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Characterisation and Spatial Distribution of Sediments on the Cote d'Ivoire Continental Shelf (Abidjan to Assinie)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The continental shelf of Côte d'Ivoire, particularly the Abidjan-Assinie area, has been studied due to its importance and potential, although little research has focused on its sedimentological aspects. Sediment samples were collected using a Shipeck grab, and grain size analyses revealed the presence of fine sands, medium sands, and rarely very fine sands. These sands exhibit a skewness toward finer grains, which is abundant, followed by nearly symmetrical and highly skewed towards finer grains, describing five (05) types of sorting. Deposited in a more or less turbulent environment or due to excess load, the sands have been transported in water — as indicated by their shiny, abraded state — by saltation, suspension, and mixed modes. These sands preferentially reside in a continental domain.

Keywords: Continental shelf; granulometry; sand; Abidjan-Assinie; Côte d'Ivoire.

1. INTRODUCTION

The continental shelf is the surface of the seabed near the coast at depths of less than 200 metres**.** Its amplitude from the coast varies, from a few metres to hundreds of kilometres**.** The continental shelf is the underwater continuation of the continents That is, its geological base is the continental crust. The continental shelf is a part of the continental margin completed by the glacis and the slope or continental slope. Each coastal country has one and it is governed by laws. This part of the sea has several activities: laying cables and pipelines under the sea, artificial islands, works, fishing, exploitation of oil and gas fields… Given its importance and potential, the continental shelf of coastal countries is provided with several scientific investigations. Côte d'Ivoire, a coastal country, is no exception to all of the above. In terms of scientific studies on the continental shelf in Ivory Coast, we can cite [1-5].

Few studies have focused on the sedimentological aspect of the Ivorian continental shelf. It is in this context that the present study entitled «characterization and spatial distribution of sediments of the continental shelf of Côte d'Ivoire (Abidjan to Assinie) » contributes to the sedimentological knowledge of the submerged Ivorian beach. It will be (i) to determine the size (Mz), the asymmetry (Sk), the sorting (So), grains of sand and their spatial distribution, (ii) to know the mode, agent and duration of sediment transport, (iii) to distinguish the type and medium of sediment deposition. This manuscript will contribute to the understanding of the Ivorian continental shelf (from Abidjan to Assinie). It will also explain the phenomenon of regression and transgression based on the paleoenvironment. Additionally, it will address the mode of sediment transport influenced by wave action.

1.1 Presentation of the Study Zone

Fig. 1 shows the sampling sites on the Abidjan-Assinie continental shelf or Eastern continental shelf. Twenty-four (24) samples (sand, muddy sand, silty mud, cream of mud, sandy mud) were taken from 3 radials : The mass of each sample was around 4 to 5 kg, due to upwelling and leaching, giving an overall mass of 96 to 120 kg. We were only interested in the sandy sediments. The Abidjan area has three (03) sandy sediments (N°9496, N°9497 and N°9498). The GRAND-BASSAM area has four (04) sandy sediments. These are the sediments N9487, N°9490, N°9491 and N°9492. The Assinie area has six (06) types of sandy samples, sediments N°9477, N°9478, N°9479, N°9481, N°9482 and N°9483.

2. MATERIALS AND METHODS

Sediment was sampled with a Shipeck-type bucket that acts by scraping and cutting the bottom. A GPS (GARMIN, 60S) was used for the positioning of sampling sites.

Sandy sediments were analyzed by the particle size method [6]. EasySieve software was used to obtain the mean (Mz), the classification index (standard deviation) and the skewness. Arcgis 10.2 software was used to produce the maps. The sedimentological treatment was done according to [7]. The average grain size is given by the mean (Mz). The mean is interpreted according to Vivek et al. [8]. The asymmetry of sandy facies is obtained by the spatial distribution of the asymmetry (Sk). The values of skweness were interpreted according to N'doufou et al. [9]. The sorting by size or

classification is done through the spatial distribution of the sorting (So). The interpretation of the sorting was oriented according to Konan [10]. This study deals with sediments found at sea. Sedimentary dynamics occur in an environment that has been difficult to access over geological timescales. Therefore, the analysis of grain sizes will involve granulometric parameters (mean grain size Mz, Skewness Sk, and Sorting So). The mean grain size graph Mz will allow us to infer the direction of the paleo-transport of sediments based on grain size. The Skewness Sk graph will indicate the predominance or lack thereof of fine or coarse particles relative to the mean of the sample. Finally, the Sorting So will provide information about the consistency of sediment transport at the time of sedimentation. Using a binocular magnifying glass, quartz grains in the 500-630 µm fraction were observed according to Parfenoff et al. [11,12] and [10]. This fraction provides information about the nature of the transport agent [13], the environment in which the grains were deposited and highlights certain reworking processes. The transport process is determined by Xiao et al. [14,15], the type of deposition by the Tricart method [16], and the medium of deposition from the dispersion diagrams of Moiola & Weiser [17,18].

3. RESULTS, INTERPRETATION AND DISCUSSION

3.1 Distribution of Detritic Sediments on the Continental Shelf from Abidjan to Assinie

The characterisation of continental shelf detrital sediments provides information on sandy facies, asymmetry of sandy facies and particle size sorting.

Quantiles were obtained from the granulometric curve produced by the EasySieve granulometric analysis software.

