1	9	MALAWI
ZAMBIA	2,345,000	28.29	6,340	220										9	41	2	7	22	ZAMBIA
ZIMBABWE	390,000	7.40	4,540	830										2	6	6	6	22	ZIMBABWE
BOTSWANA	82,000	0.80	730	910										12	2	11	8	33	BOTSWANA
SWAZILAND	17,360	0.56	380	(680)										3	4	6	14	33	SWAZILAND
LESOTHO	30,300	1.14	620	(390)										1	1	2	6	9	LESOTHO
MADAGASCAR	590,000	8.71	3,030	350										1	1	1	1	5	MADAGASCAR
COMOROS	2,240	0.35	100	(300)										1	2	9	7	19	COMOROS
MAURITIUS	1,950	0.96	1,020	1,060										1	1	1	1	7	MAURITIUS
REUNION	280	0.07	120	(1,700)										1	1	1	1	5	REUNION
SOUTHERN AFRICA																			
ANGOLA	1,247,000	7.08	3,320	470										4	11	2	7	12	ANGOLA
NAMIBIA	824,000	1.61	1,420	1,410										10	1	6	9	22	NAMIBIA
MOZAMBIQUE	785,000	10.47	2,810	270										4	2	3	5	14	MOZAMBIQUE
SOUTH AFRICA	1,271,000	29.28	66,960	2,290										15	3	19	10	47	SOUTH AFRICA

Notes: 1. World Bank data 1981. Preliminary figures. Estimated figures in brackets. 2. Topographical maps, air photography and aerometric maps are not necessarily in public domain. 3. Additional unclassified geological maps are available at many survey offices. With a few exceptions good Landsat imagery is available throughout. 4. Energy resources include: Oil, minerals, etc. 5. Maps by producers. 6. Revisions due to be brought into production.

III. FRANCE

An inventory of French sources for maps and charts of coastal areas was also carried out. The selected institutions are :

- . the "Institut Géographique National" ;
- . the "Institut d'Océanographie" ;
- . the "Institut de Géographie" ;
- . the "Office de la Recherche Scientifique et Technique d'Outre-Mer" (ORSTOM) ;
- . the "Service Hydrographique de la Marine" (SHOM) ;
- . the "Institut Français de Recherche pour l'Exploitation de la MER" (IFREMER) ;
- . the "Bureau Central d'Etudes pour les Equipements d'Outre-Mer" (BCEOM) ;
- . the "Laboratoire Central d'Hydraulique de France" (LCHF) ;
- . the "Universités" (e.g. Bordeaux, Paris ...) ;
- . the "Centre National de la Recherche Scientifique" (CNRS) ;
- . the "Service Géologique National" of BRGM.

Also we have found valuable data, especially map coverages concerning English-speaking countries, in documents from the International Mapping GEOCENTER of Stuttgart (Western Germany).

Unfortunately, we could not get any information on Angola map coverages ; because the Portuguese Hydrographic Office, who carried out mapping of the continental shelf and hydrologic measurements did not published these results.

To avoid redundancy of regional maps, the survey was restricted to maps with scales greater (1:50,000 to 1:2,000).

1) Topographical maps

The "Institut Géographique National" coverage was made at different scales : 1:50,000 ; 1:100,000 and 1:200,000. But these maps are available only after clearance of the concerned country (but for Senegal). We present, here, the coverages of these different sheets for the involved countries, except for Angola, of which no documentation was available.

MAURITANIE

Situation au
31 Décembre 1979

PUBLICATION

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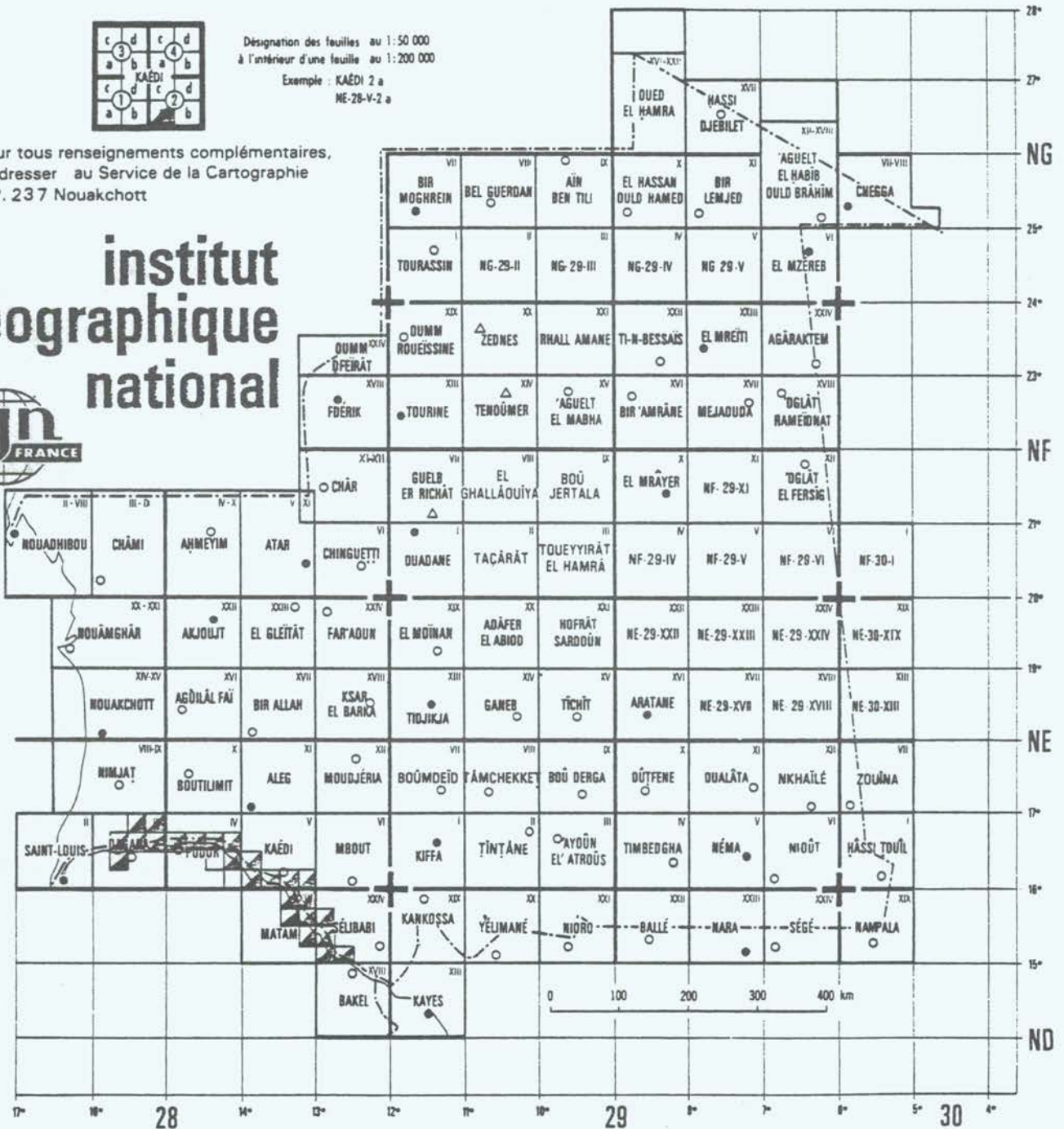
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MAURITANIE

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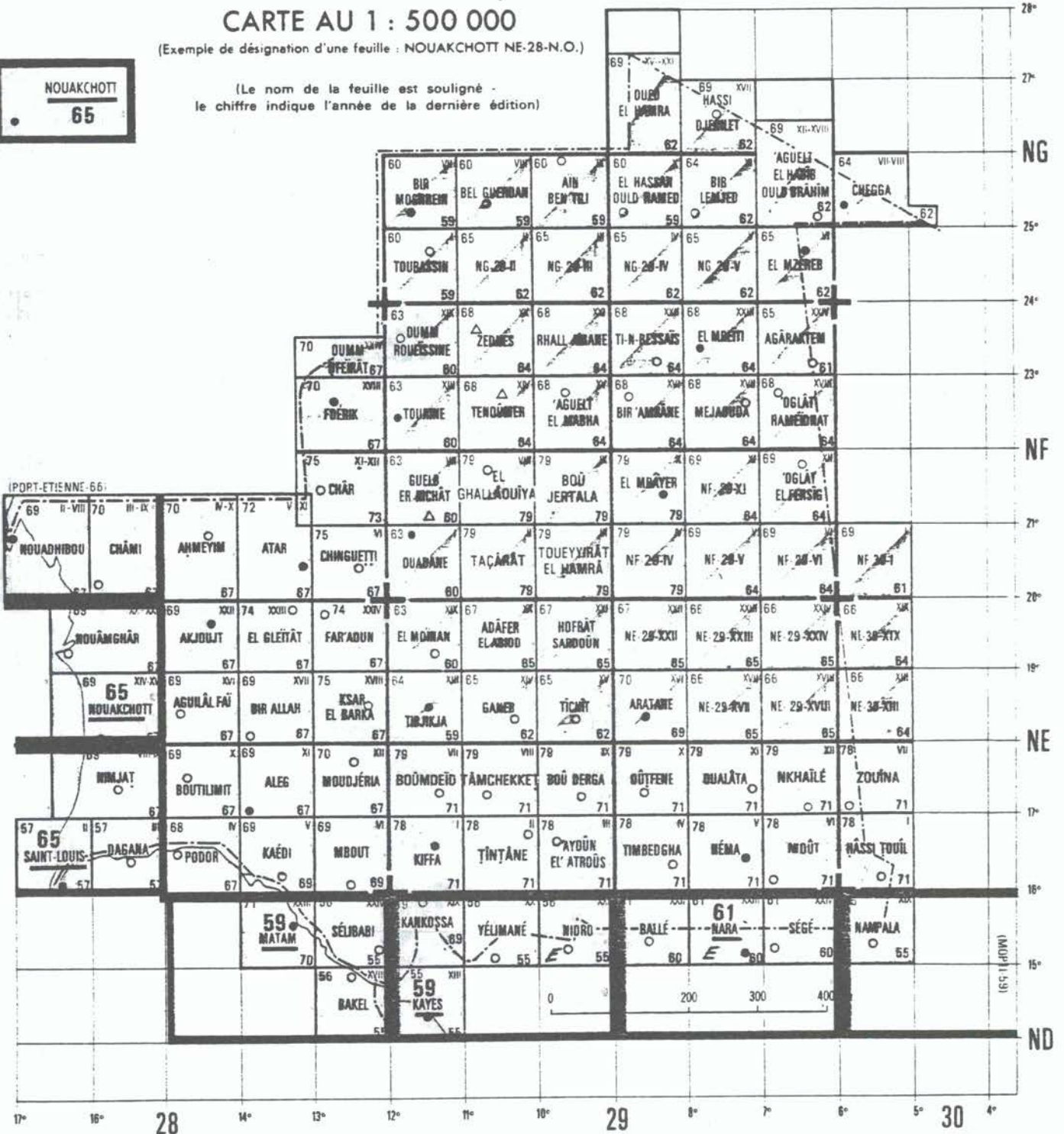
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(Exemple de désignation d'une feuille : NOUAKCHOTT NE-28-N.O.)

(Le nom de la feuille est souligné - le chiffre indique l'année de la dernière édition)

NOUAKCHOTT

65



SÉNÉGAL

Situation au
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PUBLICATION
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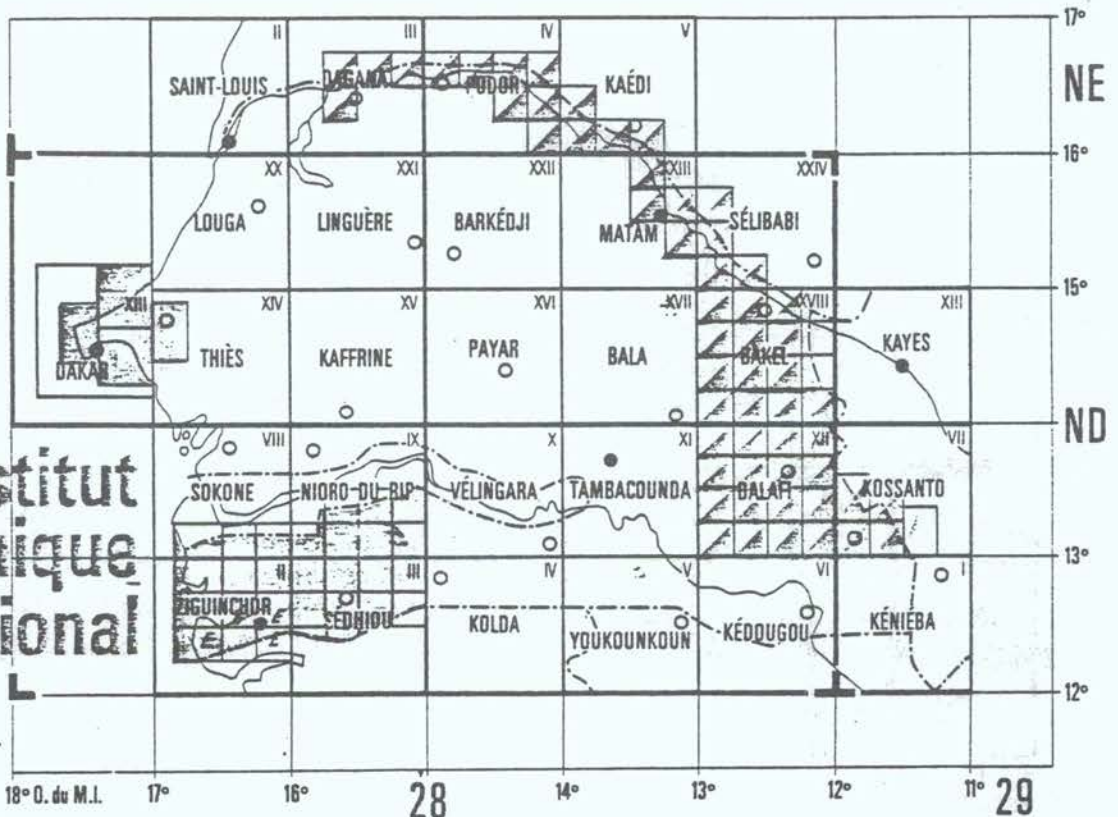
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ND-28-II-1 c



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Situation au
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Feuille publiée	Rédition en cours ou prévue

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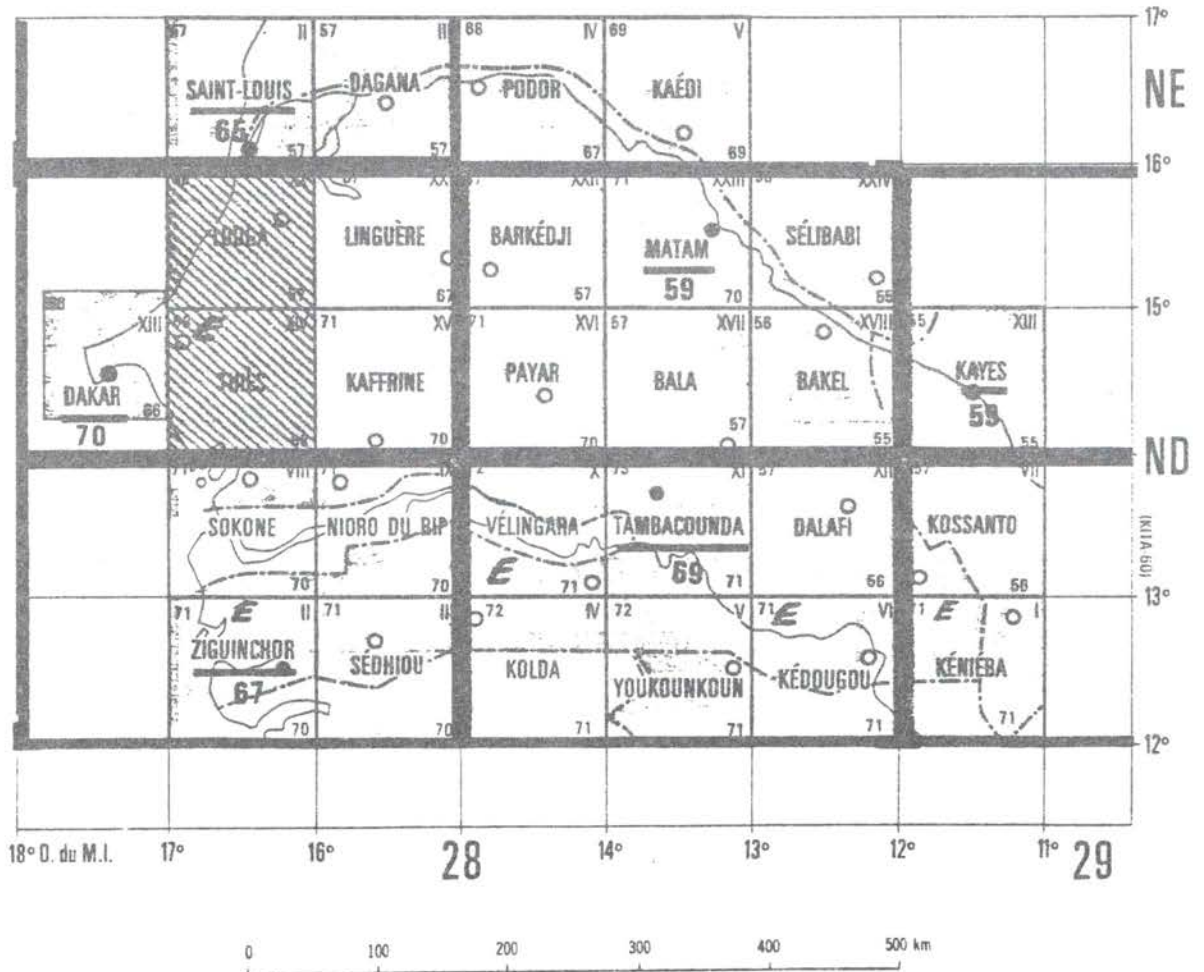
Le chiffre du bas indique l'année du complètement sur le terrain, de la révision ou de la dernière mise à jour.
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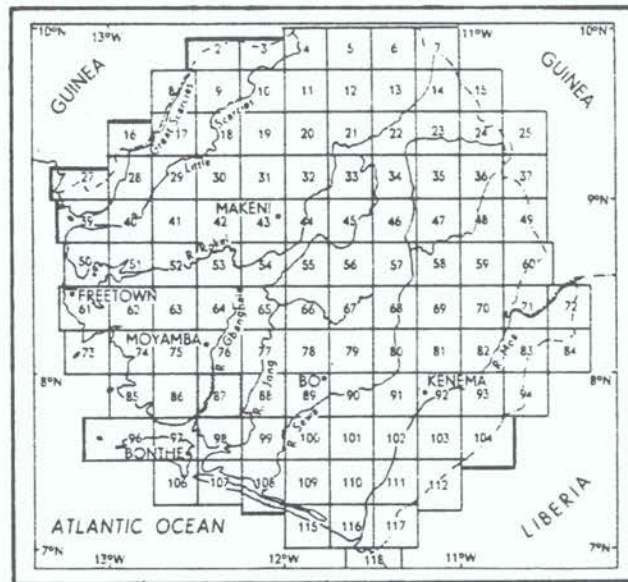
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E : cotes épuisées

S I E R R A L E O N E



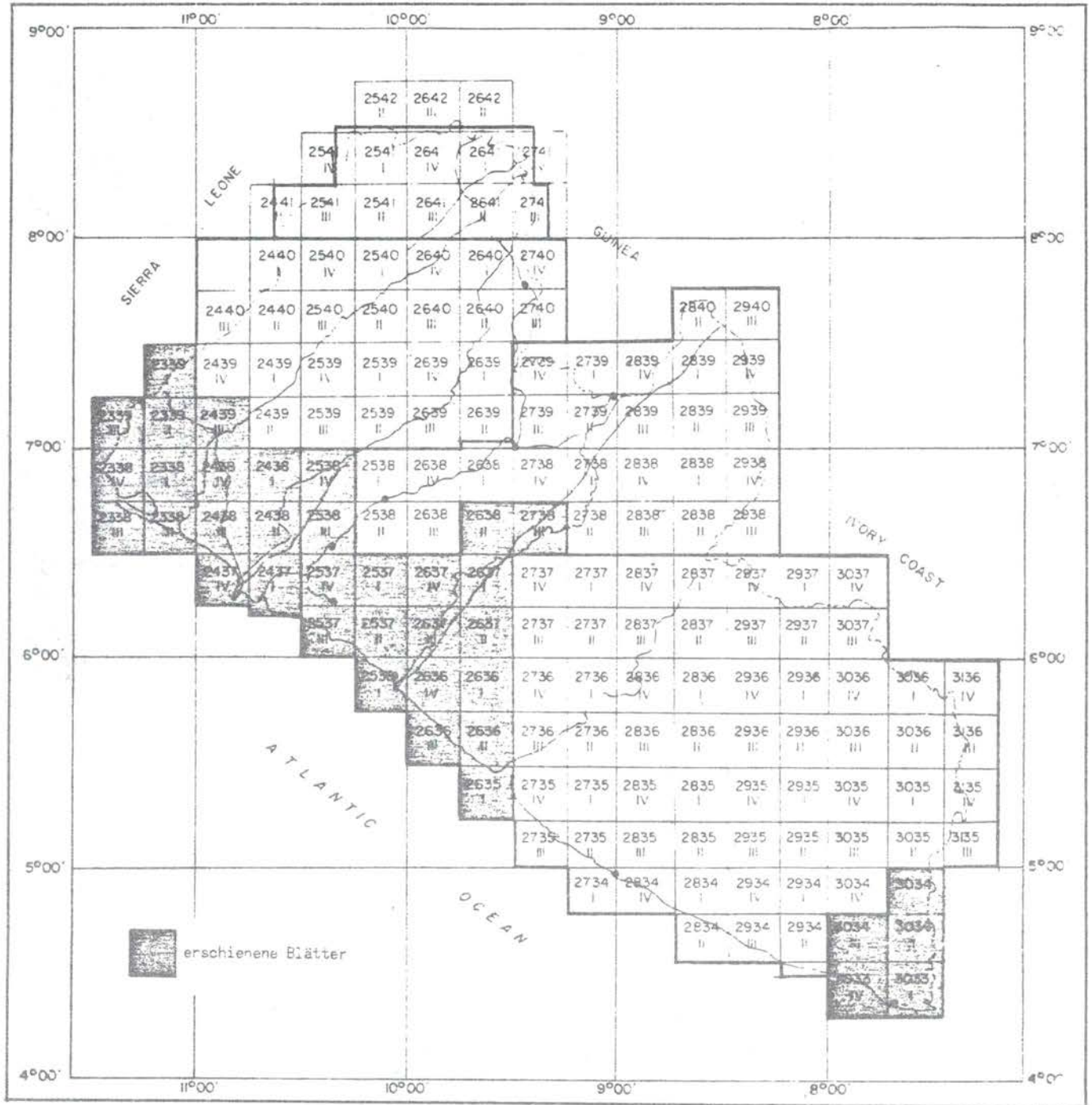
Source des données : catalogue du Geocenter de Stuttgart (RFA)

Année : mars 1982

Echelle : 1/50 000

Toutes les cartes ne sont pas disponibles.

