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Impacts of the construction of Vridi channel on the coastal sediment stocks located between Abidjan and Jacqueville (Côte d'Ivoire)

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Abstract :
This work is a contribution to the knowledge of sediments and morphology changes of the coast between Abidjan and Jacqueville. The method used for this purpose is based on processing, analysis of topographic profiles and sand sampling collected on the field during successive surveys which were conducted from the year 1998 to 2008. The approach resulted in the identification of a sedimentary deficit of -2500 m^3 in Port-Bouët and a positive sediment budget +2300 m^3 in Jacqueville. This feeding engrossment causes a coastline progradation of 13.5 m. Sediments study highlights the various sediment stocks on both sites. On one hand, there is a stock mainly composed of coarse and polished material in Jacqueville indicating a long water way carriage, and on the other hand, there is a main stock of sub-angular to angular and very coarse materials in Port-Bouët showing the closeness of the purveying source. This study highlights the effects of protection works realized on the port channel on the distribution of facies between Jacqueville and Port-Bouët.

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1. Introduction

Coastal erosion is a major phenomenon in the world. Half of the seashores are affected on the earth. Growing human activities amplify the phenomenon. In Côte d'Ivoire, Vridi channel is an example. In fact, before the breakthrough of the Vridi channel, the sand deposit in the bay of Port-Bouët due to west-east littoral drift had caused a progradation of the coastline of the order of 1 m/year (PELNARD, 1973). The trend was reversed after construction of west and east wing walls respectively in 1943 and 1950 and later on the construction of a sand dam in 1973 (TASTET *et al.*, 1985). This sector affected by coastal retreat contains the country's key economic infrastructure including the airport and particularly the Autonomous Port of Abidjan, which is the country's first economic sector.

This study follows previous work realized on this coastal segment (TASTET *et al.*, 1985; TASTET, 1987; KOFFI *et al.*, 1987; YACE, 1987; HAUHOUOT, 2000; EBA, 2005). The latest study indicated that the dynamics of Dora wreck site was under the influence of the Port protective structures at the entrance of Vridi channel with a progradation of the order of 50 m from January 1986 to September, 2004. However, the stated study, as the previous works do not provide enough information on Jacqueville's beach dynamics. Therefore, the present work is initiated to bridge the information gap and get an accurate idea about the evolution of the sand beach. In addition, Port-Bouët coastal scope is an environment where the changes are sometimes quick. This constitutes a serious threat to local residents and authorities. The coastal retreat induced by the Port facilities has severe consequences such as building destructions and reduction of constructible space. Data updating is therefore necessary for the sediment dynamics in this high socio-economic area. The present complementary study will combine our current results with those of previous studies to highlight the evolutionary trends relevant to coastal management.

2. Study area presentation

2.1 Geological and morphological framework

The area of study (Figure 1) belongs to the Ivorian sedimentary basin, which represents 3/5 of the Atlantic coast of the country (TASTET, 1972). It covers an area of 30,000 km^2, the majority of which is submerged. The visible part forms a crescent between Sassandra and the Republic of Ghana (DELOR *et al.*, 1992). It is crossed from west to east by a major fault (TASTET, 1979). North of the fault, the superficial formations are composed of clays, clayey more or less ferruginous sands and sandstone of the Continental terminal (DELOR *et al.*, 1992).