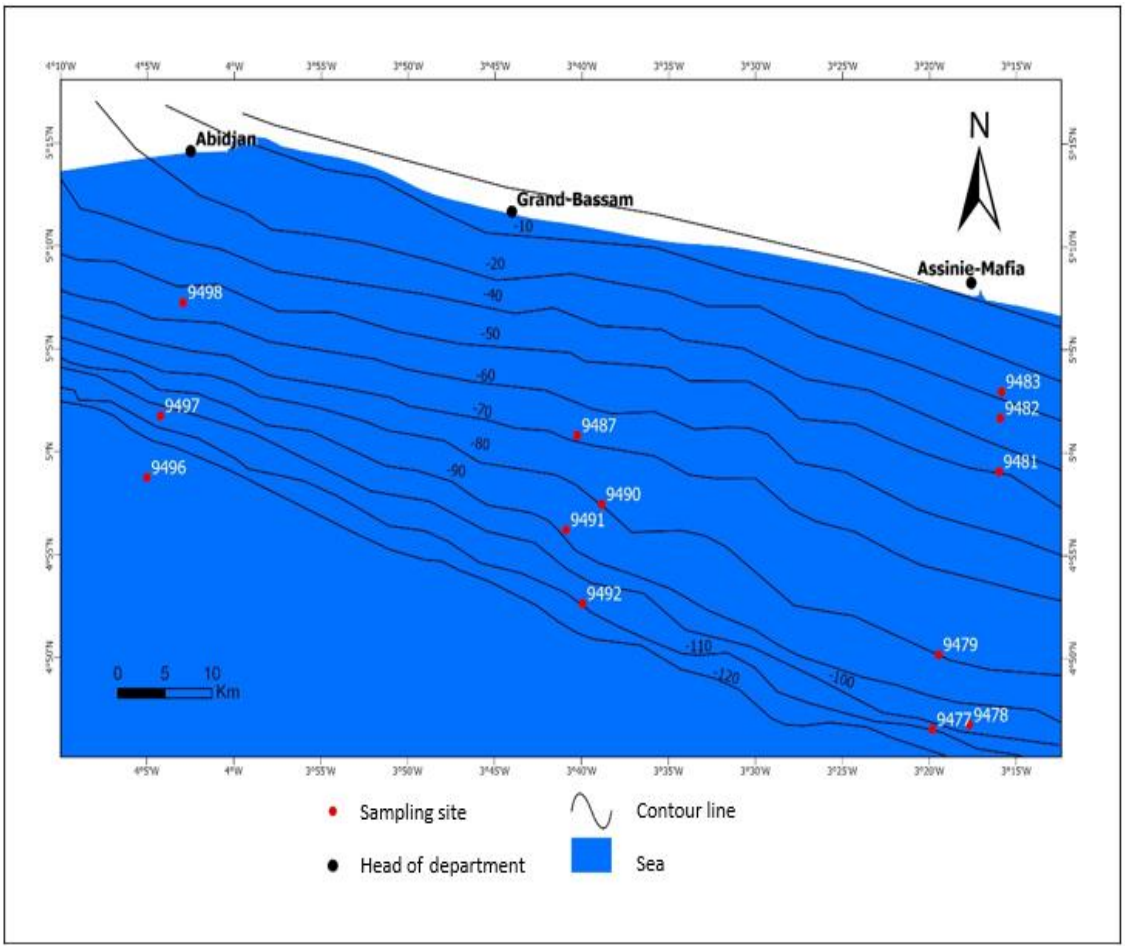

Fig. 1. Sand sediment sampling map

3.1.1 Spatial distribution of sandy facies on the continental shelf

The sandy facies or grading is obtained from the spatial distribution of the average grain size (Mz). It will cover the ABIDJAN-ASSINIE plateau.

3.1.1.1 Sandy grading of the abidjan-assinie continental shelf (Fig. 2)

 Size of sand in Abidjan
The Abidjan area includes the class of fine sands, which have an average size of between 2.102 Φ and 2.566 Φ.

 Size of sand in Grand-Bassam
This area has two sandy facies:

-the medium sand class, with Mz varying from 1.889 Φ to 1.971 Φ ;

-the fine sand class, with average grain sizes ranging from 2.41 Φ to 2.936 Φ.

 Size of sand in ASSINIE

The Assinie area records (03) sandy facies:

-medium sands with average sizes ranging from 1.201 Φ to 1.493 Φ.

-fine sands with averages ranging from 2.330 Φ to 2.869 Φ.

-very fine sands with an average of around 3.178 Φ.

The size of the grains varies from fine to very fine, through medium sizes, from Abidjan to Assinie. In Assinie, the very fine sands are found at -120 m depth.

On the continental shelf, fine sands are most dominant followed by medium sands.
Very fine sands are less abundant.

3.2 Interpretation of the Distribution of Sandy Grading

The Assinie area shows an intercalation of sand classes (medium-fine-very fine) according to depth. The distribution of sand classes is thought to be linked to the energy of the water present. The wave energy at the time of deposition is thought to be responsible for this calibre of sand. The Grand-Bassam area contains fine sands at shallow depths (-40 to -80 m), resulting from low wave energy, and medium sands at great depths (-95 to -118 m) resulting from medium wave energy.

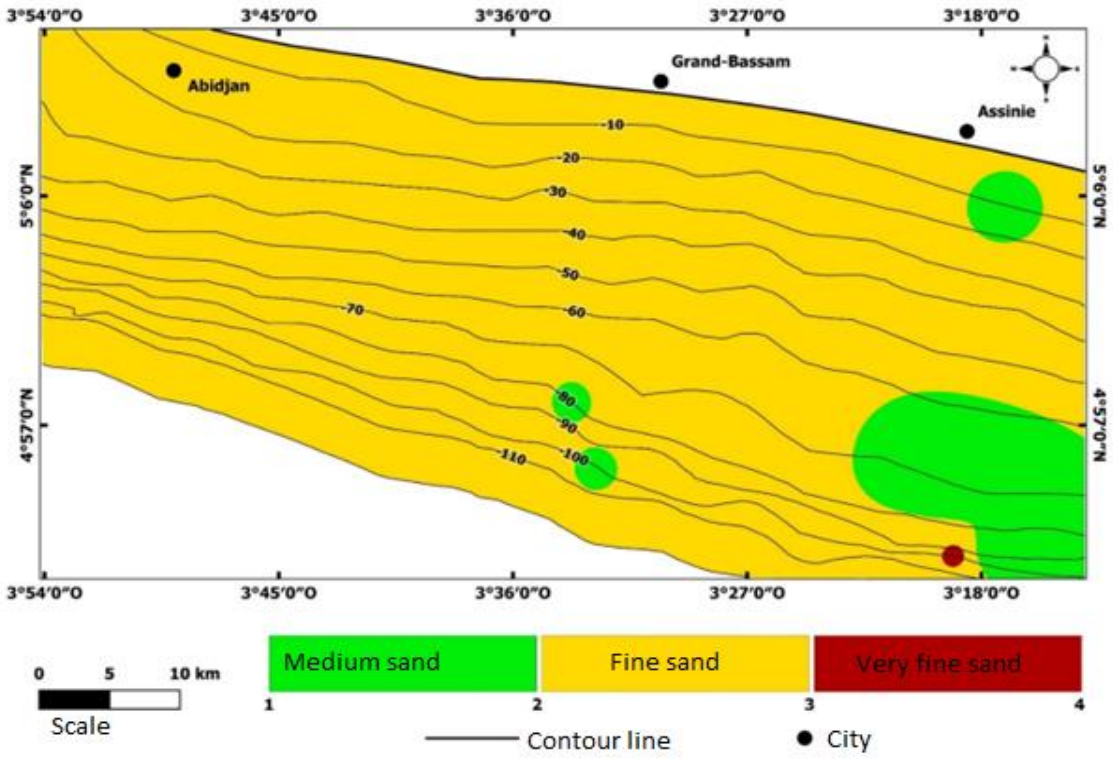

Fig. 2. Spatial distribution of sandy facies on the ABIDJAN-ASSINIE continental shelf

In Abidjan, there is a clear presence of fine sands. These sands are deposited by the rip currents after the waves have broken. The sands are then moved by a regular to slightly regular underwater current.

3.2.1 Spatial distribution of sandy facies asymmetry

The asymmetry of sandy facies is obtained from the spatial distribution of asymmetry (Sk).

3.2.1.1 Asymmetry of sandy facies on the continental shelf abidjan-assinie

 Asymmetry of ABIDJAN sediments

Abidjan sediments have a skewness that oscillates between 0.3 and 1 Φ, sorted asymmetrically towards the fines.

 Asymmetry of GRAND-BASSAM sediments

In the Grand-Bassam area, some sands have a skewness equal to 0.345 Φ and 0.356 Φ, testifying to a very asymmetrical sorting towards the fines. Other sands have a skewness equal to -0.045 Φ and 0.403 Φ. These have, respectively, symmetrical sorting and fine sorting.
 ASSINIE sediment skewness

From 30 to 70 m at Assinie, the sediments have a skewness that oscillates between 1 and 0.30 Φ. They are therefore finely sorted. On the other hand, around 10 to 25 m and 70 to 88 m, the sediments have a skewness of between -0.1 and 0.10 Φ. These sands are almost symmetrically sorted. From 75 to 120 m, they have a very asymmetric sorting towards the fines.

