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MECHANISM OF SPATIO-TEMPORAL EVOLUTION OF COASTAL SANDY BODIES IN A MOUTH: CASE OF THE COMOE RIVER ESTUARY IN GRAND-BASSAM, BAS COTE D'IVOIRE WEST AFRICA

EVOLUTION SPATIO-TEMPORELLE DES CORPS SABLEUX COTIER DANS UNE EMBOUCHURE : CAS DE L'ESTUAIRE DU FLEUVE COMOE A GRAND-BASSAM, BAS COTE D'IVOIRE AFRIQUE DE L'OUEST.

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ABSTRACT

The mouth of the Comoé River, a transition area between the marine, lagoon and river environments, makes it a dynamic environment. It is this dynamism and the spatio-temporal distribution of sandy bodies in this particular coastal area that was the subject of this work. It appears from this study carried out with the help of library data (physical and numerical) and softwares that the dynamism of the sandy bodies of the mouth has not been uniform in time. Indeed, before the opening of the Vridi canal, the high-water flow at the outlet of the grau prevented the accumulation of coarse particles. But the digging of the port structure will reduce the water flow in the Grand-Bassam estuary, which will cause the accumulation of sandy bodies at the mouth. The successive series of clogging and opening of the mouth will not be without consequence on the dynamism of the sandy bodies in this area. Indeed, before the opening, the granulometry of the deposits is much thinner and essentially made up of silt and thin sands, but after the opening, the tidal current, which becomes more important, will carry the silt and thin sands out to sea and leave much coarser sandy facies exposed.

In general, this study has shown that sand movements are dominated by a sandy increase in erosion in the vicinity of the mouth, while the opposite is observed in more distant environments.

Key words: Tidal current, Clogging, Mouth, Foreshore, Grau, Grand-Bassam.

RESUME

L'embouchure du fleuve Comoé, domaine de transition entre les milieux marin, lagunaire et fluvial fait de lui un milieu dynamique. C'est d'ailleurs ce dynamisme et la répartition spatio-temporelle des corps sableux dans cette zone côtière particulière qui a fait l'objet de ce travail. Il ressort de cette étude réalisée à l'aide de données de bibliothèques (physiques et numériques) et de logiciels que le dynamisme des corps sableux de l'embouchure n'a pas été uniforme dans le temps. En effet avant l'ouverture du canal de Vridi, le fort débit d'eau à l'exutoire du grau, y empêchait l'accumulation des particules grossières. Mais le creusement de l'ouvrage portuaire va réduire le débit de l'eau à l'estuaire de Grand-Bassam, ce qui va provoquer l'accumulation des corps sableux à l'embouchure. La série successive de colmatage et d'ouverture de l'embouchure ne sera pas sans conséquence sur le dynamisme des corps sableux dans cette zone. En effet, avant l'ouverture, la granulométrie des dépôts est beaucoup plus fine et constituée essentiellement de vases et de sables fins, mais après l'ouverture, le courant de marré qui devient plus important va entrainer les vases et sables fins en mer et laisser à découvert un faciès sableux beaucoup plus grossier.

De manière générale, cette étude a montré que les mouvements de sable sont dominés par un engraissement sur l'érosion dans les environs de l'embouchure, tandis qu'on constate le contraire dans les environnements plus éloignés.

Mots clés : Courant de marée, Colmatage, Embouchure, Estran, Grau, Grand-Bassam.

INTRODUCTION

The rivers and the lagoon system flow into the sea through outlets which are either permanent estuaries or lagoon graus and passes. There are four (4) such outlets on the sandy coast of Côte d'Ivoire. From East to West, we find the Assinie pass, the Grand-Bassam grau, the Vridi canal and the Bandama mouth at Grand-Lahou (N'go, 1996).

The natural outlet of the Comoé River at Grand-Bassam communicates with the ocean through a shallow canal (2 to 3 m) across the thin quaternary line beach (Koffi *et al.*, 1991).

This mouth, like most of the passes of the Eastern Côte d'Ivoire, is unstable. Its migration in the line, which is linked to the dynamic equilibrium between the littoral sedimentary transit and the estuarine processes, has provoked successive episodes of clogging and opening in view of the direct evacuation of floating plants at sea (Abé, 1995).

