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Granulometric and Mineralogical Characterization of Port-bouet Beach (Côte d'Ivoire)

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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

Granulometric analysis of sampled sands along Port bouet coastline, during both periods (turbulent and calm periods), shows a wide particle size spectrum ranging from fine sand to very coarse sand. It should be noted, however, that the coarse fraction is largely predominant, particularly in channel proximity. This trend continues during both periods, caused by a grain size selection resulting from west-east direction coastal drift. Study of heavy minerals shows a very uniform mineralogical cortege, largely dominated by quartz, biotite and feldspaths. These minerals would come essentially from erosion of continental shelf granites. They are distributed along the coast by a coastal drift in a west-east direction. Study of sands transport mechanisms, collected on Port Bouet coast during the two seasons, May and November shows three modes of transportation: loading for very coarse sands, saltation for medium and coarse sands, and suspension for finer particles. Saltation is the mode of transport that predominates in all sectors, regardless of the observation period. Rates vary between 80 and 90% depending on the sector. Sediments transported by suspension and loading generally do not reach 12%.

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Keywords: Granulometry; mineralogy; sand; coastaline; port-bouet.

ABBREVIATIONS

AFNOR : French standardization agency
HE : high beach
BE : low beach

1. INTRODUCTION

Port-Bouet Bay is located on a sandy cordon plain (Fig.1). It is located at the top of the "bottomless hole" canyon and corresponds to the direction changing zone of the coastline [1]. The straight coastline is interrupted by the intermittent estuary of Grand-Bassam (estuary of Comoe river) and the estuary of Assinie [1]. Quaternary deposits in this area have been widely studied (dynamics of sediments and morphology) [2,1,3,4,5] of which main conclusions are: Prior to the breakthrough of Vridi Canal (Fig. 1), Port-Bouet Bay received 800,000 m3 per year of sand, including 400,000 m3 per year still flowing eastward. The rest lay at the head of bottomless hole canyon and coast [2]. Erosion of Port-Bouet Bay is believed to be largely due to complex wave dynamics at this canyon (Tastet 1985). This bay is characterized by concave-looking topo-bathymetric profiles with medium to very strong slopes [4]. Foreshore and underwater beach (-10 m) consist of coarse to very coarse sands [3,4]. Middle sediments and vases predominate between -10 and -40 m depth [3,4]. Works of Abe [5] subsequently shows that the majority of sedimentary exchanges take place between foreshore and underwater beach. The present study is aimed at understanding of the area specific coastal drift, using granulometric and mineralogical characterization of sands transportation mechanism. The objective of this study is to determine the origin of coastal sediments through the study of facies granulometric distribution and heavy minerals. The concentration of heavy minerals in surface sediments of continental shelf may be due to several factors such as origin of input and sedimentary processes of alteration and transport [6,7]. This study also treats recent sands transport processes and mechanisms, as well as factors controlling granulometric distribution of facies.