The sediments of the eastern Ivorian continental shelf have abundant asymmetry towards the fines, followed by almost symmetrical and very asymmetrical towards the fines (Fig. 3).

3.3 Interpretation of the Asymmetry of Sandy Facies

The sandy sediments of the ABIDJAN-ASSINIE continental shelf are symmetrically and finely sorted**.** In Abidjan, the values of the asymmetry show a regular decrease of flows, therefore poorly sorted sediments, but from Grand-Bassam to Assinie, the skewness shows little marked inflows compared to long hydrological phases of decrease.

The asymmetry of the sediments of the ABIDJAN-ASSINIE continental shelf shows that the wave energy at the time of deposition is high or low in places, as the asymmetries vary from positive to negative.

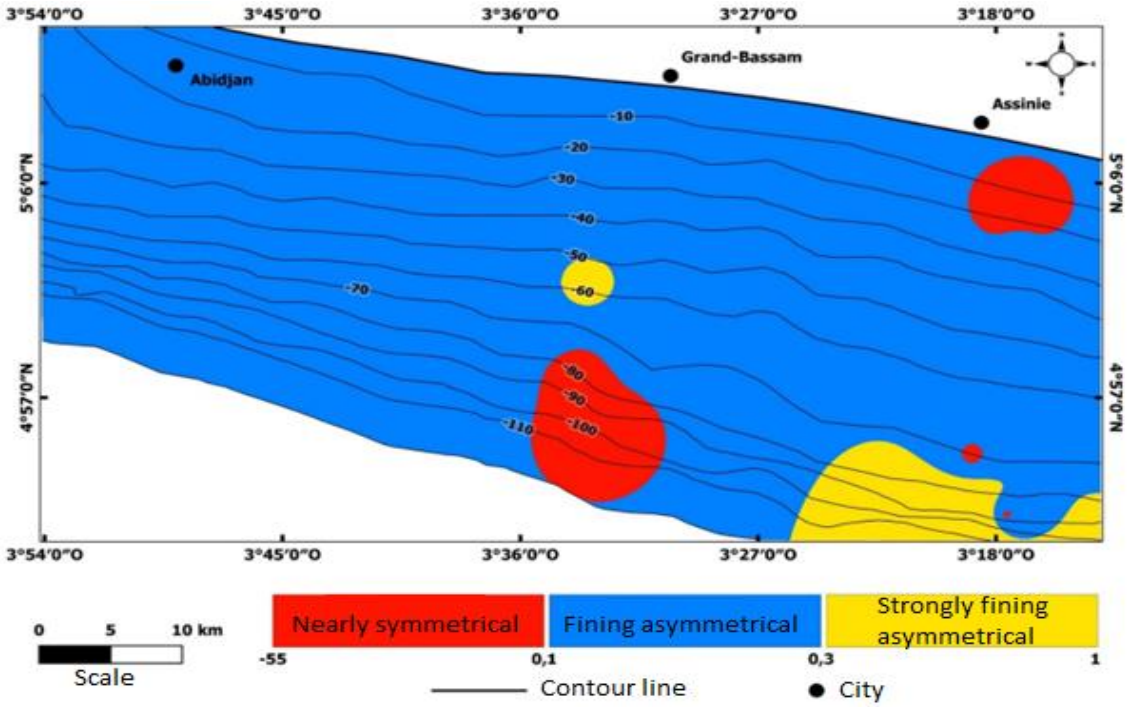

Fig. 3. Spatial distribution of the asymmetry of the sandy facies of the ABIDJAN-ASSINIE continental shelf

3.4 Spatial Distribution of Granulometric Sorting on the Continental Shelf

Granulometric sorting is based on the spatial distribution of sorting (So).

3.4.1 Granulometric sorting on the abidjan-assinie continental shelf

 Classification of sediments in the Abidjan area

Abidjan sands are moderately classified. Their sorting value is between 0.87 Φ and 0.924 Φ. These sands settle in an environment with a fairly regular current.

 Classification of sediments in the GRAND-BASSAM area

In Grand-Bassam, the sands are moderately to poorly graded. Their sorting varies between 0.815 Φ and 1.029 Φ. They therefore reside in an environment with little to fairly regular current.

- Classification of sediments in the ASSINIE area

At Assinie, the sands are fairly well to poorly classified. The fairly well graded sands have a sorting ranging from 0.604 Φ to 0.653 Φ, and the poorly graded sands have a sorting between 1.019 Φ and 1.367 Φ. The current is not very regular in this area.

The sands of the ABIDJAN-ASSINIE continental shelf are fairly poorly classified. This last class is the most dominant.

3.4.2 Interpretation of particle size sorting

The classification reflects a mixture of grain sizes. This mixture may be due to an irregularity in the energy of the transport current or to a confluence of watercourses.

Sur le plateau continental Abidjan-Assinie, les sables sont assez bien à médiocrement classés. Ils sont alors déplacés par un courant sous-marin régulier à peu régulier. Il est peu régulier à Bassam (-90 à -100 m) et à Assinie (-70 à -120 m) (Fig. 4).