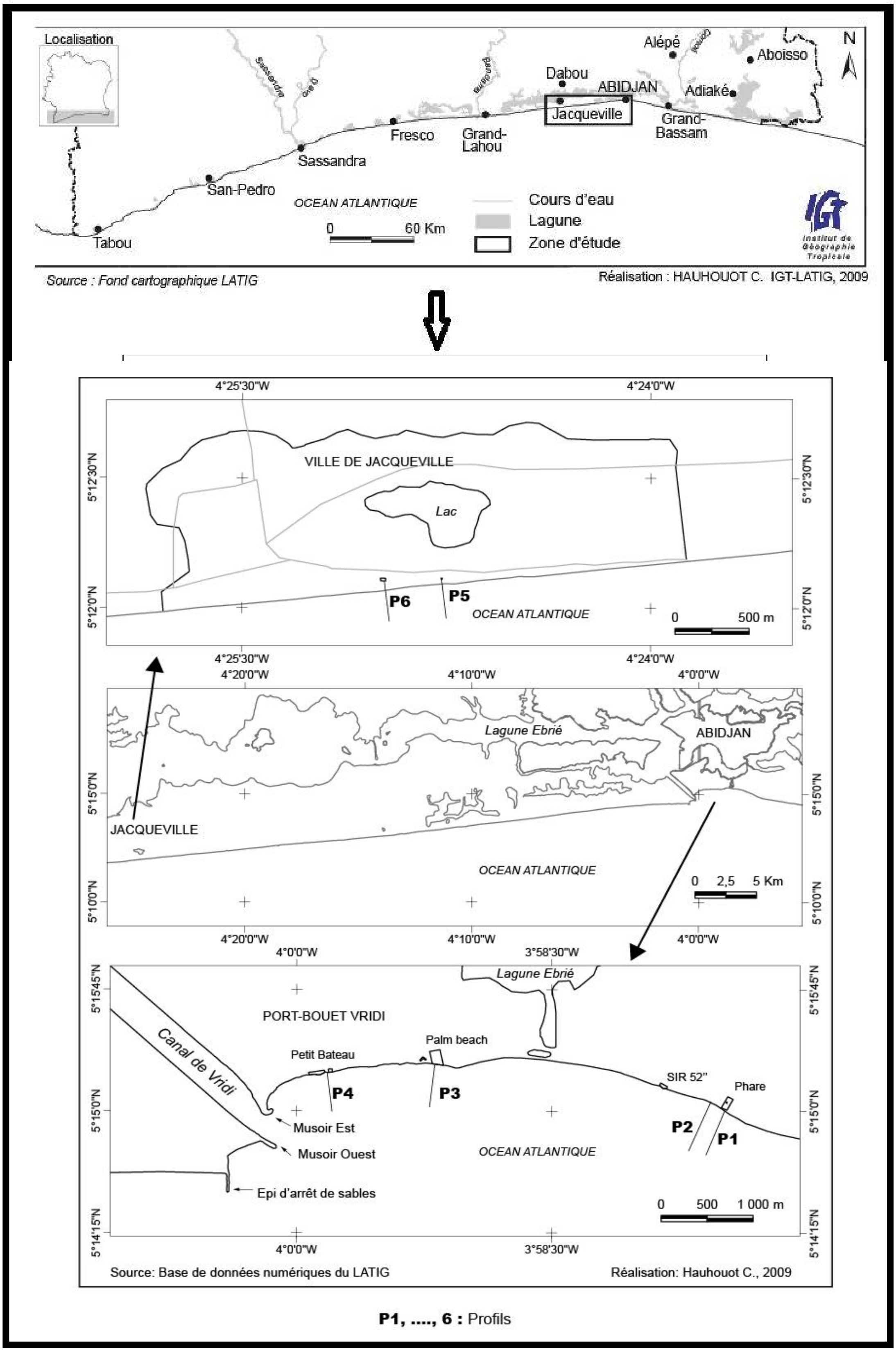

Figure 1. Location of the study area.

In the south, surface formations are quaternary deposits of sand and continental clays, white sands and river-lagoon marine clays and sands (DELOR *et al.*, 1992). From a geomorphologic point of view, the formations of the continental terminal are "high plateau" with altitudes ranging from 50 m to 110 m, while the quaternary deposits form a low coastal plain in the southern part of the lagoons. From the western end of Grand-Lahou lagoon to the republic of Ghana, the coastline is formed by a sandy beach backed by barrier beaches of variable thickness. To the west of Abidjan, cords form a narrow sand strip some hundred metres wide. From Abidjan they extend inwardly over 4km width. The shore between Abidjan and Sassandra is oriented in the 81° (ABE & KABA, 1997). In Abidjan the direction changes and moves to 100° into Ghana (ABE, 2005). This shift divides the study area into two different dynamic sectors considering the angle of wave attack.
These two areas are constituted of reflective beaches (HAUHOUOT, 2000; ABE, 2005). The beach configuration is not favorable to the construction of underwater tidal sand bars (DESMAZES, 2000; 2001). In Port-Bouët, the beach is generally uniform. On the contrary, in Jacqueville, continuous rocky banks were identified in the nearshore zone (MARTIN, 1973; AKA, 1991; MONDE, 1997) (Figure 2).

