LATE HOLOCENE EVOLUTION OF THE SALUM-GAMBIA DOUBLE DELTA (SENEGAL)

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Abstract. The post-glacial transgression up to the present sea level, which occurred about 5500 years B.P., deeply modified the coastal zone morphology, especially in the river mouth region, where, in a few millennia, the geographical pattern changed from an open bay to a delta environment. The Salum islands case illustrates this evolution. Sediments deposits and anthropic shell-middens, built in a time interval starting 6000 years B.P. up to now, based on radiocarbon dating, provide a chronological framework of the delta evolution. At first, the open post-transgression bay was subject to filling-up. A major second stage, occurring not later than 2550 years B.P., is characterized by the formation of beach barriers. The third stage is the completion of the filling-up behind the beach barriers. The whole construction is under the distinct influences first, of the Sahelian and the Salum River sediment fluxes in the Northern part of the delta and then, the Gambia River sediment input in the Southern part. Detailed analyses of the sediment testify to this double origin of the various morphosedimentary exhibited units: tidal flats and beach barriers. Grain-size analysis, SEM examination and heavy mineral assemblages revealed sand as the dominant component in the Northern part. It originated from atmospheric and fluvial conditions favouring the coarse component input. To the South, a clay dominant influx, controlled by the Gambia River discharge, is responsible for back-barrier mud-flats, accumulated in relation to the reduction or the absence of the tide-dominated fluvial processes in the Salum River. Hence, the Diomboss arm does not form one of the delta distributaries between the Northern and the Southern part as previously considered but a residual space of the former mid-Holocene bay, separating the real Salum River delta to the North and the pre-Gambian delta to the South. All morphological units described in the delta are established at a level located within the present tidal range. There is no need to refer to sea level variations to explain the geomorphologic pattern. The sedimentological input and forcing seem to be the major agents of sedimentary unit distribution.

Key words: delta – eustatic stability – beach barriers – tidal flats - Holocene – West Africa

INTRODUCTION

The delta areas are part of terrestrial environments that – apart from volcanic phenomena - have undergone the most important transformations in recent millennia, and in particular since the post glacial sea attained its current level. This event occurred between 6000 and 5000 years B.P, and for the few millennia that followed, the sea level has varied only slightly, whereas the coastal area has undergone considerable changes.

The most obvious cause of these changes in deltas is the volume of sediment fluxes redistributed by fluvio-marine dynamics, as illustrated by the morphologic and stratigraphic classification of the deltas (Galloway, 1975). The possible variations of the sea level and local or regional lithospheric upwelling or subsidence phenomena have also played a role.

In a simplified context where one of the factors can be considered as a constant, the comparison of the respective effects of the other two must be facilitated. Consequently, the share of the incidence of the hydrosedimentary factors and that of the purely eustatic component can be estimated, provided that the tectonic effects are negligible on the scale of the time considered. This comparison is difficult in large deltas such as those of the Rhone, the Po or the Mississippi, which are well known for the subsidence processes that occur there to variable degrees. It may be simpler to assess in small arrangements, such as a site on the West-African coast in Senegal, on the Petite Côte to the South of Cape Verde (Dakar): the Salum "delta," selected for this study. Small delta environments are not extensively studied and are even less known; they provide an opportunity to diversify knowledge on this type of environments.

DESCRIPTION OF THE SITE UNDER STUDY

The Salum delta, that now covers an area of 2250 km^2, opens up at about 150 km to the South of Dakar, in a Miocene geological setting known as the "Continental Terminal" which has undergone a profound ferrallitic pedogenesis (Lappartient, 1985). The sector is part of the West-African passive margin, where indications of crust mobility in the Senegalo-Mauritanian basin are limited to a certain subsidence in the Senegal River delta area (Monteillet, 1986). A general lithospheric stability prevails elsewhere (Einsele *et al.*, 1974) as attested, for instance, by observations at Cap des Biches (Diouf *et al.*, 1995). The Eemian is encountered there at a low altitude (~1 m) above mean sea level, showing that this stability is observed at a time scale that most certainly includes the Holocene.

The climate of the region is Sudanese, characterised by two alternating, contrasting seasons. Considerably different modalities are nonetheless encountered in Senegalese territory (Ausseil-Badie and Monteillet, 1985). In the North of the country, the Senegal River flows in an arid to semi-arid Sahelian region; conversely, among the "Rivers of the South," the Gambia flows in a tropical area (Diop, 1990). The Salum Delta is situated at the edge of these two areas and consequently enjoys a specific bipolar climate (Diara, 1999). The Salum River (Fig. 1) is actually a ria now fed only feebly by a limited river flow for two to three months during the rainy season, from July to September. Its hydrodynamics are governed essentially by the penetration of the tidal wave and the strong evaporation regime which develops in the vast system of interdistributaries (known as 'bolons') and mangroves of the delta (Barusseau *et al.*, 1985). Conversely, the Gambia River, which opens in the immediate South of the delta, is fed continuously with fresh water, albeit subject to wide fluctuations (Marius, 1985; Diop, 1990; Dacosta, 1993). The delta spreads out between the Salum and the Gambia rivers, and is cut by two unequal arms. The Bandiala to the South is a long, narrow and quite shallow bolon, unlike the vast Diomboss, which seems to form a border between the most extensive semi-delta in the North and the Betanti Islands in the South (Fig. 1). In the Diomboss, the greater depths (25 m) and the width (2 to 5 km) do not seem compatible with a normal fluvio-deltaic process.