The clogging of the mouth is detrimental to the shoreline population and its environment. Indeed, the floating plants covering the lagoon surface prevent good fishing and other waste stagnate in the lagoon thus polluting the environment. (Mondé, 2004). It is therefore necessary to understand this clogging process, in order to better understand the hydrodynamic and sedimentary mechanism from which it results. The study of the sandy bodies of the mouth of the Comoé under the dependence of the tide, the currents of hunting, the emptying of floods... could contribute to this approach.

It is in the perspective of bringing its contribution to the resolution of the problems posed by this clogging of the Grand-Bassam grau that the Laboratory of Sciences and Technologies of the Environment (LSTE) of the University Jean Lorougnon GUEDE in collaboration with the laboratory of Marine Geology and Sedimentology (GEOMARSE) of the University Felix Houphoue-Boigny proposed to elaborate a model by synthesizing the data obtained by some authors in the studied zone.

From a bibliographic synthesis, we will analyze the spatio-temporal evolution of the sandy bodies before and after the opening of the Vridi canal and during the successive periods of floods and low water levels in the lagoon and river at the mouth of the Comoé, during the last thirty (30) years. This study will also take into account the quantification of sedimentary deposits on both sides of the mouth of the Comoe River.

PRESENTATION OF THE STUDY AREA

Location of the study area

The study area is the estuarine sector of the Comoé River, at the eastern end of the Ebrié Lagoon. It covers the environments of the Morin Island in the North, the Moossou bridges at the confluence of the Comoé River and the Ebrié Lagoon, the Bouët Island and the line beach in the South. Geographically, this area is located north of Grand-Bassam, between 5°12 and 5°14 North latitude and 3°42 and 3°44 West longitude (Abé *et al*., 1996) (figure.1).

Definition and description of the mouth of the Comoé River

The mouth of a river is the place where the river flows into the sea. According to the way in which sediments are deposited in this privileged sedimentation zone, Dercourt and Paquet (1985) divide the mouths into two. Indeed, these two authors speak about:

- Estuaries, when the marine environment interpenetrates with the fluvial environment and takes over directly as regards the transport of materials. It is generally the lowest part of the ancient course of a river that has been invaded by the sea (Rias of Great Britain or Fjords of Scandinavia),

- Deltas, when the continental environment gains ground on the marine environment. It should be noted that a delta can evolve in the course of its history into an estuary and vice versa (Aka, 2004).