LIBERIA



Source des données : catalogue du Geocenter de Stuttgart (RFA)

Année : mars 1982

Echelle : 1/50 000

En grisé : feuilles publiées

CÔTE D'IVOIRE

Situation au
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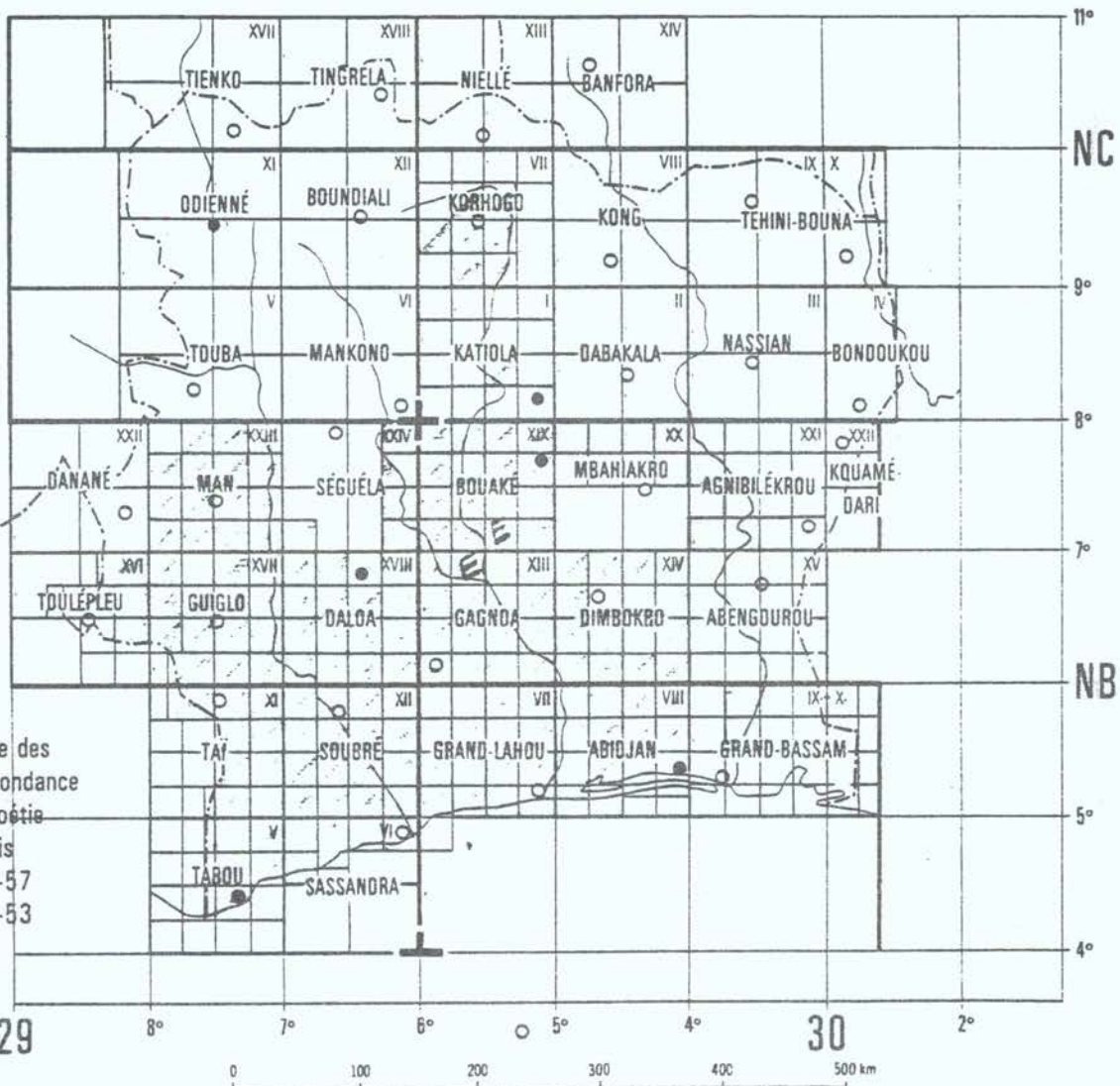
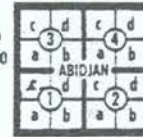
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Feuille
publiée



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Carte régulière

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Le chiffre du haut indique l'année d'édition.

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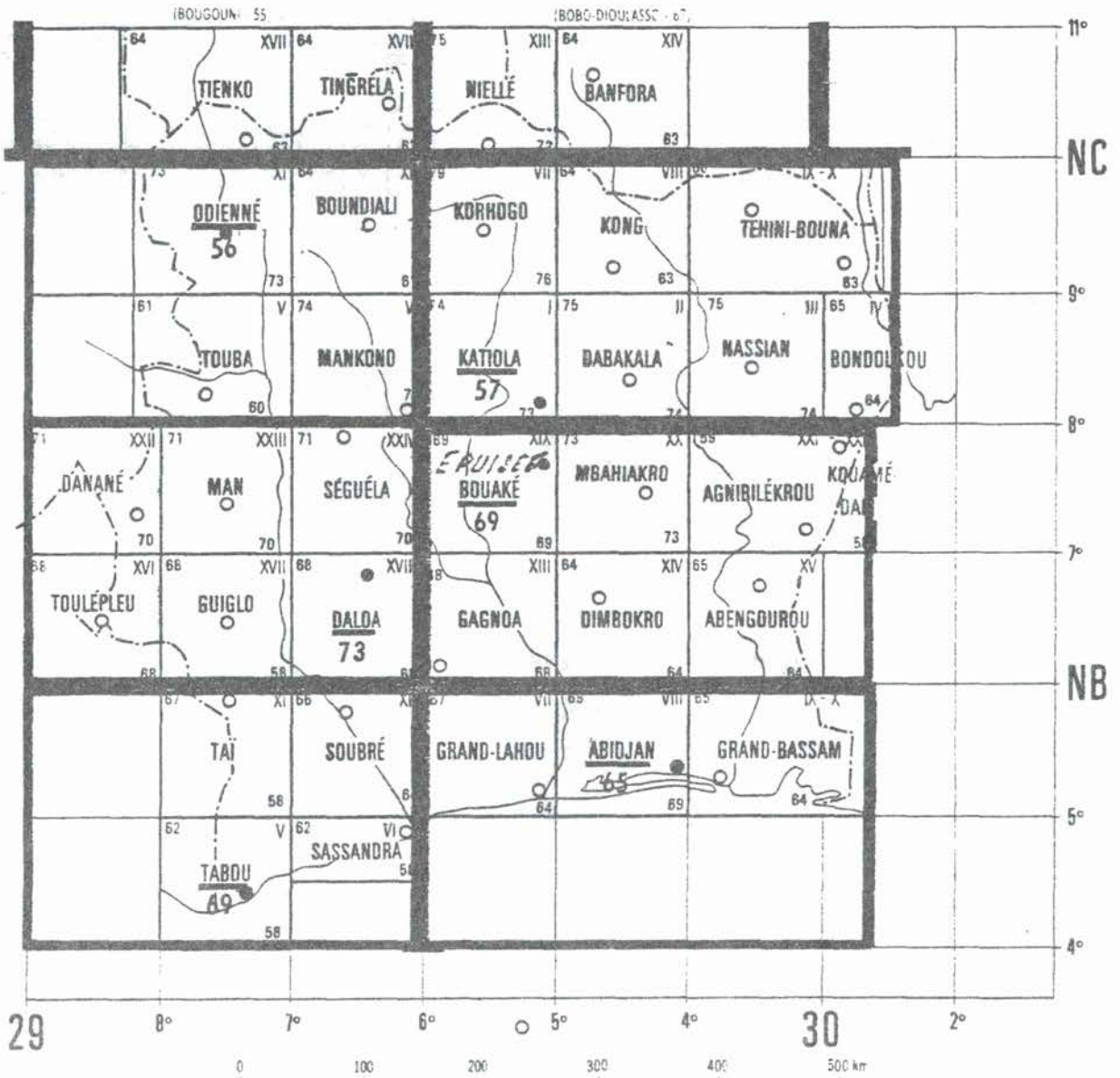
CARTE AU 1 : 500 000

Exemple de désignation d'une feuille : ABIDJAN NB-30-S O (quart. S.O.)

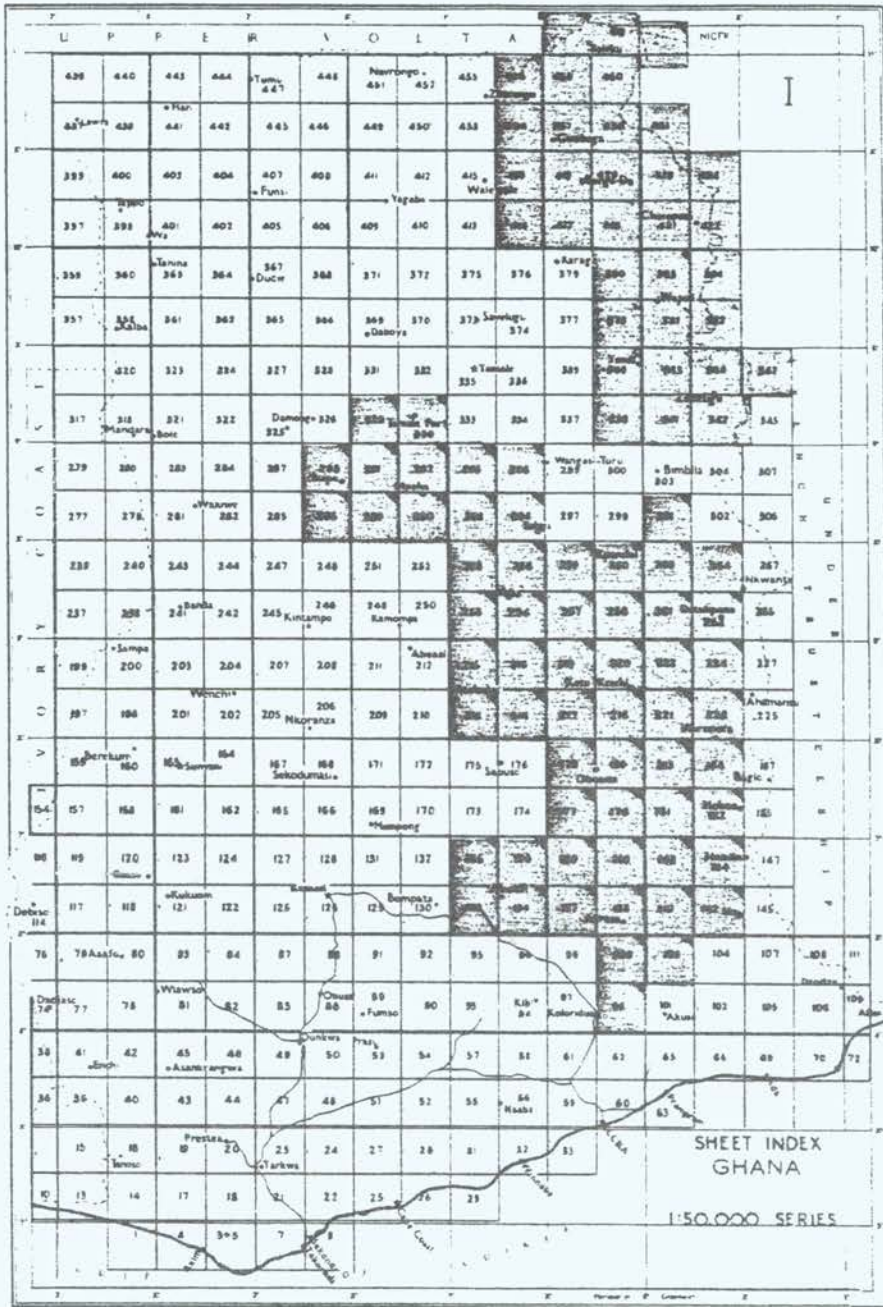


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GHANA



Source des données : catalogue du Geocenter de Stuttgart (RFA)

Année : janvier 1983

Echelle : 1/50 000





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T O G O

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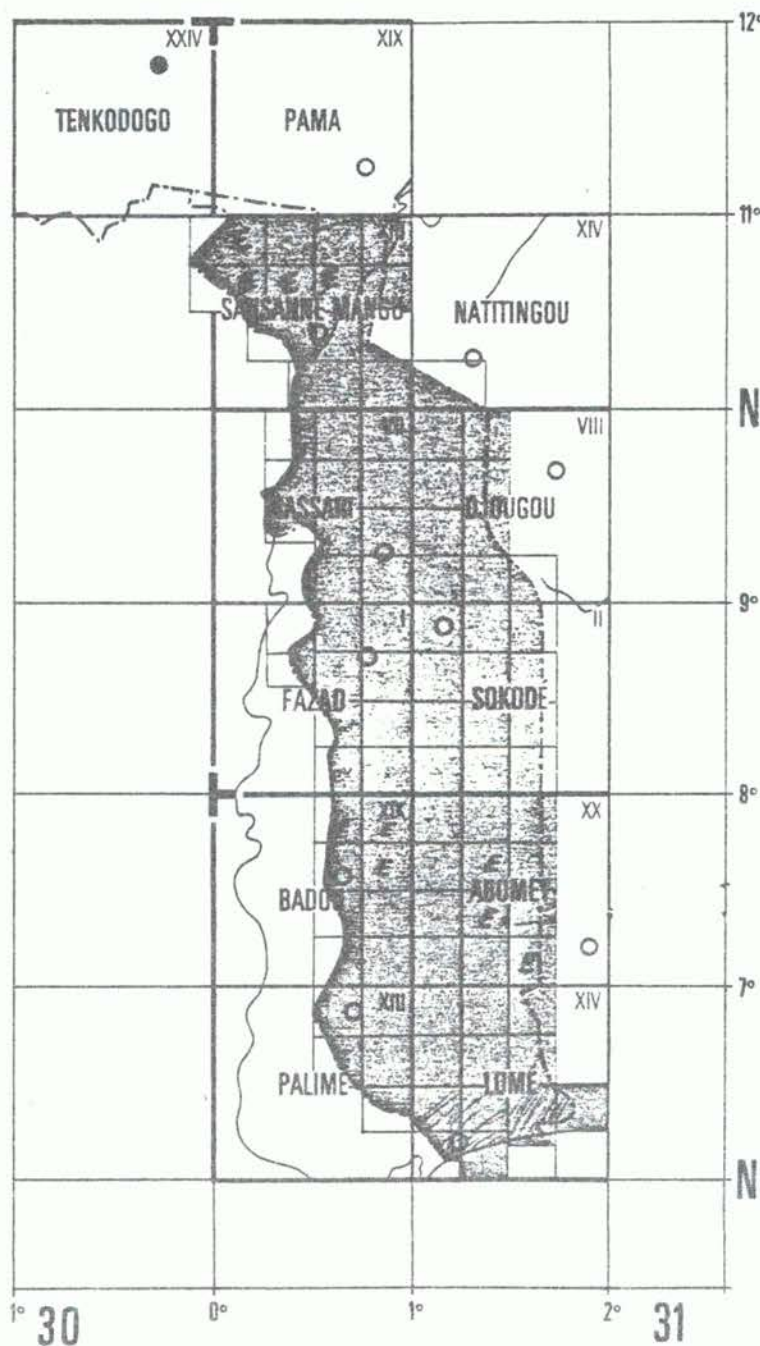
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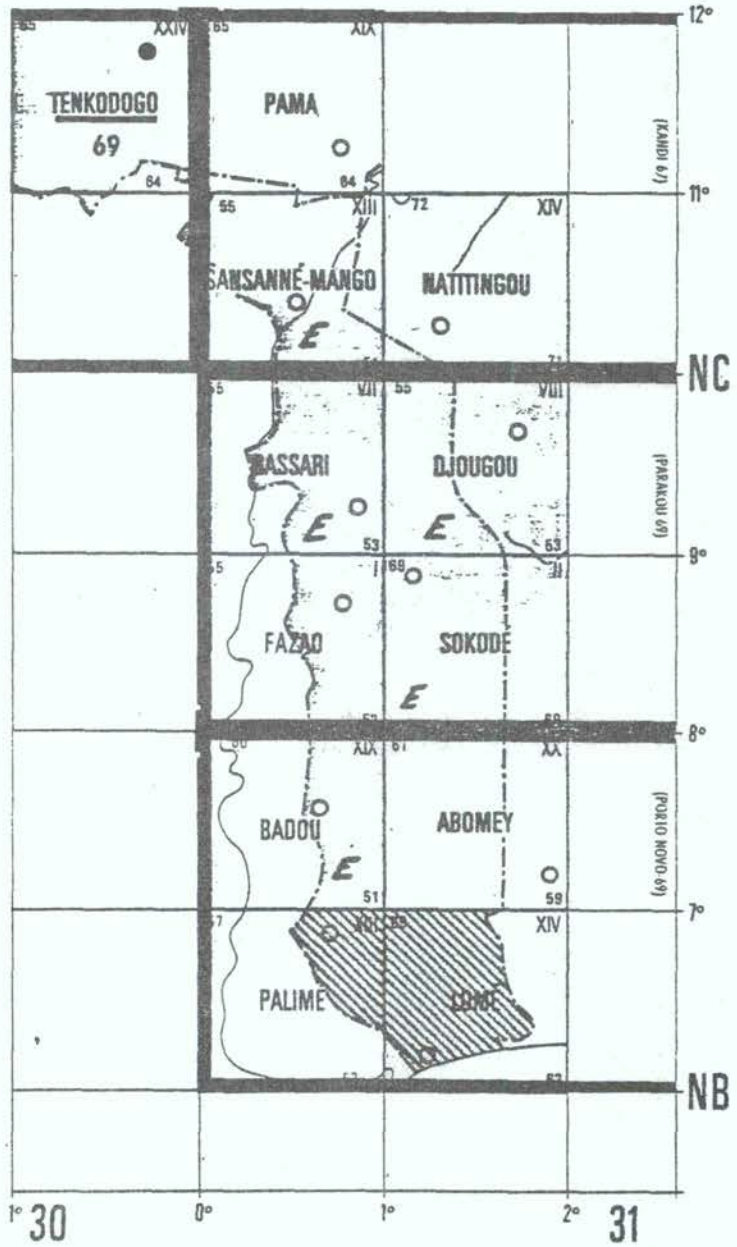
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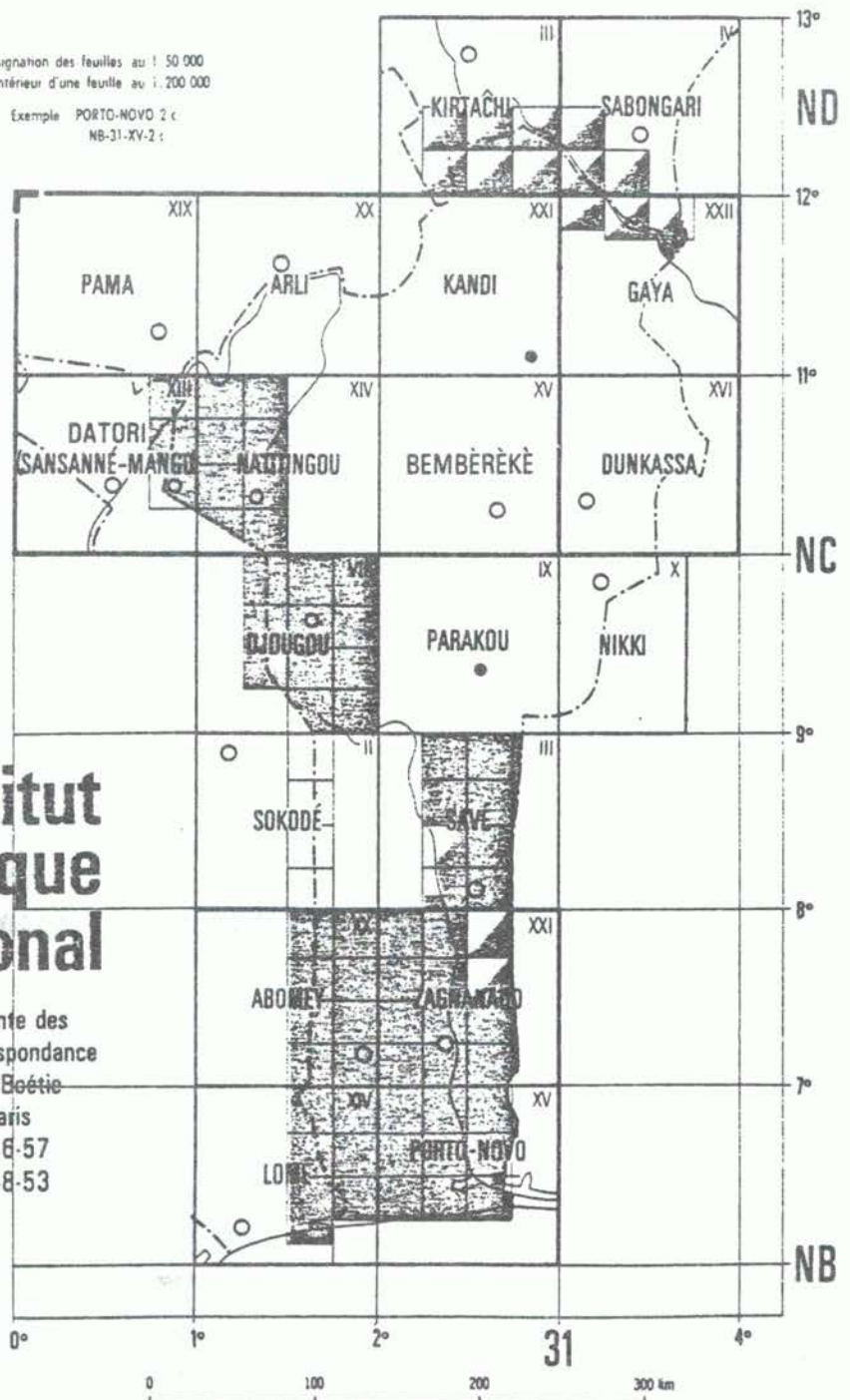
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Exemple PORTO-NOVO 2 c
NB-31-XV-2 :