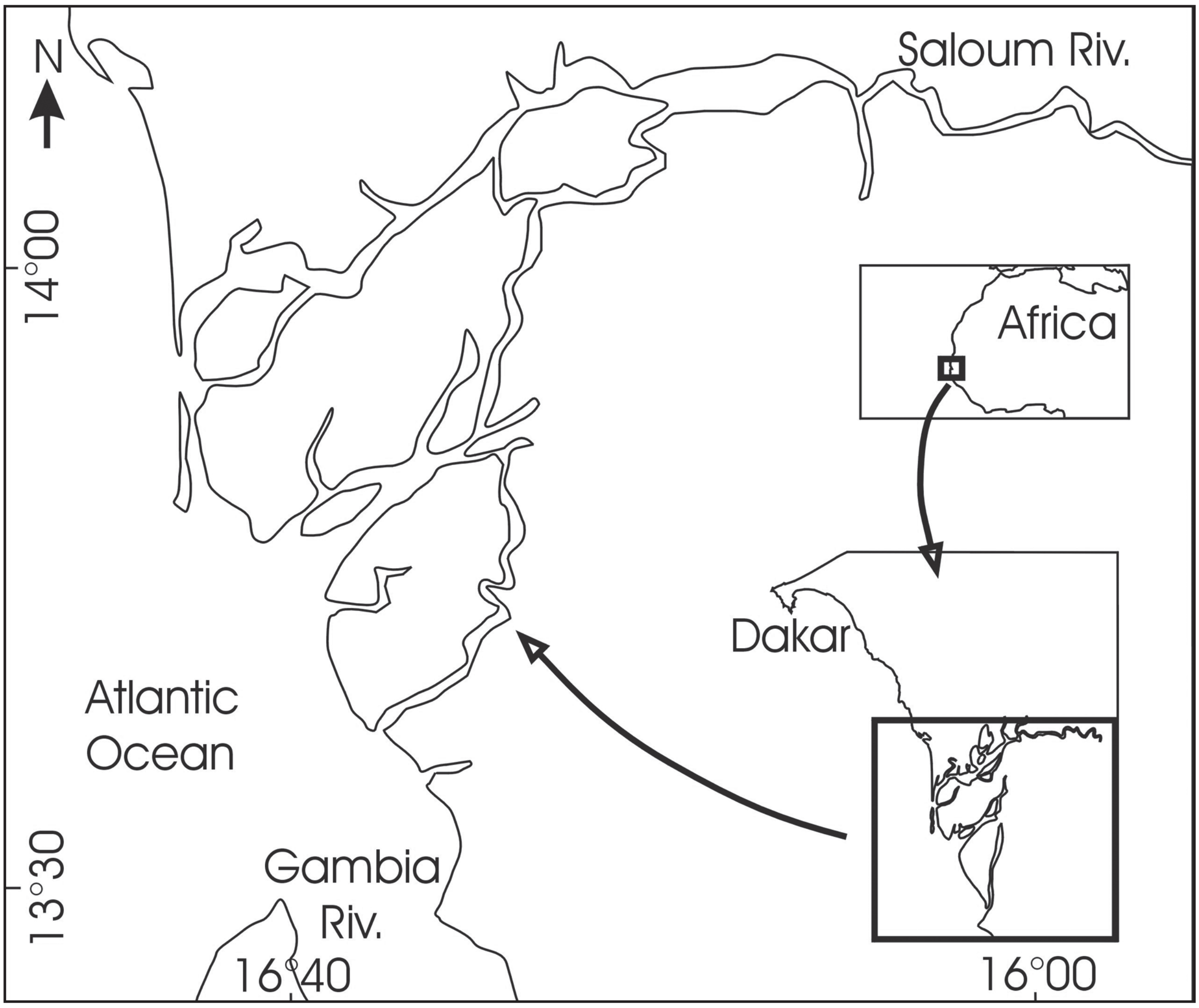

Fig. 1 Location of the studied area

In relation to Galloway's classification (1975), the Salum delta displays an organisation strongly dominated by fluviatile fluxes and tide. The latter is microtidal in the North (Diaw, 1993) and macrotidal in the South (Barusseau *et al.*, 1988; Diara, 1999). According to these characteristics, it is of a mixed type, neither clearly lobate like the delta of the Senegal, nor cuspate, like the delta of the Rhone. The influence of the swell is marked by a long, Senegalese type of spit, the Sangomar Spit, similar to the Langue de Barbarie that diverts the Senegal River when it reaches sea and shifts its mouth several tens of kilometres to the South. In two cases, however, natural (Salum) or anthropogenic (Senegal River) processes have recently created intermediate openings that tend to stay, unlike similar events in the recent past (Cuq et Diaw, 1985; Ba *et al.*, 1993; Diaw, 1997; Thomas and Diaw, 1997; Ba and Diouf, 1998). In the Salum, the spit was broken in February 1987, and the breach has widened constantly in the years that follow to reach more than 4 km. The process is indicative in particular of a sedimentary dearth responsible for erosion phenomena that are widespread in all of the Petite Côte, between the Cap Verde and the Gambia (Barusseau, 1980).

These particular features have long attracted the attention of researchers from various fields such as morphology (Michel, 1973; Sall, 1983; Diop, 1990), hydrology (Barusseau *et al*, 1985; Saos and Pages, 1985), pedology (Kalck, 1978; Marius, 1985), sedimentology and micropaleontology (Ausseil-Badie *et al.*, 1991; Barusseau *et al*., 1985, 1995) who have noted wide differences in the distribution of beach ridges, mud tidal flats and sand flats (locally known as "tanne" units) – the three main morphosedimentary units encountered between the Northern and Southern parts of the delta (Diara, 1999). Another particular feature of the Salum delta is the existence of a large number of anthropogenic shell middens. They attest to the presence of Neolithic cultures since at least 1940 B.P. (Faboura mound, to the North of delta, Descamps *et al.*, 1977; Thilmans et Descamps, 1982). They were erected near gathering areas of the main mollusc, exploited for its meat, *Anadara senilis*, along sand-mud or sand-silt areas, often in a sheltered and internal position, as can still be seen today (Descamps, 1989). The different mounds are located on the edge of reliefs that surround the delta plain, as well as inside the plain along active bolons or old distributaries that have now disappeared. They mark the different stages of the sedimentary filling of the delta plain and their chronological positioning consequently provides reference points of this history.

These works have made it possible to sketch an explanation of how the estuary functioned, as well as an initial framework for these formations (Ausseil-Badie *et al.*, 1991). Fig. 2 summarises the steps, from the open bay stage at the beginning of the filling between 6000 and 3500 B.P. (Fig. 2A), until the current stage marked by the deposit, in two episodes (2000-1500 years B.P., then 1000-600 years B.P.) of mud and sand-flats (Figs. 2C and 2D), behind vast beach ridges formed between 3150 and 2550 years B.P., with an apparently different polarity in the North and in the South (Fig. 2B).