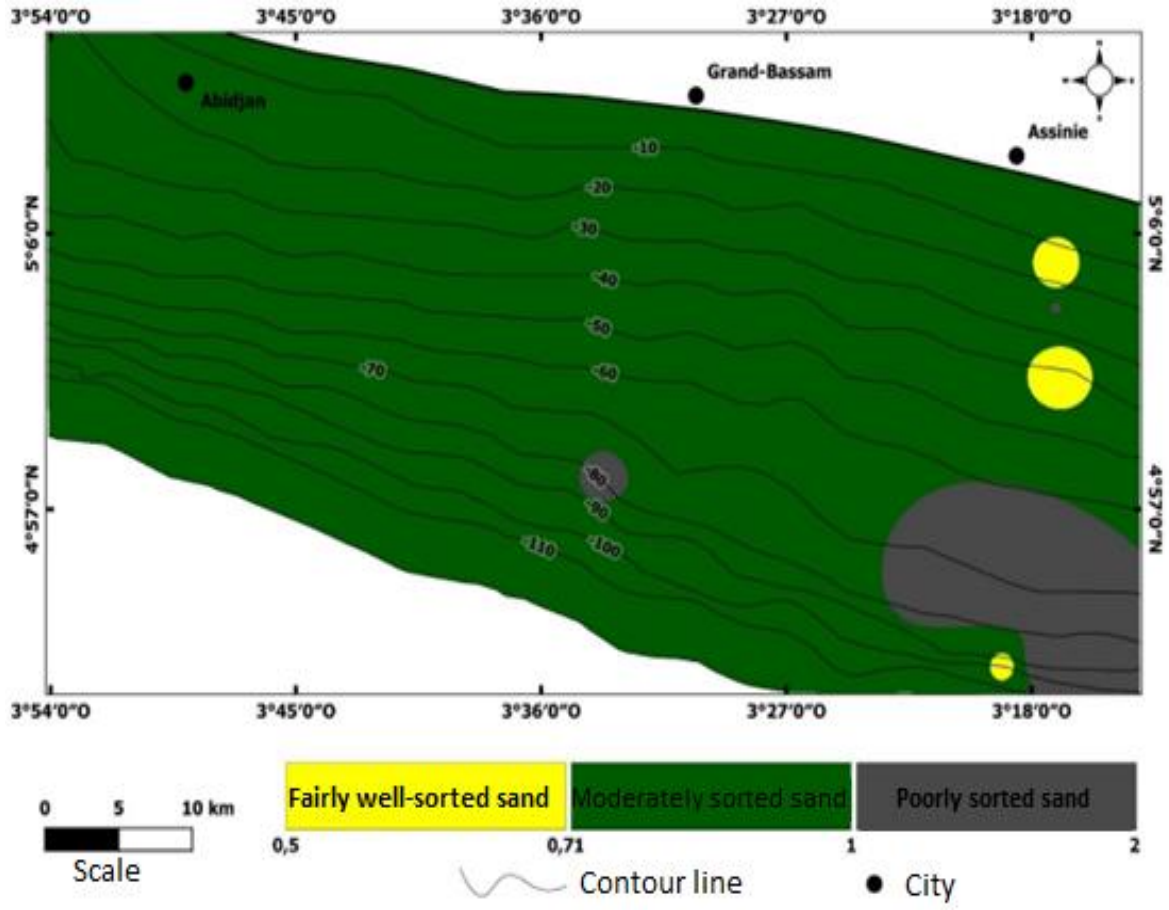

Fig. 4. Spatial distribution of grain size sorting on the continental shelf ABIDJAN-ASSINIE

3.5 Reconstitution of Detritic Transport on the Continental Shelf

To reconstruct detritic transport in the continental shelf, we used the modes (saltation or by suspension or mixed mode: salting/creep, salting/suspension), agent and duration of transport of detritic sediments from the continental shelf.

3.5.1 Transport by saltation

The grains move in small jumps. It is neither the loading, because the grains do not always remain in contact with the bottom, nor the suspension, because the particles fall back quickly.

Maciej [15] diagrams show distinct populations:

-off Abidjan, population A represents 58 to 60% and population B represents 39.99 to 41.99%. The proportion of sands by size is: medium sand = 58% to 60%, fine sand = 22%, very fine sand = 19.6% and Silt & clay= 0.39% to 0.03% (example sands N°9496 and N°9498). The mode of transport is saltation (Fig. 5);

-At -110 m off Grand-Bassam (Fig. 6), populations A&A' are in the majority with 65%, followed by population C (30%) and population B (4.99%). SM are the most important (60%). We can thus observe a saltation as a mode of transport;

3.6 Transport by Suspension

Suspension transport is observed on the continental shelf in sediments from Abidjan, Grand-Bassam and Assinie. The particles from these places remain in the fluid and only rarely fall back to the bottom**.**

The suspension of sediment and its failure to fall back are related to turbulence. In addition, some sediments from these sites are transported by a mixed mode (salting/creep and salting/ suspension).

In Abidjan (Fig. 7), we distinguish population A, representing 40%, and population B, 59.99%. Very fine sand occupy 40.95%, medium sand represent 40%, fine sands cover 19% and silts & clays 0,04%. The sands in this location were moved by suspension.

The Grand-Bassam sands (Fig. 8) show a mixture of populations. These are populations A & B. Population A (saltation) is added to population B (suspension) to give this mixture. Within this mixture, population A represents 15% and population B covers 84.99%.

