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Morphologic response of four pocket beaches to high energy conditions: including the Xynthia storm (South Brittany, France).

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ABSTRACT

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This work highlights the morphological behaviour of four reflective pocket beaches (Fogeo, Kerver, Govelins and Suscinio) during an episod of high-energy events cumulating in the *Xynthia* storm. A total of 23 topographic profiles were surveyed monthly at spring high tide using a DGPS. Located in the atlantic French rocky coastline, the studied beaches present a “low-tide terrace” morphology. They are sheltered from the Altantic wave climate by the Quiberon peninsula and islands. During high-energy conditions, the break in slope moves landward with an increasing upper beachface gradient (tanβ). For example, tanβ increased from 0.108 to 0.126 in the center of Kerver beach and the break in slope moved 4.8 m landward. This does not follow the morphodynamic behavior expected for the morphological parameters of these beaches. This trend is reversed during low-energy conditions. High-energy conditions, and especially the *Xynthia* storm, caused a massive erosion (about 10% of the initial volume) in the Suscinio embayed beach whereas the three other beaches underwent an accretion (around 2%). In spite of this erosion, the western profile of the Suscinio beach accreted which suggests a longshore drift oriented westward assimilated as a beach rotation. On other beaches, The accretion is not uniform on all beaches but it suggests a cross-shore sediment transport from the lower shoreface to the upper shoreface also associated with a beach rotation. These results highlight the importance of geological settings and wave diffraction to the variability of morphological response with high-energy events of closely-spaced reflective beaches and the need to be taken into account for predicting morphological model as much as oceanographic parameters.

Keywords: reflective beachface, beach gradient, rocky coast, beach rotation, sediment volume variations..

INTRODUCTION

Sandy beaches are some of the most active geological systems in the world. They are subject to wave climate and their topography and morphology respond to high and low-energy conditions. Storm surges, undertow processes, and wave breaking cause a rapid erosion by offshore sediment movement whereas low-energy conditions slowly increase beach sediment budget.

Swell dominated beaches respond on a seasonal temporal scale, from a steep beach face for low-wave energy (summer) to a flatter profile induced by high-wave energy (winter) (Nordstrom, 1980).

Wright (1980) and Wright and Short (1982) suggest that during stormy conditions steep sectors are more exposed to erosion than flatter ones. Moreover, Shih and Komar (1994) highlight the more susceptible coarse sand steep reflective beaches to episodic storms than more dissipative ones, due to swash motions characteristic. Recently, in China, Hongshuai *et al.* (2010) show that a low-tide terrace beach has a strong response to storms with marked changes to the upper profile while more dissipative beaches have a smaller response to intensity. In Ireland, headland embayed beaches morphodynamic is not only controled by beach parameters but also by geological settings (Jackson *et al.*, 2005).

The morphodynamic of South Brittany beaches is not well documented. Nevertheless, Dehouck *et al*. (2009) related the morphodynamic of pocket beaches in western Brittany. Regnault *et al*. (2004) underline that the sea floor morphology of the western France coastline accounts for different responses of neighbouring beaches’ behaviour under stormy conditions, because of an intense wave refraction. Furthermore, Regnauld and Louboutin (2002) explained that Rhuys peninsula beaches erosion or accretion do partly depends on cyclonic to anticyclonic conditions. Recently, Pian (2010) described the patterns of the Rhuys peninsula beaches and discussed the areas more vulnerable to erosion. This work aims to consider and understand variable morphologic responses for four closely-spaced reflective beaches, considering different shoreline orientations, under variable wave-energy conditions.