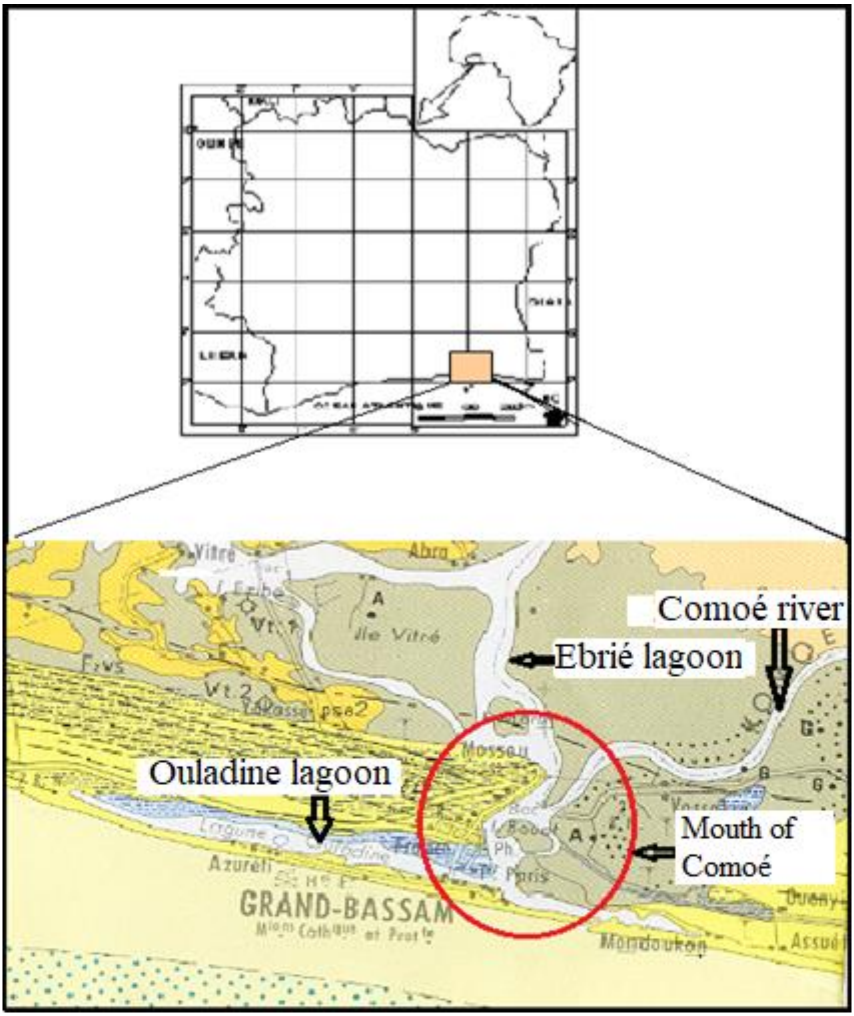

Figure 1: Map showing the study area

The mouth of the Comoé River, in particular, is an estuary. It is the largest estuary of the Ivorian coastline, shallow (2 to 3m) through the thin quaternary line (Aka, 1991).

This bifid estuary is fed by the Comoé River which drains from north to south 78,000km^2 according to a tropical transitional regime (mean annual flow in 1987 was 156.8m^3/s), with a single flood (September to October) and by the Ebrié lagoon system and the forest rivers with a double flood (June-July and October-November) (Abé, 1995)

MATERIALS AND METHODS

Material used

The material that we used to conceive this article consists of computer tools and cartographic data. Indeed, we used four (4) softwares (Word, Excel, PowerPoint, Paint), geological maps, data of granulometry, mineralogy and morphology.

- Word 2010

This software was used to store information, data, and other items that we felt were important during the bibliography.

- PowerPoint

It allowed us to make a mosaic of the scanned maps in several parts of their size.

- Paint

Paint allowed us to clean and perfect the maps drawn with MapInfo.

- Geological maps

During this study we used maps such as "the square degree of Grand-Bassam" to better locate the different study localities and maps of superficial sedimentary facies to appreciate the different positions occupied by the sands over the years.

Working methods

Most of the methods used in the design of this work consisted in researching via digital and physical libraries such as those at UJLoG, C.R.O, C.R.E of UJLoG and U.F. R-S.T.R.M.

All the data used in this dissertation come from work done by Martin (1973); Yacé (1987); Koffi *et al* (1991); Abé (1995); Abé *et al* (1996); Coffie (2002); Konan (2004); Wognin (2004); Yao (2005) and many others.

The exploitation of this work consisted in making chronological interpretations of the results and getting partial conclusions concerning the spatio-temporal evolution of the sands at the mouth of the Comoé.

RESULTS, INTERPRETATION AND DISCUSSION

Spatial evolution of sandy sedimentary facies at the mouth of the Comoé River

The presentation of the spatial evolution of sedimentary facies is based on the work of Martin (1973), Koffi *et al*. (1991) and Abé (1995).

Situation of the muddy zone in relation to the Comoé

In his study of the morphology, sedimentology and paleogeography of the Ivorian continental shelf, Martin in 1973 located the muds at the mouth of the Comoé River. In fact, according to the author, to the east of the mouth, there is no mud, strictly speaking. On the bottom of the river from 10 to 30 m, there is a tongue of thin sandy mud that overlaps the sands. Most of this mud is located west of the mouth. The muddy zone extends to the eastern edge of the bottomless pit with a small extension to the other bank, (Martin, 1973).