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Feuille
publiée



Rédition en cours
ou prévue



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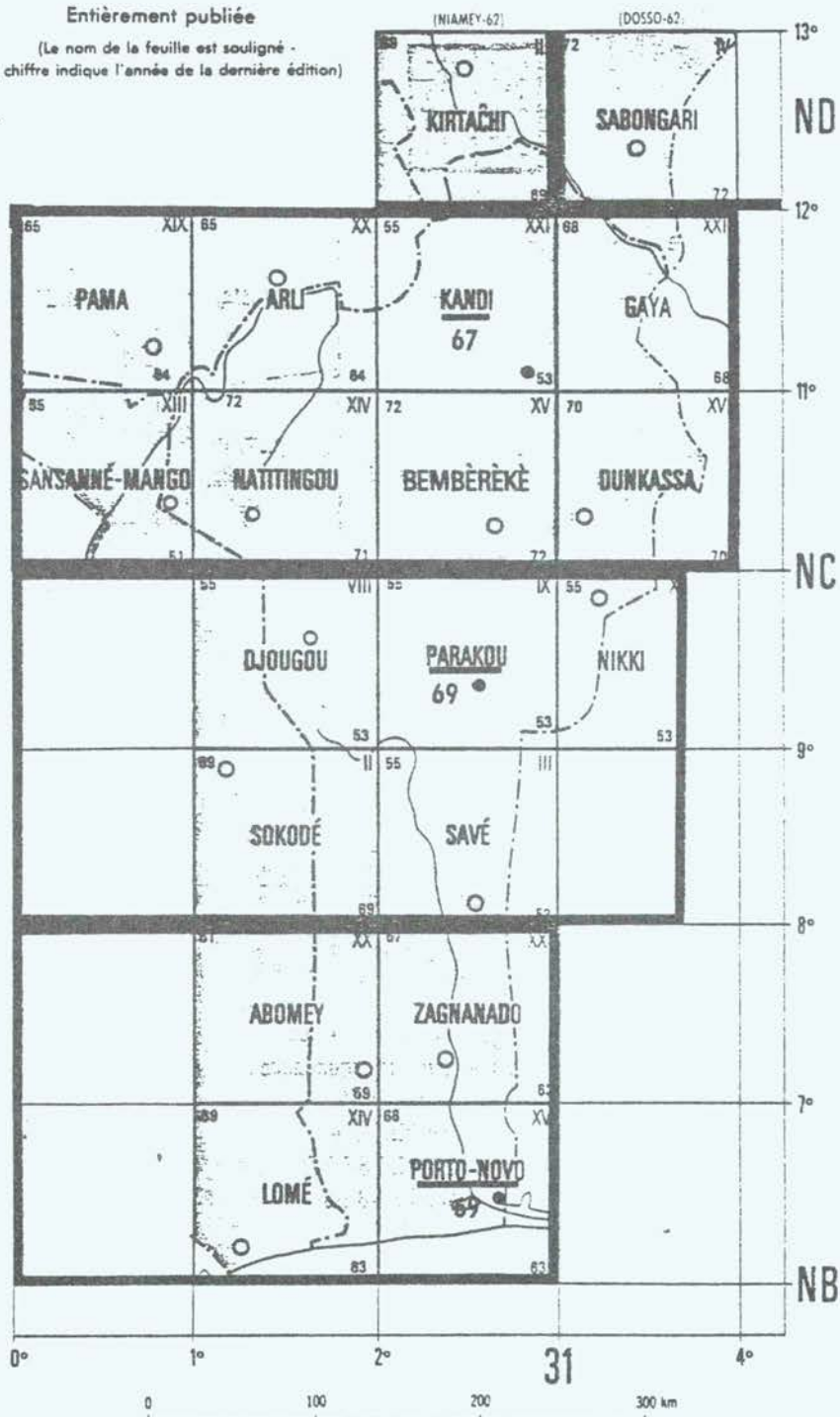
Entièrement publiée

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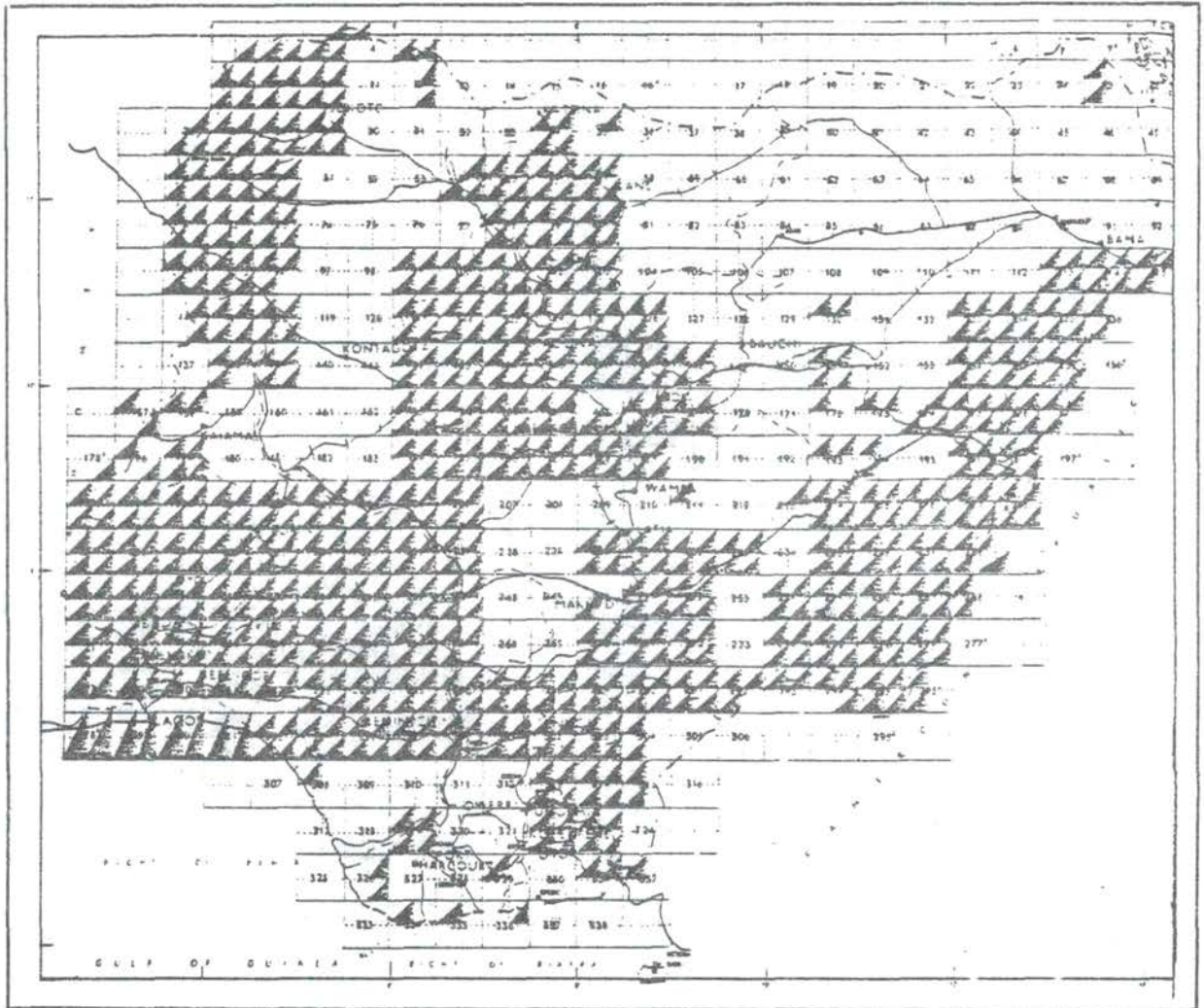


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NIGERIA



Source des données : catalogue publié par la Survey Division
du Ministère du Travail de la République
Fédérale du Nigéria

Année : juin 1976

Echelle : 1/50 000

CAMEROUN

PUBLICATION

CARTE AU 1 : 50 000

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		Carte régulière
		Carte éditée en 1977.

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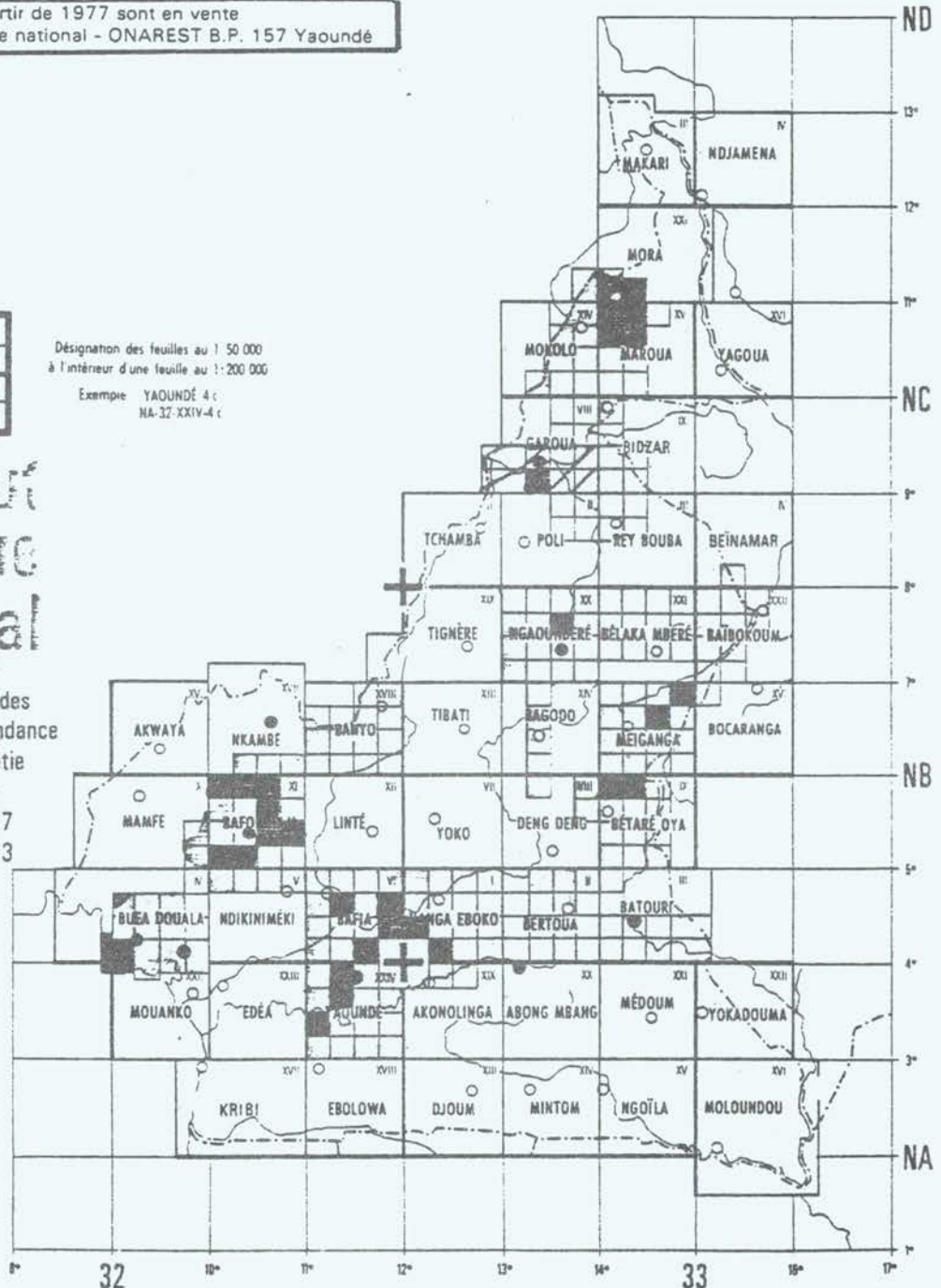


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NA-32-XXIV-4 c

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CAMEROUN

PUBLICATION

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Situation au
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Feuille publiée	en cours ou prévue

Carte régulière

Carte provisoire

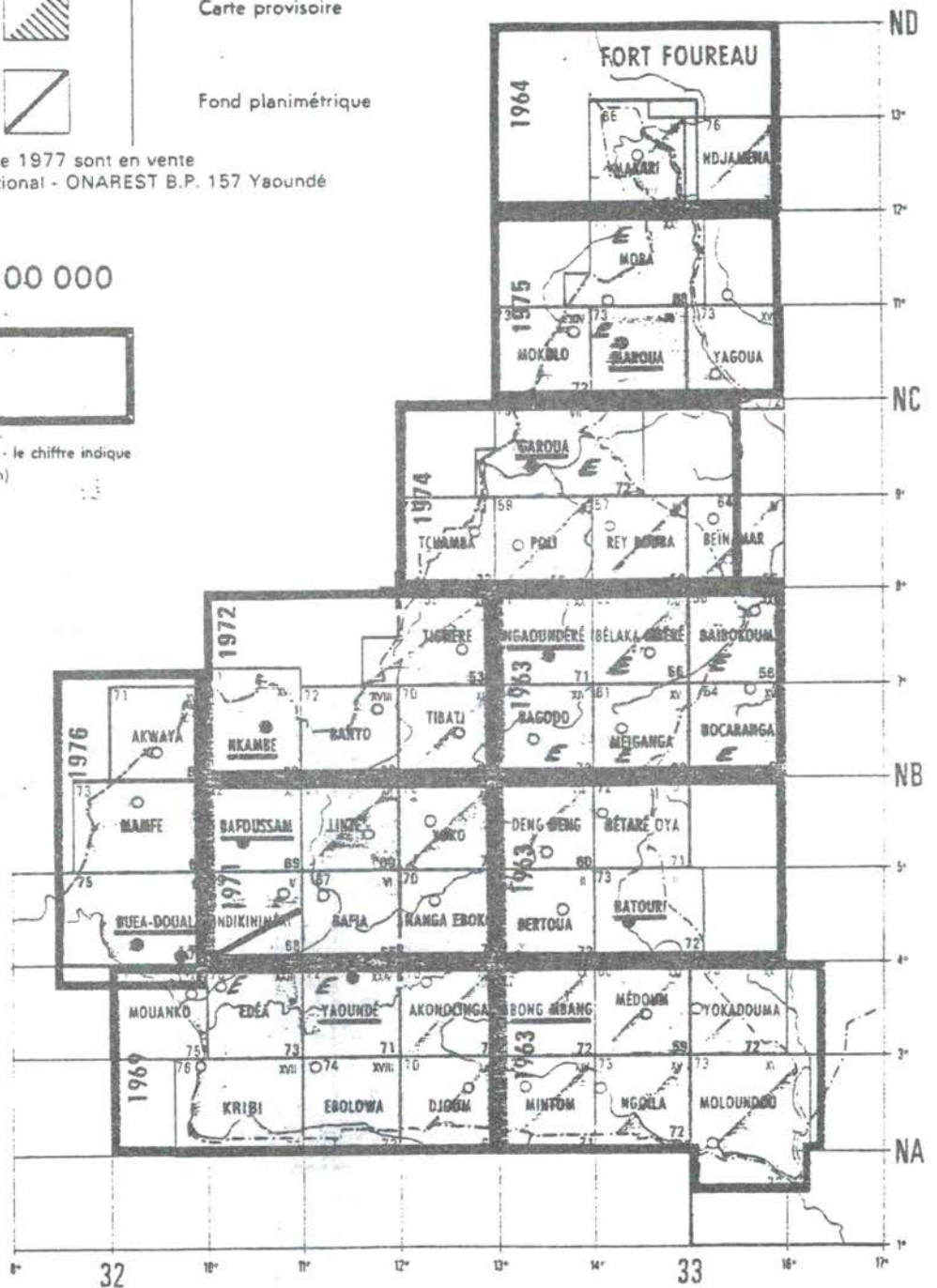
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GABON

Situation au
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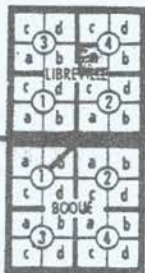
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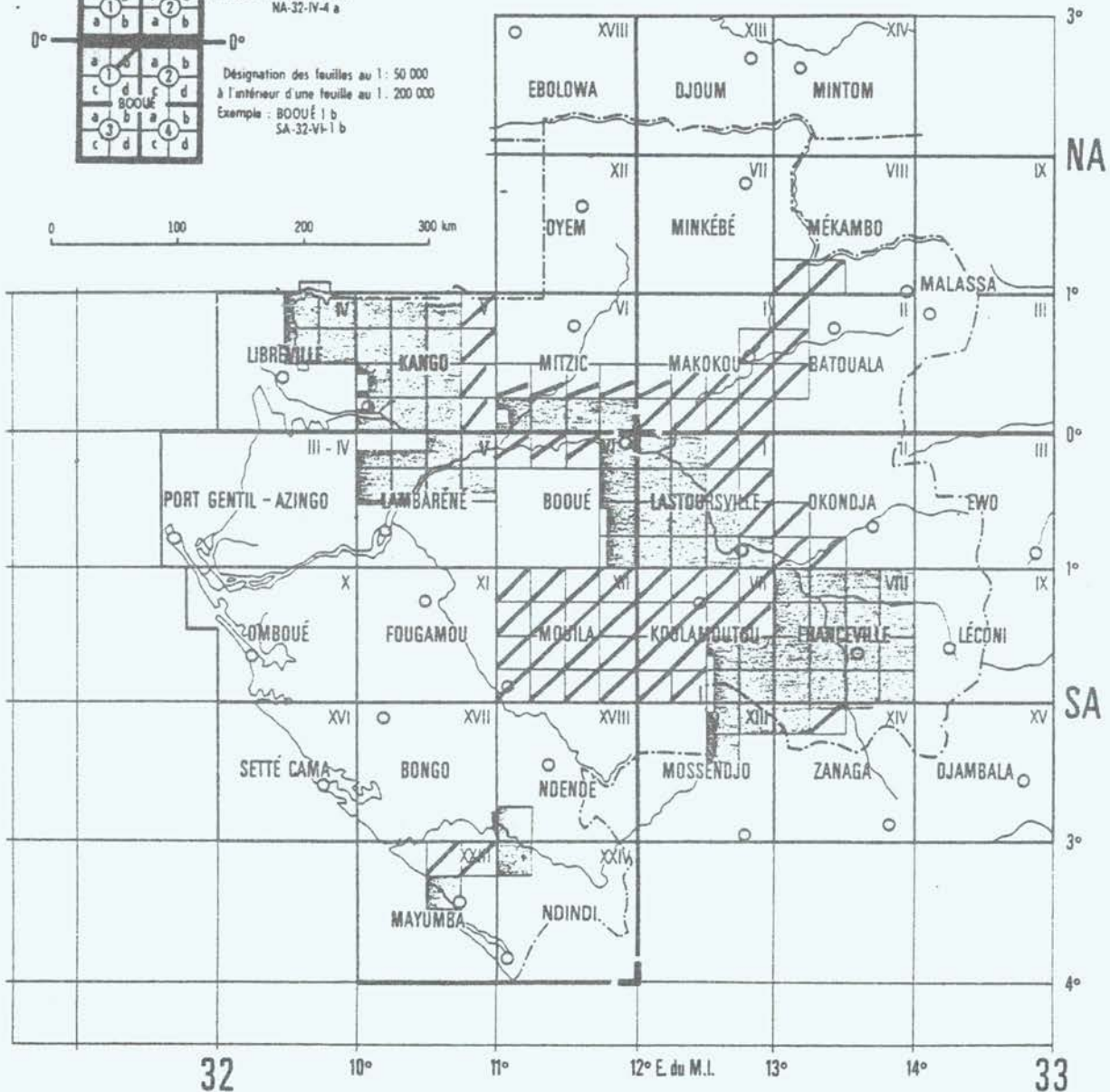
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NA-32-IV-4 a

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Exemple : BOUÉ 1 b
SA-32-VI-1 b



GABON

Situation au
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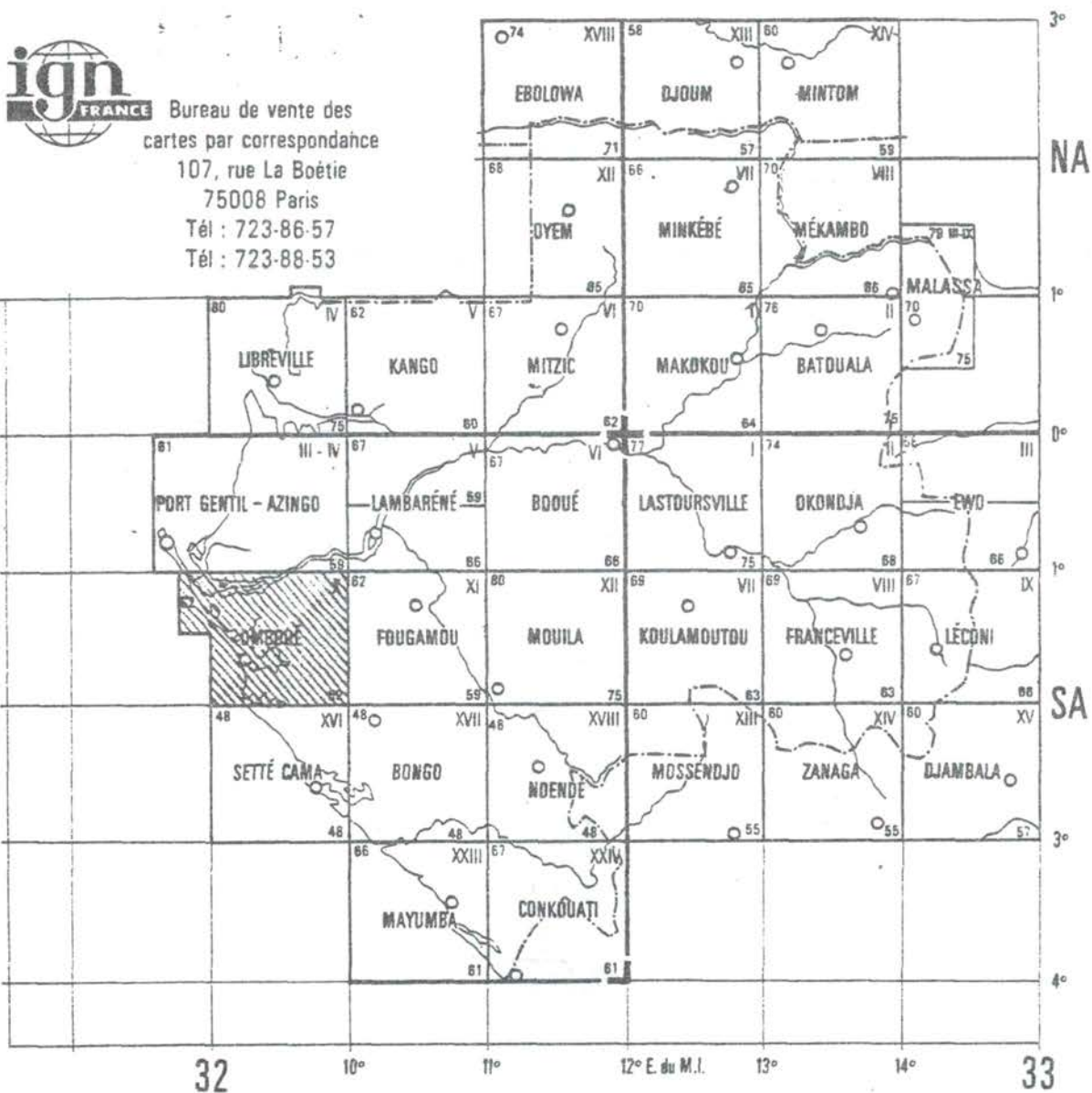
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CONGO

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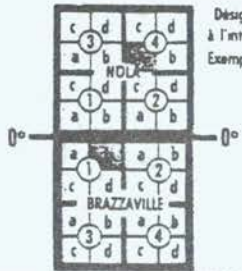
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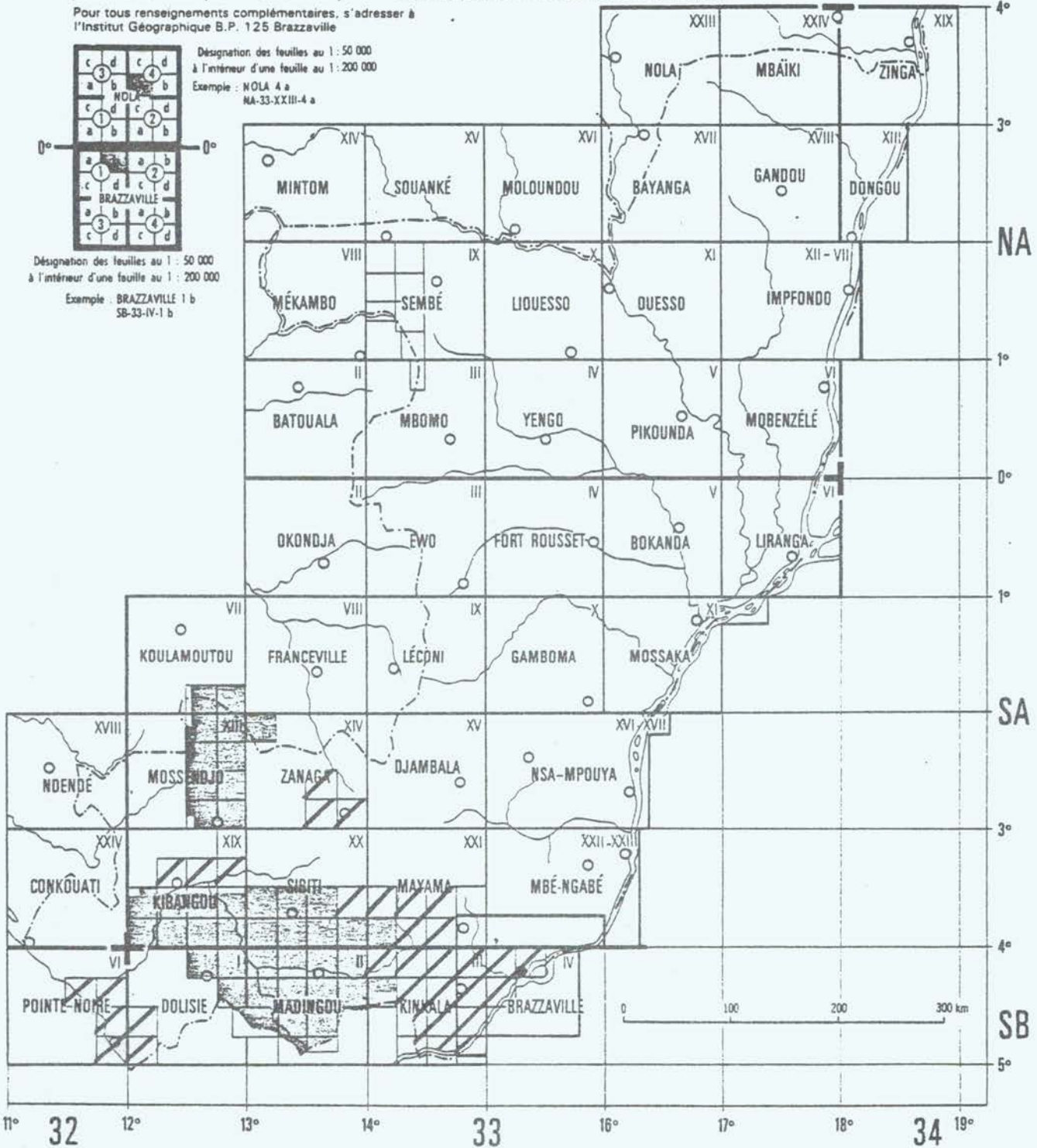
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Exemple : BRAZZAVILLE 1 b
SB-33-IV-1 b







CONGO

Situation au
31 Décembre 1979

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Carte régulière

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Document provisoire : fond topographique ou planimétrique, esquisse, croquis.