GENERAL SETTINGS

Beaches morphology

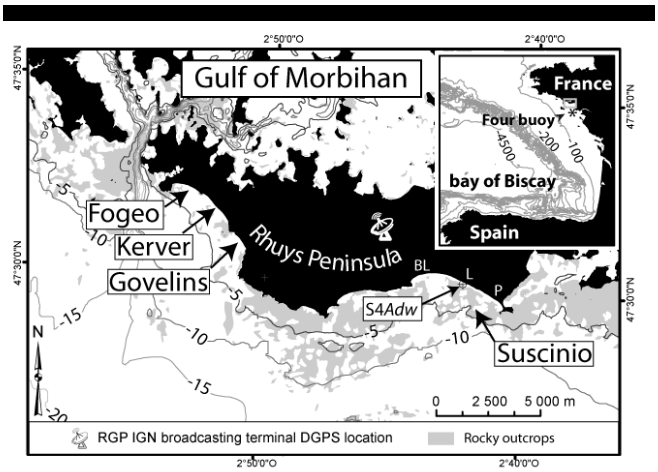

Figure 1: Locations of the four pocket studied beaches, the RGP-IGN broadcasting terminal used for DGPS post-treatment correcting datas and the S4*Adw* during the *Xynthia* storm. BL=BegLann, L=Landrezac and P=Penvins.

The south Brittany coast is composed of hard igneous metamorphic rocks inherited from the Hercynian orogeny. Faults and differential erosion has led to a ragged coastline. Thus, the shoreface of south Brittany shows mainly seacliffs and pocket beaches. Fogeo, Kerver, Govelins and Suscinio beaches are the four pocket beaches studied in this paper and are located south of the Rhuys peninsula (Figure 1).

This area, sheltered from the Atlantic wave climate by the Quiberon peninsula and islands, is a rocky coast context with low sediment supply (Menier *et al.*, 2010. The studied beaches present reflective "low-tide terrace" beachface following the classification of Wright and Short (1984) with a steep upper reflective beachface composed of coarse material and a gentle flat dissipative lower beachface made of fine cohesive sand. A break in slope associated with exfiltration of the water table separates these features. Most of the time, the beaches are featureless. However, Suscinio beach shows rythmic megacusps between its central and eastern parts.

Hydrodynamic conditions

The Four buoy, provided by the C.E.T.M.E.F (Centre d'Etude Technique de la Mer Et Fluviale) is more exposed to the Atlantic wave climate than the Rhuys peninsula beaches. Less energetic, the Rhuys peninsula shorefaces are subdued to energetic conditions recorded by the Four buoy. For example, a S4*Adw* (wave-gauge currentmeter) has been deployed in the centre of the Suscinio embayed beach, in the intertidale zone (Figure 1), from the 26th of February to the 5th of March 2010, including modal and energetic conditions.

The *Previmer* wave propagation model, provided by the Ifremer and the S.H.O.M (Service Hydrographique and Océanographique de la marine) displays, from offshore hydrodynamic records (including the Four buoy), values of significant wave height at the shoreface of the studied area. These values given by the *Previmer* model at the Suscinio beach correlated to the S4*Adw* records during the period of deployment indicated a good correlation (Figure 2a). In addition, the model predicts a lower hydrodynamic agitation for Fogeo, Kerver and Govelins beaches (Figure2b) compared to Suscinio. The obtained expressions are given by:

Hs (*Previmer* S) = 0.96 Hs (S4*Adw* measures) with $R^2 = 0.57$ (1)

and

Hs (*Previmer* FKG) = 0.83 Hs (*Previmer* S) with $R^2 = 0.87$ (2)

Where F=Fogeo, K=Kerver, G=Govelins and S=Suscinio

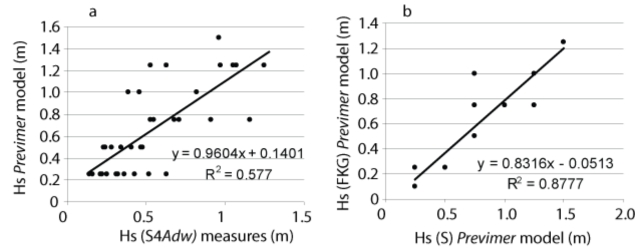

Figure 2: Relationships between significant wave height predicted by the *Previmer* model and measured by S4*Adw* at Suscinio beach. F=Fogeo, K=Kerver, G=Govelins, S=Suscinio.

Fogeo, Kerver and Govelins are thus under less energetic-wave conditions than Suscinio. In addition, this model provides wave directions of propagation with minor changes in direction for the four studied beaches. Nevertheless, taking account of rocky headlands and shore platforms standing between pocket beaches, a strong wave refraction and diffraction occurs in each site. This plays a significant role in longshore sediment transport but unfortunately, no sensors have yet been deployed in Fogeo, Kerver or Govelins beaches to measure such phenomena and any differences on wave direction of propagation in each site.