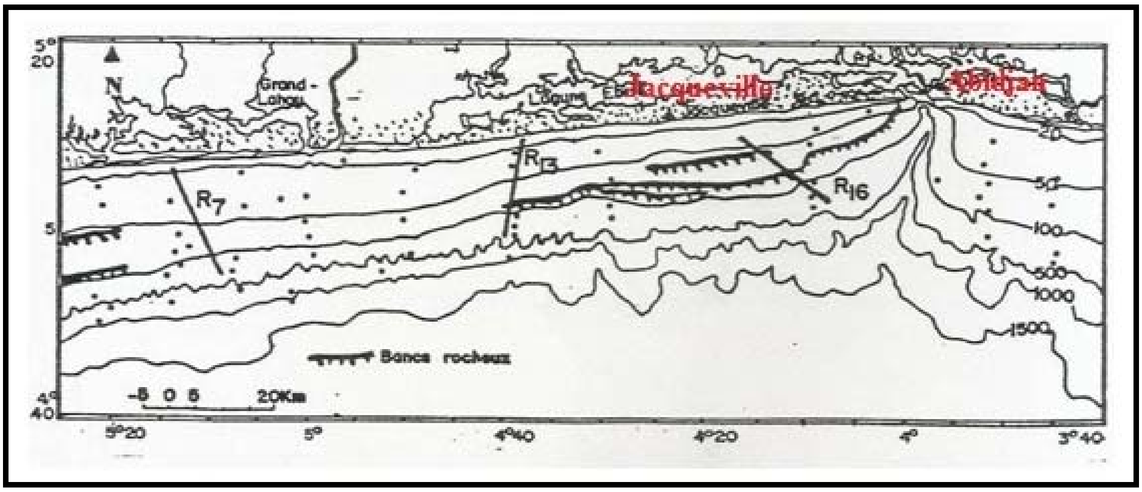

Figure 2. Bathymetric contours of the Ivorian continental shelf (AKA 1991).

2.2 Dynamic agents

In the region, the shore is frequently beaten by waves of 0.80 and 2.00 m amplitude, and 10 to 12 seconds period. Exceptionally, waves of greater amplitude up to periods of 20s break on the coast (VARLET, 1958). They are very destructive. Swells that usually occur in the region, despite their average characteristics have significant morphological effects on the coastline in the present dynamic environment. They approach the shore with a southwest to south preferred direction. South-southwest oriented swells approach Grand Lahou-Abidjan coast segment with a 60° angle (HINSCHBERGER, 1977) so that a strong shore drift estimated at 800,000 m^3/year of sand occurs (MARTIN, 1973). It is therefore a coastal segment dominated by sediment transport. It is also a coast where erosion is significant because, if we consider that the segment receives about 200,000 m^3/year of sands from the West Coast (Tabou-Sassandra), we understand that the difference comes from sedimentary stocks of the region (MARTIN, 1973). Stabilization of the shore, the "permanent" presence of micro cliff (2 to 3 m) and the destruction of buildings observed on the backshore are other effects of the coastal erosion.

To the east of Abidjan, south to southwest swells approach the coast with an 85° angle (HINSCHBERGER, 1977). They are almost perpendicular to the coast which significantly reduces the effectiveness of the coastline drift. This area is favorable for deposits; the occurrence of drift in the opposite direction generated by southern swells also contributes to the accumulation. However, in front of Abidjan the "Trou-sans-fond" (name given to the canyon that cuts underwater continental shelf in front of Abidjan) and the presence of the Vridi channel make sediment dynamics much more complex. The general characteristics of waves in front of Abidjan are shown in Table 1. Other marine agents have little impact on the coastal dynamics. The superficial Guinea current and its counter-current do not impact directly on the coastline morphology. They redistribute on the continental shelf fine particles expelled at sea by rivers. The Guinea current is effective between zero and thirty metres. Particles are spread towards the east. Beyond thirty metres, the counter-current traps particles; it moves them in the opposite direction and releases them at the west side of river inlets (MARTIN, 1973). The tide in Côte d'Ivoire is semi-diurnal with one metre amplitude (VARLET, 1958). It is too small to influence the coastal morphology in a significant way. At most, the currents associated with tide reshape the tip of sand banks that form in the inlets. The tidal range recorded at the Port of Abidjan varies between 0.40 m in neap and 1.30 m in high waters (VARLET, 1958).

Table 1. Characteristics of swells in front of Abidjan (TASTET et al., 1985).

Swell	*Amplitude (m)*	*Period (s)*	*Direction at shore*	*Annual Frequency*	*Season of dominion*
Feeble	*0,8 - 1*	*7 - 11*	*S – SW*	*30%*	*Nov. - Dec.- Jan.*
Average	*1 – 2*	*10*	*S – SW*	*50%*	*Whole year*
Strong	*1,8 - 2*	*10 - 20*	*S – SW*	*20%*	*May - June*

3. Working materials and methods

Fieldwork realized in 2006, 2007 and 2008 were topographic surveys of lines perpendicular to the shoreline using optical levels, 4 m leveling rods and tripods.