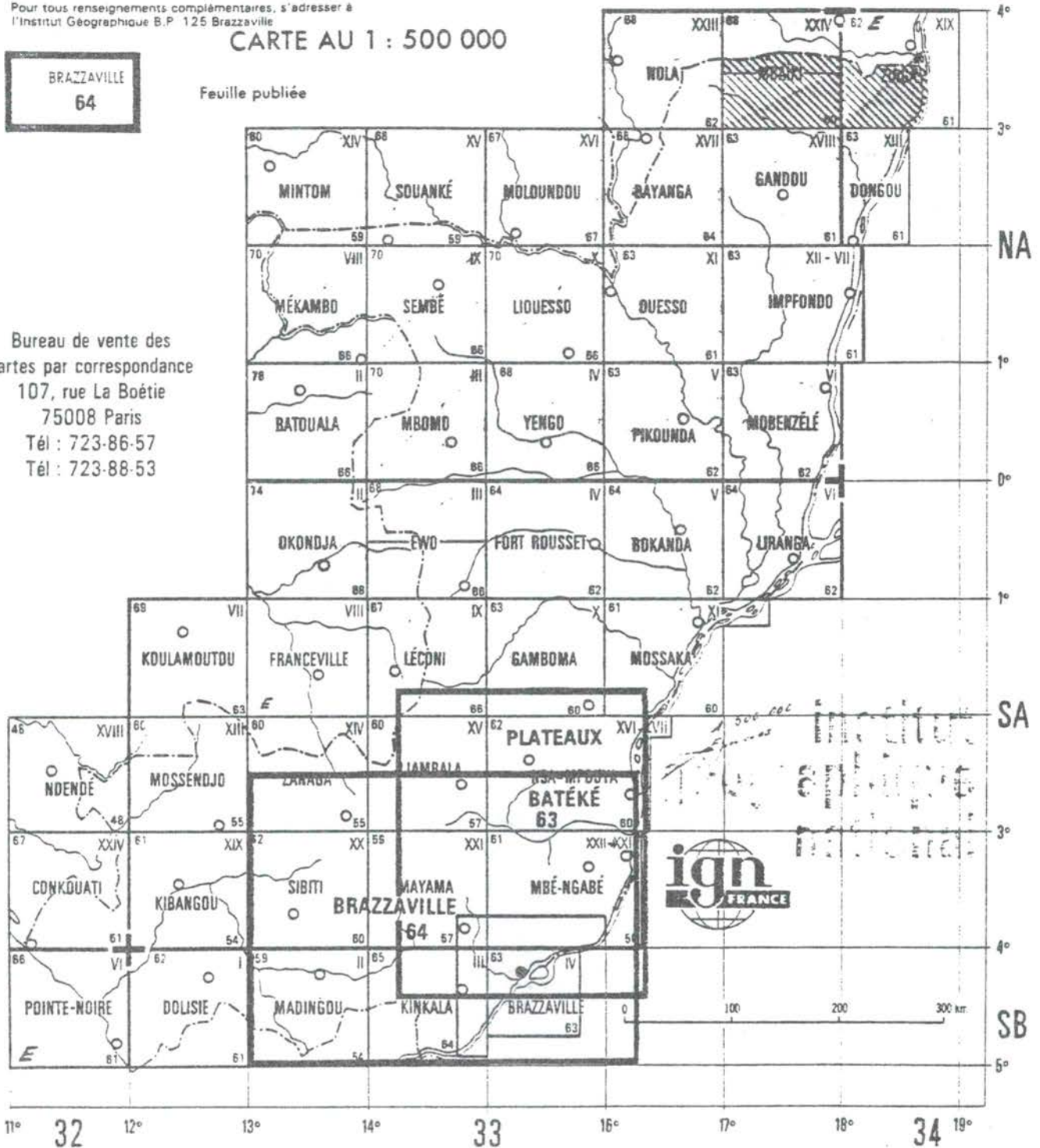
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CARTE AU 1 : 500 000

BRAZZAVILLE
64

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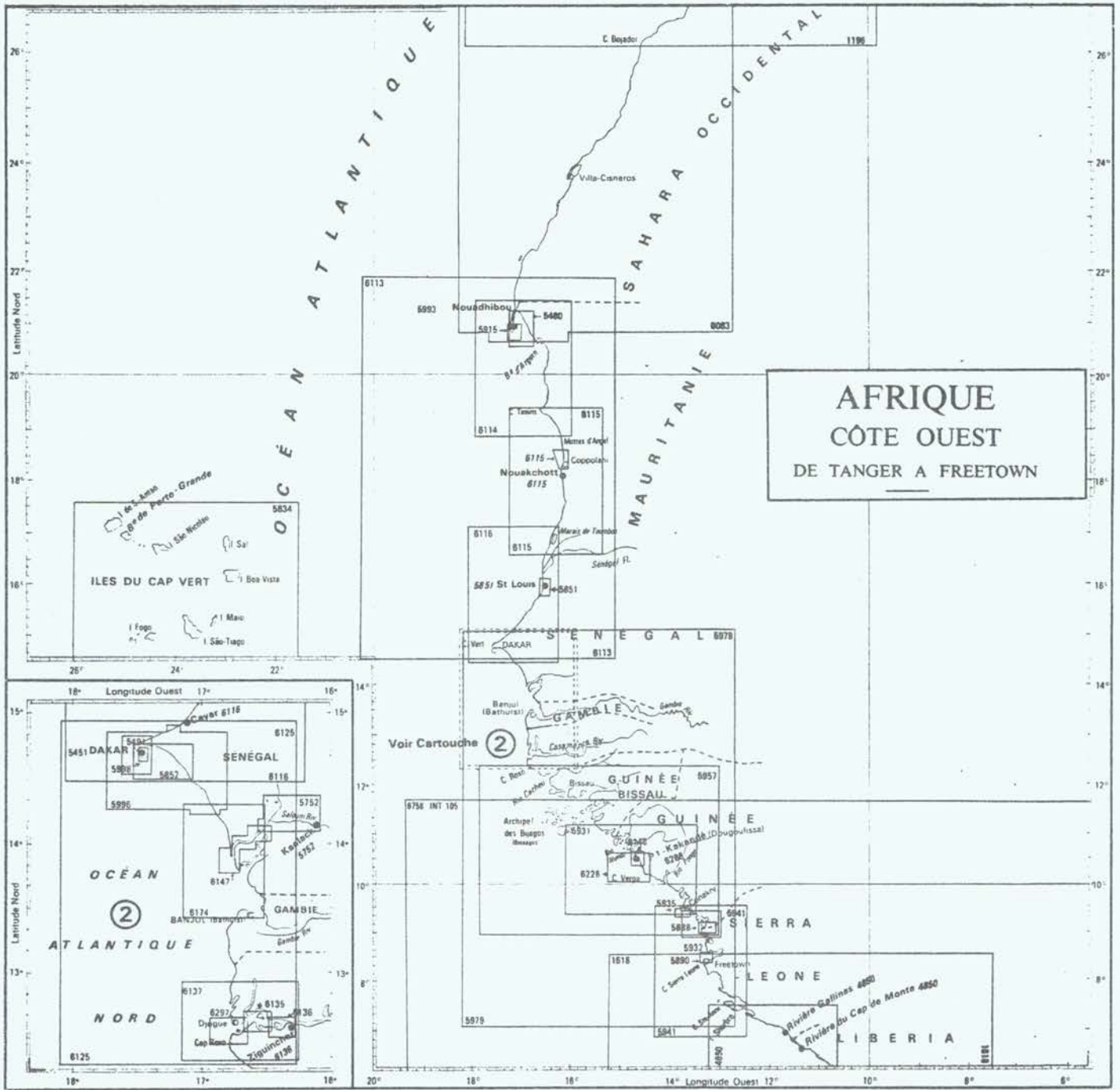
2) Shelf continental sedimentological maps

These maps are published by the Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM) at a scale of 1:200,000. The main maps concerning the Atlantic African coasts are :

- . CROSNIER, A. - Fonds de pêche le long des côtes du Cameroun.
- . CROSNIER, A. et BERRIT, G.R. (1963) - Fonds de pêche le long des côtes des républiques du Dahomey et du Togo. ORSTOM, Pointe-Noire, 1963 in PLIYA, J., 1980.
- . DOMAIN, F. (1977) - Carte sédimentologique du plateau continental séné-gambien, de la Mauritanie à la Guinée-Bissau, au 1/200 000 (3 feuilles) + notice 16 p. ORSTOM, Paris.
- . GIRESSE, P. (1969) - Carte sédimentologique des fonds marins du delta de l'Ogooué : 1/200 000. 1 coupure. Cahiers Océanographiques, tome 21, pp. 965-994.
- . GIRESSE, P. (1980) - Carte sédimentologique du plateau continental du Congo : 1/200 000. 3 coupures. ORSTOM, Paris.
- . GIRESSE, P. et KOUYOUMONTZAKIS, G. (1973) - Cartographie sédimentologique des plateaux continentaux du sud du Gabon, du Congo, du Cabinda et du Zaïre. Cahiers ORSTOM, série Géologie, vol. V, n° 2, 1973, pp. 235-257.
- . MARTIN, L. (1974) - Carte sédimentologique du plateau continental de Côte d'Ivoire, au 1/200 000 (3 feuilles couleur) + notice 19 p. ORSTOM, Paris.
- . RANCUREL, P. (1968) - Topographie générale du plateau continental de la Côte d'Ivoire et du Libéria. ORSTOM, Paris.

3) The nautical charts are published by the SHOM (Service Hydrographique et Océanographique de la Marine) ; following tables and figures present the coverage of the different nautical charts available in the coastal areas concerned with this report.

Among the maps at a scale close to or greater than 1:50,000, we have looked for older editions with the idea of assessing the evolution of the shoreline in areas subject to modifications (maps underlined in the tables ; for documented local studies, refer to chapter III.2.).



N°	TITRE	DATES			FORMAT	ELEMENTS DE L'ECHELLE		LATITUDE MOYENNE
		Publication ou Edition	Grande Carte	Derrière Plan au CC		en millimètres	en lignes	
1818	Entre le cap Serra Leona et le cap des Palmes	1935			1	m = 2.0	867 000	06° 05' N
4850	Du cap Sainte-Anne au cap Mesurado Cartouche Rivière du cap de Monse Cartouche Rivière Gatinas	1934			1	m = 8.2 m = 30.0 m = 37.0	283 000 80 000 49 000	06° 45' N 08° 46' N 06° 55' N
5451	Port de Dakar	1989	1982		1/2	m = 385	5 000	14° 40' N
5460	Baie du Lévrier	1942	1976		1	m = 22.0	78 900	20° 52' N
5491	Presqu'île du cap Vert	1939	1943		1	m = 40.0	45 000	14° 40' N
5752	Rivière Saloum de Foutidougbe à Kadiack, rivières Sola et Sali Cartouche Port de Kadiack	1967			1	m = 25.8 m = 179	50 000 10 000	14° 14' N 14° 07' N
5834	Îles du Cap Vert	1939			1	m = 3.6	496 000	16° 00' N
5861	Moutillage de Saint-Louis Cartouche Port de Saint-Louis	1937			1/2	m = 29.7 m = 118	80 000 15 000	15° 55' N 15° 00' N
5862	Baie de Gorée	1944			1	m = 36.0	80 000	14° 37' N
5865	Rivière Mataccorde, moutillage de Berth, rivière Tanham, rivière Foutarakh	1943	1956		1/2	m = 26.5	90 000	09° 09' N
5890	Entrée de la rivière Sierra Leona (Freetown)	1935	1977		1	m = 73.5	28 000	08° 30' N
5915	Accès de Nouadhibou	1952	1976		1	m = 48.2	27 900	30° 46' N
5921	Du Rio Grande aux îles de Los	1965			1	m = 6.0	304 000	10° 21' N
5932	De Conakry à la rivière Mataccorde Cartouche Manguébo	1943			1/2	m = 15.0 m = 16.0	122 000 122 000	09° 18' N 09° 15' N
5936	Abords de Conakry, îles de Los Moutillage de Conakry	1944	1951		1	m = 73.0	25 000	09° 29' N
5961	Des îles de Los à l'île Sherbro	1963			1	m = 6.0	306 000	08° 16' N
5967	Du île Cachou aux îles de Los	1965			1	m = 3.3	847 000	10° 41' N
5979	De Dakar à l'île Sherbro	1964			1	m = 1.9	894 000	11° 12' N
5983	Baie de Casadio, Nouadhibou (Port-Etienne)	1969			1/2	m = 99	17 500	30° 53' N
5986	De Dakar à M'bour	1964			1	m = 18.0	100 000	14° 33' N
5990	Rade de Dakar	1963			1/2	m = 119	15 000	14° 41' N
6003	Du cap Juler au cap Blanc	1965			1	m = 2.0	845 000	24° 32' N
6113	Du cap Blanc au cap Vert	1965			1	m = 2.0	882 000	18° 10' N
6114	Du cap Blanc au cap Timere	1976			1	m = 6.0	291 000	20° 08' N
6115	Du cap Timere aux marais de Toumbou Cartouche Des Momes d'Angel à Coppelen Cartouche Abords de Moutchoron	1974	1974		1	m = 6.0 m = 23.5 m = 117	254 000 75 000 15 000	18° 05' N 18° 26' N 18° 02' N
6116	Des marais de Toumbou à Dakar Cartouche Coyer	1967			1	m = 6.0 m = 18.0	298 000 100 000	15° 46' N 14° 55' N
6125	De Dakar au cap Roxo	1962			1	m = 6.0	301 000	13° 28' N
6135	Cours de la Casamance, du pont de Ouargaran à la pointe Sams	1966			1/2	m = 52.0	25 000	12° 37' N
6138	Cours de la Casamance, de la pointe Sams à Ziguinchor Cartouche Ziguinchor	1966			1/2	m = 62.0 m = 181	16 000 10 000	12° 33' N 12° 35' N
6137	Cours de la Casamance de l'embouchure à Ziguinchor	1991			1	m = 18.0	101 000	12° 38' N
6147	Cours du Saloum de l'embouchure à Foutidougbe Cartouche Cours du Saloum Cartouche Cours du Saloum (suite)	1954			1	m = 81.0 m = 81.0 m = 81.0	35 300 25 300 25 300	13° 52' N 14° 00' N 14° 05' N
6148	Embouchure du Rio Nunez	1969			1	m = 52.0	25 000	10° 32' N
6174	De Jol à Bathurst	1959			1	m = 18.0	109 000	13° 52' N
6220	Aboko au rio Nunez	1961			1	m = 18.0	101 000	10° 23' N
6228	Du cap Saint-Vincent au delta de Gberah, du delta de Gberah au cap Ghr	1963			1	m = 2.0	771 000	33° 46' N
6296	Guinée, Rio Nunez, abords de Port-Salerno (Dougouhata)	1960			1/2	m = 152	12 000	10° 37' N
6307	Embouchure de la Casamance	1960			1	m = 52.0	25 000	12° 33' N
6798	De Freetown à Luanda (INT 106)	1976			1	m = 29.4	3780 000	01° 59' N

Assemblage et liste des cartes marines (côtes NW de l'Afrique) éditées par le SHOM

Map coverage of North-West African coasts by the Hydrographic Office of the French Navy (SHOM)

N°	TITRE	DATES			FORMAT	ELEMENTS DE L'ECHELLE		LATITUDE MOYENNE
		Publication au 1/1000	Cartes au 1/5000	Données au 1/5000		m d'altitudes	et hauteur 1	
1017	Du cap des Palmes au cap Coast Cartouche : Moutillage du cap des Palmes	1929			1	m = 2.0 m = 92.0	945 000 20 000	04° 19' N 04° 22' N
1018	Entre le cap Sierra Leone et le cap des Palmes	1935			1	m = 2.0	967 000	06° 05' N
1717	De cap Coast au fleuve Niger	1934			1	m = 2.0	946 000	04° 18' N
2833	Du cap Saint-Paul à Porto Novo	1962			1/2	m = 6.3	296 000	06° 02' N
3357	De la pointe Banda à la rivière Coenas Cartouche : Cabeca de Cobe	1968			1/2	d = 99.0 m = 24.5	1 100 000 75 000	06° 47' S 06° 33' S
4820	Du Grand-Bereby au cap des Trois-Pointes Cartouche : Du Grand-Bereby au cap des Trois-Pointes (suite) Cartouche : Grand Lahou	1905			1	m = 6.3 m = 6.3 m = 92.0	294 000 294 000 20 000	04° 53' N 05° 02' N 05° 08' N
4832	De la pointe Baffu au Grand-Bereby, abords du cap des Palmes Cartouche : Rivière Sangann et baie Baffu Cartouche : Baie Sinu Cartouche : Les Butu ou les Butteaux	1906			1	m = 6.3 m = 37.8 m = 37.4 m = 17.8	283 000 49 000 49 500 104 000	04° 53' N 05° 11' N 04° 59' N 05° 04' N
4846	Du cap Mesurado à la pointe Baffu Cartouche : Rivière Junk Cartouche : Grand-Bassa, port de Buchanan Cartouche : Baie Catoe Cartouche : Baie de Monrovia	1906			1	m = 6.3 m = 25.0 m = 45.0 m = 29.0 m = 57.0	282 000 70 000 40 000 64 000 32 000	05° 54' N 06° 08' N 05° 53' N 05° 26' N 06° 20' N
4880	Du cap Saint-Anne au cap Mesurado Cartouche : Rivière du cap de Monte Cartouche : Rivière Gallinas	1934			1	m = 6.2 m = 30.0 m = 37.0	283 000 80 000 48 000	05° 45' N 05° 46' N 06° 58' N
5390	Cameroun, Fernando-Poo	1930			1	m = 6.0	308 000	03° 29' N
5802	De la baie de Bibundi à la rivière Cameroun Cartouche : Rivière Dibamba, moutillage de Yaneou	1963			1	m = 18.0 m = 123	103 000 15 000	04° 01' N 03° 57' N
5835	Du fleuve Niger au cap Lopez	1966			1	m = 2.0	928 000	02° 30' N
5853	Côte d'Ivoire, port d'Abidjan (lagune Ebré) Cartouche : Moutillage de GRAND-BASSAM	1938 1978			1/2	m = 52.5 m = 52.5	35 000 35 000	05° 16' N 05° 11' N
5907	De Saint-Paul de Luanda au cap Frio Cartouche : Baie de Santa-Marta	1969			1	d = 99.4 m = 45.0	1 080 000 40 000	13° 40' S 13° 51' S
6881	Port de Lomé Cartouche : Rade de Kalmé Cartouche : Rade et lagune de Cotonou Cartouche : Port de Lagas	1967			1/2	m = 74.0 m = 74.0 m = 74.0 m = 74.0	25 000 25 000 25 000 25 000	06° 07' N 06° 12' N 05° 22' N 06° 25' N
6023	Port de Douala Cartouche : Rivière Wouri	1962			1/2	m = 121 m = 121	18 000 15 000	04° 02' N 04° 06' N
6076	Du cap des Palmes à Grand-Bereby	1905			1	m = 18.4	100 000	04° 26' N
6076	Estuaire du Cameroun Cartouche : Moutillage de Maraca	1958 1966			1	m = 52.8 m = 122	35 000 15 000	03° 57' N 03° 52' N
6126	Côte d'Ivoire, Port d'Abidjan Cartouche : Port d'Abidjan (suite)	1978			1	m = 154 m = 154	12 000 12 000	05° 18' N 05° 16' N
6127	Côte d'Ivoire, abords d'Abidjan	1973			1	m = 18.5	100 000	05° 04' N
6122	Port de Pointe Noire	1973			1	m = 185	10 000	04° 45' S
6123	Baie de Corisco, rivières Mondah et Murry Cartouche : Rivière Minzombi et rio Mitong	1980			1	m = 18.0 m = 18.0	103 000 103 000	01° 53' N 01° 03' N
6296	Moutillage de Tabou	1959			1/2	m = 184	10 000	04° 24' N
6321	Grand-Bereby Cartouche : Sessandis	1960 1964			1/2	m = 123 m = 123	15 000 15 000	04° 39' N 04° 36' N
6380	Du cap Essava à Iguela	1973 1976			1	m = 8.0	308 000	00° 43' S
6388	Estuaire du Gabon	1963 1964			1	m = 37.0	80 000	00° 23' N
6372	Du cap Essava à la pointe Ekoueta	1966			1	m = 18.0	103 000	00° 48' N
6372	De la pointe Ekoueta au cap Lopez	1964			1	m = 18.0	103 000	00° 30' S
6378	Port de Libreville	1964			1/2	m = 155	12 000	00° 23' N
6419	Grand Bassa (Tolou) Cartouche : Petit Bereby Cartouche : Dogbele (réc. Bereby) Cartouche : Drown (Monogaga)	1961			1/2	m = 82.3 m = 82.3 m = 82.5 m = 82.3	20 000 20 000 20 000 20 000	04° 28' N 04° 33' N 04° 38' N 04° 48' N
6448	Baie du cap Lopez, Port-Gentil	1962 1963			1	m = 61.5	30 000	00° 40' S
6453	Fleuve Congo de l'embouchure à Oulimanga Cartouche : Rade de Banana	1964			1	m = 37.0 m = 92.0	50 000 20 000	06° 00' S 06° 00' S
6688	Côte d'Ivoire de Grand-Bereby à Sessandis Cartouche : Port de San-Pedro	1971			1	m = 18.5 m = 92.5	100 000 20 000	04° 44' N 04° 44' N
6688	Congo, abords de Pointe-Noire	1972 1974			1	m = 53.0	35 000	04° 45' S
6844	Ports et moutillages d'Angola, baie de Mocimadas Cartouche : Baie de Luanda Cartouche : Baie de Cabinda Cartouche : Baie de Lobito	1976			1	m = 86.5 m = 61.1 m = 61.6 m = 80.4	30 000 30 000 30 000 30 000	15° 09' S 08° 45' S 05° 32' S 12° 19' S
6888	De l'estuaire du Gabon à l'estuaire du Congo Cartouche : Baie de Mayumba	1977			A0	m = 2.8 m = 37.0	713 000 80 000	02° 47' S 03° 21' S
6785	De Freetown à Luanda (INT 105)	1978			1	d = 29.4	3 790 000	01° 58' N
6789	De Luanda à la baie Walvis, île de l'Ascension, île de Saint-Hélène (INT 203)	1978			1	d = 28.4	3 820 000	15° 58' S

Assemblage et liste des cartes marines (côtes W de l'Afrique du Centre)
éditées par le SHOM

Map coverage of Central African coasts by the Hydrographic Office of the
French Navy (SHOM)

A P P E N D I X I I

AERIAL PHOTOGRAPHY AND REMOTE SENSING IMAGERY

Map coverage

I. AERIAL PHOTOGRAPHY

Aerial photography is a tool well suited to detect shoreline variations, because it allows the comparison of photographs of the same area taken at different time intervals. The main problem is the lack, until recently, of systematic coverage of the African coasts (we have no data concerning Angola), restricting, thus, the historical surveys.