During the period of experiment, three phases of agitation are identified (Figure 3). The first one refers to a low energy-wave conditions. It corresponds to the period from the 11th of January to the 21st of February 2010. During this period, significant wave height Hs > 2 m occured over 100 hours and Hs > 3 m occured for 15 hours. The second phase, more energetic, occured from the 21st of Febuary 2010 untill the 3rd of March 2010. During this period, Hs > 2 m exceeded 150 hours within 9 days, culminating

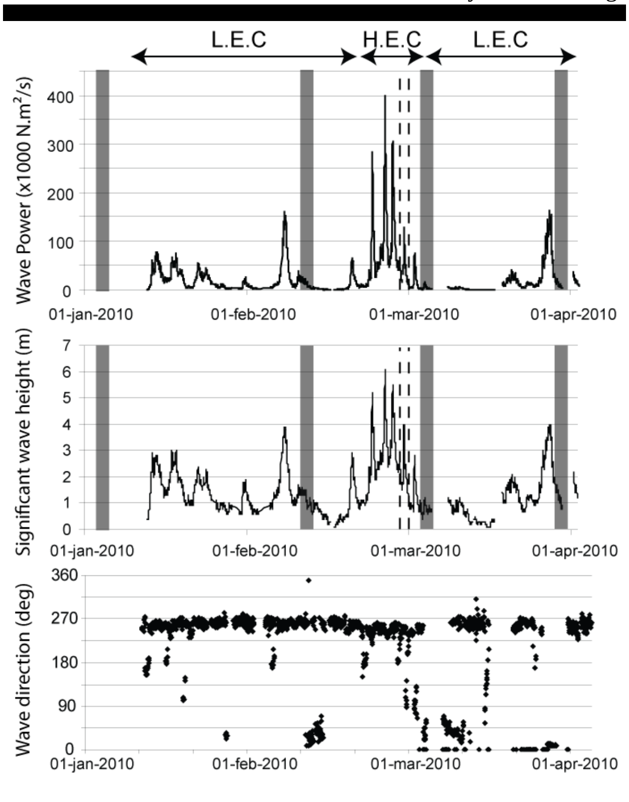

Figure 3: Offshore hydrodynamic parameters recorded by the Four buoy. L.E.C and H.E.C reffer respectively to Low Energy Conditions and High Energy Conditions. During H.E.C dotted lines indicates the special *Xynthia* storm topographic survey at Suscinio beach.

Table 1: Variations of upper and lower beach gradients and the break in slope distance to the shoreline observed for the four main topographic surveys involving the 23 profiles of the four beaches. Grey columns indicate results after the High Energy Conditions. BL=BegLann, L=Landrezac and P=Penvins.