Surveys were conducted in order to compare them with previous data obtained from topographic profiles calibrated to reference marks. The Research Centre of Abidjan provided the data date from 1998 still unexploited. Regarding Port-Bouët area, March 1990 profile was associated to enrich knowledge. Lack of data for that period as regards Jacqueville area does not diminish the interpretation of other profiles. The surveys were carried out at low tide to explore a maximum width of the beach. In this study, the upper side of the beach was taken as representative reference line of the coastline. In the case of sandy coastline, the upper side of the beach turns out to be the most reliable (ROBIN, 2002).

It is marked by a break in the slope easily identifiable (Figure 3). Sediment budgets are based on the determination of eroded and/or accretion areas using the trapezoidal rule (BRABANT, 2003). Superficial sand were sampled during each profile survey on the high beach area and low foreshore for particle size and morphoscopic studies in order to see if there are significant differences in the sediment beaches material. Sands particle size analysis was performed after a 15 minutes sieving through a 13 sieves column in accordance with the AFNOR standards. The results were interpreted according to standard sediment processes (FOLK & WARD, 1957; FRIEDMAN, 1967). The morphoscopic analysis consisted of sorting particle fractions ranging from 250 to 400 µm, reference size proposed by CAILLEUX (1943) and ranks them after observing them through a binocular microscope, two criteria were taken into account: the shape of the grains and the state of their surface. Estimating sphere and blunt quartz grain was made according to scale of Power (1953, *in* ROCHELEAU, 1997).

In order to better visualize the shape and appearance of quartz grains, analyzes are conducted using a scanning electrons microscope (SEM). SEM type FEG SUPRA 40 VP Zeiss has an X-ray microanalysis system and energy dispersive spectrometry (EDS). Sample processing by SEM consisted of sweeping quartz grain surface with an electron beam. In response, these grains have issued some particles. Then these particles were analyzed by EDS detector. This allowed reconstruction of a three-dimensional image of the quartz grain surface. These analyzes by SEM are required in order to obtain enough accurate information regarding the origin of the sandy material.

Figure 3. Erosion threat at the level of Hotel Le Baron in Port-Bouët.

4. Results and interpretation

4.1 Morphological evolution of beaches

4.1.1 Evolution of the beach in Jacqueville

In Jacqueville, profiles have a convex shape and indicate a favorable zone for accumulation (Figure 4). This sector is gaining sandy material estimated at +2300 m^3. It results in an estimated 13.5 m coastline progress. The eroding dynamics in this sector located downstream of the beach in Grand-Lahou is hard to explain; for these two beach areas are located on a portion of perfectly straight sandy coast oriented in 81° (TASTET, 1972). In fact, the shoreline perimeter of Grand Lahou underwent a retreat of about 1 m/year (N'DOUFOU, 2005). Losses recorded in the mouth of the sector were estimated at 10.7 ha from 1993 to 2006 (HAUHOUOT, 2008). One can assume the hypothesis that the Jacqueville beach is fed by contributions from neighboring areas in erosion specifically the Grand-Lahou beach.

Like the sand bars that play an essential role in the beach dynamics, particularly in terms of erosion and change of the coastline during storms (LIPPMANN & HOLMAN, 1990), the continuous rocky banks located in front of Jacqueville beach (Figure 2) should mitigate wave's effect and confirm the hypothesis. This phenomenon has already been described in other coastal regions, among others, the Ghanaian ribs (AKOBÉ, 2010). Jacqueville beach should not logically be influenced by works located at forty kilometres. Moreover, evidence on the ground shows that this dynamic is prior to the first developments in the channel area.

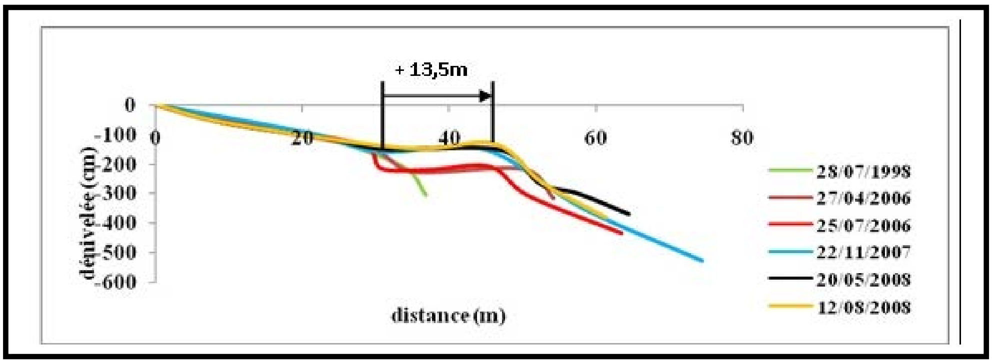

Figure 4. Evolution of the beach in Port-Bouët.