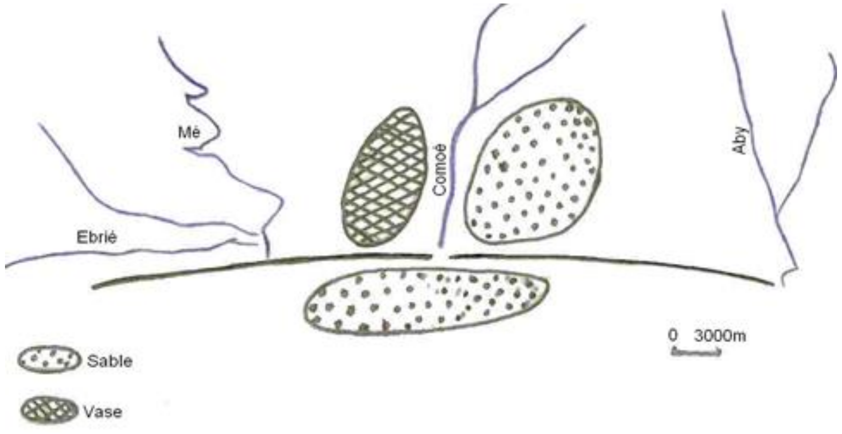

Figure 2: Sandy body at the mouth of the Comoé seen by Martin (1973)

Spatial arrangement of sandy formations at the mouth of the Comoé before the opening of the Vridi canal

Depending on its location in the central zone of the Ivorian sedimentary basin, where Miopliocene to quaternary formations are observed from north to south (Tastet, 1989; in Abé, 1995), various sandy formations can be distinguished at the mouth of the Comoé. Indeed, the Mio-Pliocene sandy-clay formations of the terminal continental in the north dominate the clayey sands of the ante-Holocene lowlands, which are replaced in the south by fluvio-lagoon mud and leached sands.

The quaternary line beach to the south is formed by successive sandy marine line from West to East. These strips are made up of big red to medium sands relayed by medium to thin yellowish white sands.

It should be noted in passing that after the opening of the Vridi canal in 1951, this location of sandy formations in the Comoé channel underwent a profound change (Tastet, 1985 and Koffi, 1988).

Spatial arrangement of sandy bodies at the mouth after the opening of the Vridi canal

The opening of the Vridi canal has had a considerable influence on the hydrology of the waters of the Comoé grau, which has also affected the distribution of the sands. In fact, each hydrological zone has its own surface facies. Thus, according to Tastet (1979) and Abé (1995), at the Comoé station, which is under strong fluvial influence, the biggest facies such as red sands and fluvio-lagoon sands are found. The mud is located on the banks which are strongly colonized by floating plants. The confinement of the waters of the station of Moossou causes their decantation. The bottoms are then formed of mud and fine to very fine sand. The superficial facies show a beginning of erosion with the appearance of medium sands. From the grau to the Ouladine confluence (mouth station), we observe the propagation of medium marine sands over the thin lagoon sands due to tidal currents as illustrated in figure 3.

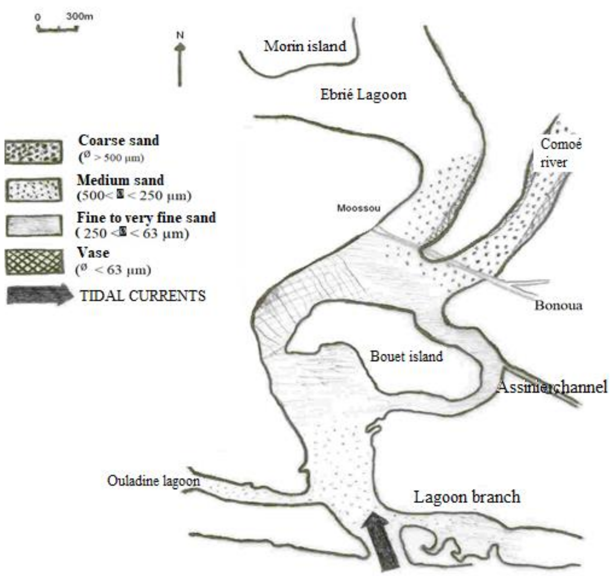

Figure 3: Spatial distribution of sandy bodies after the opening of the Vridi canal. Abé (1985)

PARTIAL CONCLUSION

Before the Vridi Canal was opened, various sandy formations could be distinguished at the mouth of the Comoé. To the North, there are sandy-clay formations of the terminal continental Miopliocene that are dominant over the clayey sands of the ante-Holocene lowlands. In the South, we have the silt and the fluvio-lagoonary leached sands. The line beach away in the South is formed by successive marine line from West to East, made up of big red to medium sands relayed by medium to thin yellowish white sands.