The detailed study of these photographs enables also some quantification of the characteristics of the swell (amplitude, direction), the littoral drift, the sedimentary accumulation rate, and of the current circulation.

1 - Amérique du Nord - North America

Country	Date	Scale	Film Type	Firm	Project
Gambia	1972	1:10,000		Mark Hurd	Ministry of Economic and Industrial Planning
	1981	1:10,000		Teledyne	Government of Gambia
	1983	1:50,000	B&W, CIR	Mark Hurd Teledyne	(OMVS) Senegal River Basin Development Organization
Liberia	1979	1:70,000	CIR	Mark Hurd	Liberian Forestry Development Authority
Nigeria	1983 a number of dates	1:25,000 a variety of scales	IR	Kenting Kenting	Nigerian Federal Survey Department entire coast
Senegal	1982-83	1:50,000	B&W,CIR	Mark Hurd	Senegal River Basin Development Organization (OMVS) with USAID
	1983	large scale low altitude		Kenting	OMVS
	1984	1:15,000		Photosur, Inc.	Port St. Louis and Kayes
Zaire	1979		color	Kenting	Government of Zaire, forest project
* B&W = black & white IR = infrared CIR = color infrared					

Photographies aériennes réalisées par des sociétés nord-américaines

Aerial surveys performed by North American firms

2 - United Kingdom

Aerial photographs used for the comparative studies (see table below, in Collins et al., 1983) come from the "Directorate of Overseas Surveys (DOS), Talworth".

COUNTRY	SURVEYS	DATE	SCALE	RESULTS
Gambia	1. the complete coast-line	1946	1:30,000	Growth of sand bars at river mouths : <ul style="list-style-type: none"> . Bald Cape - extending northwards . Saniang Point - extending southwards
	2. from Bald Cape to the Senegal border	1972	1:25,000	
Sierra Leone	1. Sherbro Island and Sierra Leone river to Liberia	1957	1:25,000	<ul style="list-style-type: none"> . Little change was observed along the Freetown peninsular coast-line. . The Barlow Point sandbar was seen to extend towards the north. . South of Barlow Point : the sand spit was running perpendicular to coastline is changing shape.
	2. Freetown to Barlow Point	1947	1:32,000	
	3. idem	1968	1:40,000	
Liberia	1. a single survey	1984	1:58,500	
Ghana	1. Accra to Togo border	1946/1947	1:27,000	
	2. the Volta delta area	1971	1:30,000	
	3. 1°W to Ivory Coast border	1972/1973	1:40,000	
	4. Accra to 1° W	1973/1975	1:40,000	
Nigeria	1. Cross river to Cameroon border	1959	1:40,000	<ul style="list-style-type: none"> . <u>Bonny Beach</u> (eastern end of the delta) : the change in the coastline morphology, mostly erosional, is on the scale of 100 m over the 11-year interval. This erosion has been attributed to the steady eastward migration of the river. . The <u>Bilabri sand spit</u> (western edge of the delta) : substantial growth of the spit to the north-west, on the scale of hundreds of metres over the 11-year interval.
	2. whole coastline	1973/1979	1:25,000	
	3. Niger delta	1949/1958	1:20,000 to 1:30,000	
	4. Niger delta	1963/1965	1:25,000	
	5. Port Harcourt to Calibar	1969	1:40,000	
Cameroon	1. from Victoria to the Nigerian border	1959	1:40,000	

3 - France

The IGN (Institut Géographique National) has at its disposal, for a fair number of countries, coverage maps at 1:50,000 scale, with aerial photographs coverage superimposed.

These documents are generally available at IGN, after agreement from the concerned countries ; nevertheless, some countries (e.g. Nigeria) have recovered the management of the pictures. Once again, we could not get data from Angola.

MAURITANIE

Situation au
31 Décembre 1979

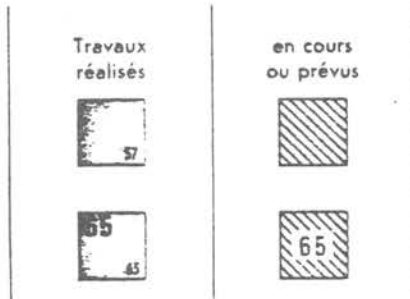
COUVERTURE PHOTOGRAPHIQUE

(Le chiffre noir indique l'année de la dernière prise de vue)

planche II - Pour tous renseignements complémentaires, s'adresser
au Service de la Cartographie B.P. 237 Nouakchott

Couverture panchromatique au 1 : 50 000

Couverture à d'autres échelles
(65 : lire 1 : 65 000)

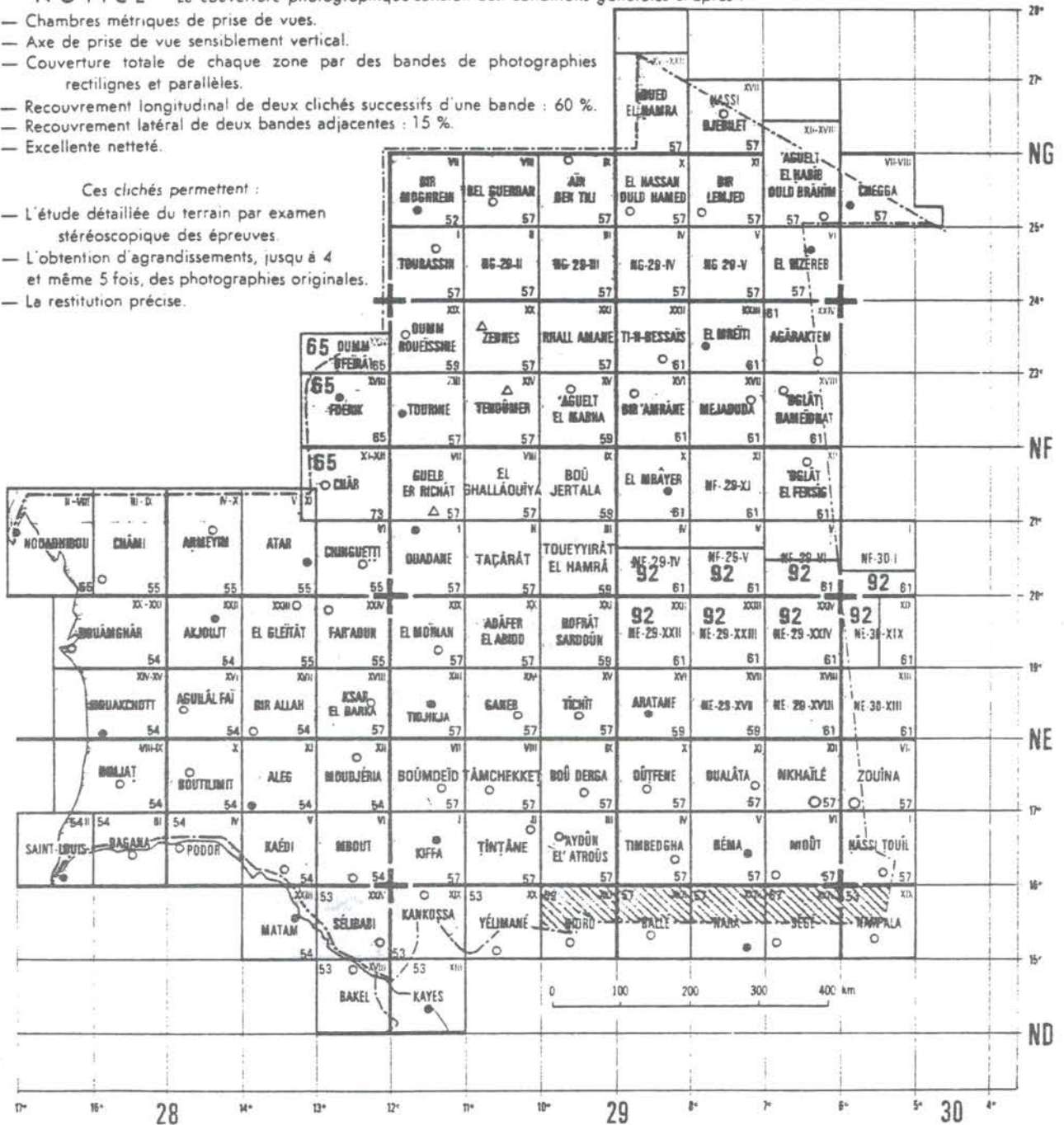


NOTICE — La couverture photographique satisfait aux conditions générales ci-après :

- Chambres métriques de prise de vues.
- Axe de prise de vue sensiblement vertical.
- Couverture totale de chaque zone par des bandes de photographies rectilignes et parallèles.
- Recouvrement longitudinal de deux clichés successifs d'une bande : 60 %.
- Recouvrement latéral de deux bandes adjacentes : 15 %.
- Excellente netteté.

Ces clichés permettent :

- L'étude détaillée du terrain par examen stéréoscopique des épreuves.
- L'obtention d'agrandissements, jusqu'à 4 et même 5 fois, des photographies originales.
- La restitution précise.



SÉNÉGAL

Situation au
31 Décembre 1979

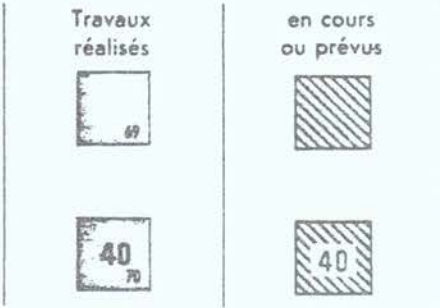
COUVERTURE PHOTOGRAPHIQUE

(Le chiffre noir indique l'année de la dernière prise de vue)

Couverture panchromatique au 1 : 50 000

Couverture à d'autres échelles
(40 : lire 1 : 40 000)

Pour tous renseignements complémentaires,
s'adresser au Service Géographique du Sénégal
14, rue Victor-Hugo B.P. 740 Dakar

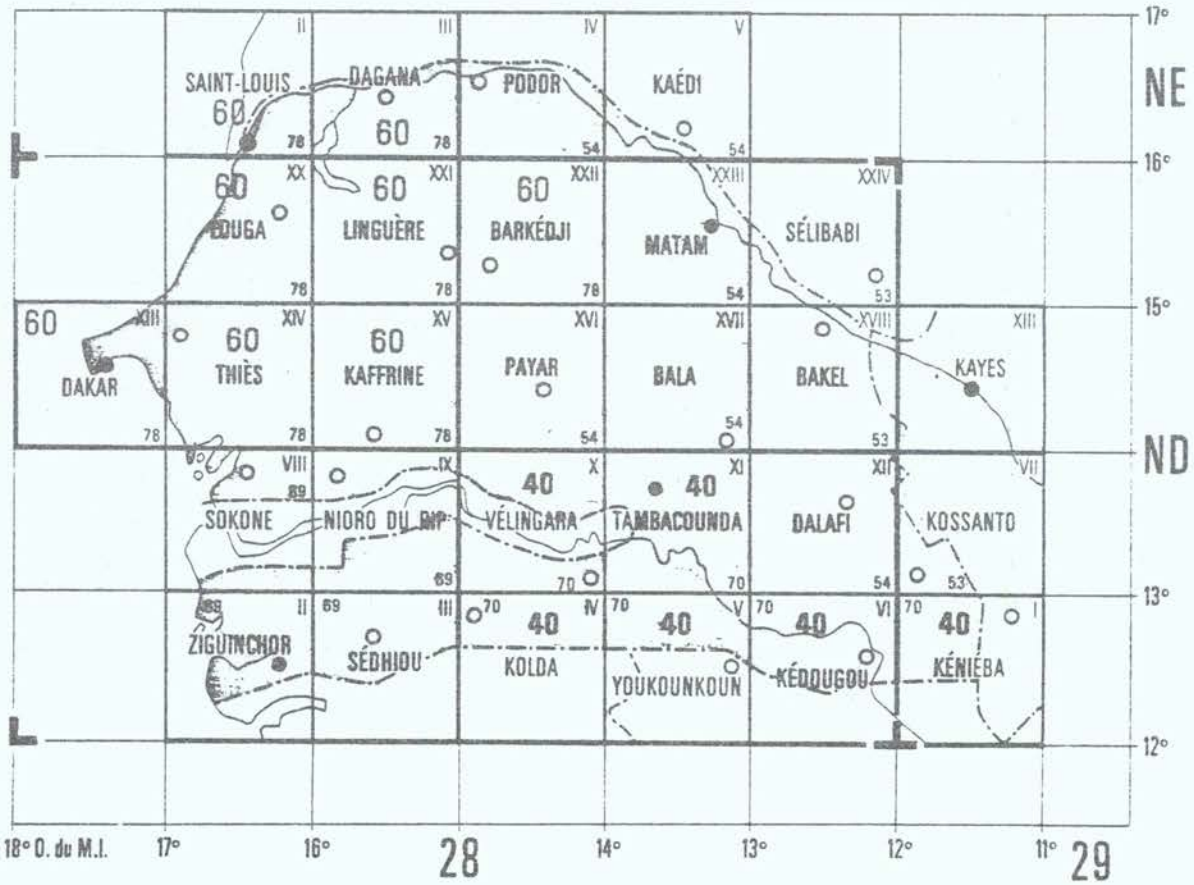


NOTICE — La couverture photographique satisfait aux conditions générales ci-après :

- Chambres métriques de prise de vues.
- Axe de prise de vue sensiblement vertical.
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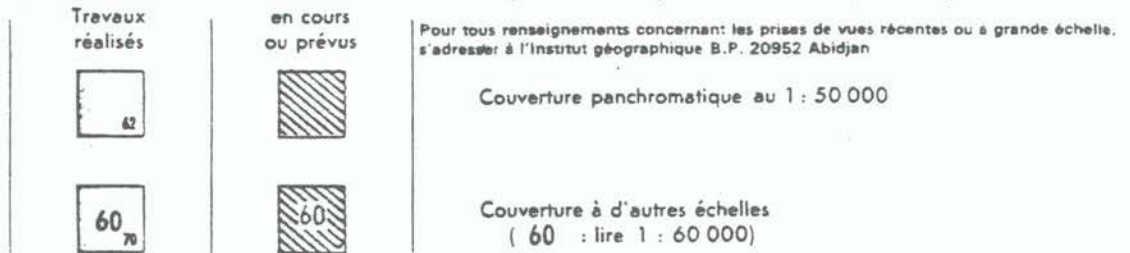


CÔTE D'IVOIRE

Situation au
31 Décembre 1979

COUVERTURE PHOTOGRAPHIQUE

(Le chiffre noir indique l'année de la dernière prise de vue)

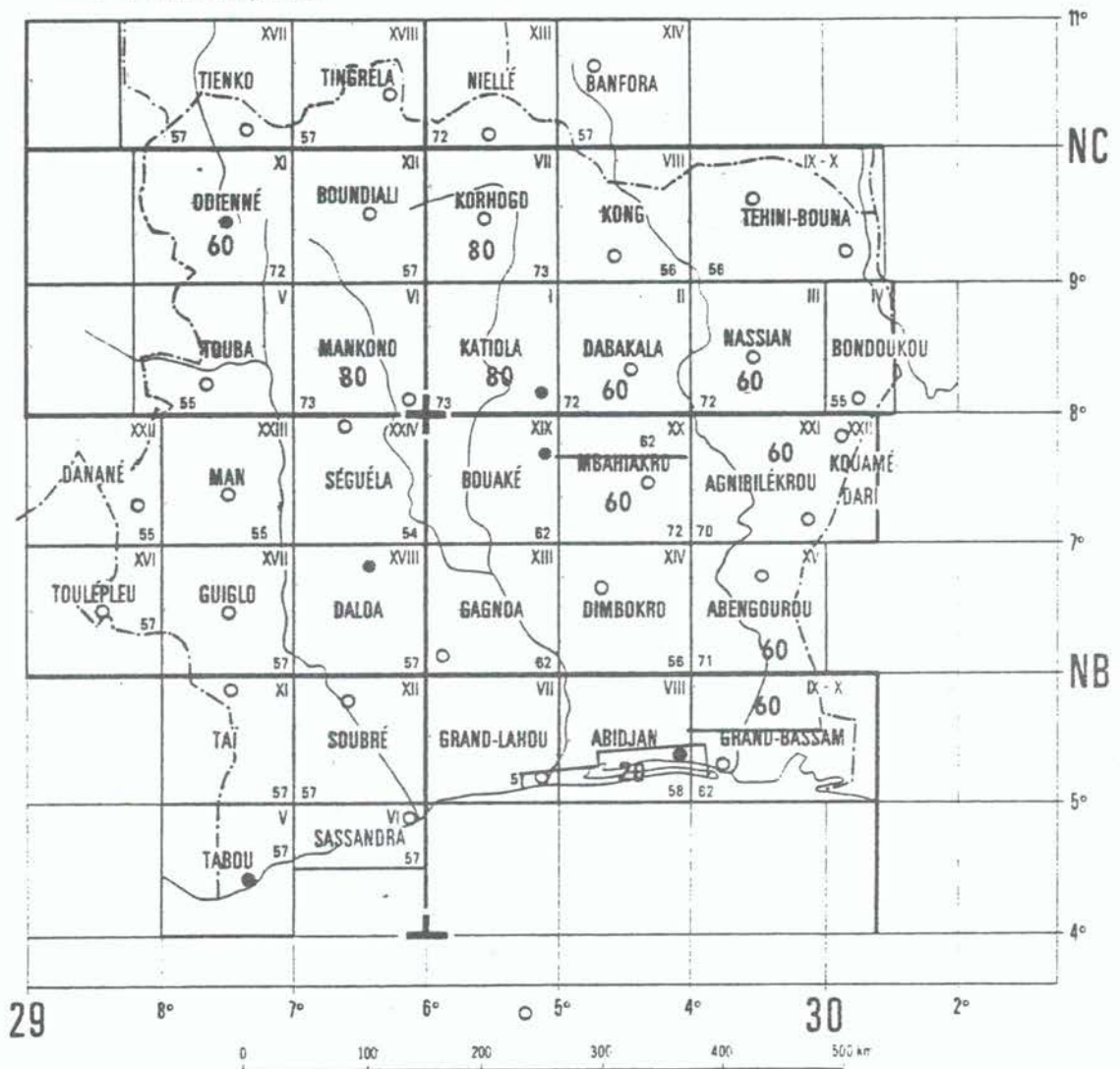


NOTICE — La couverture photographique satisfait aux conditions générales ci-après :

- Chambres métriques de prise de vues.
- Axe de prise de vue sensiblement vertical.
- Couverture totale de chaque zone par des bandes de photographies rectilignes et parallèles.
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- L'étude détaillée du terrain par examen stéréoscopique des épreuves.
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- La restitution précise.



GUINÉE

Situation au
31 Décembre 1979

COUVERTURE PHOTOGRAPHIQUE

(Le chiffre noir indique l'année de la dernière prise de vue)

Travaux
réalisés

en cours,
ou prévus



Couverture panchromatique

(l'échelle est comprise entre le 1 : 40 000 et le 1 : 50 000)

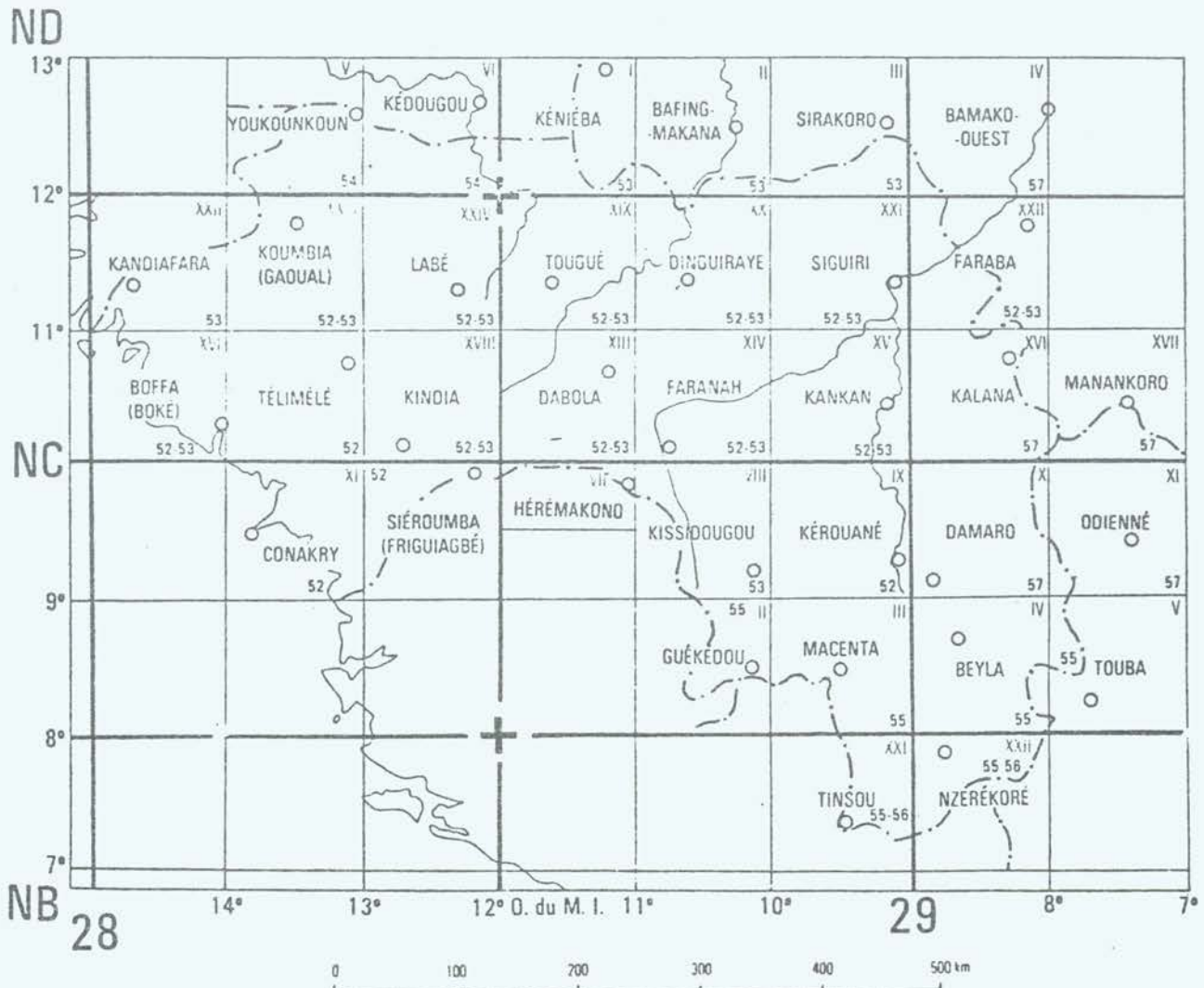
Pour tous renseignements complémentaires, s'adresser au Service Topographique et Géographique
B.P. 159 Conakry

NOTICE – La couverture photographique satisfait aux conditions générales ci-après :

- Chambres métriques de prise de vues.
- Axe de prise de vue sensiblement vertical.
- Couverture totale de chaque zone par des bandes de photographies rectilignes et parallèles.
- Recouvrement longitudinal de deux clichés successifs d'une bande : 60 %.
- Recouvrement latéral de deux bandes adjacentes : 15 %.
- Excellente netteté.