4.1.2 Evolution of the beach in Port-Bouët

In Port-Bouët, profiles are mostly concave in shape. Superposition of profiles shows two major periods in the coastline evolution (Figure 5). From March 1990 to July 1998 there has been a significant erosion of the beach showing a decline of 7.6 m from the coastline. In this sector, port facilities reduce the sediment stocks mobilized on the shore and accelerate erosion. The next period from July 1998 to September 2008 sees erosion progress, specifically in the lower beach area. Sediment balance is negative and is estimated at -2500 m^3. The coastline however remains unchanged while the high beach area is almost stable. We can therefore consider that surprisingly the reduction of the sand stock does not necessarily leads to a decline in the shore. In fact, the coastline has undergone a retreat of about 1 m/year from 1990 to 1998 before being stabilized by the road due to rocks resistance (asphalt, gravel, ...) used in the embodiment of the road infrastructure (Figure 5 and 6). The coastline stability in this unstable deemed area (TASTET *et al*., 1985; HAUHOUOT, 2000; ABE, 2005) could be explained as well.

Between July 1998 and September 2008, the largest sediment movements took place on the low beach area. This looks normal because the beach is party subject to combined effects of tides and waves (DESMAZES, 2005). These are the most important hydrodynamic factors which influence and determine the dynamic behavior of the beaches (IBE & QUELENNEC, 1989). In addition, the low beach area is the area where the swelling energy is the strongest (ZEIGLER & TUTTLE, 1961). From September 2007 to November 2007, the beach recovers gradually. This dynamic corresponds to the months where the swell is less agitated and indicates a sedimentary sand movement towards the coast. The reconstitution is interrupted from May to July 2008. During that period, the sea is very rough (TASTET *et al*., 1985).

Natural phenomena significantly contribute to both morphologic and sediment change of the beach. The segment recorded during the study period, violent storms particularly in August 1993, April 1997, and August 2007 (Figure 7). If we refer to storms frequency, the following deduction is necessary: that of the predominant possible

impact on this coastal segment, hence the need to relate the information because they are very useful to understanding the evolution of the beach area.
In 1984, the phenomenon which lasted only one night had reduced the coastline of 20 m near Port-Bouët lighthouse (ABE & N'GUESSAN, 1995). The beach of Port-Bouët has a complex functional system because it is difficult to distinguish between marine dynamics (storms in particular) and the action of coastal structures (groins and jetties) over the long term.

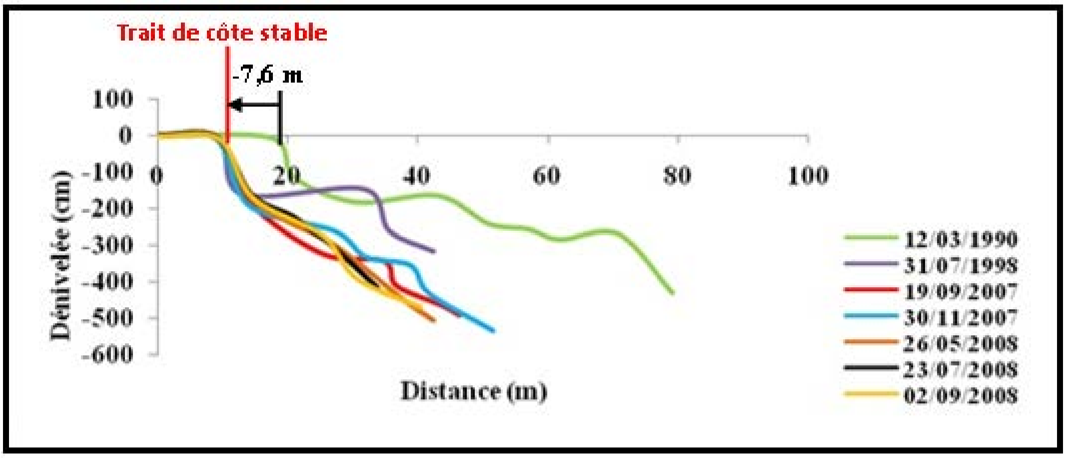

Figure 5. Evolution of the beach in Port-Bouët.

Figure 6. Road interrupted by erosion at Port-Bouët lighthouse.

Figure 7. Damages caused by Aug. 2007 storm at the west side of the lighthouse.

4.2 <u>Study of beach sedimentology</u>

4.2.1 Particle size in western Vridi channel

In Jacqueville, size distribution of sand sampled along profiles shows that sediments are moderately graded $0.53<\sigma<0.62$ with an abundance of coarse sands of $592<Mz$ (µm)<626. The beach sands are symmetrical $0.00<Sk<0.01$ (see Table 2).