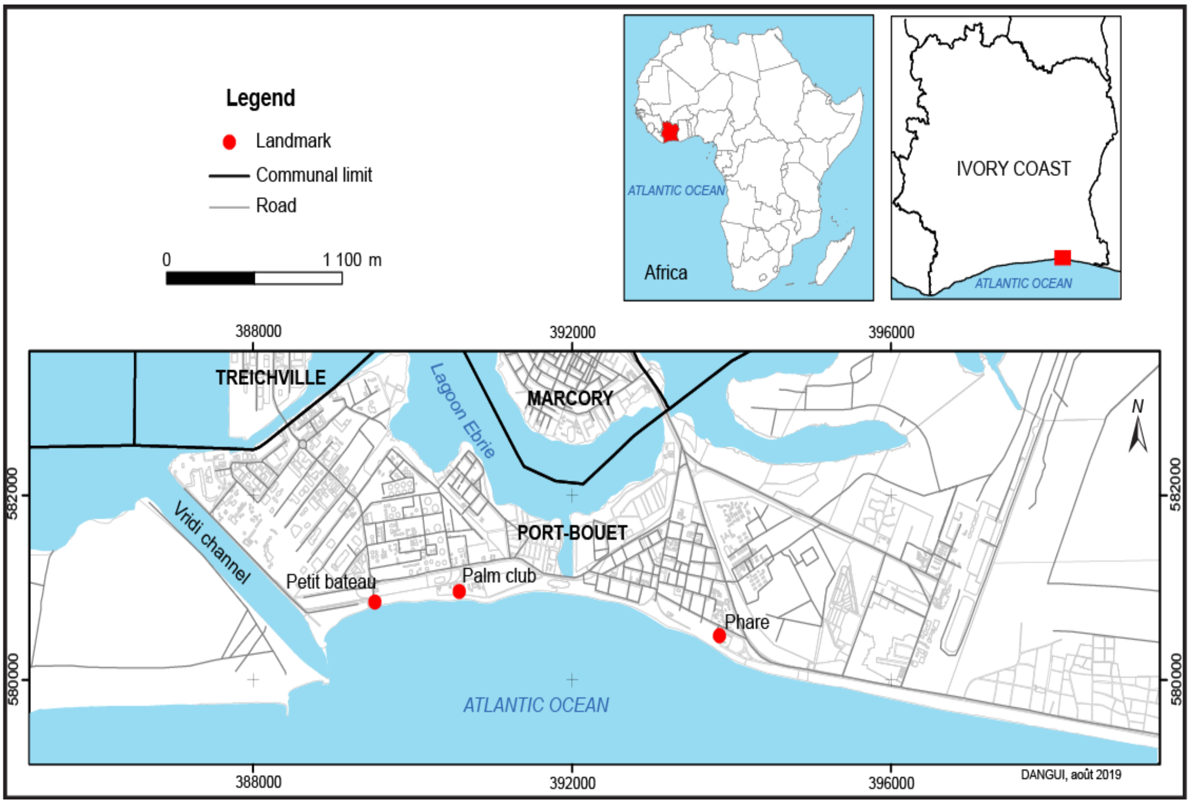


Fig. 1. Localisation of study area

2. MATERIALS AND METHODS

Characterization of sandy sediments was done in laboratory by granulometric and mineralogical analysis from a sampling data on Port-Bouet coastal perimeter.

2.1 Mineralogy

Sediments for this study were collected during turbulence (May) and calm (November) periods on the beach. After processing and screening on a series of compliant sieves according to AFNOR norms, samples with diameters between 63µm and 125 µm were selected for the study. This fraction contains the maximum amount of minerals. Indeed, various studies [8,9,10,11] have shown that the heavy residue of this fraction is representative of a detrital sediment. It is then possible to establish the mineralogical pathways that may exist between various formations to locate the petrographic provinces from which they have originated. The mineralogical composition of sands was determined by optical microscope and electronic microscope (MEB-EDS), using thin blades of sand samples.

Thin blades were observed with optical microscope under natural light (LN) and polarized light (LP) at PETROCI Research and Analysis Center. The device used is an Eclipse 5Oi POL polarizing microscope coupled with a digital camera. Digital images were processed using software. The estimation of mineral content was based on the diagram prepared by Cailloy and Tricart [12].

Thin blades have also been subjected to chemical analyses at MEB-EDS with a minimum analyzed surface of 4 mm^2. The MEB FEG SUPRA 40 VP Zeiss type allowed morphology and chemistry characterization of different mineral phases of samples. Some spectral characteristics in energy dispersion of several mineral phases have been carried out to specify the content of present elements. The backscattered images and micro-analyzes were performed at an acceleration voltage of 12 kV.

2.2 Granulometric Parameters

Main granulometric parameters such as: mean, standard deviation, skewness, kurtosis and median were calculated using [13] method.

Quartiles (Φ 25 ; Φ 50 Φ 75), pentiles (Φ 5 ; Φ 95) and fractiles (Φ 16 ; Φ 84) were determined. These are particle dimensions corresponding to specific cumulative percentages [14]. Thus:

- quartiles Φ25, Φ50 and Φ75 correspond respectively to 25 %, 50 % and 75 %;
- pentiles Φ5 and Φ95 correspond to 5 % and 95 %;
- fractiles" Φ16 and Φ84 correspond respectively to 16 % and 84 %. Φ = -log2d(mm)
  (d = grain diameter).

Mean (Mz): It is the typical sample grain estimate. The mean gives an idea of environment energy [15] and is influenced by the particle size of original sediment [16]. It was useful in comparing different sampling sites.

It is defined by the following formula:

$$Mz(\Phi) = \frac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3}$$

Standard deviation or classification index (σ): The ranking index measures the dispersion of sizes relating to the sample average or its degree of ranking. This measure is linked transport capacity of erosion agent and separation capacity. The classification index formula is:

$$\sigma = \frac{\Phi_{84} - \Phi_{16}}{4} + \frac{\Phi_{95} - \Phi_{5}}{6,6}$$

Skewness or asymmetric index (Sk): the third parameter used in granulometric analysis is asymmetric index. Its formula is:

$$Sk = \frac{\Phi_{16} + \Phi_{84} - 2\Phi_{50}}{2(\Phi_{84} - \Phi_{16})} + \frac{\Phi_{5} + \Phi_{95} - 2\Phi_{50}}{2(\Phi_{95} - \Phi_{5})}$$