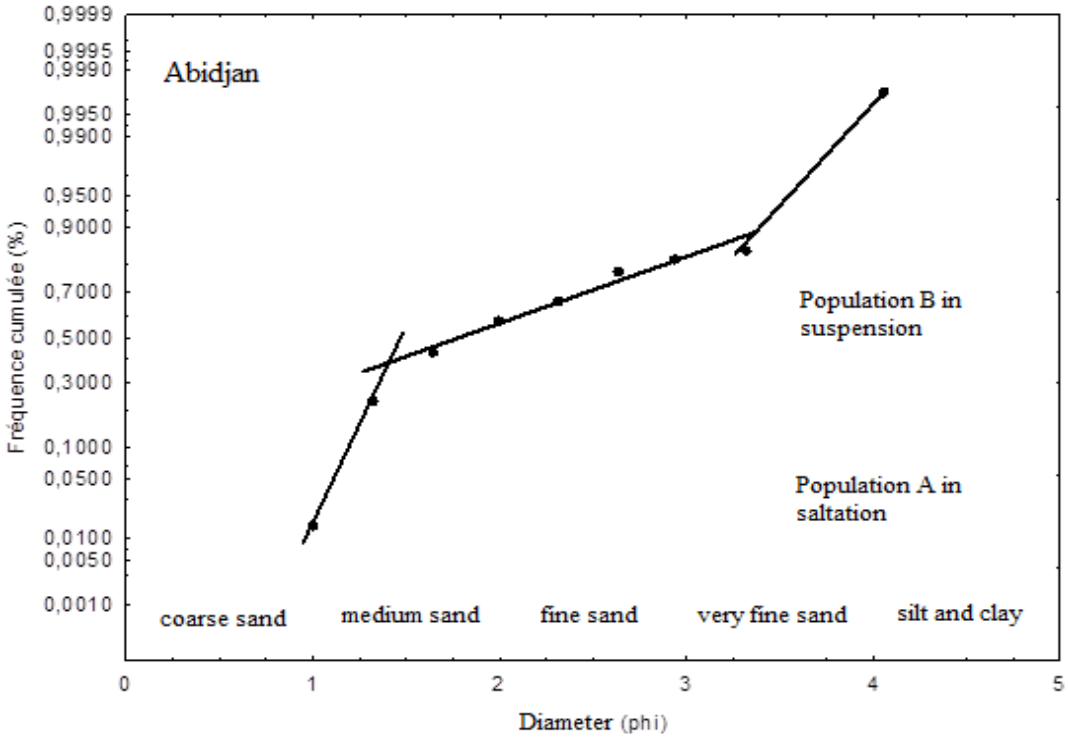

Fig. 5. Saltation sediment transport diagram in Abidjan

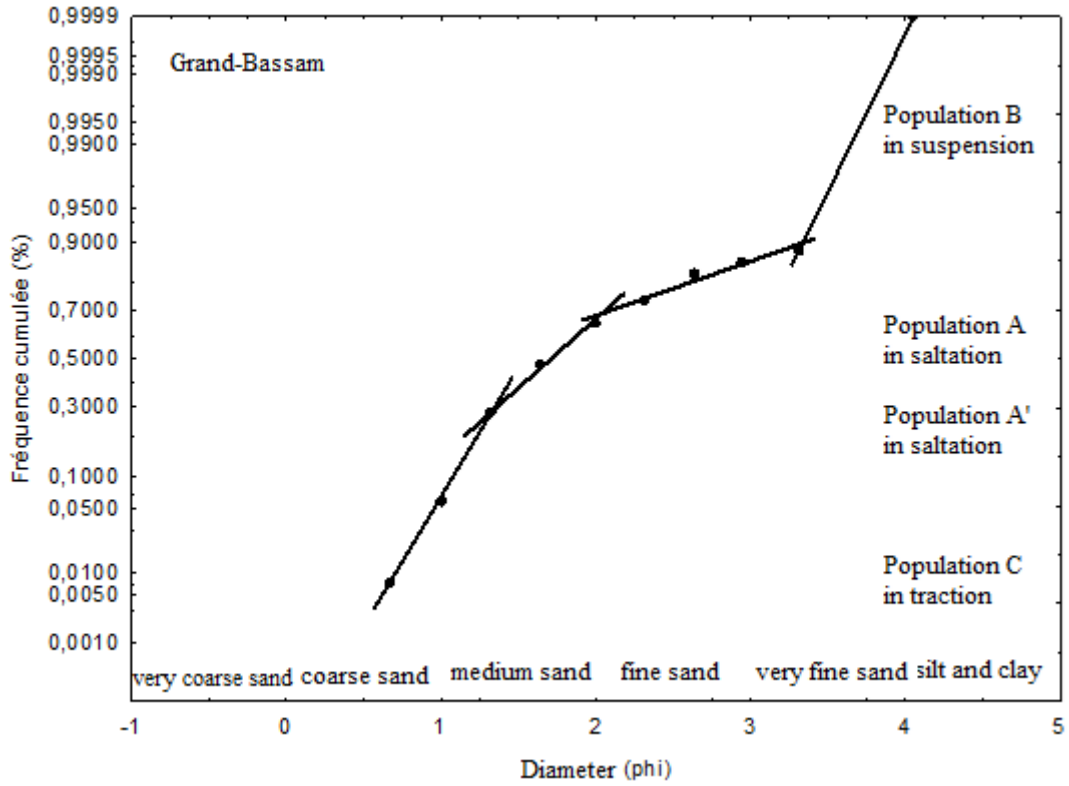

Fig. 6. Saltation sediment transport diagram in Grand-Bassam

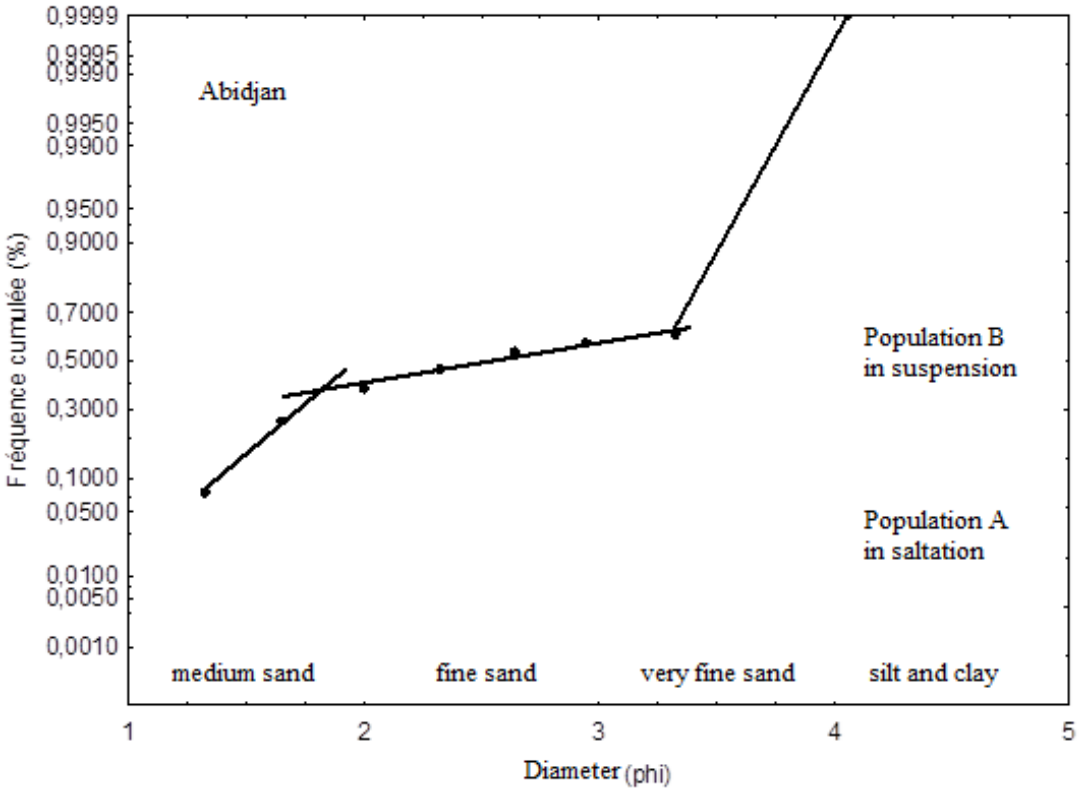

Fig. 7. Suspension sediment transport diagram in Abidjan

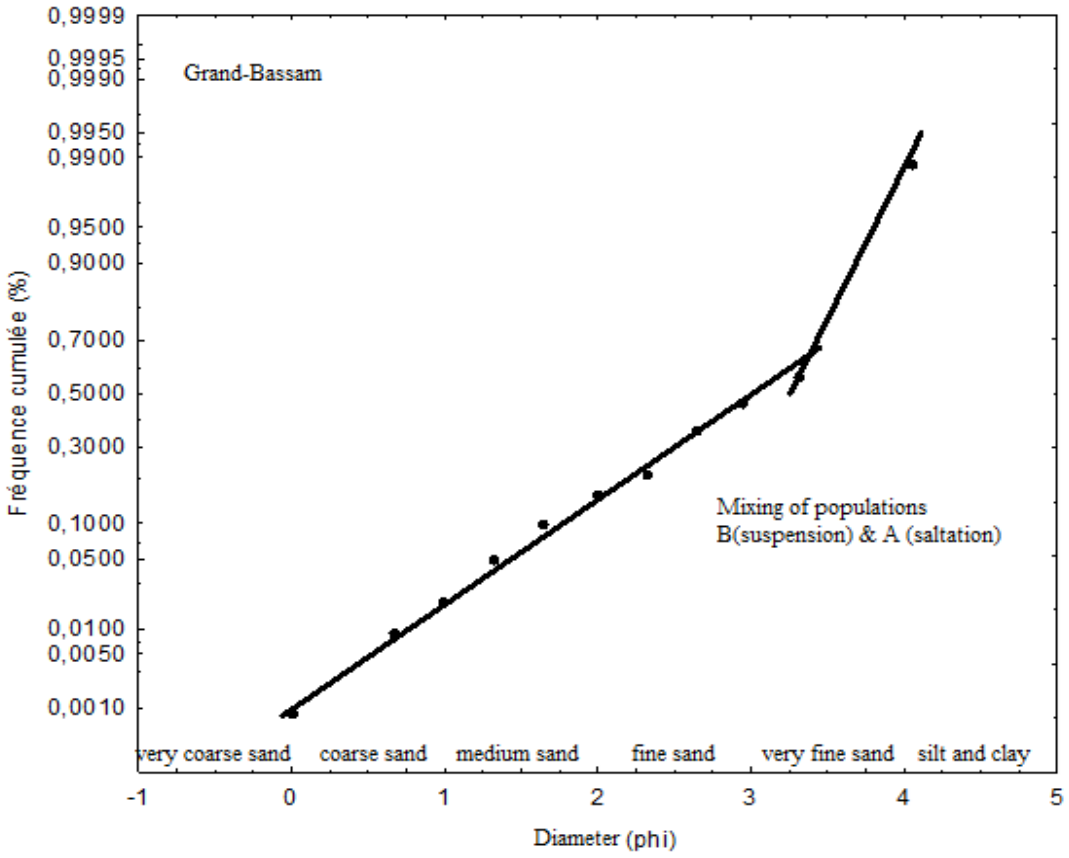

Fig. 8. Suspension sediment transport diagram in Grand-Bassam

The proportions of sands are : coarse sand = 2%, medium sand = 13%, fine sand = 35%, Very fine sand= 48.9% and Silt & Clay= 1.09%. The sediments in this area were mobilised by suspension.