4.2.2. Particle size in eastern Vridi channel

Near the channel (Palm Beach and Petit Bateau, see Table 2) the sand is very coarse ($1078<Mz$ (µm)<1419), although classified ($0.42<\sigma<0.47$) and balanced ($-0.03<Sk<0.04$).

At the lighthouse (see Table 2) the sand is coarse ($764<Mz$ (µm)<821). Low intertidal sediments are symmetrical and well sorted. However, those in the upper tidal they are moderately classified with a strong asymmetry towards the coarse elements. Particles classification substantially decreases toward the upper beach area, indicating that a sorting or a winnowing is carried out as per deposit. Very coarse sediments seen in Port-Bouët demonstrate a high energy environment. In this area, the nearby canyon amplifies wave energy (TASTET *et al.*, 1985).

Table 2. Parameters of sand particle size at Port-Bouët and Jacqueville.

		Average (µm)	***Variance-type (σ)***	***Skewness (Sk)***
East Channel of Port-Bouët	*P2 HE* ***Lighthouse***	*821*	*0,58*	*-0,38*
	P2 BE ***Lighthouse***	*764*	*0,48*	*0,04*
	P3 HE ***Palm Beach***	*1078*	*0,48*	*0,04*
	P3 BE ***Palm Beach***	*1419*	*0,42*	*-0,03*
	P4 HE ***Petit Bateau***	*1362*	*0,43*	*-0,02*
	P4 BE ***Petit Bateau***	*1183*	*0,47*	*0,05*
West Channel of Jacqueville	*P5 HE* ***Monument***	*592*	*0,62*	*0,01*
	P5 BE ***Monument***	*626*	*0,53*	*0,00*

The grain size study shows that the sediments are coarser in the east of the channel i.e. in the direction of sediment transport (Figure 8) unlike the proposed model of MC LAREN (1981). This distribution of facies observed on both sides of the Vridi channel would be the result of two phenomena: a change in the dynamics of the environment in Port-Bouët, a dynamic influenced by the presence of the Trou-sans-fond; blockage of sediments moving up from the west by the groin and a new source of sediment from the perimeter of Port-Bouët shoreline and this as stated by the model of Mc LAREN (1981) the size of the sediment gets finner in the direction of transport.

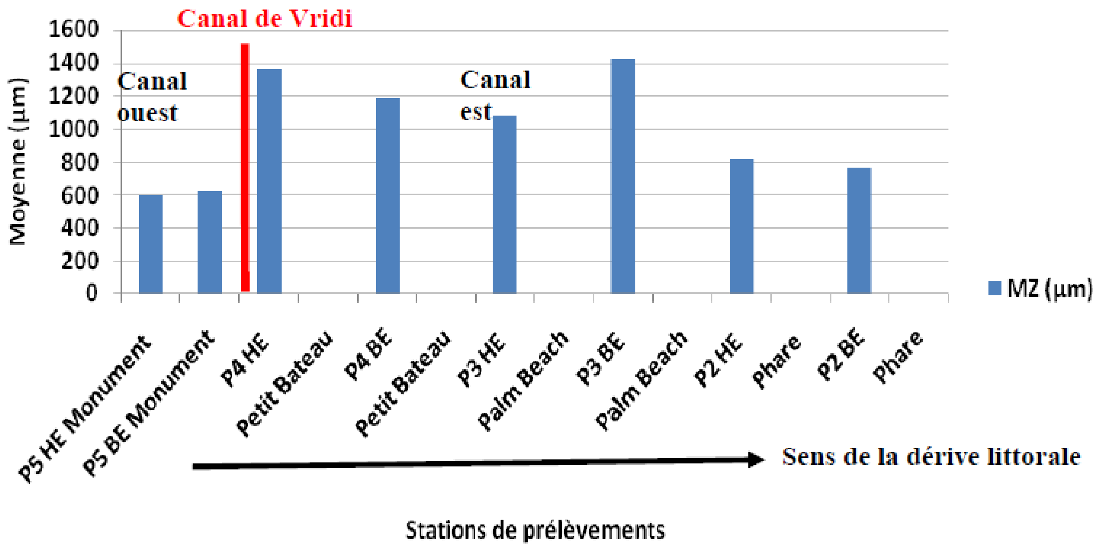

Figure 8. Change in the average grain size on the eastward and westward foreshore of Vridi channel

4.2.3 Morphoscopy and exoscopy of quartz grains in the west of Vridi channel

Morphoscopic and exoscopic analysis shows that the quartz grains are generally sub rounded and shiny rounded (Figure 9a and 9b). Their proportion varies between 70 and 80%. We distinguish aquatic polished friction types (Figure 9d). The polishing tends to erase traces of shock. This can be explained by a prolonged stay in the swelling action area. Rounded matt (Figure 9c) were observed in conjunction with the blunt shiny. Their representation is low (10-15%) and show a transportation of long distances (SAAIDI 1991). The matt aspect is produced as a result of many shock of grains (VATAN, 1967). Some authors attribute this aspect in a calcite cementation (LINDHOLM, 1987). Non worned grains occur in very small proportion (<3%).