Kurtosis (K): The acuity coefficient (Kurtosis) is used to measure the distribution intensity. The formula for kurtosis is:

$$K = \frac{\Phi_{95} - \Phi_{5}}{2,44\,(\Phi_{75} - \Phi_{25})}$$

Median or Median grain (Md): Median grain defines the central trend in grain size distribution. The median is defined by the following equation with **d** in mm:

$$Md = \Phi_{50} = -3,3219\log(d)$$

2.3 Mode of Sediments Transport

Sediment transport mode was determined from Visher test [17]. In fact, sediment granulometric distribution from cumulative curves most often shows curves formed from several straight segments. This suggests that the sediment consists of a mixture of several granulometric families. Curves types obtained are directly related to transport modes of particles. This method defines three modes of transport [18]:

- suspension (90 to 100 %): particles move in the current direction within the liquid without ever falling, except very occasionally, on the bottom;
- saltation (10 to 90%): particles move by jumping and fall successively at relatively significant distances;
- loading or turnover (0 to 10%): particles slide and roll (or slightly jump) in the direction of the current on the bottom."

2.4 Granulometric Facies

Different granulometric facies were determined from Cumulative curves. Determination was based on Tricart method [19]. Granulometric facies reflect either a method of deposition or a type of evolution after deposition [20]. A deposit environment is associated with each figure and an interpretation is given based on curve curvature [21]:

- parabolic facies is a fragment of parable that starts either from the origin or from any point on the abscissa axis. This facies indicates a sudden stop during the transportation of these sediments. This facies is most often associated with sediments where particles transportation has been carried out in graduated suspension for coarse particles and in uniform suspension for fine particles [19]:
- hyperbolic facies or sigmoid facies represented by a sigmoid curve results from a limited selection of only one slice of material. Sedimentation was done by free accumulation [19];
- Logarithmic facies is represented by a curve more or less similar to a straight line. The inclination of this line varies largely according to fine elements proportion. Central part slope is even steeper than the current slowdown. This facies indicates an overload deposit resulting from a reduction of competence of transport agent [19].

2.5 Deposit Environment

Deposit environment was determined from dispersion diagram of Moiola and Weiser [22]. Sk-Md Dispersion diagram allows differentiation of continental deposit environment from coastal deposit environment with the following equation Y= -0.53x+1.24. Md-S_0 dispersion diagram allows to differentiate river sands from beach sands according to the following equation Y= -4.9x+3.76.

3. RESULTS

3.1 Granulometric Characteristics of Beach Sediments during Turbulent Times

Two large sets of sediments are distinguished based on the mean (Fig. 2), standard deviation and asymmetry: sands from Phare and those from Palm Beach and Petit Bateau. Close to the canal (Palm Beach and Petit Bateau), sand is very coarse (1078 µm < Mz < 1419 µm), well classified (0.42 < equivalent < 0.47 µm) and symmetrical -0.03 < Sk < 0.04). Their good ranking shows relatively stable hydrodynamic conditions over time. At Phare, sand is coarse (764 µm < Mz < 821 µm). Sediments of low foreshore are symmetrical and well classified. On the other hand, sediments of upper foreshore are moderately classified with a strong asymmetry towards the coarse elements. Sediments are platykurtic (0.33<K<0.58).

3.2 Granulometric Characteristics of Beach Sediments during Calm Period

As in May 2018, two major sediment sets stand out. However, this distinction is mainly based on the mean (Fig. 2), ranking and kurtosis, with symmetrical sediments on all three sites. Close to the canal, sand is very coarse (1056 < Mz < 1379), generally well classified (0.35 < 0.51) and platykurtic (0.24 < K < 0.52). At the Phare, sand is coarse (677 < Mz < 745) and moderately classified (0.58 < equivalent < 0.59). Sediments of high foreshore are mesokurtic (K = 0.6) whereas those of BE are platykurtic (K = 0.53). Sediment transport by shore jet may be stopped by the previous wave withdrawal current. This is expected to disturb sediment distribution on the beach. Study of granulometric characteristics during turbulent and calm periods shows that sediments are coarser near the canal. This trend is maintained during both periods (Fig. 3) through a granulometric selection generated by west-east coastal drift. Wave's energy may not be enough to drive the coarser to the east. Sediments near the channel are generally better classified (Fig. 3). There is evidence that ranking improves with increasing grain size.