– Ces clichés permettent :

- L'étude détaillée du terrain par examen stéréoscopique des épreuves.
- L'obtention d'agrandissement, jusqu'à 4 et même 5 fois, des photographies originales.
- La restitution précise.



T O G O

Situation au
31 Décembre 1979

COUVERTURE PHOTOGRAPHIQUE

(Le chiffre noir indique l'année de la dernière prise de vue)

Couverture panchromatique au 1:65 000

Couverture à d'autres échelles
(30 : lire 1 : 30 000)

Pour tous renseignements complémentaires,
s'adresser au Service Topographique B.P. 500 Lomé

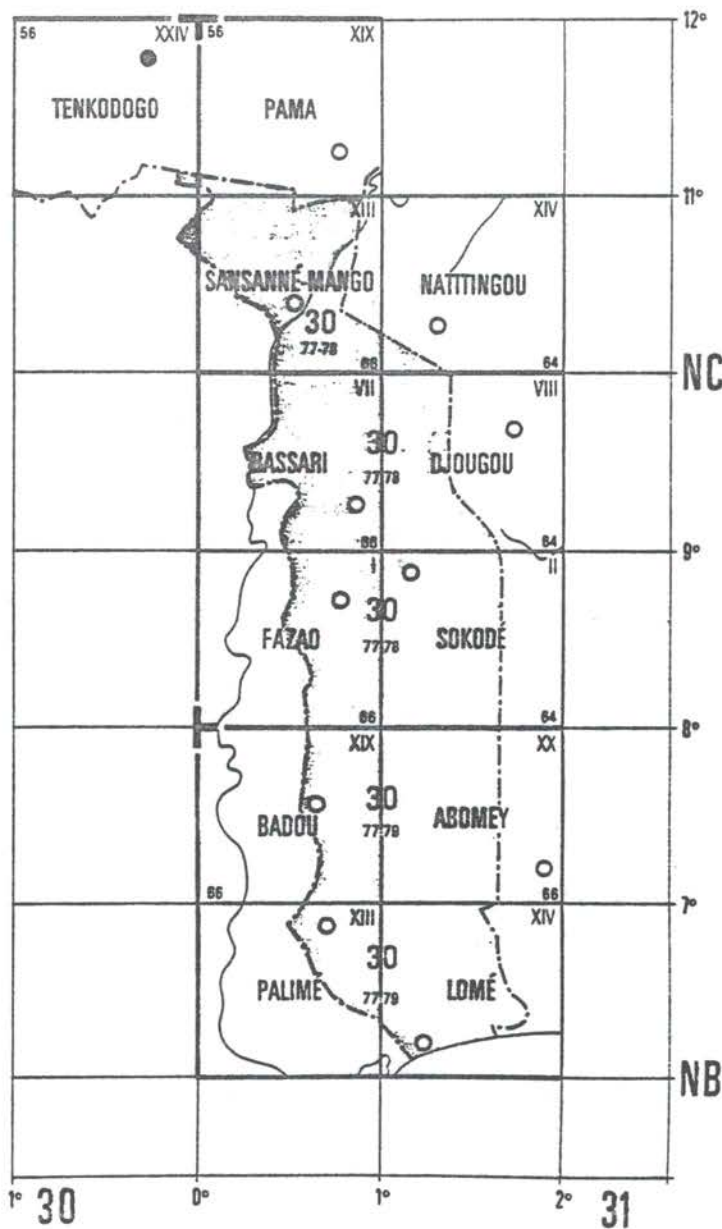
NOTICE

— La couverture photographique satisfait aux conditions générales ci-après :

- Chambres métriques de prise de vues.
- Axe de prise de vue sensiblement vertical.
- Couverture totale de chaque zone par des bandes de photographies rectilignes et parallèles.
- Recouvrement longitudinal de deux clichés successifs d'une bande : 60 %.
- Recouvrement latéral de deux bandes adjacentes : 15 %.
- Excellente netteté.

Ces clichés permettent :

- L'étude détaillée du terrain par examen stéréoscopique des épreuves.
- L'obtention d'agrandissements, jusqu'à 4 et même 5 fois, des photographies originales.
- La restitution précise.



B É N I N

Situation au
31 Décembre 1979

COUVERTURE PHOTOGRAPHIQUE

(Le chiffre noir indique l'année de la dernière prise de vue)

Couverture panchromatique au 1 : 50 000

Couverture à d'autres échelles
(65 : lire 1 : 65 000)

Travaux réalisés



en cours
ou prévus



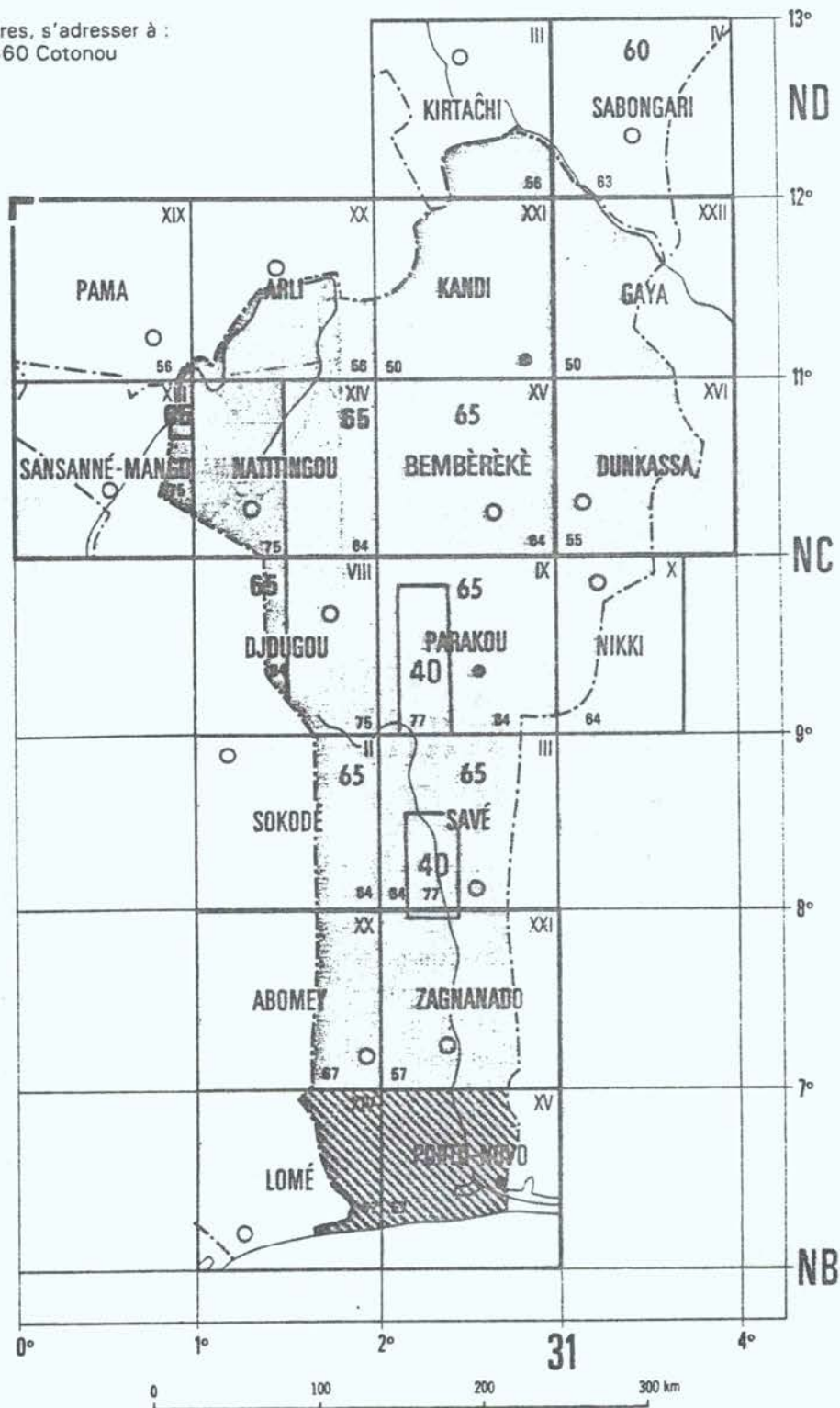
Pour tous renseignements complémentaires, s'adresser à :
l'Institut National de Cartographie B.P. 360 Cotonou

NOTICE — La couverture photographique saisit aux conditions générales ci-après :

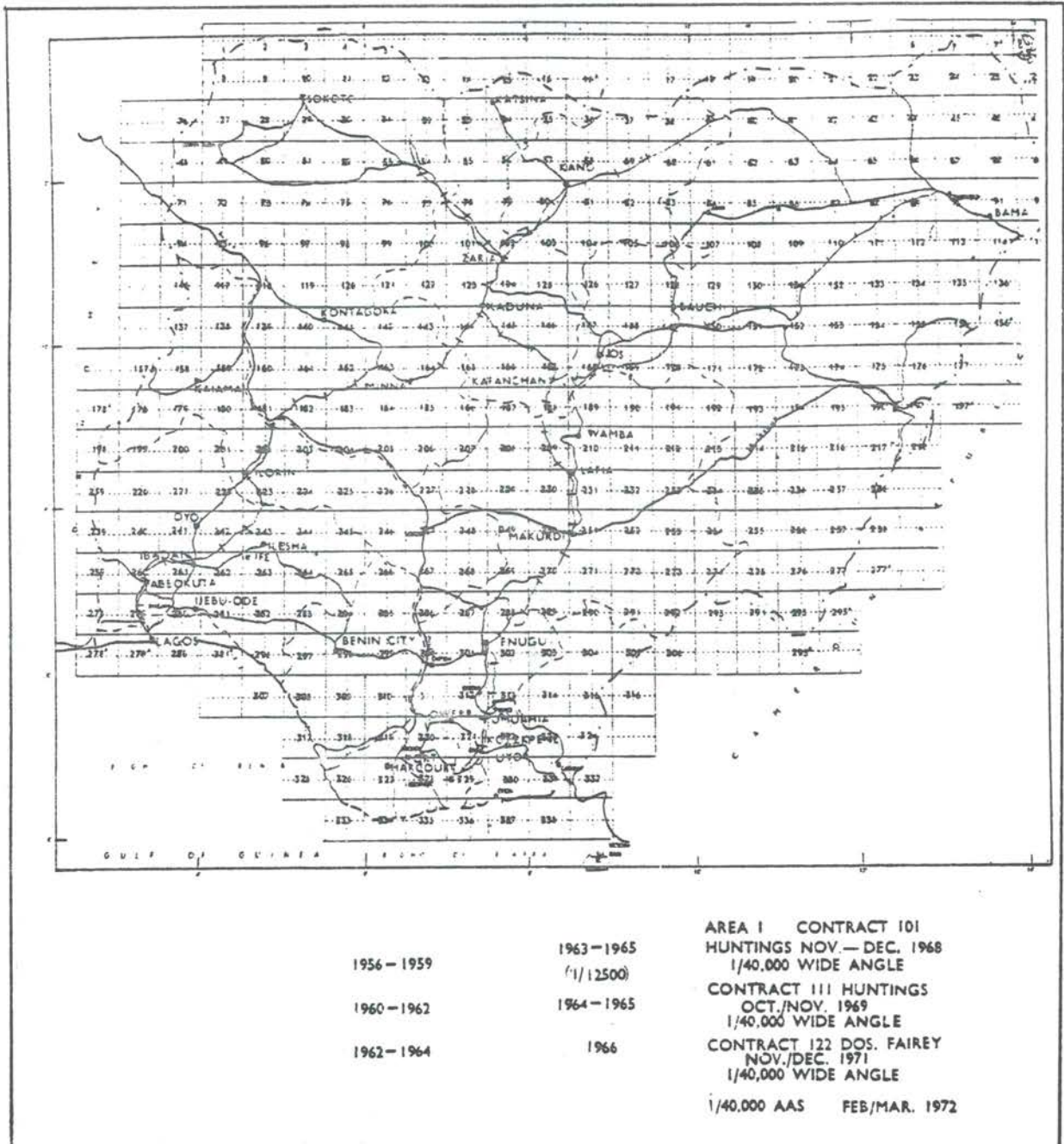
- Chambres métriques de prise de vues.
- Axe de prise de vue sensiblement vertical.
- Couverture totale de chaque zone par des bandes de photographies rectilignes et parallèles.
- Recouvrement longitudinal de deux clichés successifs d'une bande : 60 %.
- Recouvrement latéral de deux bandes adjacentes : 15 %.
- Excellente netteté.

Ces clichés permettent :

- L'étude détaillée du terrain par examen stéréoscopique des épreuves.
- L'obtention d'agrandissements, jusqu'à 4 et même 5 fois, des photographies originales.
- La restitution précise.



NIGERIA



Source des données : catalogue édité par la "Survey Division" du
Ministère du Travail de la République Fédérale
du Nigéria

Année : juin 1976





Echelle : 1/40 000

CAMEROUN

COUVERTURE PHOTOGRAPHIQUE

Situation au
31 Décembre 1979

Le chiffre noir indique l'année de la dernière prise de vues.
Certaines feuilles ont fait l'objet de couvertures partielles échelonnées entre les deux dates indiquées. Dans ce cas, pour des localisations plus précises, il est recommandé aux utilisateurs de s'adresser au Centre géographique national - ONAREST B.P. 157 Yaoundé

Travaux réalisés	en cours ou prévus
	
	

Couverture panchromatique au 1 : 50 000

Couverture à d'autres échelles
(30 : lire 1 : 30 000)

La diffusion des prises de vues est soumise à l'autorisation
du Centre géographique national - ONAREST B.P. 157 Yaoundé

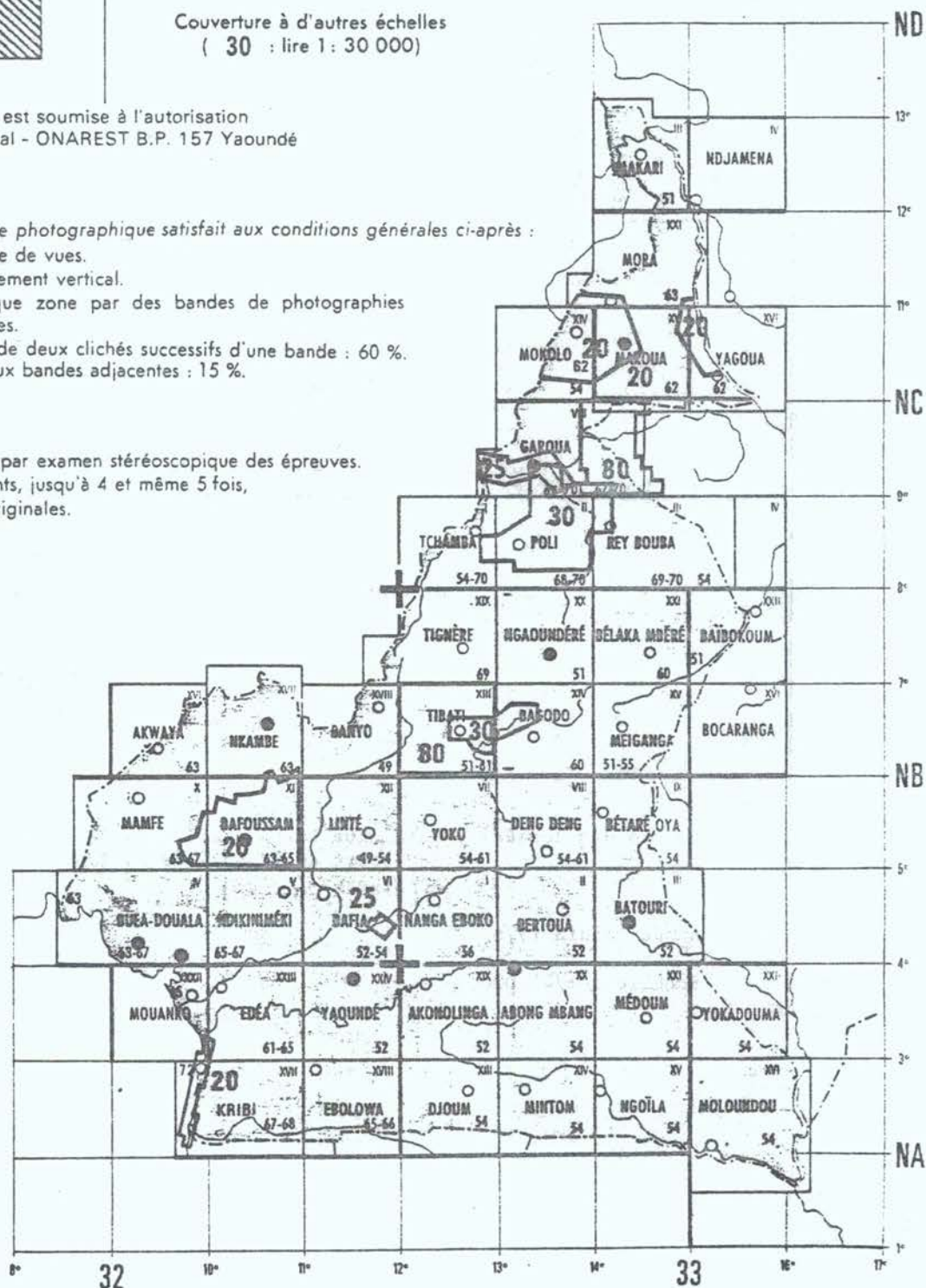
NOTICE — La couverture photographique satisfait aux conditions générales ci-après :

- Chambres métriques de prise de vues.
- Axe de prise de vue sensiblement vertical.
- Couverture totale de chaque zone par des bandes de photographies rectilignes et parallèles.
- Recouvrement longitudinal de deux clichés successifs d'une bande : 60 %.
- Recouvrement latéral de deux bandes adjacentes : 15 %.
- Excellente netteté.

Ces clichés permettent :

- L'étude détaillée du terrain par examen stéréoscopique des épreuves.
- L'obtention d'agrandissements, jusqu'à 4 et même 5 fois, des photographies originales.
- La restitution précise.

0 100 200 km

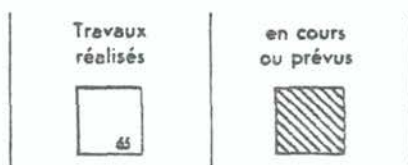


GABON

Situation au
31 Décembre 1979

COUVERTURE PHOTOGRAPHIQUE

Couverture panchromatique au 1:50 000 environ



30 Autres échelles
(lire 1 : 30 000)

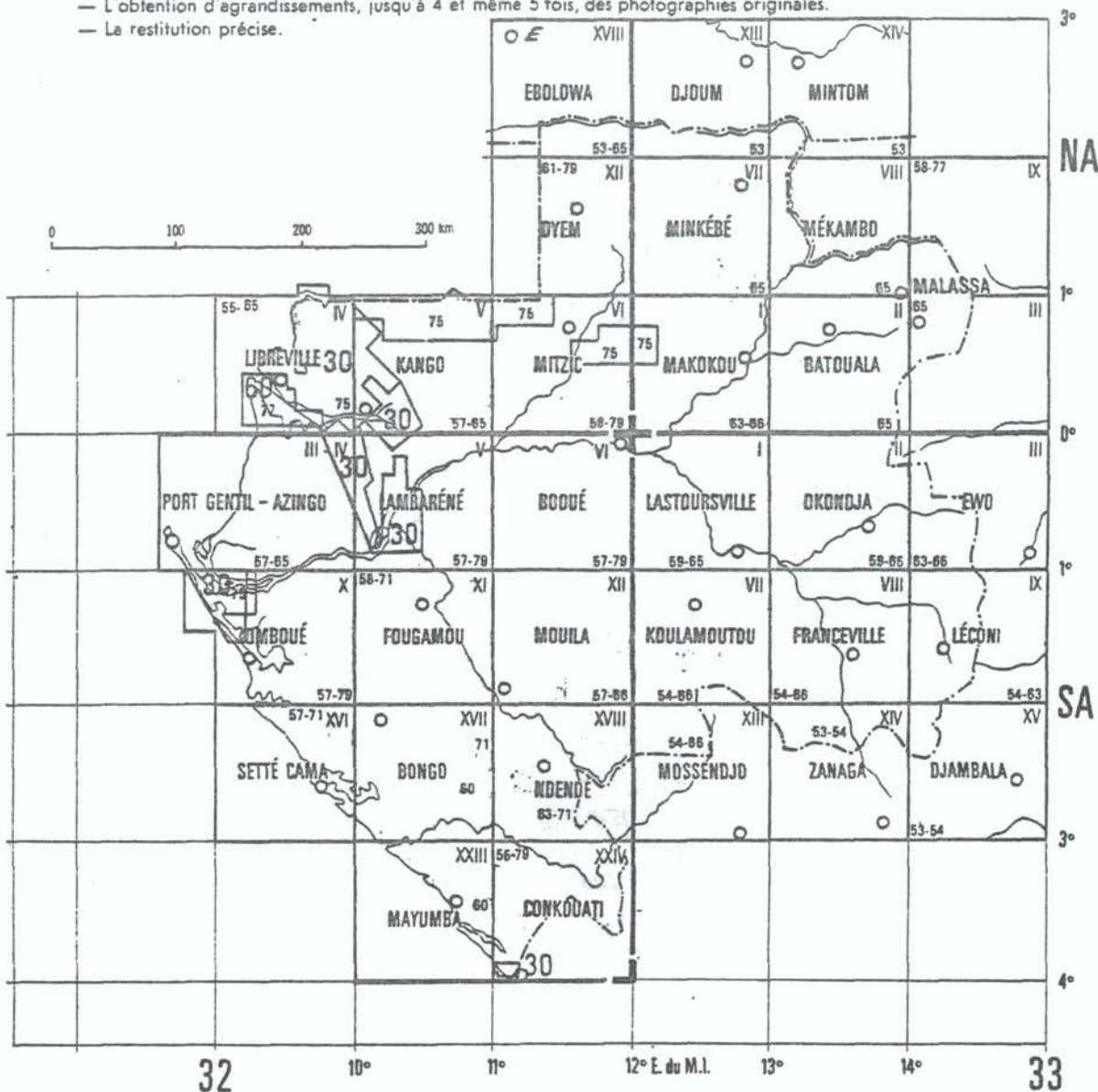
Le chiffre noir indique l'année de la dernière prise de vues.
Certaines feuilles ont fait l'objet de couvertures partielles échelonnées entre les deux dates indiquées. Dans ce cas, pour des localisations plus précises, il est recommandé aux utilisateurs de s'adresser à l'Agence locale de l'I.G.N. ou 2 Avenue Pasteur - 94160 St-Mandé (Photothèque).