4.2.4 Morphoscopy and exoscopy of quartz grains in the east of Vridi channel

Quartz grains are mostly sub-angular to angular (65 to 83%) (Figure 10a and 10d) followed with secondarily sub blunted and shiny elements (<5%) (Figure10b). Quartz grains the contour of which is angular is characteristic of a transmission over a short distance (SAAIDI, 1991). Very rounded grains are observed together with zero (or little) worned out grains (Figure 10c). Their proportion varies between 1 and 2%. These very rounded grains which show transport over a long distance escaped through the sand stopping dike due to their very small proportion.

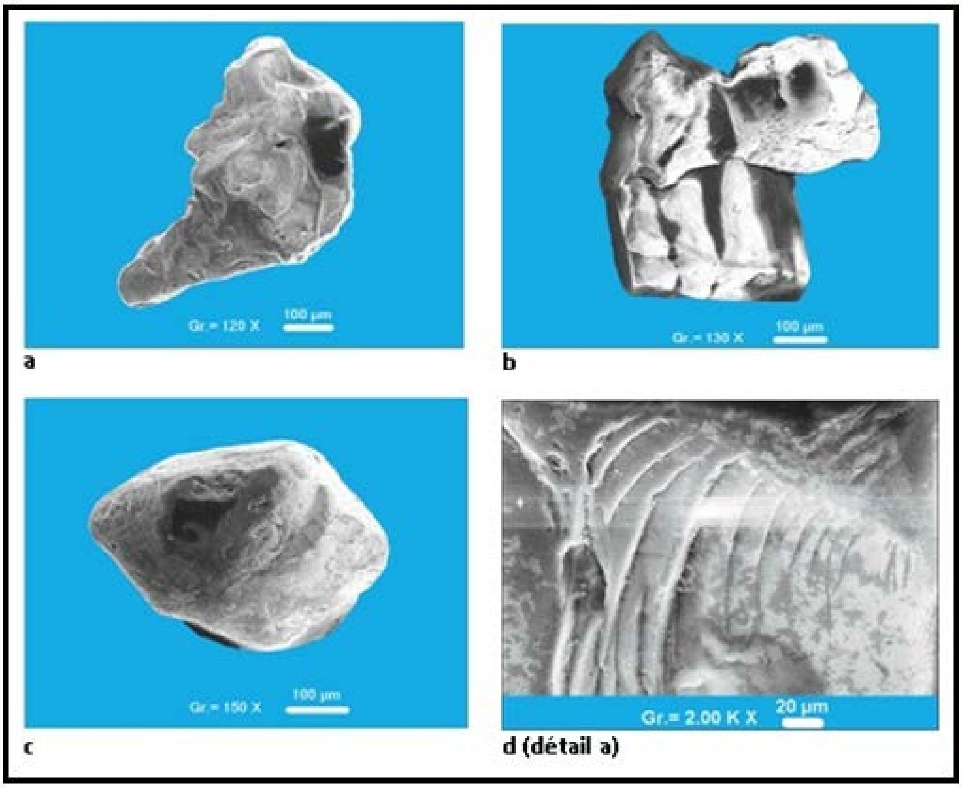

Figure 9. Quartz grains in west of Vridi channel (Jacqueville).