		January			February			March			April		
		tan β		Break slope distance to shoreline (m)	tan β		Break slope distance to shoreline (m)	tan β		Break slope distance to shoreline (m)	tan β		Break slope distance to shoreline (m)
Beaches	profiles	upper	lower		upper	lower		upper	lower		upper	lower	
Fogeo	1	0.096	-	-	0.079	0.031	61.6	0.092	0.036	59.2	0.087	0.036	61.3
	2	0.089	-	-	0.077	-	-	0.091	0.038	64.8	0.089	0.035	65.3
	3	0.089	-	-	0.083	-	-	0.095	-	-	-	-	-
	4	0.093	-	-	0.086	-	-	0.099	-	-	-	-	-
	5	0.104	-	-	0.099	-	-	0.107	-	-	-	-	-
	6	0.101	-	-	0.103	-	-	0.109	-	-	-	-	-
Kerver	1	0.101	0.028	61.2	0.095	-	-	0.111	0.025	60.6	0.107	0.023	62.0
	2	0.113	-	-	0.109	0.029	53.4	0.115	0.027	45.7	0.112	0.026	49.6
	3	0.122	0.018	40.2	0.108	0.018	45.6	0.126	0.018	40.8	0.124	0.018	42.4
	4	0.123	0.023	41.1	0.112	0.020	42.6	0.125	0.029	36.2	0.119	0.030	39.3
	5	0.108	0.028	38.5	0.096	0.028	49.7	0.118	0.028	35.7	0.110	0.027	42.6
Govelins	1	0.098	0.026	69.0	0.092	0.023	67.8	0.104	0.022	60.4	0.103	0.022	64.3
	2	0.093	0.023	56.8	0.090	0.022	57.9	0.096	0.022	53.3	0.093	0.022	57.6
	3	0.079	0.022	50.5	0.088	0.022	52.1	0.094	0.019	49.9	0.091	0.020	55.1
Suscinio	1	0.085	0.018	32.6	0.083	0.021	31.3	0.079	0.018	37.0	0.094	0.018	29.4
	2 BL	0.111	0.017	40.6	0.107	0.016	45.4	0.125	0.016	42.7	0.094	0.016	51.4
	3	0.100	-	-	0.094	0.011	73.7	0.108	0.020	67.9	0.107	0.020	66.7
	4	0.091	-	-	0.085	0.037	80.0	0.097	0.022	72.7	0.094	0.025	72.2
	5 L	0.088	0.020	53.5	0.094	0.023	53.4	0.119	0.013	50.2	0.120	0.018	47.7
	6	0.112	0.023	47.6	0.113	0.020	47.8	0.128	0.014	48.7	0.129	0.019	46.4
	7	0.129	0.017	43.6	0.097	0.017	42.5	0.142	0.018	40.6	0.137	0.016	40.7
	8 P	0.123	0.016	38.0	0.121	0.016	39.7	0.118	0.016	38.0	0.121	0.014	40.8
	9	0.132	0.020	22.3	0.132	0.023	20.1	0.147	0.016	23.9	0.116	0.018	24.0

with the *Xynthia* storm. Hs > 3 m occured about 45 hours. The third phase started on 3rd of March 2010 and ended with the last topographic survey monitored on the 31th of March 2010. This is characterized by Hs > 2 m occuring for about 80 hours and Hs > 3 m for only 13 hours. Waves are mainly oriented WSW (Figure 3).

METHODS AND DATA FIELD

The Four buoy (located lat. 47°18.60'N long. 02°39.00'W, water depth 30 m) recorded the significant wave height (m), mean period (s) and peak direction (deg). Wave power P is obtained following the Airy linear wave theory. The wave power P is given by equation (3):

$$P = E.Cg \quad (3) \quad \text{with} \quad E = \frac{1}{8}.\rho.g.Hs^2 \quad \text{and} \quad Cg = \frac{g.Ts}{4\pi}$$

where ρ is the sea water density, g is the acceleration gravity, Hs is the significant wave height and Ts is the mean wave period.

A total of 23 transects (Figure 2 and Table 1) were surveyed monthly at spring low tide using a Trimble GeoXH DGPS. These field datas were corrected post-treatment using the Sarzeau RGP-IGN broadcasting terminal (Figure 1). Vertical accuracy is less than 5 cm. The changes in morphology are related to offshore hydrodynamics as carried out by authors (Stépanian and Levoy, 2003; Quartel et al., 2008).

In this study, four main topographic surveys were conducted (Figure 3 and Table 1). Since it takes three daylight low tides to survey the 23 profiles, the first survey took place on the 4th, 5th and the 6th of January. The second one took place on the 10th, 11th and the 12th of February. Next, on Suscinio beach, a special field deployment was surveyed one day before and one day after the *Xynthia* storm (Figure 3) which reached the Atlantic French coast early in the morning of the 28th of February 2010. This special survey involved three transects monitored monthly which are located in the western part, the central part and the eastern part corresponding to profiles numbers 2, 5 and 8 (Table 1). The following days all other profiles were conducted on all other beaches. Finally, the last topographic survey was carried out the 29th, the 30th and 31st of March, assimilated to the 1st of April 2010 (Figure 3 and Table 1). for all the beaches, profiles are numbered from 1 to 9 (for Suscinio) from the North-West toward the South-East.

RESULTS

Morphologic response to different energy conditions

During the first phase of L.E.C, changes are observed on beach gradients (Figure 3 and Table 1). Upper reflective beachfaces are less steep with a decrease of tanβ values (Table 1). However, the low-tide terrace gradients show negligable to non-existant changes. During this period, the break in slope moved offshore.