NOTICE — La couverture photographique satisfait aux conditions générales ci-après :

- Chambres métriques de prise de vues.
- Axe de prise de vue sensiblement vertical.
- Couverture totale de chaque zone par des bandes de photographies rectilignes et parallèles.
- Recouvrement longitudinal de deux clichés successifs d'une bande : 60 %.
- Recouvrement latéral de deux bandes adjacentes : 15 %.
- Excellente netteté.

Ces clichés permettent :

- L'étude détaillée du terrain par examen stéréoscopique des épreuves.
- L'obtention d'agrandissements, jusqu'à 4 et même 5 fois, des photographies originales.
- La restitution précise.



II. REMOTE SENSING IMAGERY

1) LANDSAT imagery

The Landsat (satellite) sensor system is different from aerial photography, not only in its altitude, but also in that imagery rather than photography is generated. Similar to color infrared photography, the Landsat sensors are not bound by the limits of human vision, so they are able to pick up reflection patterns in a greater range of the electromagnetic radiation spectrum.

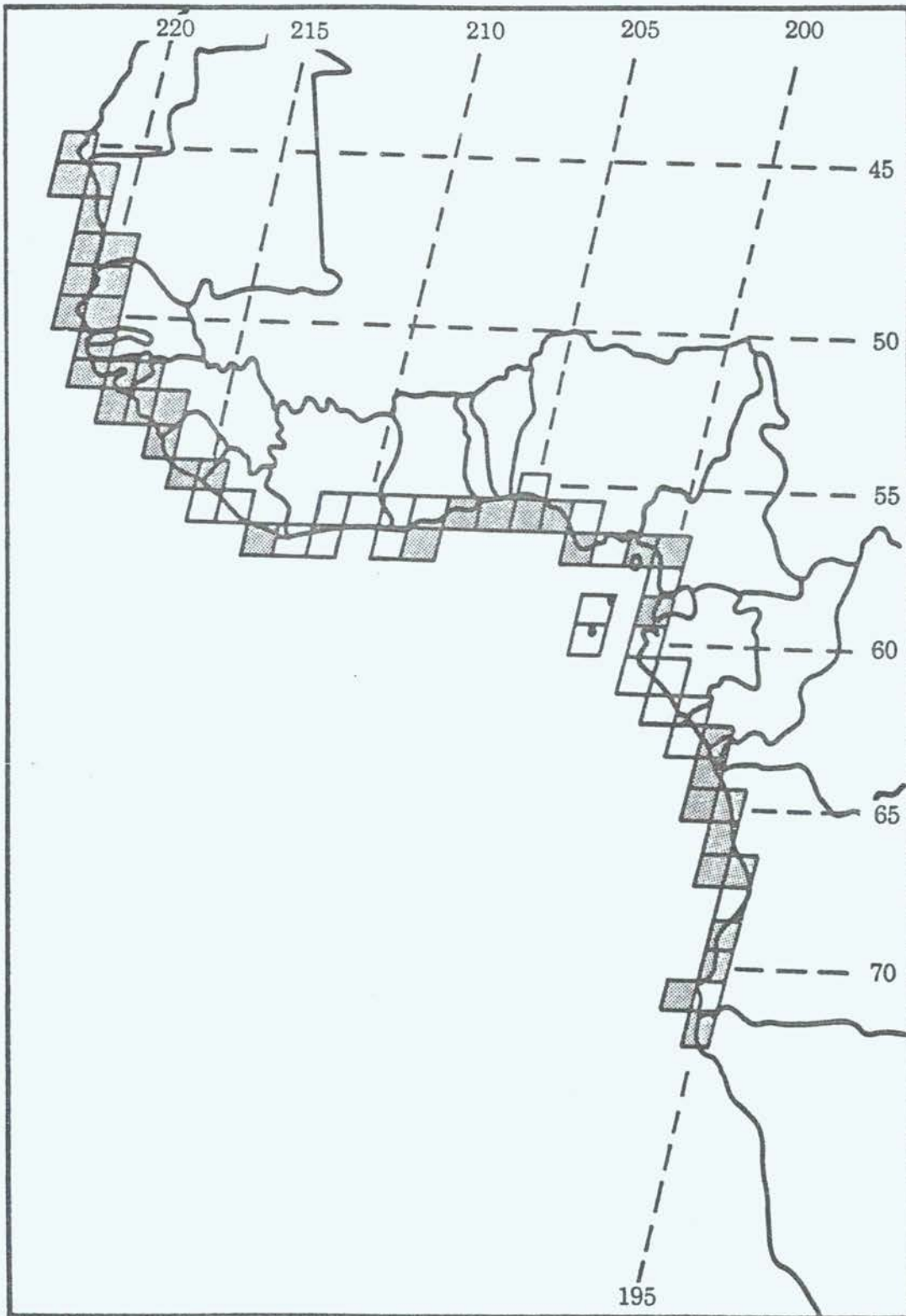
Informations derived from Landsat system has been useful for general studies such as land use mapping, but the spatial resolution of the system (80 metres) is too coarse for delineating shoreline change (the more recent Landsat satellites has an improved resolution of 30 by 30 metres). With the 80 metres resolution, a resultant scale of no better than 1:100,000 can be expected.

The images from Landsat system enable a coastal coverage of the 20 West African nations to fall within 64 Landsat scenes (of 185 km² each, see map coverage). Although the 16-day orbit of the Landsat provides coverage of a given area 22 times a year, very few scenes have much available imagery on an annual basis. The major problem, particularly in tropical areas, is the cloud cover which renders portions of the scene or the entire scene useless.

2) SPOT system

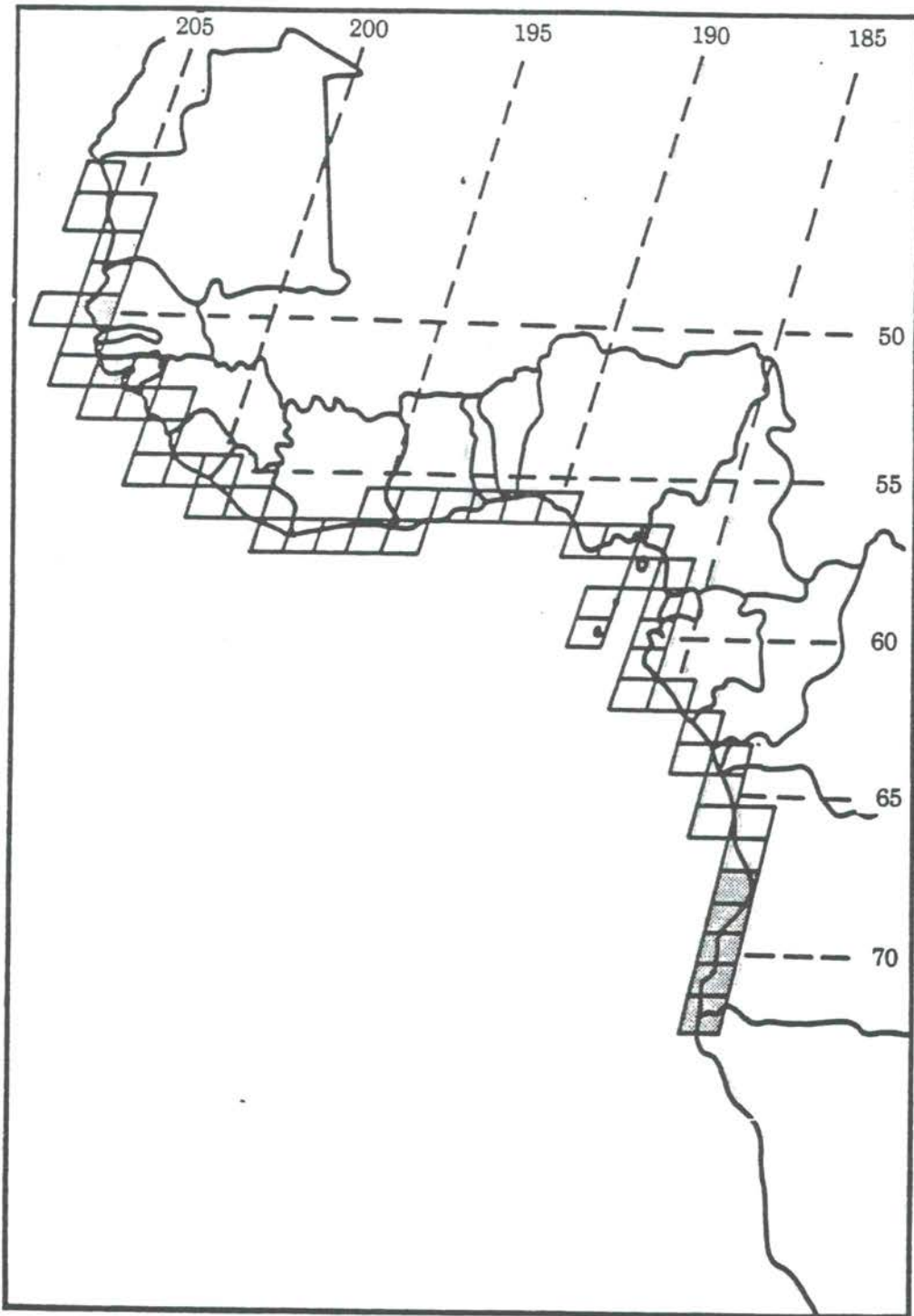
The new French multispectral scanner, the SPOT satellite, is mentioned here because it may replace the Landsat system for global coverage. The system was launched in the spring of 1984 and works on essentially the same principles as the Landsat system. SPOT has an improved resolution of 10 metres, but there are only 3 bands (green, red, and infrared). The 10 metres resolution of SPOT is expected to benefit satellite-based coastal mapping for erosion studies.

Other teledetection systems, presently more or less experimental, will be used in the future, as commonly as aerial photographs ; but their use depends on their resolution power and their cost.



Carte d'assemblage des images Landsat 1/2/3. Les zones ombrées représentent moins de 40 % de couverture nuageuse

Availability of Landsat 1/2/3 data. Shaded scenes are available with 40 percent cloud cover or less



Carte d'assemblage des images Landsat 4/5. Les zones ombrées représentent moins de 30 % de couverture nuageuse

Landsat 4/5 data. Shaded scenes are available with 30 percent cloud cover or less

A P P E N D I X I I I

SYNTHESIS MAPS

(modified after Collins et al., 1983)

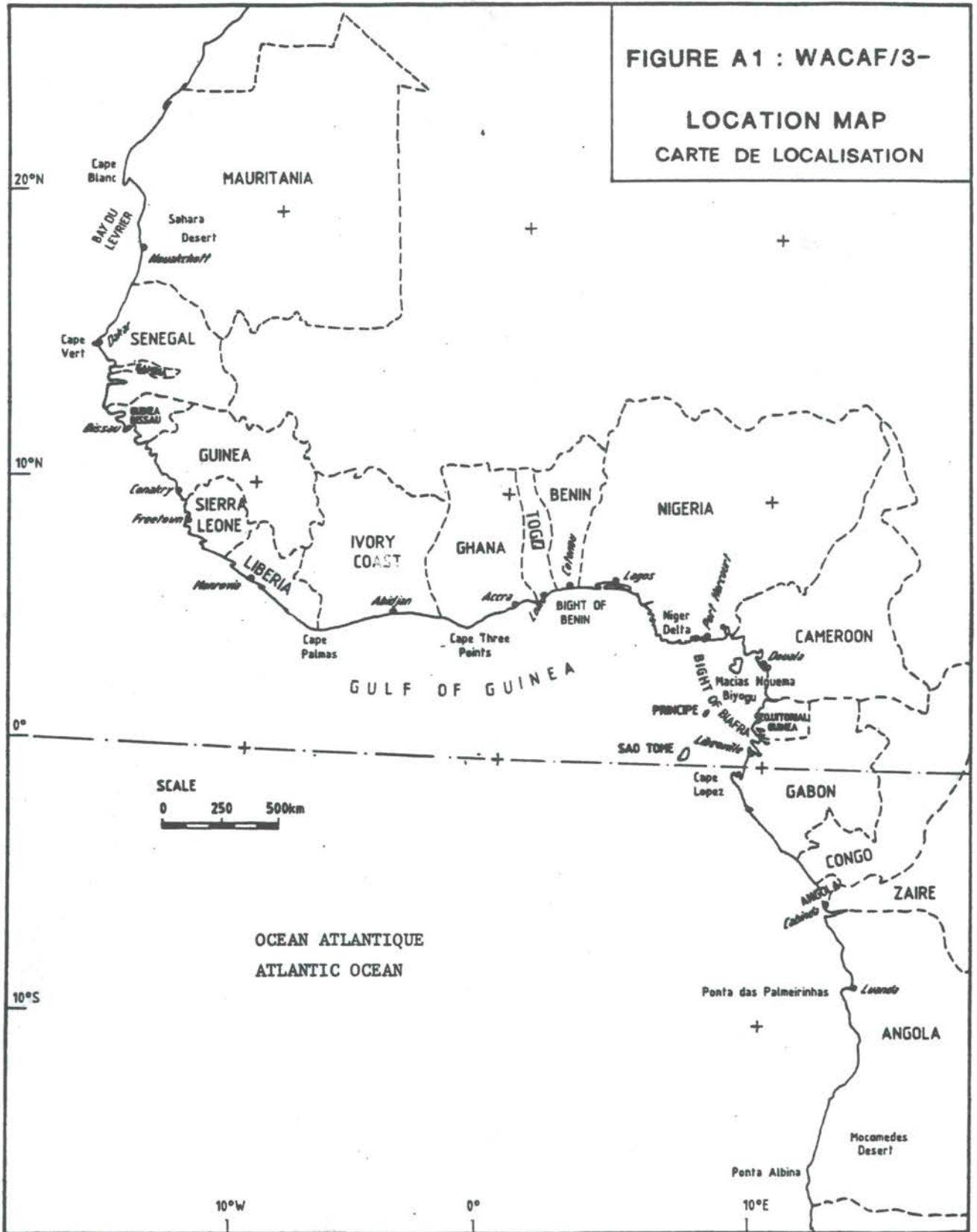
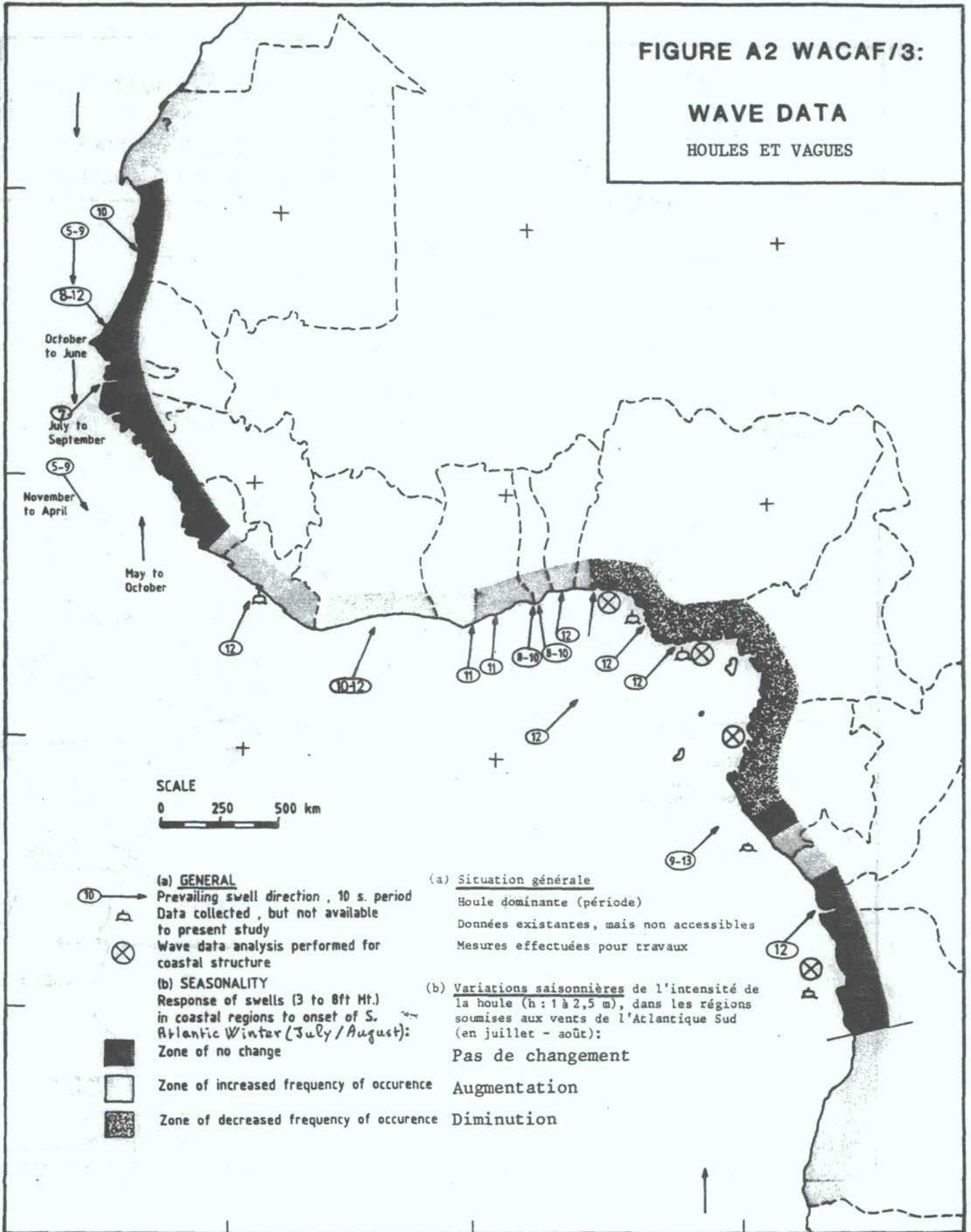


FIGURE A2 WACAF/3:

WAVE DATA

HOULES ET VAGUES



**FIGURE A3 WACAF/3:
CURRENTS/CIRCULATION
PATTERNS
CIRCULATION OCEANIQUE**

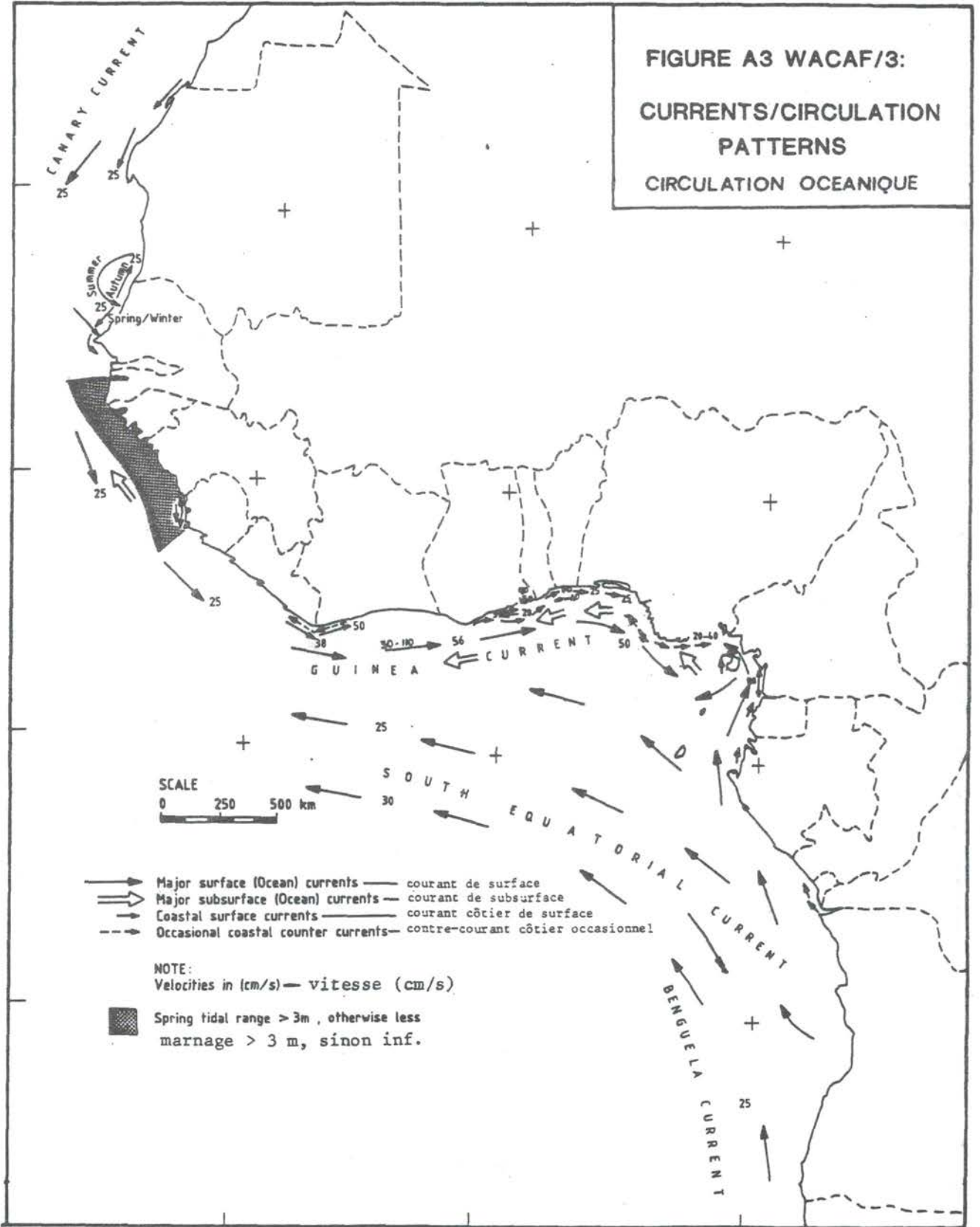
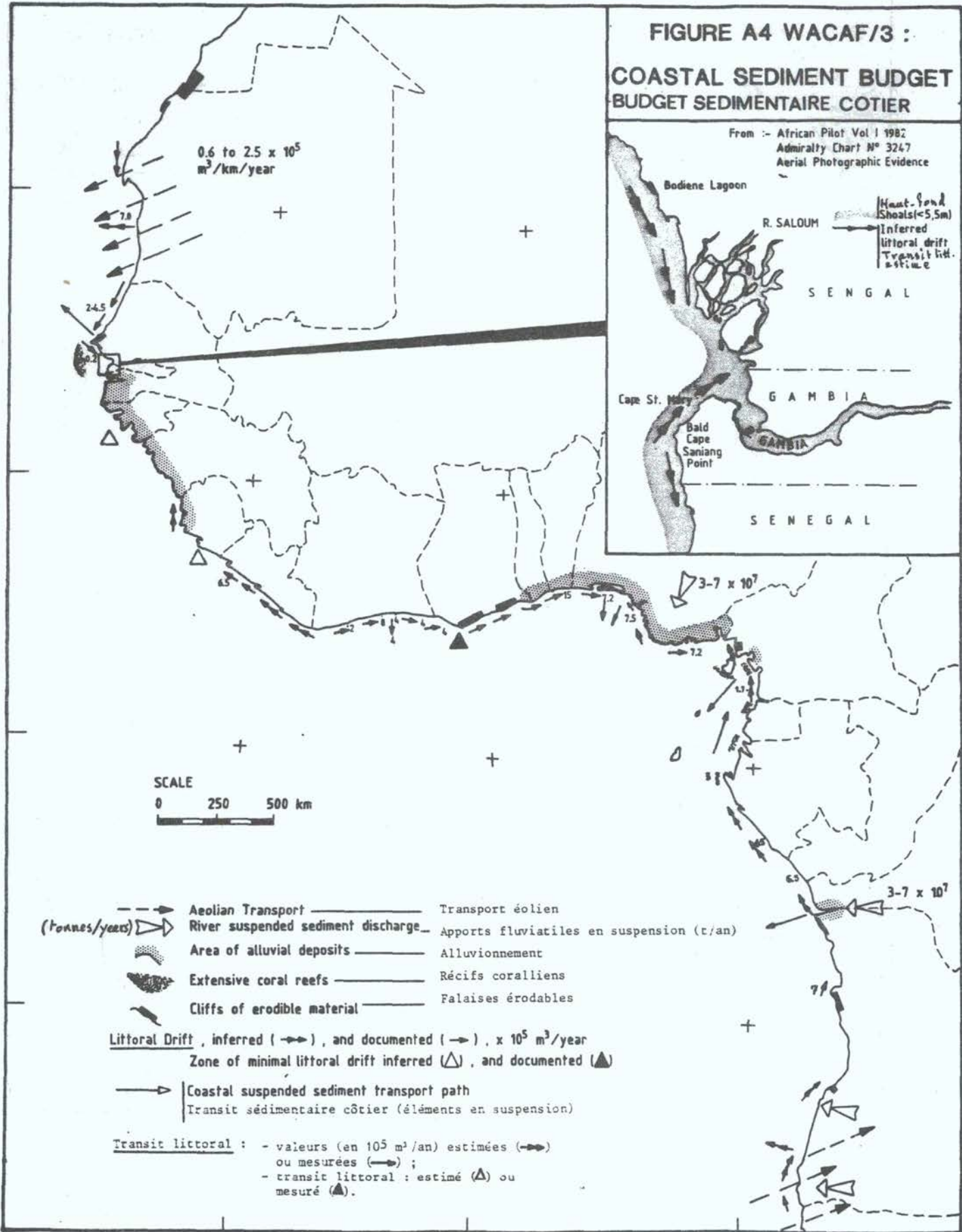
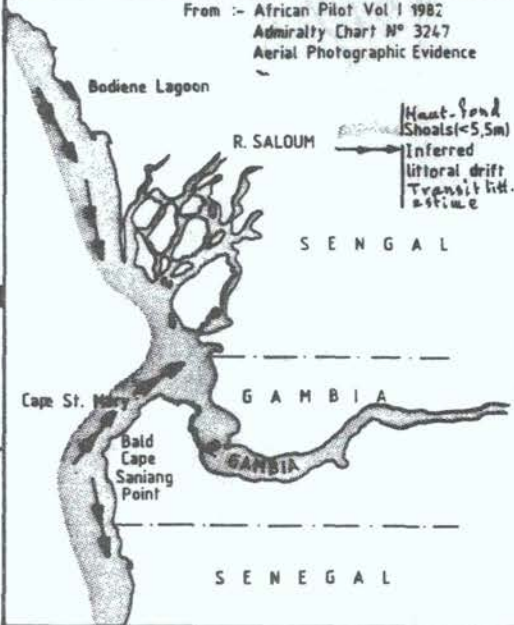