Questions nonetheless remain unsolved and pertain more particularly to two clearly distinct issues. The first concerns the relative importance of factors that determine the nature and abundance of deposits as well as the articulation of its constituent units. The second has to do with the origin of the median Diomboss (Fig. 1) and to the origin of the differences between the two parts of the delta that it separates. The purpose of this article is to present the state-of-the-art about these two issues.

METHODOLOGY

The delta plain consists of deposits organised into distinct geomorphic and sedimentologic units, which were studied by Diara (1999). The indication of the role of possible fluctuations of the sea level in the formation and architecture of these units implies that their altimetric position is determined in relation to the sea level, in light of the tidal and/or marine variations (storm surges) that affect it. The methods used fall under topography. In each point study, a reference level was defined in relation to the level of the highest watermarks on the shore or the banks. All the stratigraphic limits marked in the cross-sections and boreholes have thus been connected to this reference level. Nevertheless, with no zero adjustment, and taking the tidal range into account, the precision of these evaluations is subject to an error of up to ±0.50 m. Some verification with a total station has shown that the altitude of the units varies in particular from North to South, depending on a likewise variable tidal range.

To understand the formation of the delta and its evolution through time, surface and subsurface samples were taken down to – 6.80 m on the ridges and – 5.20 m in the tidal flats – positions measured in relation to the reference level determined in the field. Their analysis in the laboratory has made it possible to define their grain-size and SEM grain surface characteristics, to study their heavy minerals, and to determine their clayey minerals with X rays. Some additional radiocarbon dating was performed on shells.

A total of 53 stations to the North of Diomboss and 39 to the South have been described and studied. They are more concentrated around the beach ridges, entailing a less homogeneous distribution to the North than to the South of Diomboss, because they are located to the West of the delta plain in the North, whereas they are vaster and regularly distributed in the South.

RESULTS

Their main sedimentological and morphological characteristics are described below, underlying the differences between the Northern and Southern parts on either side of the Diomboss.

The three types of morphosedimentary units of the delta

The sediments are organised into morphosedimentary units, which show clear differences between the Northern and Southern parts in terms of their distribution and mutual – in particular stratigraphic – relations.

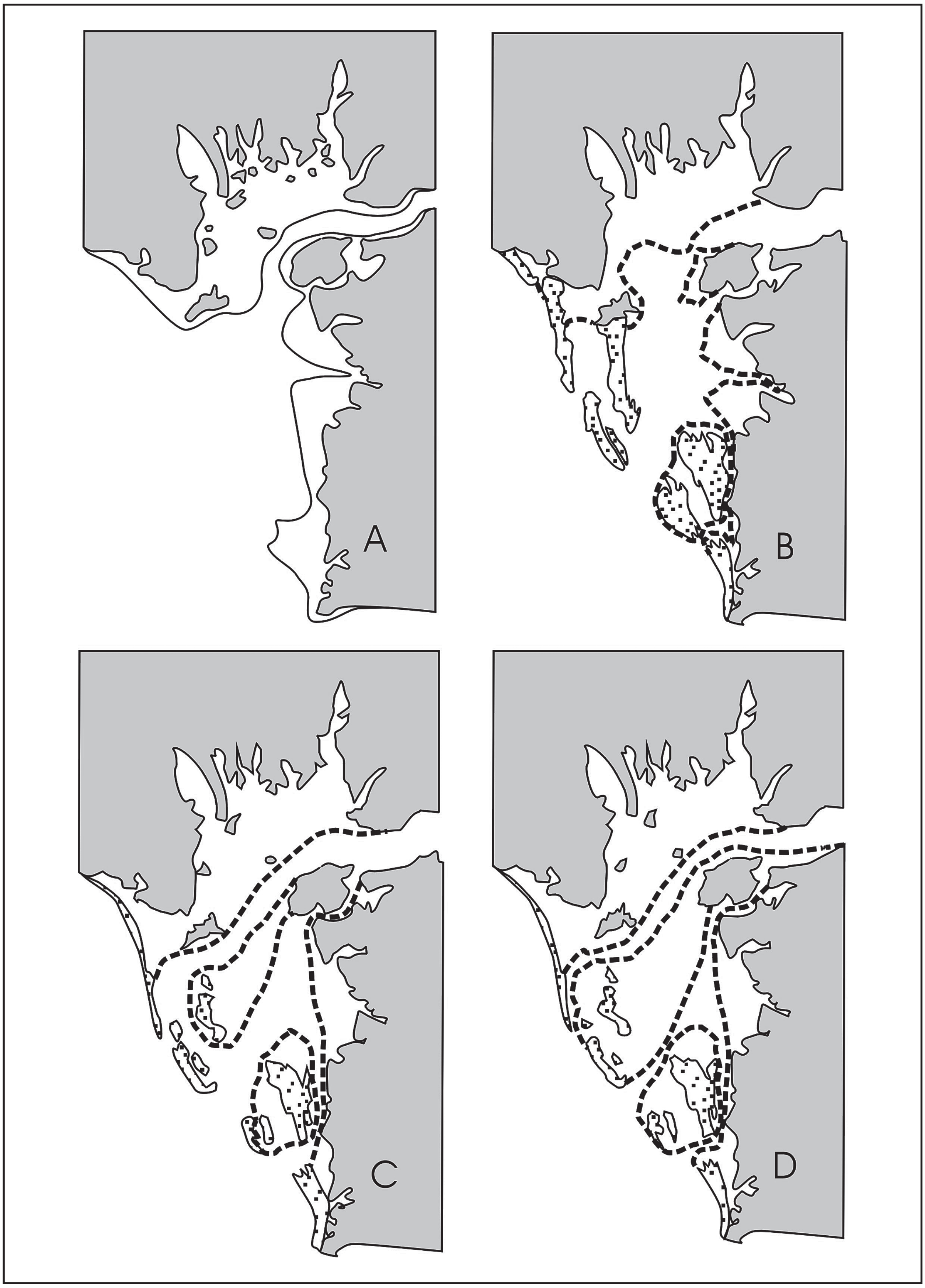

Fig. 2 The four major stages of the delta construction according to Ausseil-Badie *et al*.(1991). Explanations in text