After the opening of the canal, each hydrological zone will correspond to a given surface facies. Thus, at the level of the Comoé River, under high fluvial influence, there are bigger facies such as fluvio-lagunar sands. The silt is located on the beiges. At the level of Moossou, the bottoms are formed of silts and thin to very thin sands. From the grau to the Ouladine confluence, we observe the spread of the medium marine sands on the thin lagoon sands due to the tidal currents. (Table 1)

Table 1: Summary of the spatial evolution of sandy bodies before and after the opening of the Vridi canal.

Localities / Authors	Morin Island area	Moossou area	Comoé River area	Bouët Island area	Ouladine confluence area	Lagoon branch area (southeast of the grau)
Abé (1995) (before the opening of the canal)	-Clayey sands	-Clayey sands	–	- Silt - Leached sands	- Silt - Coarse red sands	-Medium to fine white sands
Abé (1995) (after the opening of the canal)	-	- Silt -Fine sands -Very fine sands	-Reddish coarse sands fluvio-lagunar	-	- Medium marine sands -Fine lagoon sands	-Fine lagoon sands

Influence of the opening of the channel on the spatial evolution of sedimentary facies

The sediments of the mouth of the Comoé were mapped before and after the opening of the pass in September 1987.

Before the opening of the pass. (Status of 15 April 1987)

Before the opening, the condition of April 15, 1987 shows that in the Moossou area, the biggest facies are big red to medium fluvial-lagoon sands (Koffi *et al.*, 1991). Silts are localized on floating plants and the area around Morin Island in the north is covered with thin sands. In the area north of Bouët Island to the Ouladine confluence in the South, the outcrops of sand (medium and big) in this area form the bank and shoal; the lagoon branch opposite the Ouladine lagoon is very confined with deposits of black fluid silts with strong odor of H_2S (Koffi *et al.*, 1991) (figure 4)

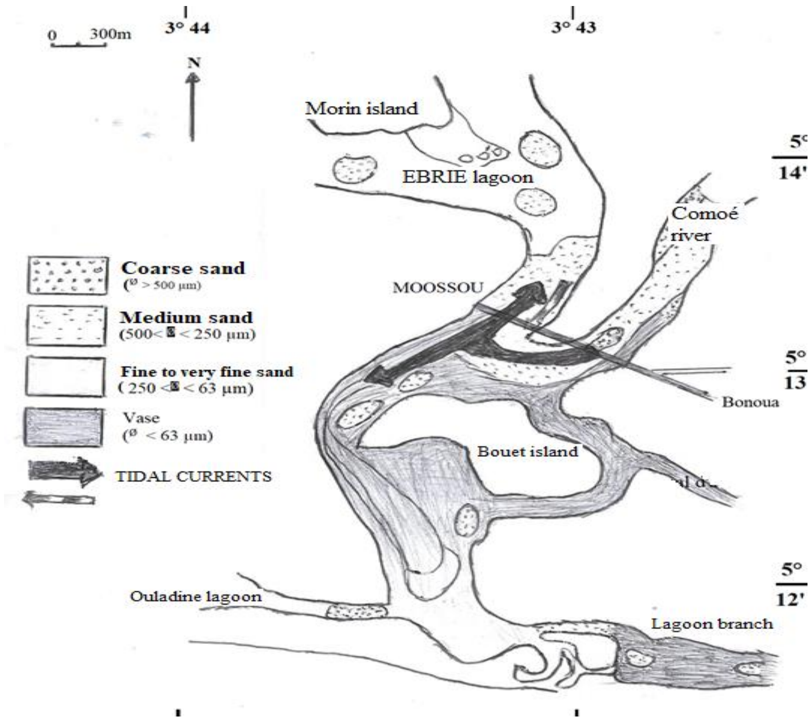

Figure 4: Spatial distribution of sandy bodies before the opening of the channel. (Status of 15 April 1987) (Koffi *et al*., 1991)

After the opening of the channel

State from October 8 to 10, 1987

The distribution of surface facies, compared to the initial state, shows the beginning of erosion of the bottom with the appearance of an external zone under marine influence (swell).