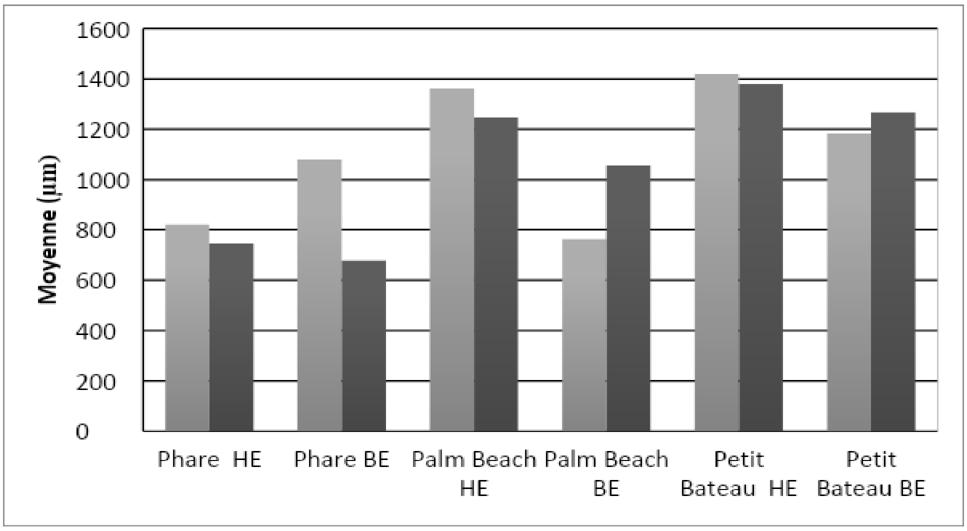


Fig. 2. Variation of sediment size of Vridi-Port-Bouët (November and May)

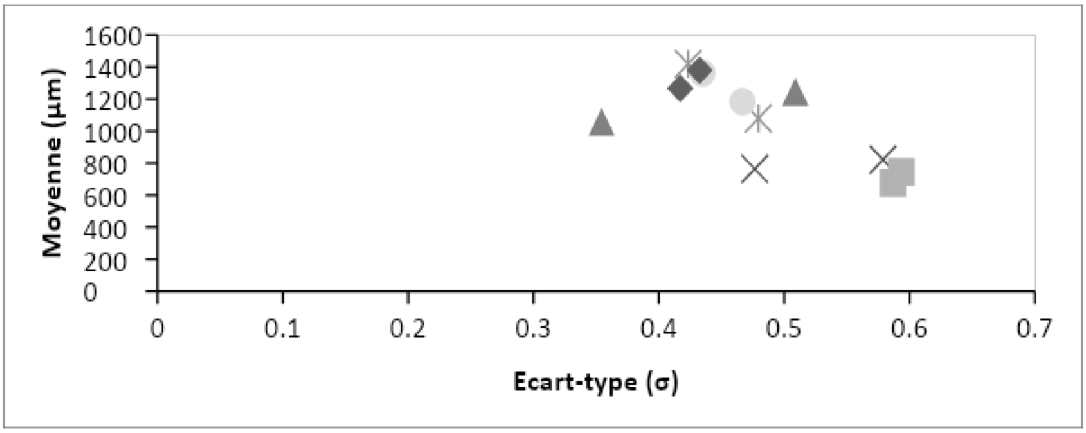


Fig. 3. Distribution of beach sands in dispersion diagrams

3.3 Transportation Mode of Beach Sediments

On all 3 sites, sediments are generally transported by saltation in May (81.75%) (Fig. 4). Transportation by suspension represents 6.25%. Loading is estimated at 12%. In November, transport by loading represents 6% compared to 90.75% for saltation transport (Fig. 5). Very few types of sediments are transported by suspension (3.25%). In turbulence period as well as calm period, dominant mode of transportation is saltation.

3.4 Granulometric Facies of Beach Sediments

Granulometric curves have a sigmoidal appearance in Port-Bouët (Fig. 6). A partial curves straightening occurs during periods of agitation at Phare and during periods of calm at Palm Beach and Petit Bateau. Indeed, when the swell arrives to the coast, shore jet leads a certain amount of sediment to the beach, which characteristics are function of shore jet intensity of each wave. Partial straightening of curves reflects abundance of coarse sands spilled on the beach by shore jet in May and November, respectively at Phare and near the canal (Palm Beach and Petit Bateau). On a same beach, deposit conditions vary according to sectors under consideration.

3.5 Deposit Environment

In Port-Bouët Bay, there is no river contribution in the diagram (Fig. 7). This could be due to the renewal of sandy stock from Port-Bouët following blocking of sandy material at sand stop dam. Presence of a sand reserve at underwater beach allows possibility of feeding the beach of Port-Bouët by south long swells. Sk-Md diagram shows a cloud of points spread across coastal dune domain (Fig. 8).