Three types of units were considered (Fig. 3):

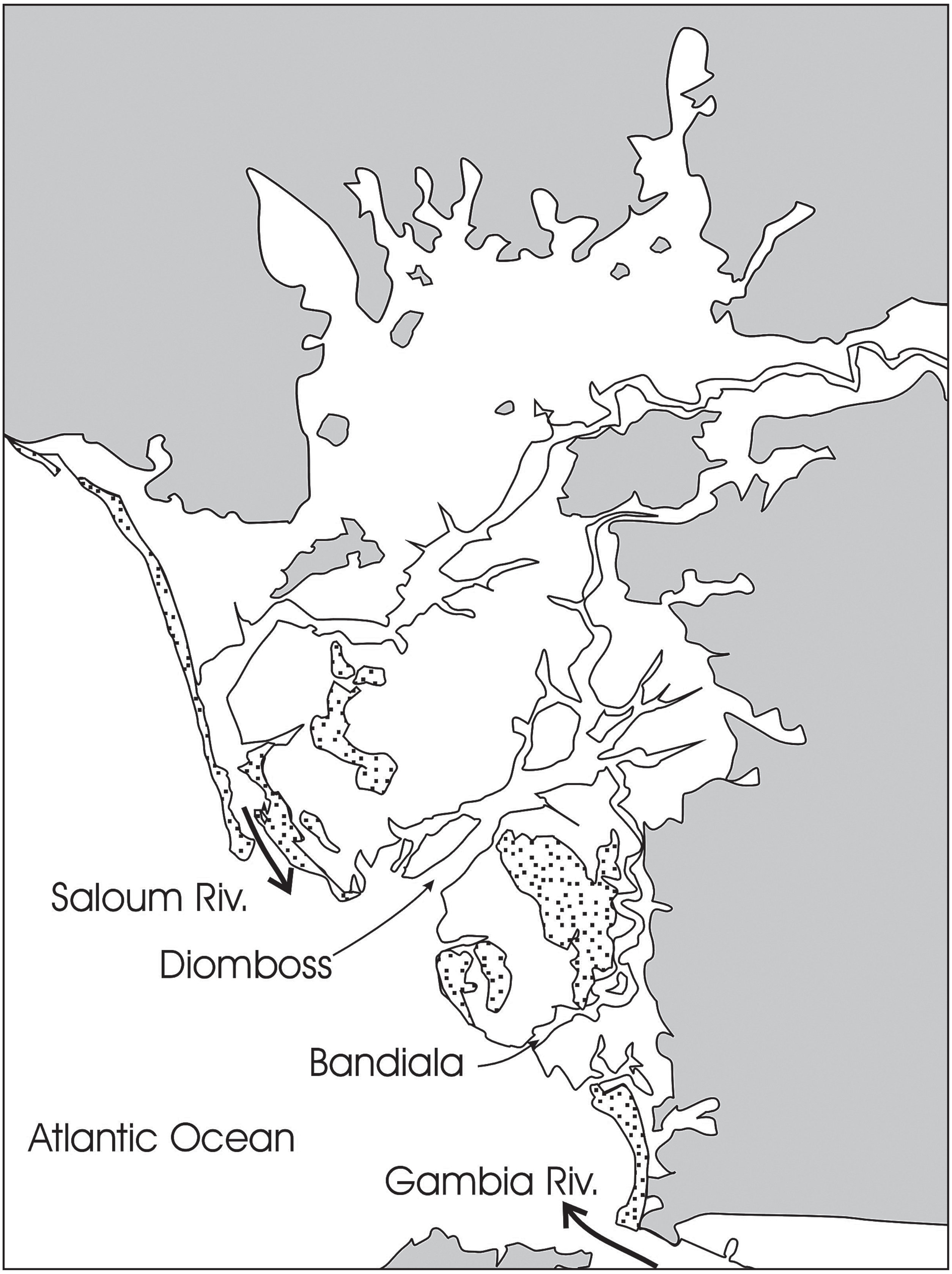

Fig. 3 The main geomorphic and sedimentary units in the delta. Dotted areas: beach barriers; white surfaces: tidal flats (mud flats and the so-called "tannes"= sand-flats are not distinguished). The grey surfaces correspond to the geological substratum outcrops (= "Continental terminal")

- The morphology of the beach ridges is very different depending on the sector studied. In the Northernmost part, the ridges are flat and dismantled, at a low altitude that does not exceed 1 m. In descending towards the South, they gradually become more imposing and form long, wide, voluminous and high barriers, at an altitude that at time reaches 10 m. Fine, at times cross-bedded laminations show on the fresh sections of the ridges in the South but, generally, because of the very homogeneous deposits, both in the North and in the South, stratigraphic correlations cannot be established.
- The mud tidal-flats are actually complex units, rarely totally composed of mud, but most often of mixed sand-clay, and at times sand-silt sediments: they correspond to the slikke of the mud-flats. They are located at the base of the ridges or at the edge of the third units, the "tannes," and do not exceed some twenty metres in thickness above the Continental Terminal (Marius, 1985). On the high parts of the mud tidal-flats develops the mangrove, thick and often inextricable in the South, poor and sparse, in riparian position in the North. The mud tidal-flats in the North are characterised by abundant sand interlayers from the ridges that are dismantled, striped and swept by the wind. The boreholes in the mud tidal-flats in the North are rapidly stopped by sandy beds and exceptionally exceed 1.50 m under the surface, whereas a depth of 6 m is attained more easily in the South. The mud tidal-flats of the South are more developed and more clayey; although they too often show alternating beds of very fine sand and of clay, they show a less developed pedogenesis.
- The "tannes" form very flat areas, most often emerged during spring tides and the rainy season; they correspond to bare or herbaceous schorre, except where geochemical processes occur because long periods of desiccation alternate with short periods of flooding. From the South to the North, the evolution of the "tannes" is accompanied by an increasingly more intense pedological transformation due to oxidation phenomena whereby pyrite is transformed into jarosite, and *Rhizophora* roots are fossilised into iron pipes (Vieillefon, 1974). The "tannes" are much extended in the extreme North, and have evolved into hyper-salted and acid soils.