In the Assinie area (Fig. 9), sediments have three types of populations: These are populations A, B and C, and mixed populations. Population B and mixed populations A & C are recorded. Fine Sands remain the most abundant. These sediments were therefore mobilised by suspension.

3.7 Agent and Transport Time for Continental Shelf Sands

This is the purpose of quartz morphoscopy, which looks at the surface state and shape of the grains. It provides information about the transport agent and the length of time the grains have been transported from the source.

3.7.1 Grain surface condition

It can be seen that almost all (98%) of the quartz on the continental shelf is of the gleaming blunt (GB) type. The omnipresence of shiny blunt grains highlights the influence of aquatic transport, in this case from the sea. Very few (2%) are of the clean round matte type (RMP). The presence of dull grains indicates a nearby source**.**

3.7.2 Grain shape

Quartz from the continental shelf has a sphericity of between 0.3 and 0.5 and a roundness coefficient of between 0.3 and 0.7. These show that the grain shapes are subangular, subrounded and rounded.

3.7.3 Interpretation of the transport process

Analysis of the mode of transport and morphoscopy shows that continental shelf sediments, transported mainly by suspension, have a shiny blunt surface, indicating that they were transported mainly by water. These sediments are found in an environment where water circulation is irregular. The grains are moderately spherical, with a degree of rounding that varies from sub-angular to rounded,

reflecting friction between the grains and the saltation mode of transport of certain grains, during which they make small jumps. It is also evidence of moderate to heavy wear, the main agents of which are hydrodynamic forces such as swell.

3.8 Reconstitution of Detritic Deposits on the Continental Shelf

The type of deposit was reconstructed according to the TRICAT classification [16]. This classification, based on semi-logarithmic particle size curves determines the types of deposition by settling or by excess charge.

3.8.1 Settling detrital deposits

Deposits by settling are given by sector:

3.8.2 Grand-bassam sector

In the Grand-Bassam area, we find the sigmoid facies. In fact, the sediments have cumulative curves that are S-shaped with a spread-out appearance and medium slope (Fig. 10).

3.8.3 Assinie sector

The sediments contain sands with S-shaped curves that are more or less upright, with an average slope. This gives a hyperbolic or sigmoid facies (Fig. 11).

3.9 Detritus Deposits Due to Excess Load

Deposits by excess load are presented sector by sector:

3.9.1 Abidjan sector

The sediments of Abidjan are deposits left by river or marine currents due to excess load. The facies is therefore parabolic (Fig. 12).

3.9.2 Grand-bassam sector

The sediments are characterised by logarithmic and parabolic facies respectively. These sediments are therefore deposited by an excess load (Fig. 13).

3.9.3 Assinie sector

The sediments are characterised by logarithmic and parabolic facies. These sediments are deposited following a reduction in fluvial or marine currents due to excess loading (Fig. 14).

3.9.4 Interpretation of the deposit process

Interpretative analysis indicates that the cumulative curves for continental shelf sands show hyperbolic, parabolic and logarithmic facies. The first facies suggests sedimentation in a more or less agitated environment, while the last two (02) facies indicate sedimentation due to excess loading. The sediments on this part of the submerged beach, which vary in size from medium, fine to very fine and rarely coarse, were deposited in an environment with slow water circulation in some cases. Others were deposited in graduated suspension (coarse and medium particles) and in uniform suspension (fine particles).

3.10 Reconstitution of the Environment of Detritic Deposits on the Continental Shelf

3.10.1 Environment of detrital deposits on the continental shelf

The deposition environment is determined from the Md-So and Sk-Md dispersion diagrams. It can be of the beach/coastal dune type (marine environment) or river/continental dune type (continental environment) according to the Moiola and Weiser classification [17].

3.10.2 River deposit environment in abidjan, grand-bassam and assinie

The Md-So and Sk-Md diagrams of the evolution in the granulometric parameters of sediments in Abidjan, Grand-Bassam and Assinie were used to determine the main sediment accumulation sites. The dispersion of points in the Md-So diagram is solely (100%) in the area of rivers. This shows that the sediments come from a fluvial environment.

The Sk-Md diagram shows a predominance of continental sediments, with 62% of points in the continental domain. However, marine sediments are also present, with 38% of points in the coastal zone (Fig. 15).

This research has scientific interest as it helps to locate areas covered by sandy sediments. This information can guide fishermen in finding fishery resources and assist those involved in seabed operations (such as laying telephone cables). It also provides a clear explanation of the phenomena of regression and transgression, as the sediments currently collected at sea might have been found on a beach or in a river in the