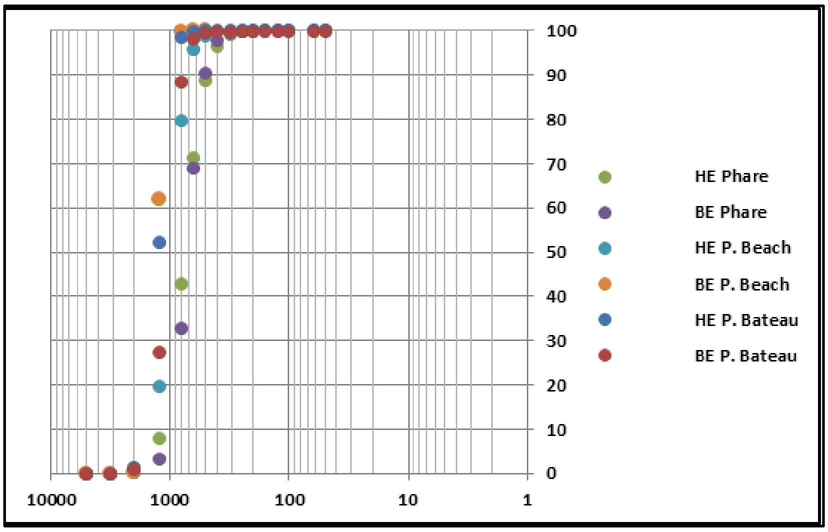


Fig. 4. **Granulometry and transportation mode (May)**

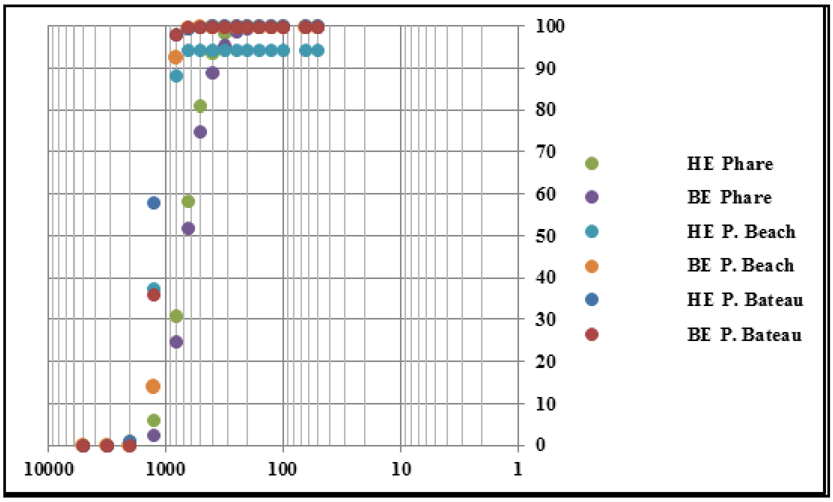
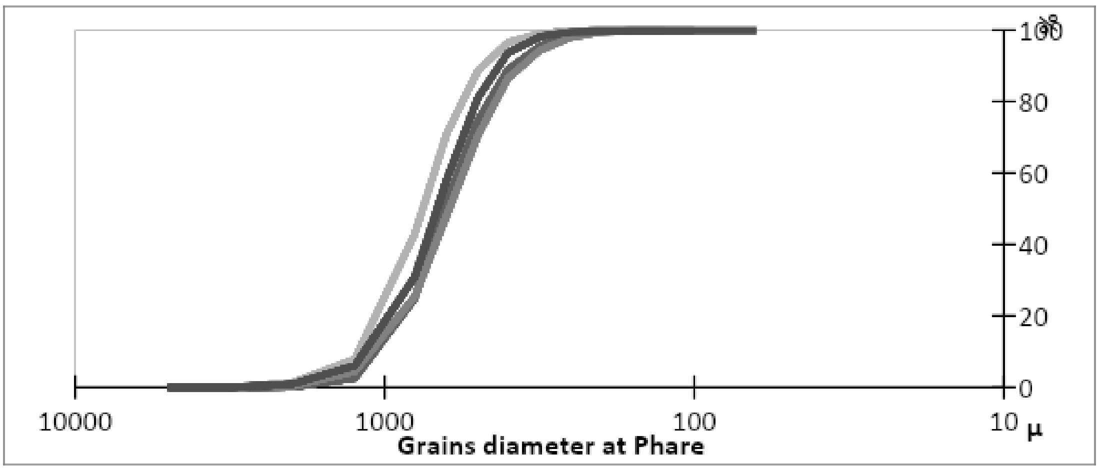