These latter trends seem to be reversed after a period of high energy events. Indeed, a significant increase of the upper reflective beachface gradient (tanβ) was observed (Table 1). This is associated with a onshore movement of the break in slope. The low-tide terrace gradient does not show significant variations except for the profiles Nos 3, 4 and 5 at Suscinio beach (Table 1) where it decreased. It is interesting to note that Suscinio's profiles No 1 and No 9 show a different trend during this period, with decreasing tanβ values with a 5.7 m and a 3.8 m offshore net movement of the break in slope respectively for the profile No 1 and the profile No 9. Such behavior is generally observed after an L.E.C. After the second period of L.E.C, many upper beach gradients decreased but did not get the values they had after the first period of L.E.C.

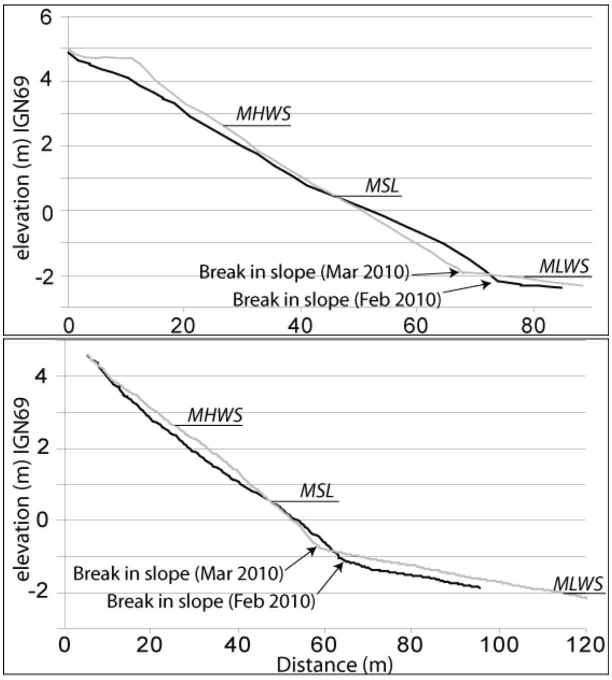

Figure 4: Exemple of surveyed profiles on February (black lines) and in March (grey lines) at the Suscinio site (profile n°3) (top) and at the Govelins beach (profile n°2) (bottom). *MHWS*: Mean High Water Spring. *MSL*: Mean Sea Level. *MLWS*: Mean Low Water Spring.

For the studied beaches, high-energy conditions led to an upper steep beachface accretion, a lower steep beachface erosion, an increasing of steep beachface gradient and a resulting landward movement of the sharp break in slope (Figure 4 and Table 1). This is partly due to swash motions and maximum run-up (Hughes et al., 1997) occuring during energetic episods on steep beaches. A good example is the berm build after H.E.C at Suscinio (Figure 4).

Volume variations in the Suscinio embayed beach

The *Xynthia* storm reached the French Atlantic coastline early in the morning of the 28^{th} of February 2010. It caused important damages and 53 casualties were reported. Offshore significant wave height reached 4 m at the Four buoy. Atmospheric pressure dropped to 963 hPa and wind speed reached 17 $m.s^{-1}$ over the studied area. The *Xynthia* storm was indeed a high energy event impacting the south Britanny coast but the energy input during this storm was not the most energetic event (Figure 3). The *Xynthia* storm was actually the last energetic event of a series of four more energetic events (Figure 3) during February 2010.

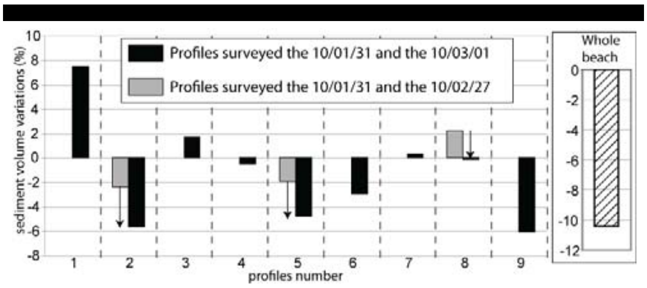

Figure 5: Volume of sediment variations calculated for the nine profiles at the Suscinio beach during H.E.C. Black arrows represent the erosion caused by the *Xynthia* storm on the three profiles monitored before and after this event.