Location of the mud tidal-flats in relation to sea level

The highest level (in altitude) of the mud tidal flats is always situated at the high tide limit and varies from North to South. The high tide accompanying the gradual increase in the tidal range in this direction rises from 0.50 m in the North to 2.5 m in the South.

Sand fraction grain-size

An often abundant sand fraction is found in the ridge, mud tidal flat and "tanne" sediments. It must therefore be examined.

The sand barrier sediments of the three units are fine to very fine (Figs. 4 and 5). The Northern sand barriers have a grain-size modal value essentially between 160 and 250 µm, generally higher than that observed in the Southern sand barriers. The same difference is noted between the sands of the Northern and of the Southern mud flats, even if the grain-size modes of the quartz component are finer than those of the barriers. It is worth noting, in fact that the sands of the mud flats often have bi-modal grain-size curves. This is due to two particular features. The texture of the pelitic fraction of the muds is in fact favourable to the development of an endofauna that produces a coarse bioclastic component. Furthermore, prismatic or saccharoid gypsum stemming from the authigenic processes is often encountered. Shell debris like gypsum crystals appear only after the sediment has been deposited, in the final development phase of mud tidal flats. Consequently, unlike the quartz framework population, this post-depositional formation provides no argument on the deposition process.

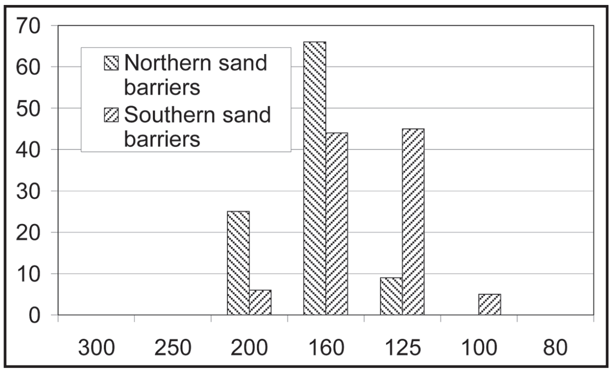

Fig. 4 Grain-size mode distribution in sand-barrier sediments (x-coordinate in microns; y-coordinate in %).

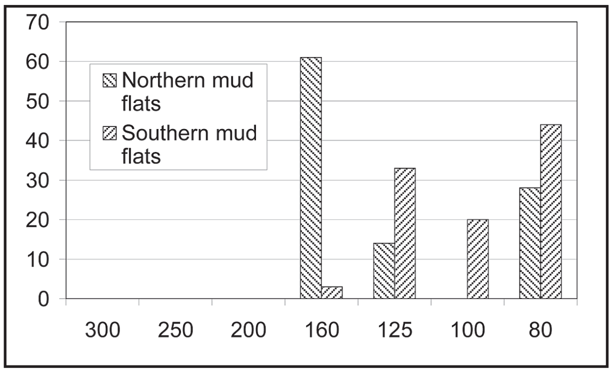

Fig. 5 Grain-size mode distribution in mud-flat and "tanne" sediments (x-coordinate in microns; y-coordinate in %).

The textural grain-size duality observed is also underscored by the distribution of the asymmetry indices which reveal significant differences between samples from the delta to the North and to the South of the Diomboss. Sand-barrier sediments in the North show a preponderant asymmetry towards the coarse tail of the grain-size distribution, while those of the South clearly show an asymmetry towards the fine end. In mud flats, this opposition is reversed, with an asymmetry towards the fine in Northern sand barriers, whilst the majority of those in the South have an asymmetry towards the coarse end of the distribution (Fig. 6 and Fig. 7).

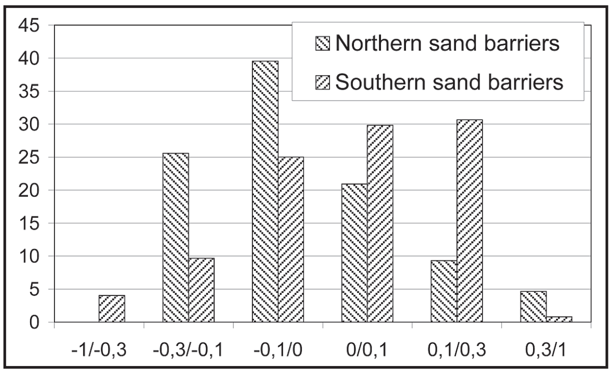

Fig. 6 Asymmetry index distribution in sand-barrier sediments (y-coordinate in %).

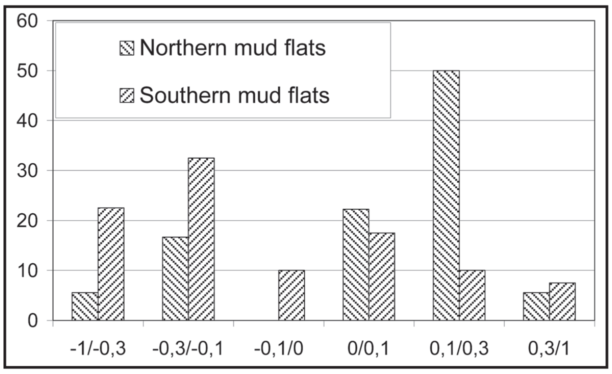

Fig. 7 Asymmetry index distribution in mud-flat and "tanne" sediments (y-coordinate in %).

Nature and quantitative distribution of pelites

Pelites are not a dominant category in the Salum delta, even in the mud tidal flats, as we have seen. They are present in higher proportion in the mud tidal flats of the South than in those of the North; the opposite is true in the "tannes" (Table 1).