Fig. 5. **Granulometry and transportation mode (November)**



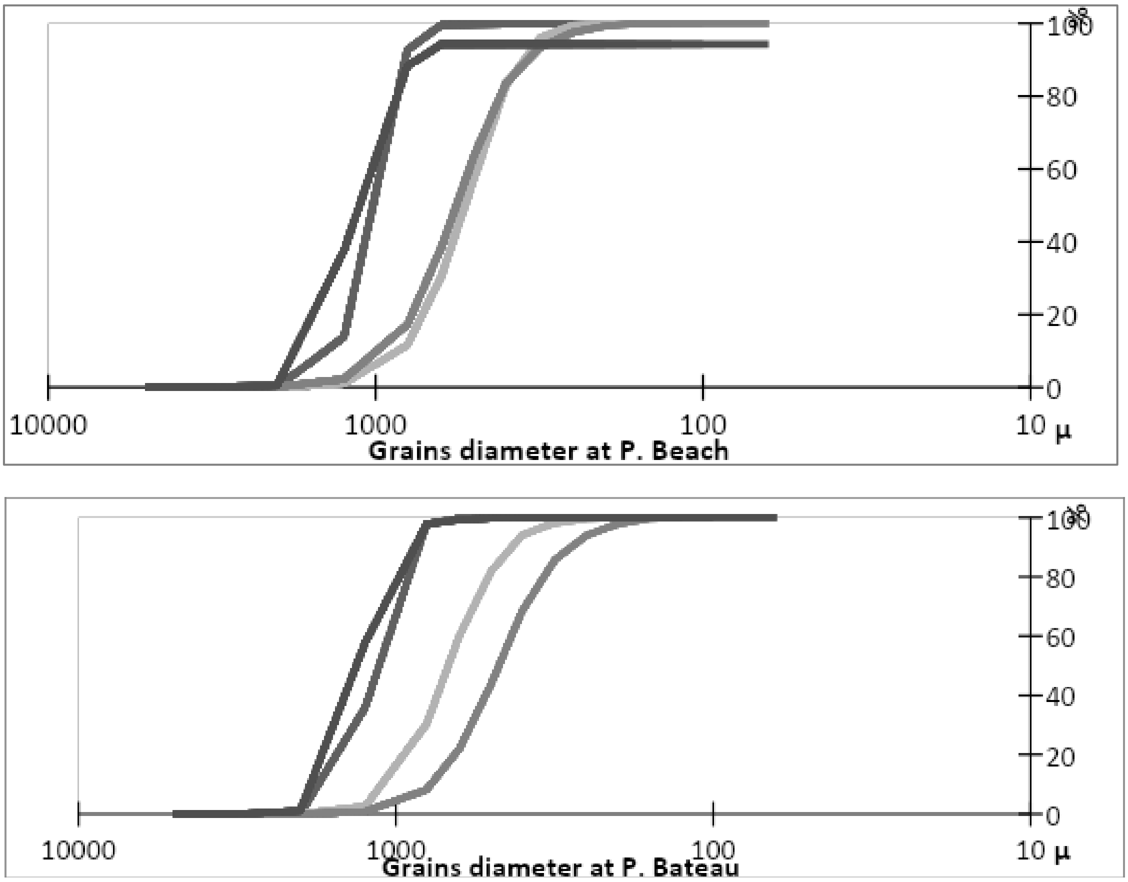


Fig. 6. Granulometric facies of Port-Bouët

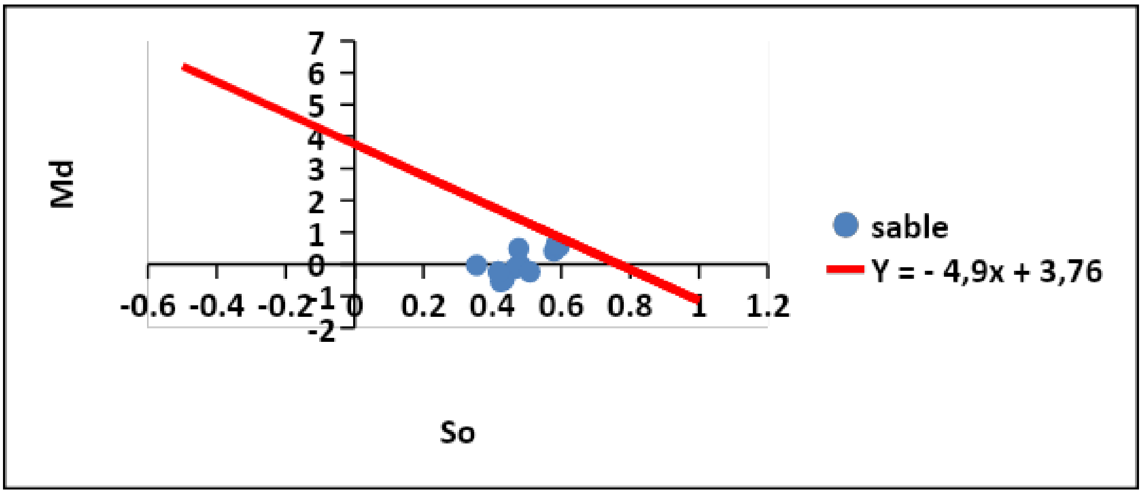


Fig. 7. Sands Dispersion Diagram (Md-So) of Port-Bouet

3.6 Mineralogy of Beach Sediments

Chemical analysis reveals high levels of SiO_2 (Fig. 9). Other chemical elements have very low levels, which vary between 0.05 and 1%. Predominance of quartz (55%) is observed using polarizing microscope (Fig. 10). In addition to quartz, there are biotites (10%), feldspaths (8%), pyroxene (6%), ilmenite (6%), amphibole (5%), and sphene (2%).