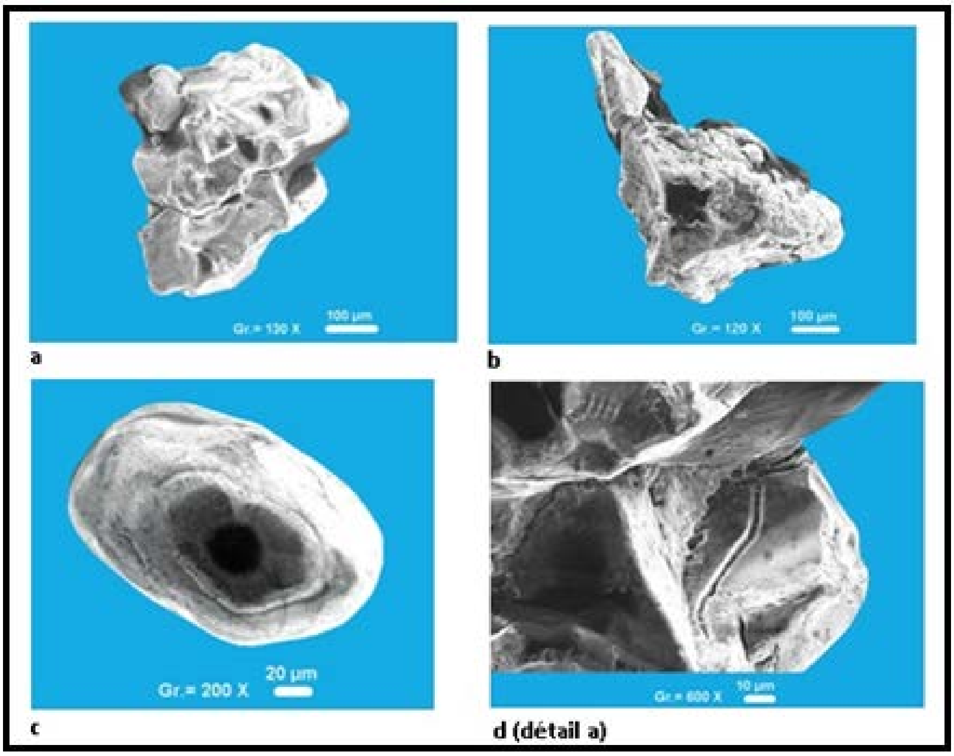

Figure 10. Quartz grains in east of Vridi channel (Port-Bouët).

5. Discussion-conclusion

The comparative study of both sites permits to highlight two distinct morphologic and sediment areas. One is located at the east of the channel, merely powered by the lateral movement of the sandy material, in erosion (-2500 m^3). This sector is the result of sediment transport interruption from west to east at the sand stopping dike with a retreat of 1 m/year. Works done by TASTET *et al*. (1985) showed erosion of the coastline toward the east of Vridi channel and accretion to the west since the construction of the sand stopping dike in 1973. These observations were confirmed by YACE (1987), HAUHOUOT (2000) and ABE (2005). The results of this study are coherent with the above mentioned work. However, in the present study the evolution of the beach is marked by a shoreline stability from 1998 to 2008, meanwhile previous works rather describe a continuous retreat of the shoreline.

In fact, the conventional operational scheme predicts a retreat of the coastline during storms, due to sand moving offshore (STIVE & DEVRIEND 1995). In our study, the position of the coastline is relatively stable while the trend is towards erosion. This is due to the fact that erosion does not affect the upper beach area, which is strengthened by the bitumen. It only affects the low beach area. We deduce that the morphological units can progress independently in accordance with the work of SABATIER (2001) showing that on the coast of the Rhône delta, the position of the coastline remains fixed while the front coast bars recede. The results and those of previous studies reinforce the erosion threat on infrastructure that is adjacent to the shore. However, Jacqueville beach area engrosses (+2300 m3). It is estimated at about 1 m/year. This beach area would be fueled by contributions from eroding neighboring areas.

Accretion in this beach area should be useful in the context of Port-Bouët bay reloading. Facies distribution on both sites reveals existence of two sedimentary stocks. On one hand there is a stock in Jacqueville constituted mainly of coarse sediment, dull and shiny materials, which highlights the influence of a long water carriage by streams and the influence of fluvio-marine dynamics. In Port-Bouët, the study shows a stock mainly constituted of very coarse, sub-angular to angular materials. The presence of these non (or little) worned out grains reflects a closer input source. In Port-Bouët, sandy materials indicate higher size values than those reported by YACE (1987) and ABE (2005). This can be attributed to the exceptional storms of August 2007 during which temporary storage of sandy material occurred on the beach. These storms should encourage deposition of very coarse sediments on the beach during the run-up due to the very high wave energy. On the contrary, when moving offshore, the speed of the current is low; the fraction of coarse sediments could not be driven out to sea.

Wave actions also induces sediment sorting, fine sediments are winnowed to sea while coarse sediments accumulate on the coast (ZENKOVICH, 1946; MURRAY, 1967). The different stocks identified between Abidjan and Jacqueville are related to natural factors and the rocky banks recorded off Jacqueville to which must be added the development work conducted at Port-Bouët, including the sand stopping dike. If no specific development is realized, the Port-Bouët bay will continue to undergo the phenomenon of erosion threatening tourism development and socio-economic infrastructure, and Jacqueville beach will grow sandy at a rapid pace. Such information is useful in the coastal area management.

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