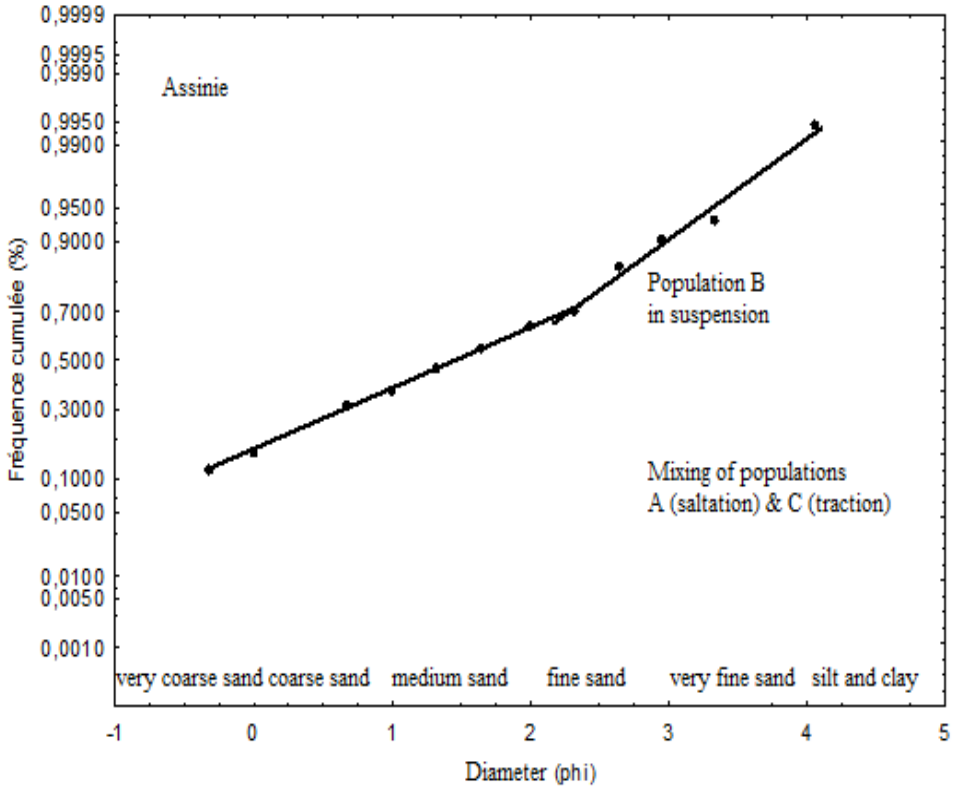

Fig. 9. Suspension sediment transport diagram at Assinie

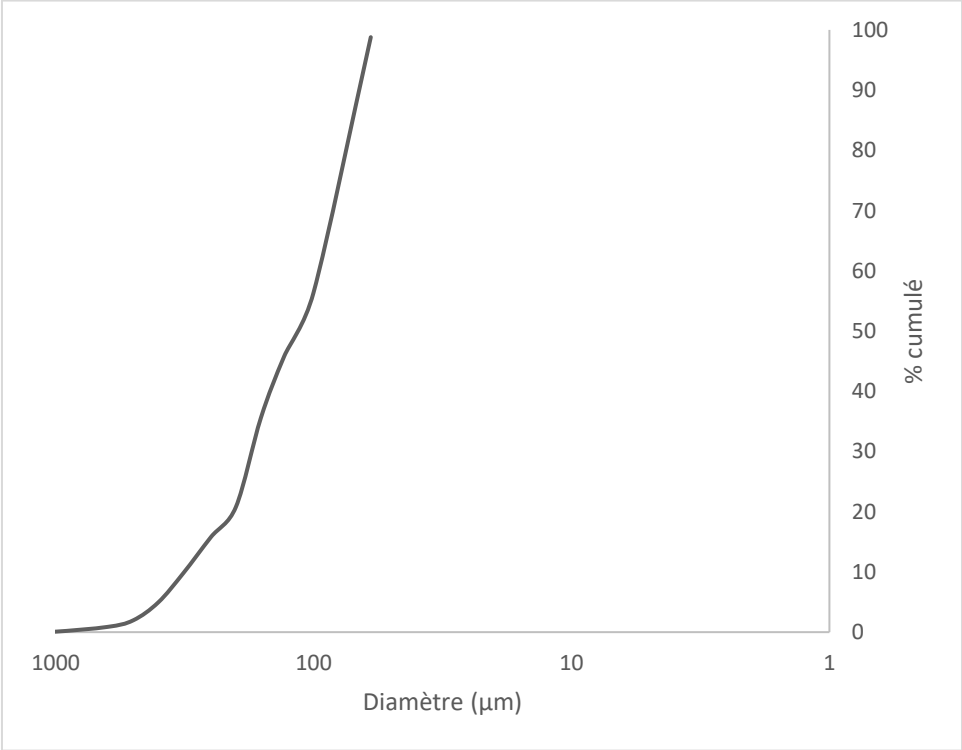

Fig. 10. Sigmoid facies of the Grand-Bassam sands

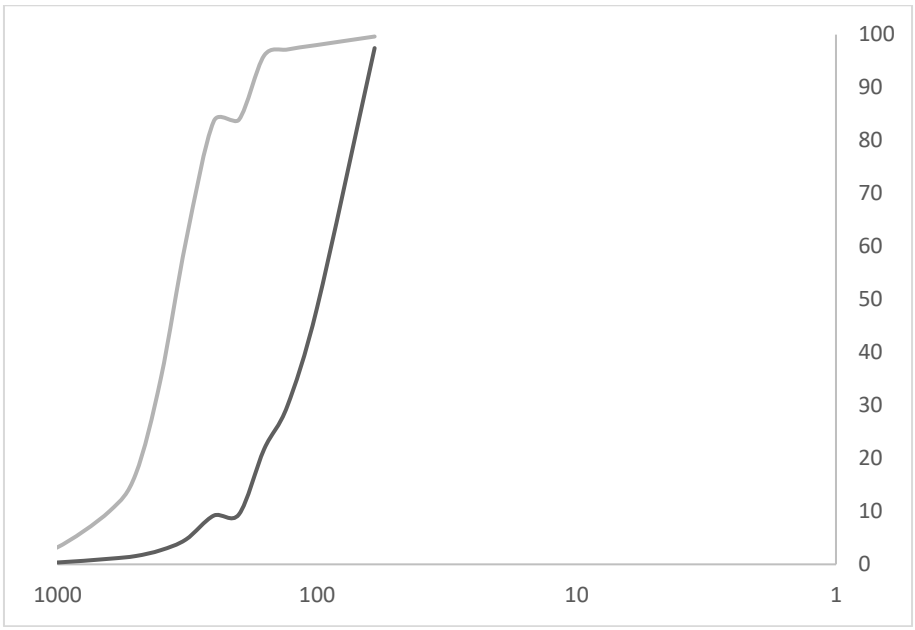

Fig. 11. Sigmoid facies of Assinie sediments

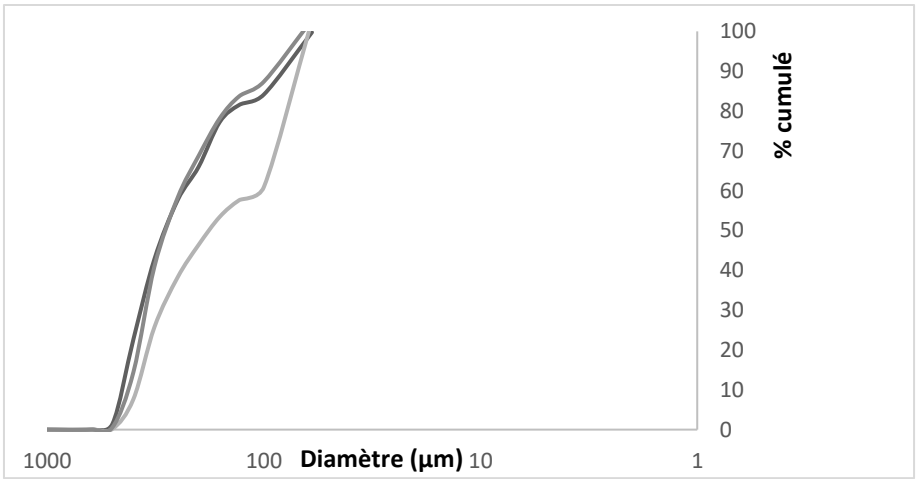

Fig. 12. Parabolic facies of the Abidjan sediments

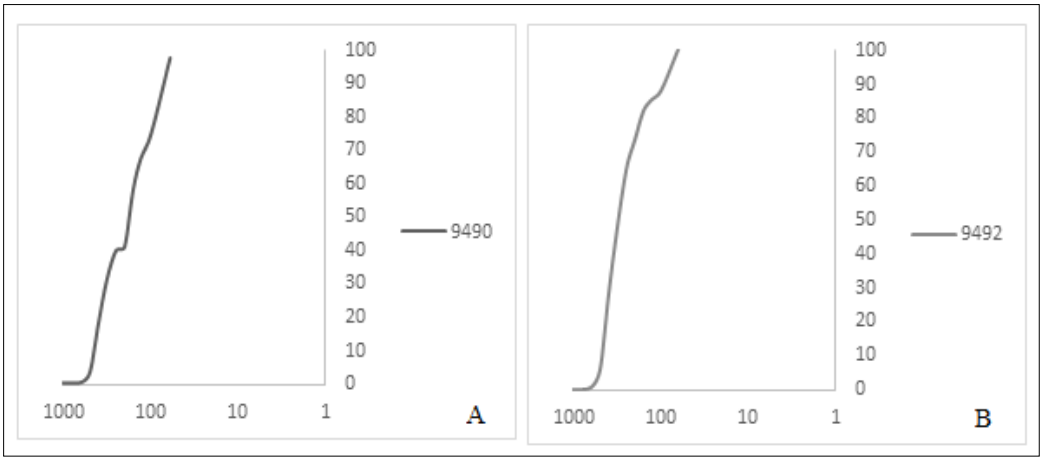

Fig. 13. Logarithmic and parabolic facies at Grand-Bassam

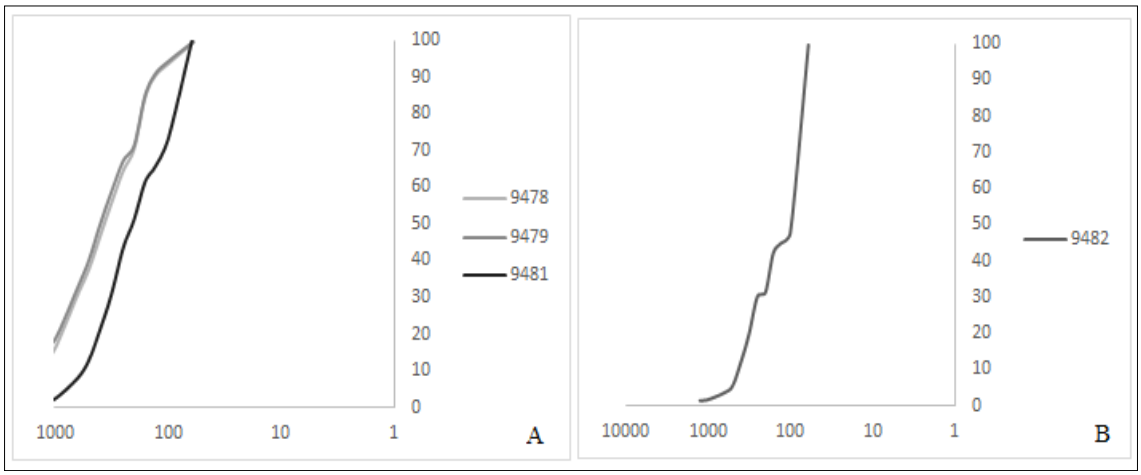

Fig. 14. Logarithmic (A) and parabolic (B) facies at Assinie

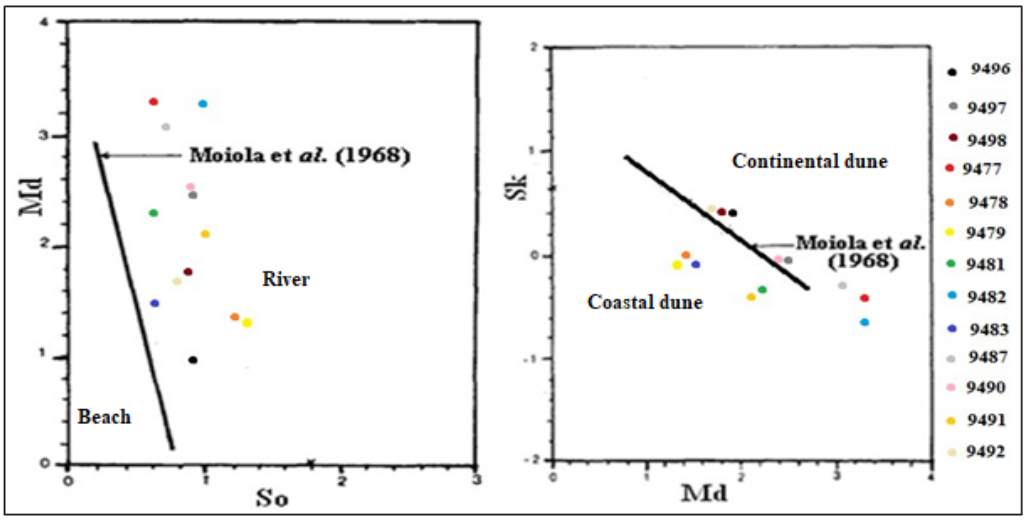

Fig. 15. Md-So and Sk-Md dispersions of sands in Abidjan, Grand-Bassam and Assinie

past, which has since been submerged. Thus, this manuscript reconstructs paleo-environments. Additionally, for navigation purposes, it could guide ships by identifying calm and turbulent areas.

4. DISCUSSION

On the ABIDJAN-ASSINIE continental shelf, the sands are moved by a regular to irregular underwater current. In the Gulf of Guinea, on the Guinea Conakry continental shelf, similar observations were made by Domain and Bah [19].

The sands of the Ivorian continental shelf were transported by saltation and suspension, given the different sizes observed and taking into account the energy of the environment. They are also transported by mixed modes, namely saltation/fluid or saltation/suspension, resulting from sediment mixtures. These modes of transport are also observed on the beach [20,21] also observed mixed sediments during their work. They think there may be mixtures of two or three particle size populations during dredge or dumpster sediment sampling, or it may be due to nature. The shiny blunt grains on the continental shelf indicate transport by water. The variation in sorting is similar to a selective winnowing of fine sands during low flows or to a more massive displacement of all the sediment [22]. The hyperbolic, parabolic and logarithmic facies observed in continental shelf sediments indicate sedimentation in a more or less agitated environment, while the last two (02) facies show sedimentation due to excess loading.

Martin [23] notes hyperbolic and parabolic facies in coarse and medium sands. In fine and very fine sands and mixed sediments, he observed parabolic and logarithmic facies.