In the Moossou area, the middle sands occupy a larger area due to the leaching of silt from the eastern banks of the Comoé River and the Ebrié Lagoon (Koffi *et al*., 1991).

In the zone located from the north of Bouët Island to the north of the Ouladine confluence, the erosion of the bottom of the northern banks of Bouët Island uncovers medium sands.

The bottom remains in the sector of the island. The remobilized silts are evacuated in permanent suspension towards the open sea.

In the area of the canal at the Ouladine confluence, we observe the spread of the medium marine sands on the thin lagoon sands thanks to the flood tide currents. The eastern lagoon branch has not evolved. The bottom remains silty. (Figure 5)

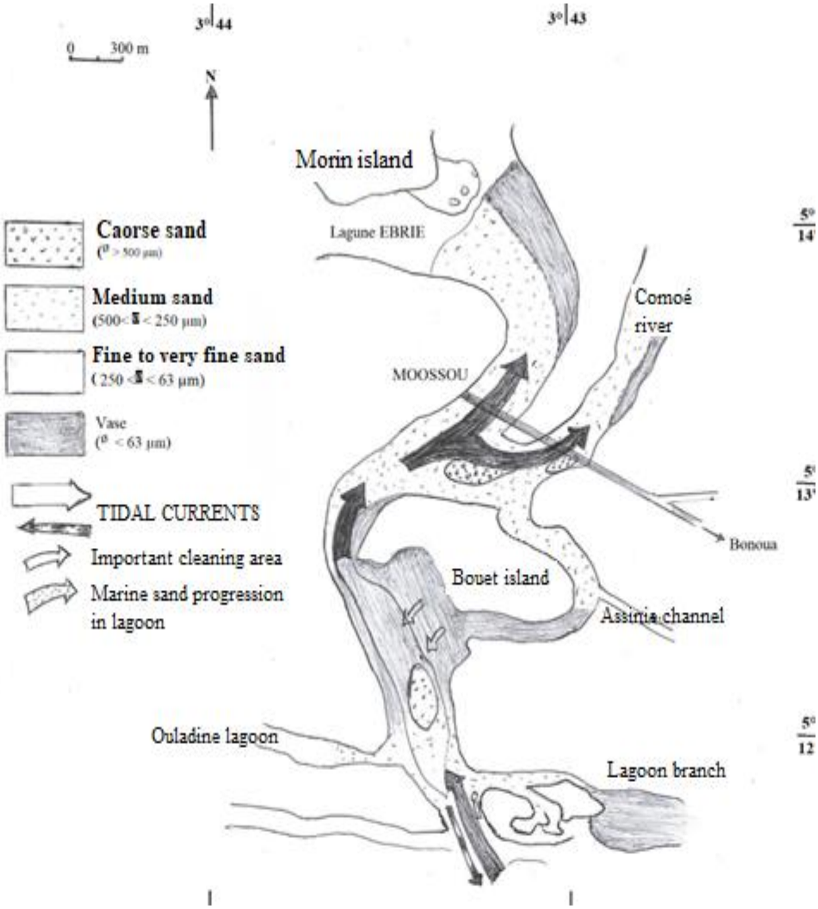

Figure 5: Surface distribution of sedimentary facies at the mouth of the Comoé River after the opening of the canal (status of 8 October 1987) (Koffi *et al.*, 1991).

Status from 6 to 11 January 1989

After the opening of the grau, the condition from January 6 to 11, 1989, shows that the erosion of bottom sediments is at a very advanced stage; sandy facies (big and thin sands) are very dominant. The Moossou area has not changed significantly, but the leaching of silt from the northern part of Bouët Island is very significant (Koffi *et al.*, 1991).

Thin particles are localized on a few mud beaches in the northwestern part of the southern bay of Bouët Island. The thin to very thin sands that are found in this internal zone correspond to facies of thin sand/silty mixture.

In the area South of the Ouladine confluence, the medium marine sands are reduced to the axis of the canal of the opening canal.