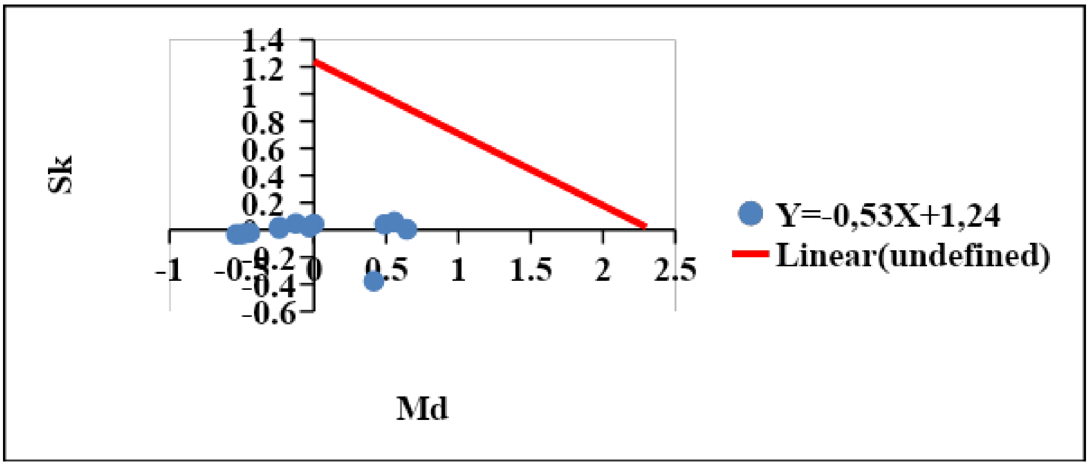


Fig. 8. Sands Dispersion Diagram (Sk-Md) of Port-Bouet

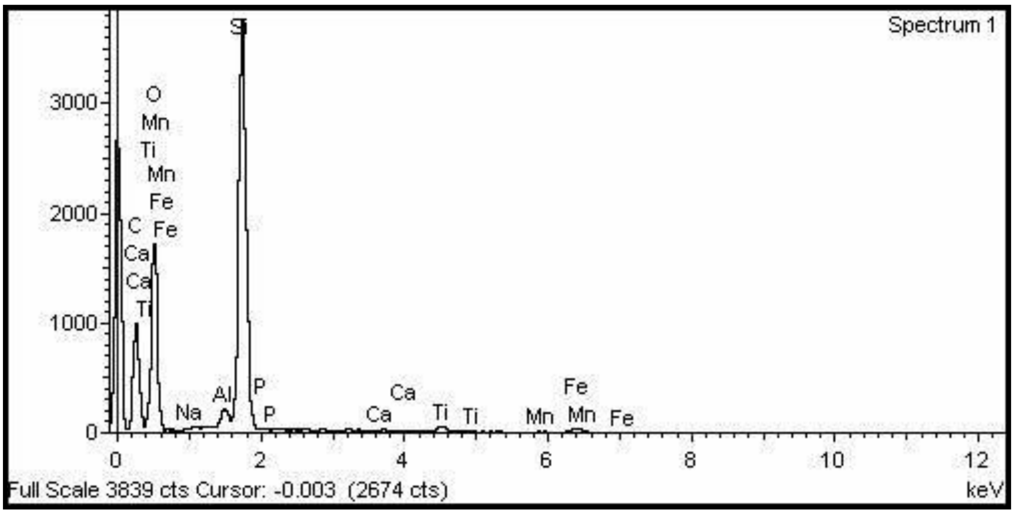


Fig. 9. Sediment spectrum using MEB

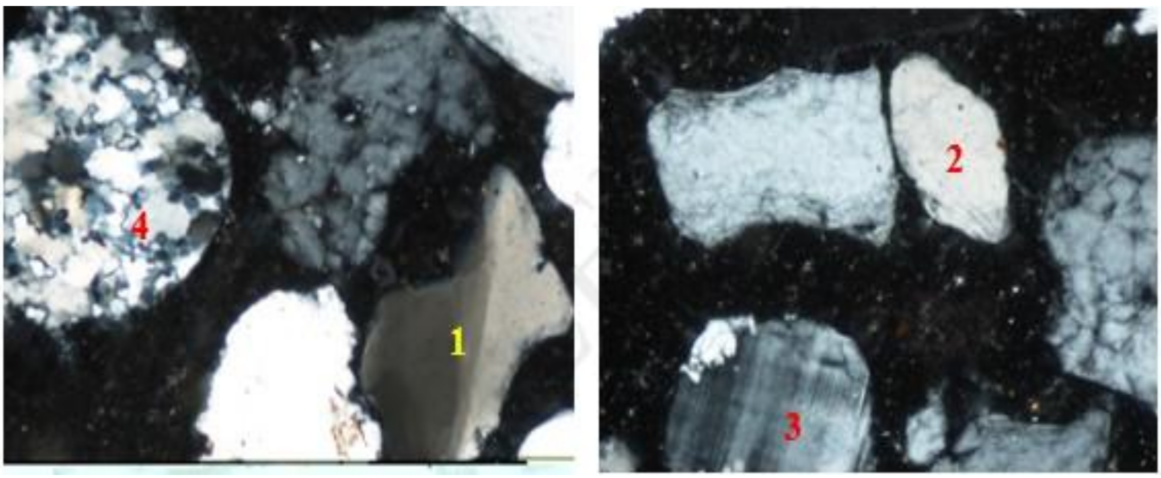


Fig. 10. Thin blade of sand using Polarized Light 1: albite with single macle; 2: Sphene; 3: plagioclase; 4: quartz with corrugated extinction

4. DISCUSSION

Study of granulometric characteristics during turbulent and calm (May and November) periods shows that sediments are coarser near the canal. This trend continues during both periods due to a granulometric selection resulting from West-Est coastal drift. Energy of waves may not be enough to drive coarser sand to East. This corroborates Mc Laren interpretation [23] from a type of sediments set supported by transportation, coarse (or heavy) grains are deposited faster than the fine grains (or light) particles. Based on this analysis, sediments at Palm Beach should be coarser than those at Petit Bateau. This is not always verified. This remark does not challenge original hypothesis because significant grain size sorting cannot occur over a short distance [24].

Observation of Mz-σ diagrams shows that sediment classification improves with increasing grain size. Complex swell plans related to the landless hole may explain the presence of very coarse sediments on the beach [25,26]. In this area, the average swell amplitude is 1.3 m [1]. Underwater beach (-10 m) should consist of coarse to very coarse sand [3,4].

5. CONCLUSION

Sand characteristics during both periods in Port-Bouët confirm presence of a West-East coastal drift, with sediments near the canal (Palm Beach and Petit Bateau) being coarser than those from Phare. Indeed, it is found a steady decline of grains size from west to east, which reflects a gradual deposition, by loss of load, of most coarse particles during their transit eastward under swell action.