The sands of the continental shelf sediment in a coastal dune-type environment for some and in a fluvial/continental dune-type environment for others. The sources of sediment input likely come from the lagoons and waterways bordering the Ivorian sedimentary basin [23], in his work on the sedimentation of the continental shelf, indicates the same sources of input in the sedimentary basin of Côte d'Ivoire.

5. CONCLUSION

The Abidjan-Assinie continental shelf is bordered by fine sands, medium sands and rarely very fine sands. The sediments of the continental shelf are characterised by three (03) types of skewness: asymmetry towards the fines, almost symmetrical and very asymmetrical towards the fines. The sediments are sorted towards the fines, almost symmetrically and very asymmetrically towards the fines.

The standard deviation or sorting (s) is an important parameter in sediment studies. It allows us to know the type of sand classification and, at the same time, the regularity of the sedimentation flow. Thus, through our study, we describe five (05) types of classification : very well classified sands, well classified sands, fairly well classified sands, moderately classified sands, and finally poorly classified sands. These types of classification reflect a more or less regular current. On the underwater beach, the sands are fairly well to poorly classified. The flow is not very regular at Bassam (-90 to -100 m) and Assinie (-70 to -120 m).

Sediments on the continental shelf are transported by saltation and suspension. However, some have been moved by mixed modes of transport, that is saltation /suspension and saltation/traction.

Morphoscopy of the quartz shows that the sands in this study area were transported by water and reworked by the sea, given their shiny nature, although round mast sediments can be observed. The submerged beach is characterised by hyperbolic, parabolic and logarithmic facies.

Thus, sedimentation on one part of the continental shelf took place in a more or less agitated environment as a result of a gradual reduction in the strength of the current and, on the other part of the continental shelf, sedimentation as a result of an excess load. This article has helped to understand the sedimentary dynamics on the eastern continental shelf of Côte d'Ivoire. It could serve as a guide for maritime operators in Côte d'Ivoire.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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