The thin to very thin sands carried to the canal occupy the Ouladine lagoon and the left bank of the waterfront. The fluid black silts of the lagoon branch are not reworked. (Figure.6)

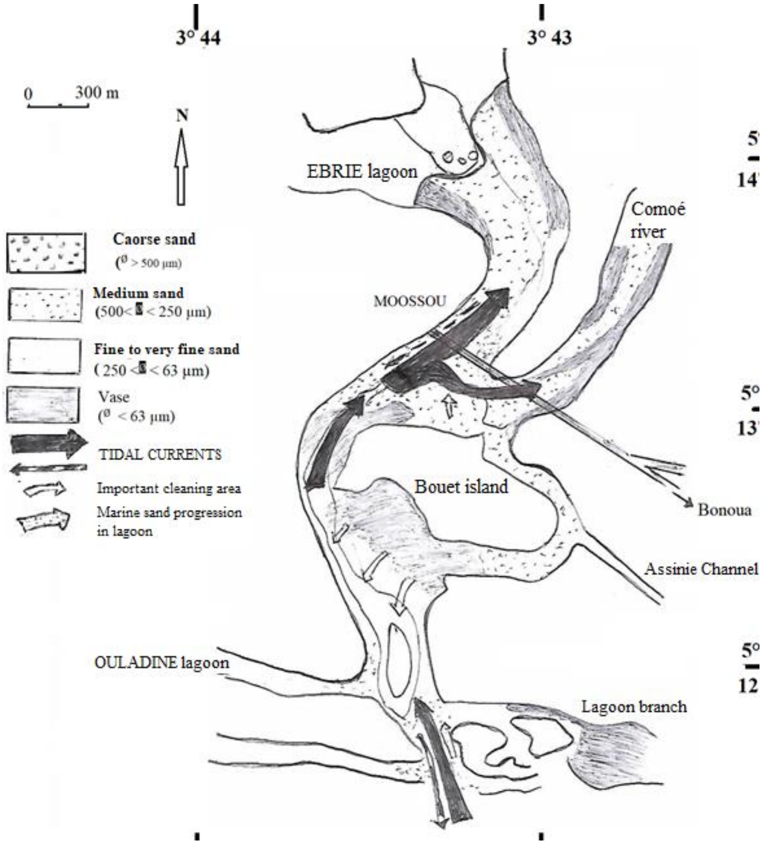

Figure 6: Surface distribution of sedimentary facies at the mouth of the Comoé river (status of 11 January 1989). (Koffi *et al.*, 1991)

PARTIAL CONCLUSION

The opening of the sandline has a strong influence on the spatial distribution of sandy bodies at the mouth of the Comoé River. In fact, the cleaning that began as soon as the mouth was reopened has continued in the two states mapped (October 8, 1987 and January 11, 1989).

The action of the tidal currents on the bottom has led to an important remobilization of these cohesive sediments (silts) evacuated in suspension towards the open sea. Leaching of these confined bottoms has uncovered bigger facies: fine and medium sands in the Ouladine-Ile Bouët confluence zone; medium to big sands in the Comoé River confluence zone at Moossou. The particular domain of the canal, which is very unstable, reflects a spread of the medium marine sands towards the internal domain on the fine lagoon sands in the form of shoals and free arrows. (Table 2)

Table 2: Summary of the spatial evolution of sandy bodies before and after the opening of the sandy line (September 1987) at the mouth of the Comoé.

Authors	Localities	Morin Island area	Moossou area	Comoé River area	Bouët Island area	Ouladine confluence area	Lagoon branch area (southeast of the grau)
Koffi et *al.*, (1991)	Before the opening: As of April 1987	-Mud - Fine sands	-Medium fluvial-lagoon sands	-Coarse red sands - Medium fluvial-lagoon sands	-Mud - Fine sands	-Fine sands - Mud	-Black fluid mud
	After opening: Status October 1987	Fine to very fine sand	-Sands medium -Sands coarse	-Fine sands - Mud	Medium sands (mud leaching)	-Medium sands - Fine sands	-Black fluid mud
	After opening: As of January 1989		-Coarse sands -Medium sands	-Mud -Fine sands	(Leaching of mud is very advanced)	Fine to very fine sand	-Black fluid mud