The main mineral found in beach sand samples is quartz, with a percentage varying between 35 and 60%, depending on sectors. It is a very strong mineral and its abundance in sediments reflects a supplying source rich in quartz. In addition to the quartz, the mineralogical set on Port-Bouet beach is composed of biotite, pyroxene, plagioclase, microcline, sphene. Results of Moiola and Weiser tests show that the beach is fed mainly by the sand reserve at the underwater beach. Heavy mineral species, and the sand in which they are located, result from local inputs. However, it is certain that they are the exact sources of minerals, according to the complexity of deposits related to complex swell plans in this sector on one hand and, on the other hand, lack of detailed studies of heavy minerals in formations of the region that could feed directly or indirectly the studied deposits. These sandy minerals can be inherited from both metamorphic and eruptive rocks. Quartz, biotite, and feldspaths may come from alteration of surrounding rocks, particularly granites. These minerals should be transported to the beach from erosion of continental shelf granites. Across the study area, granulometric curves have a sigmoidal appearance. However, sigmoidal curves obtained at certain times have a very particular appearance. They tend to straighten, thus reflecting a large proportion of the coarse fraction and showing changing deposit conditions over time. Saltation is the mode of transportation that predominates in all sectors during both observation periods. Rates vary between 80 and 90% depending on the sector. Sediments transported by suspension and loading generally do not reach 12%.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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