Table 1 Pelitic index in mud-flats and "tanne" sediments (number of samples in parentheses)

	Northern part	Southern part
Content of pelites in mud flat sediments	36.5±14.12 (18)	45.8±27.15 (39)
Content of pelites in "tanne" sediments	18.6±18.60 (63)	7.4±10.01 (9)

The clayey paragenesis is highly constant, as already recognised by Kalck (1978). It is represented by two species, kaolinite and smectite, which constitute more than 80% of the clayey fraction under 2 µm, whereas illite, more subsidiary, represents only 5 to 20%. Kaolinite constitutes more than 50% of the clayey assemblage of the sediments. According to Kalck (1978), kaolinite is inherited from the alteration of the Continental Terminal; illite comes from the same source. According to this author, smectite (of the ferriferous beidellite variety) is always symptomatic of a marine flux.

This situation must be compared with a certain abundance of pelites at the outlet of the Gambia, in the inner-shelf zone (Barusseau, 1983), over an area of more than 20 km², at times exceeding 25% of the total sediment. The Gambia actually has real floods and a solid flow rate of 660000 tons/year at 530 km from the mouth (Lerique, 1975). This river therefore has the necessary capacities to bring fine elements in suspension. At the outlet of the Salum, on the other hand, this proportion is lower, about 5 % over a reduced area.

SEM examination of the quartz fraction

A SEM surface analysis of the quartz grains has shown that, all the grains in the delta have marks indicating that they passed in a coastal area, at times in high energy sectors. The grains are often very clean and show marks of current shock. However, a clear distinction appears among all the sand barrier, mud flat and "tanne" sediments: the quartz grains of the Northern clearly demonstrate a prevailing wind component with a high percentage of round and mat grains, traces of wind-derived scratch, sharp edge fractures and, at times, even flat surfaces reminiscent of dreikanters. Grains are also often found with traces of shocks on silica coatings typical of desert areas. The SEM examination of these grains shows a provenance from a desert environment and, very frequently, indications of wind transport. In the Southern units, on the other hand, the wind-derived component is always feebly represented and grain shapes are largely dominated by rougher forms; among which exoscopy has shown numerous alterations manifested by, *e.g.* rounded edges and blunted peaks. This set of characteristics, together with the frequency of non-worn grains (15 to 50%) attests to a consequent fluvial flux and suggests that the Southern delta was fed from sources nearby. Only the Gambia – because of its proximity and water discharge – can be considered as a valid source for this type of sediments.

Quantitative and qualitative analysis of heavy minerals

The same opposition is established when the distribution of heavy minerals is considered. The weighted percentage of heavy minerals is three times higher in the Southern than in the Northern beach barriers: the average in the South is 0.70%, but only 0.21% in the North. When notable percentages are on occasion recorded in the North (Niodior: 0.42 % and Fandong: 1.42), it is because the light fraction is winnowed, thereby implying residual enrichment.

The dominant mineralogical species in the delta are zircon, tourmaline, rutile, highly resistant minerals; then come metamorphic minerals: staurotide, andalousite and disthene. Garnet, sphene, and muscovite, chemically or mechanically more fragile, are in low quantity. The distribution of these mineral species shows two tendencies: the Southern barriers are richer in rutile, whereas the Northern beach barriers are richer in muscovite. All the other heavy minerals show a homogeneous distribution between North and South of the delta.

Dating

Several new dates have been obtained on samples of shell remains (*Anadara senilis, Dosinia isocardia* and *Gryphea gasar*) taken from beach barrier sediments (4), "tanne" sediments (2) and tidal flats (4). The results are given in Table 2.

These dates supplement, but do not challenge the scheme of relations between the different units and the chronology of the steps shown by Ausseil-Badie *et al.* (1991) as presented above (Fig. 2).

Table 2 ^{14}C dates on shell remains from various morphosedimetary units of the Salum delta

Morphological unit	Location	Depth (m)	Species	^{14}C Date (years B.P.)
Beach barrier	Falia	0.80	*Dosinia isocardia*	3670±100
Beach barrier	Dionewar	2.10	*Anadara senilis*	2370±50
Beach barrier	Dionewar	2.50	*Anadara senilis*	2780±60
Beach barrier	Niodior	0.70	*Anadara senilis*	570±40
Tidal flat (slikke))	Niodior	0.10	*Gryphea gasar*	170±50
Tidal flat (slikke)	Niodior	0.47	*Gryphea gasar*	390±70
Tidal flat (slikke)	Niodior	0.63	*Anadara senilis*	530±70
Tidal flat (slikke)	Djiffère	0.25	*Gryphea gasar*	1180±80
Tidal flat (schorre)	Diogane	0.10	*Gryphea gasar*	580±60
Tidal flat (schorre)	Diogane	0.35	*Gryphea gasar*	400±60

INTERPRETATION - DISCUSSION

Relative weight of eustatic and sedimentary forcing factors

The sequence of deposits formed during the filling of the primitive estuary bay of Salum represents a dynamic system, where the evolution in time and space is regulated by a balance between three allocyclic factors (Vail *et al.*, 1977): variation in sea level (i.e. the change in the volume of the world's ocean water), isovolume deformation of the solid substrate (i.e. variation of its geometry), and sedimentary fluxes that modify the form of the substrate locally through the addition of new material.

The problem in the Salum delta is actually limited to establishing the share between the relative weights of two factors only: eustatism and sedimentary forcing, for the sector belongs to the West African passive margin, where a general lithospheric stability prevails (Diouf *et al.*, 1995).

It can point out first that the sedimentary reservoir was considerable throughout the period. There were voluminous ergs to the North of the Salum-Gambia region from the previous glacial phase ("Ogolian"; Michel, 1977). In the South, the entire first half of the Holocene was marked by a hot and humid climate, favourable to abundant fluviatile sediment fluxes.

The question arises as to possible positive and/or negative variations in the sea level during the entire interval of the construction of the delta plain. Such variations have frequently been cited in the region to explain the arrangement of the deposits (Faure and Elouard, 1967). The observations reported here seem to suggest that no considerable variation in sea level is either necessary or demonstrable. The argument is provided by the altitude of the mud tidal flats.

This unit is established according to the tide, and its highest level is always at the limit of mean high tide (De Vries Klein, 1985).