INTERPRETATION OF RESULTS AND DISCUSSION

According to our work, the evolution of the sandy bodies at the mouth of the Comoé River was done according to a dynamic that can be appreciated in two main times:

(a) before the opening of the Vridi canal, the water flow at the mouth was strong enough to drain all its sedimentary load to the sea,

(b) Since the opening of the port structure (the Vridi Canal), a water deficit has been noted at the natural mouth of the Comoé. Only about 1/3 of its flow uses this outlet (Koffi *et al*. (1991) and Adopo (2004)). This drop in water volume greatly reduces the speed of the currents in the estuary. These changes have made the Comoé unable to drain the mass of sediment (estimated at about 400,000 m3/year) into the sea that it receives as a result of longshore drift. This drop in water volume is consistent with the work of Abé *et al* (1996) who quantified it and found that it oscillated between 0.05 and 0.32 m/s.

We also note that before the opening of the channel, the surface sedimentation is essentially muddy while after the opening, the surface facies becomes sandier. This could be explained by the fact that, before the opening, the water flow is low, the bottom of the estuary is covered with big particles (medium and big sands), buried under silt and thin sand (Koffi *et al*., 1991). The thin particles were transported in suspension and then settled by the river. In the vicinity of the islands line, the bottoms are covered with thin sands of marine origin. When the canal is open, the flow rate increases. A sorting will then take place. The thin sediments are thus put back in movement and evacuated at sea by the ebb tide, thus discovering the facies of sands of more important caliber. The spatial distribution of sediments at the mouth of the Comoé River as seen by Martin in 1973 divided the sediments into two (2) major groups, muds and sands (without taking into account the granulometry of the sands). This study showed that already at that time the sedimentary cover of the mouth was essentially sandy, especially in the area closer to the grau. These results were later confirmed and supported by subsequent works. This is the example of those of Koffi *et al* (1991); Aka (1995) and Abé (1995) who studied this distribution of sandy bodies taking into account their granulometry. These works point out that the granulometry of the sands is increasingly thin when approaching the outlet and concerns more fluvio-lagunar sands.

Studies conducted by Konan in 2004 on the coastal segment between Grand-Bassam and Assouindé showed that the Bassam-Mondoukou region is a dominant erosion zone. These results are similar to those of Yacé (1994), taken up by Adopo (2009), who quantified the sediments at the mouth of the Comoé River. According to this author, 421,528 m^3 of sediment were deposited against 60,062 m^3 eroded. This means a significant increase that caused the closure of the mouth of the Comoé River. However, in the environments closer to the East of the Comoé River canal, there is a very high level of increase of sand. This observation is similar to that of Wognin (2004) on the Bandama River. Indeed, Wognin (2004) emphasizes that the beach is formed in calm periods in the part close to the canal while it erodes in the more distant part.

CONCLUSION

At the end of this study based essentially on the exploitation of bibliographic data, we can retain that the silting at the mouth of the Comoé River has been greatly influenced by the opening of the Vridi canal. Indeed, before the opening of the port, the high water flow at the outlet carried the sediments to the sea. Thus, silting was very limited. But the layout of the Vridi canal, having reduced the flow of water at the mouth, will cause an accumulation of sand, which will lead to the regular clogging of this particular coastal area. Diagnosed over thirty years, it appears that this phenomenon obeys the lagoon and river seasons, but particularly the successive episodes of opening and silting of the grau. Indeed, before the opening of the pass, the sedimentary deposits at the mouth of the Comoé River are dominated by a much finer granulometry, consisting essentially of thin sands and silts. However, the mapping of the bottom after the opening of the mouth shows bigger facies (medium sand at the confluence Ouladine - Bouet Island, medium to big sand at the confluence Comoé River - Moossou). This is due to the tidal current that carried the cohesive sediments, which are the silt, out to sea in suspension.

However, in general, the sedimentary movements are dominated by an icrease on erosion, in the vicinity of the mouth. This is at the origin of the regular silting of the grau. But in more distant environments, it is the opposite (erosion dominates over silting).

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