FIGURE A4 WACAF/3 :
COASTAL SEDIMENT BUDGET
BUDGET SEDIMENTAIRE CÔTIER

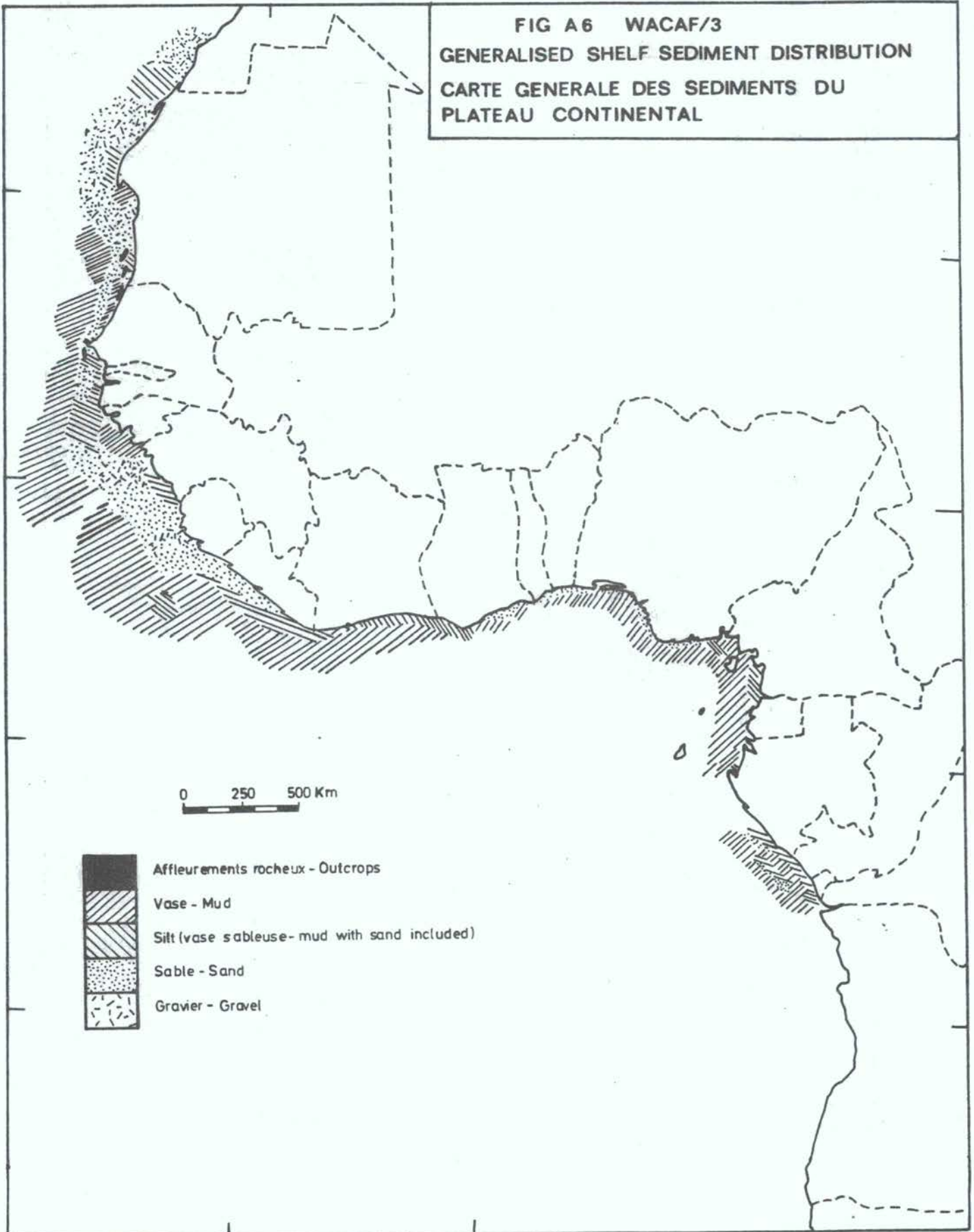
From :- African Pilot Vol 1 1982
 Admiralty Chart N° 3247
 Aerial Photographic Evidence

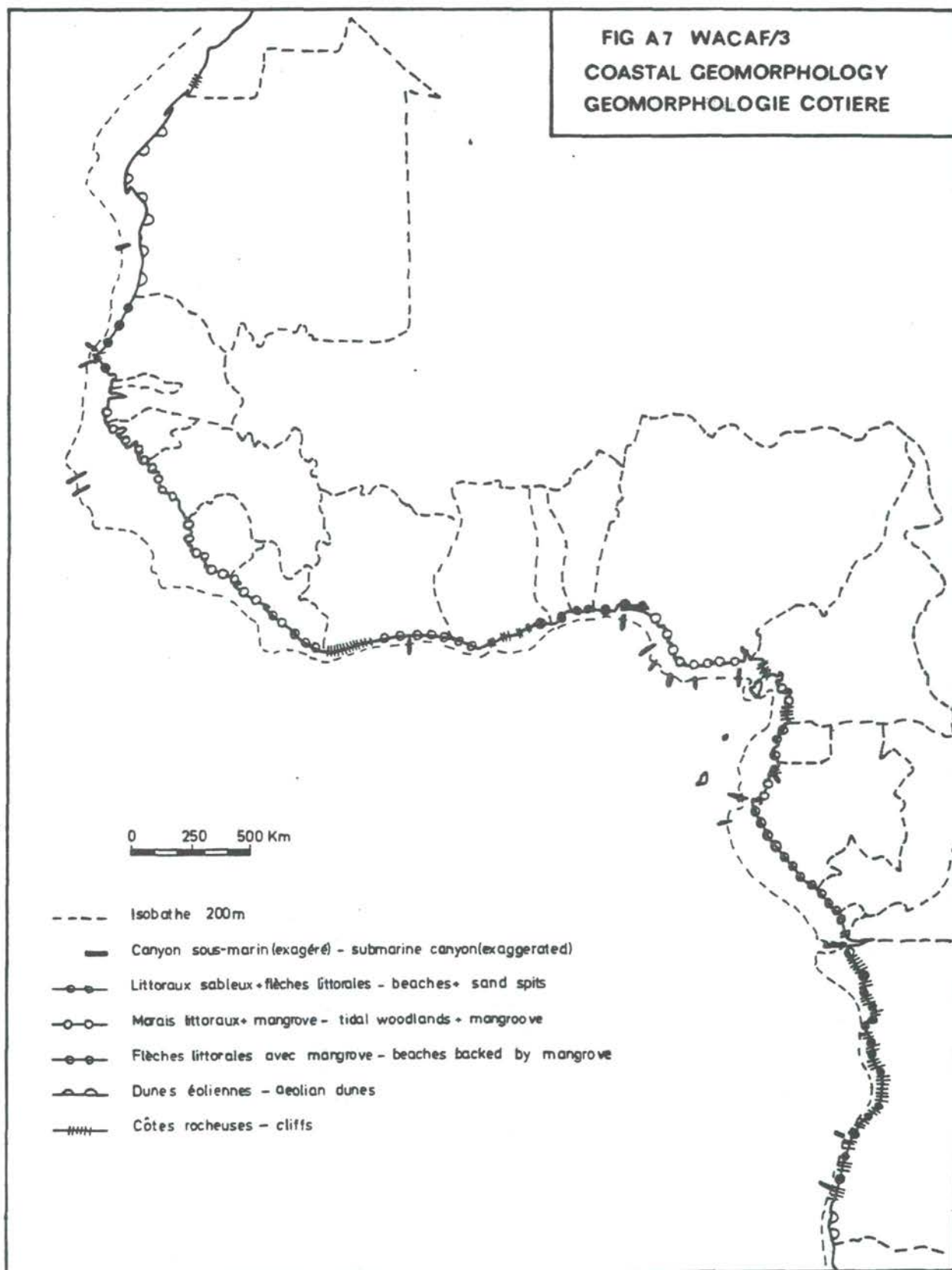


SCALE
 0 250 500 km

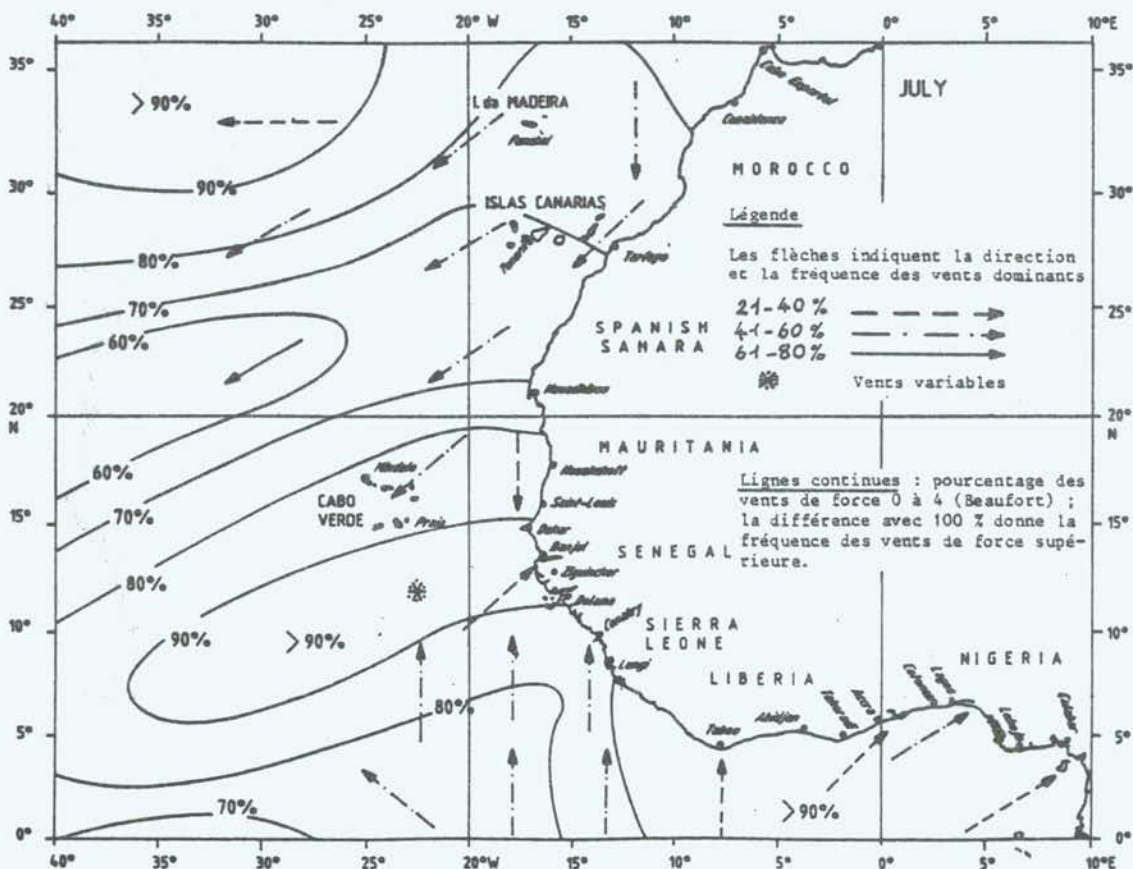
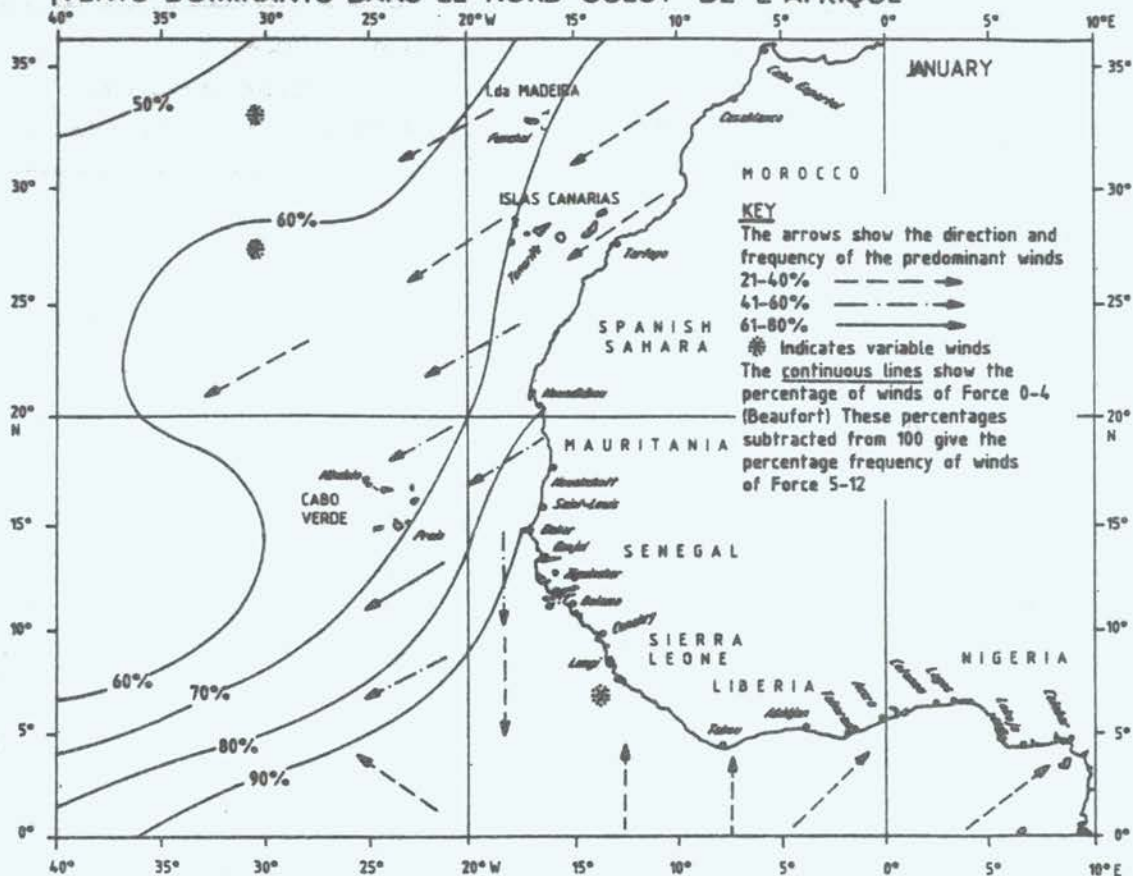
- > Aeolian Transport ——— Transport éolien
- (Tonnes/years) >>> River suspended sediment discharge — Apports fluviaux en suspension (t/an)
- Area of alluvial deposits ——— Alluvionnement
- Extensive coral reefs ——— Récifs coralliens
- Cliffs of erodible material ——— Falaises érodables
- Littoral Drift, inferred (--->), and documented (--->), x 10⁵ m³/year
- Zone of minimal littoral drift inferred (△), and documented (▲)
- Coastal suspended sediment transport path
 Transit sédimentaire côtier (éléments en suspension)
- Transit littoral : - valeurs (en 10⁵ m³/an) estimées (--->) ou mesurées (--->);
 - transit littoral : estimé (△) ou mesuré (▲).

FIG A6 WACAF/3
GENERALISED SHELF SEDIMENT DISTRIBUTION
CARTE GENERALE DES SEDIMENTS DU
PLATEAU CONTINENTAL

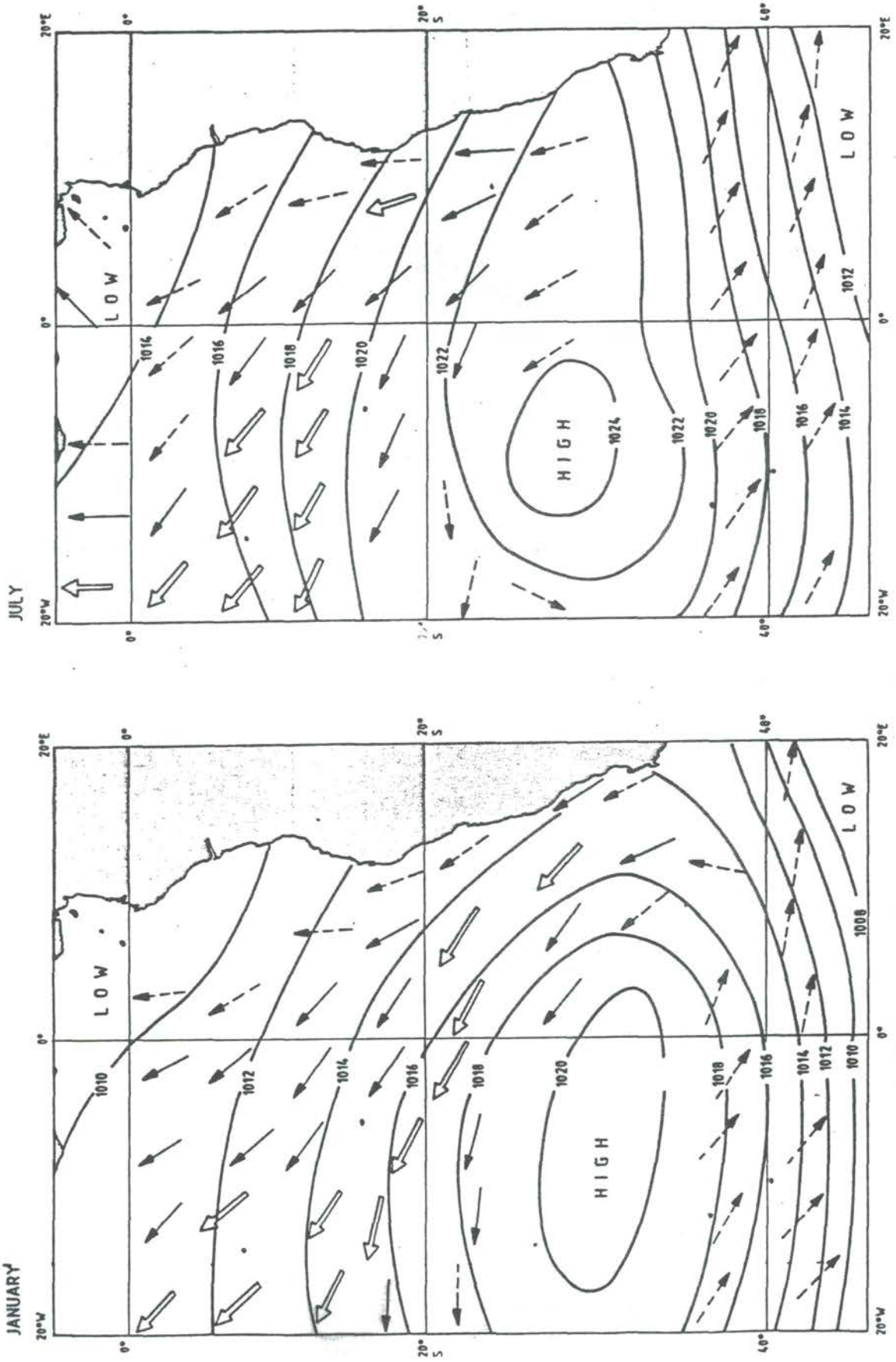




PREVAILING WIND PATTERNS, NORTH WEST AFRICA
VENTS DOMINANTS DANS LE NORD-OUEST DE L'AFRIQUE



NOTE : From British Admiralty Pilots



VENTS DOMINANTS DANS LE SUD-OUEST DE L'AFRIQUE
FIGURE A9 WACAF/3 : PREVAILING WIND PATTERNS SOUTH WEST AFRICA

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