The considerable variation of the tidal range in the delta, although progressive from North to South, is not linear. On the coastal sector from the North of Salum to Guinea-Bissau, the spring tidal range rises from 1.10 m in Djiffère to 1.60 m in Banjul (Gambia) and to more than 4 m in Guinea-Bissau. This rise in the tidal range essentially explains the variations observed in the delta. It is not sufficient, however, and the abruptly tapered end of the funnel-shaped morphology of the Bandalia helps explaining a strong, hypersynchronous characteristic in the bolons of the South, whereas the maintained width beyond the neck of the distributary explains a synchronous behaviour in the internal reach (Diara, 1999). A local amplification of the tidal range results (up to 2.50 m) and the variation in altitude of the mud tidal flats corresponds to this exaggeration, and not to eustatic variations in the sea level. So there seems to be an adjustment in the organisation of the mud tidal flats of the entire delta depending only on present conditions.

The delta construction: a two-fold process

This dual formation is expressed by the origin of the sediments at the interface of two climate zones: Sahelian and tropical. The origin may be defined from the distribution of morphosedimentary units, the results of the grain-size, SEM surface aspects and mineralogical analysis of the sand fraction and the distribution of pelites.

Two types of sedimentary units in the Salum delta have a clearly antagonistic distribution between North and South: the sand barriers and the "tanne" sediments. The sand barriers are long, numerous, but not very high in the North. They have undergone multiple modifications connected to the movement of channels and the arms of the Salum (Ausseil *et al.*, 1991). They are more massive and not much affected by the variations of the delta process in the South. The extension of the "tanne" sediments is nowhere in the world as important as in Northern part of the Salum delta. It is, however, very limited in the South of the Diomboss.

The sedimentological study of the constituents of the different units also leads to underscore wide differences between the two parts of the delta on either side of the Diomboss. The central role of a terrigenous quartz population was noted, as it is still present and coarser to the North than to the South of the Diomboss, even if it is at times masked by circumstantial components (bioclastic, authigenic). The causes of this grain-size duality are to be found in the two possible sources of the terrigenous sand material.

To the North and to the North-East of the delta extend the Ogolian ergs of the Ferlo (Michel, 1973; Barbey, 1982); then, further North, the Mauritanian desert. These two areas are reservoirs of sediment easily blown away by the wind – and the North and North-West winds are frequent in this region, where vegetation is very sparse when not totally absent, or by streaming during rain periods, or by the North-South coastal drift (Gac *et al.*, 1992). They can also transport coarser sediments (Kocurek and Lancaster, 1999). Consequently, sandy material from the North can be thought to have their source in the North.

The second potential source is in the South with the powerful hydrological system of the Gambia, the existence of which at the Southern edge of the delta cannot be ignored. Draining a catchment area where the tropical hydrolysis systems are highly active, it plays a role in both the coarse input and the arrival of fine materials.

The SEM examination provides convergent arguments. The quartz grains show surface states that justify distinguishing them according to their belonging to two different provinces separated by the Diomboss sound.

To the North, the sediment has the same origin as the coarse component. This predominantly wind-originated sand with obvious marine reworking has constituted the Northern delta in part during climatic periods of the late Holocene interval.

In the South, the sediments show quartz grains of essentially fluvio-marine origin with a secondary wind component. The distance of the Salum from this part and the proximity of the Gambia justify identifying the latter as the vector of the dominant fluvial-marked component.

Based on the above, the quartz grains finally show that they belong to two different provinces separated by the Diomboss sound, a hydraulic border that prevents grains with fluviatile marks from crossing from the South to the North. The wind component, on the other hand, crosses this space and its presence is recognized in the sediments of the South, albeit not as abundant as in the North.

The North-South duality thus underscored is confirmed by more discrete signals such as the assemblage of heavy minerals and the distribution of the pelites. In the case of Salum, two distinctive heavy minerals are present: muscovite in the North and rutile in the South. They are available not only because they exist in the sources, but also because of different processes that occur after they are mobilised: a pedogenetic alteration in the source massifs and geological formations, weathering or fracturing during the different transport phases in a fluvial or marine environment, involving their mechanical and chemical resistance, early post-depositional diagenesis (Morton and Hallsworth, 1999).

The fragility of the muscovite, crystallised into flakes, excludes transport in an energetic hydrodynamic environment. Its relative abundance in the North could suggest relatively nearby sources, transport in a calm environment and, consequently, reduced shocks. The Salum corresponds to a low energy outflow. It would have conveyed the muscovite from the sedimentary layers of the Meso-Cenozoic basin up to its deposit in the delta. On the contrary, the rutile is a mineral both mechanically and chemically resistant. Although generally small in size, it is a highly dense mineral (4.2 to 5.5). Its more frequent presence in the South may therefore adapt to the conditions of a sedimentary history that adds transport phases and alteration phases. Other mineralogical species are relatively less represented, because they have not resisted as well. The high density of the rutile moreover entails that it can be transported only by energy outflows. Its rounded form does not, in fact, make it particularly buoyant. It is therefore necessary to acknowledge a sufficient flux to understand how it got established in the South. There too, the Gambia, the floods of which produce high flow rates, must be the essential agent of this transport.

The muscovite and the rutile therefore help identify a Northern mineralogical province (the Meso-Cenozoic sedimentary basin), the sediments of which are conveyed by the Salum, and a province originating in the South-East, the folded range of the Mauritanides, one of the culminating points of which is the Fouta Djalon, the source of the Gambia.

The different relative abundance of the heavy mineral fraction in the North and the South also confirms this distinction. Whereas in the Northern part, the material is fed by the reworking of the sedimentary strata where the heavy residue has already extensively diminished and is being transported and deposited under not very energetic agents, the direct flux from the crystalline massifs by a powerful river is easier to understand in the South.

The distribution of pelites provides a second discrete yet significant signal. The pelitic assemblage is homogenised by a dynamic, geochemical mixing; it is not discriminating. The same cannot be said when its relative abundance is considered; we have seen that mud flats are incomparably more abundant in the Southern half than in the Northern part.

The fine materials are generally dispersed in the sea by a turbid plume. Their evolution then depends on the proximity of the deposit zones characterised first and foremost by hydrodynamic calm. Two preferential sites generally have such potential: the depths of the inner shelf below the storm wave-base and the sheltered areas of the coast. This pattern is encountered near large estuaries, such as the Gironde and the Marennes-Oléron Basin (Lesueur *et al.*1994; Barusseau. 1973) or, closer to Senegal, in the mud tidal flats of Guinea (Rüe, 1988) and Guinea-Bissau (PNUE, 1985).

It is also found off the Gambia, in the sheltered environments of the nearby continental shelf (Domain. 1977; Barusseau, 1983) and in the entire delta, in all the parts of the former estuary bay, as it was protected by the sand barrier structures erected from 4000 B.P.

Furthermore, the fact that the mud tidal flats to the North of the Gambia are dated 6000 B.P. at 10 m of depth (Kalck, 1978) show that the delta bedrock was established there from the beginning of the sedimentary filling under the influence of fluxes from this river, at the Southern edge of the area. The North of the delta, being far from the source, receives less fine sediments.

Finally, the relative abundance of muds, highly imbalanced between the North, rather poor in pelites, and the better provided South, attests to a separation between the Northern and the Southern part of the delta (Fig. 8).

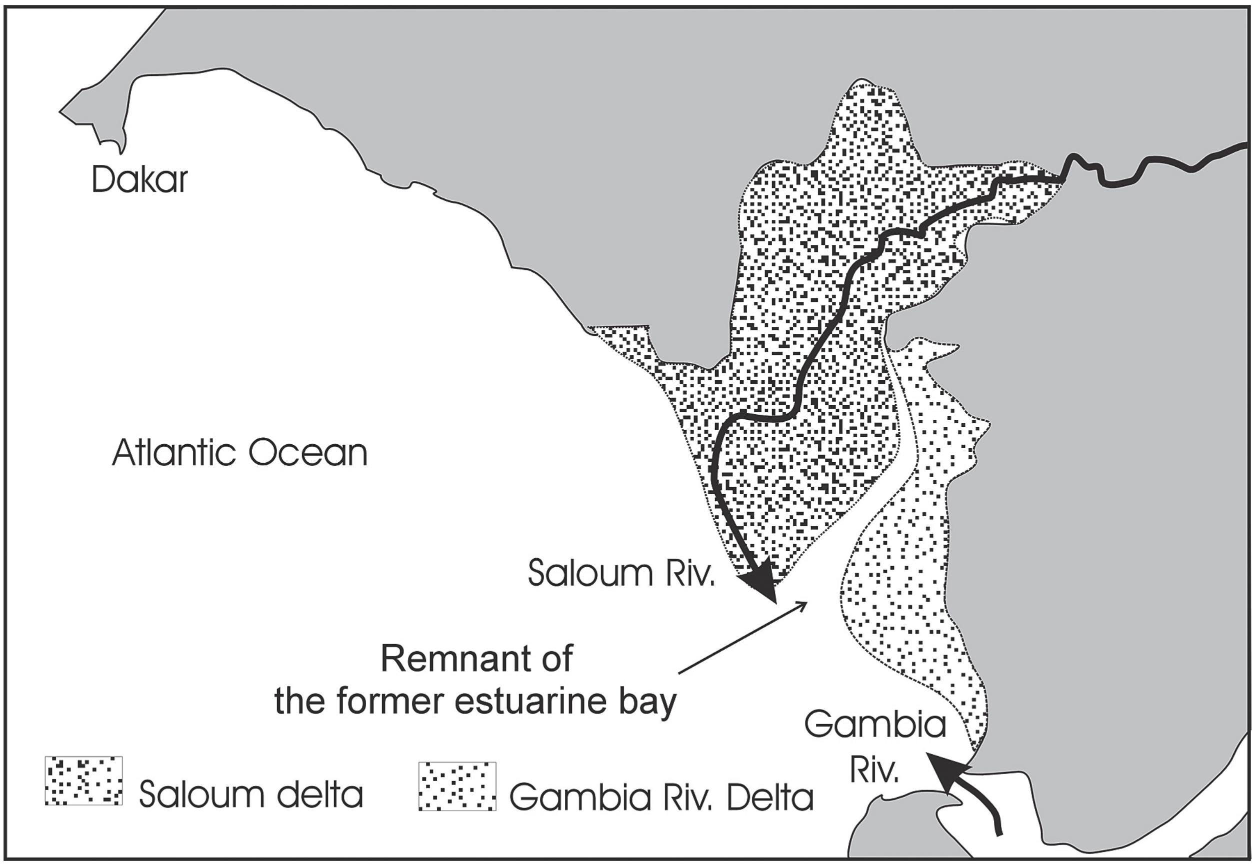

Fig. 8 The distinct origin of the Northern and Southern parts of the delta.

CONCLUSION

At the end of a discussion that takes into account the results obtained on the arenic and pelitic fractions of the sediments, on the exoscopic characteristics of the quartz grains and on the formation of the heavy fraction, a double origin of the sedimentary flux emerges clearly, identifying two provinces of origin, two modes of flux and two parts of the delta:

- a Northern part, characterised by a quartz flux, chiefly wind-transported, reworking slightly the deposits of a highly altered sedimentary basin. The fluvial hydrodynamics are discrete and subordinated to the coastal transfers by waves and tidal currents in the reverse estuary part of the Salum;
- a Southern part under the influence of the wide catchment area of the Gambia, and the mineralogical province of the Mauritanides that it drains. The fluvial hydrodynamics produce a recognizable imprint, even if the last marine characteristics attenuate it somewhat.

The Salum delta must therefore be reduced in the Northern part; whereas the Southern part represents the pre-Gambian delta.

Between the two, the Diomboss, originally considered as one of the distributaries of a large delta of the Salum, actually represents only a remnant of the original estuary bay that existed when the sea reached its current level.

There are no indications that justify retaining the idea of extensive changes of the eustatic position of this level in the period after the establishment of the last beach ridges (ca. 3500-4000 years B.P.). The variations observed in the tidal mud flats in terms of altitude are due to the increase of the tidal range, exaggerated by local effects owing to the shrinkage of the Bandiala in the South. They consequently pertain to the current tidal variations and not to recent changes of the average sea level.

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