The special survey of the three sites in the Suscinio beach showed an important erosion of the profiles surveyed. Within one day, the Beg Lann profile indicated a loss of 5.5% of the initial sediment volume. The Landrezac profile highlighted a sediment loss of 3% and a loss of 2.3% at Penvins to the eastern part of the Suscinio embayed beach (Figure 1 and Figure 5).

Nevertheless, other profiles surveyed monthly on this beach did not show such losses (Figure 5). The maximum sediment loss is observed on the ninth profiles (eastern end) and the maximum sediment gain, up to 7%, is observed on the first profile, (western end) (Figure 5). This suggests a longshore sediment movement westward with an updrift in most eroded areas, by-passing in non-changing sites and downdrift in the western end of the bay associated with a global downdrift to the lower shoreface accounting for such amount of sediment volume loss.

The accretion observed does not balance the sediment volume lost. The nine profiles indicate a total loss of around 10% for the whole beach compared to the initial volume calculated from the survey conducted on the 31^{st} of January 2010 in the Suscinio embayed beach (Figure 5). Thus, high energy conditions including the *Xynthia* storm caused an important erosion in Suscinio.

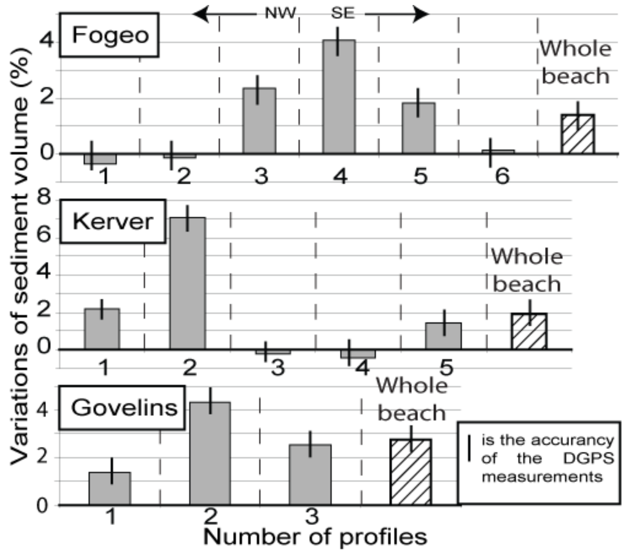

Figure 6: Variations of sediment volume calculated from the profiles of the Fogeo, Kerver and Govelins beaches surveyed in February and March 2010.

Volume variations in Fogeo, Kerver and Govelins beaches

Undergoing lower energy conditions (Figure 2), the three other beaches showed different variations. An unexpected accretion is observed on many profiles (figure 6) with values up to 2.8% in Govelins, 2% in Kerver and 1.4% in Fogeo after the period of high energy conditions. Furthermore, this accretion is not uniform on all beaches. For example, the central part of Fogeo beach is accreted whereas only the eastern part of Kerver beach is accreted. However, a small erosion is noted in profiles No 1 and 2 (Fogeo), No 3 and 4 (Kerver), but because of the low amount of erosion, smaller than DGPS accurancy (figure 6), they could be considered as stable profiles. This suggests a littoral drift with different directions due to wave refraction and diffraction, bringing material from the lower shoreface.

DISCUSSION

This work highlights the different behaviour of four reflective closely-spaced beaches of the Rhuys peninsula. The *Previmer* propagation wave model emphasises the different exposure of Fogeo, Kerver and Govelins beaches on one hand and Suscinio beach on the other. However, with fair-weather conditions, these beaches underwent an offshore movement of their break in slope associated with a decrease of their upper beachface gradient (tanβ). This does not follow the intermediate sandy beaches geomporphological behavior observed (King, 1972) which tend to decrease their beach gradient under high-energy conditions and to adapt their morphology to the hydrodynamic conditions (Masselink and Hegges, 1995). This unexpected behaviour could be directly related to the low sediment stock available which does not allow a flatter, more dissipative adjustment to stormy conditions, and by rocky outcrops and platforms which limit their normal morphological adjustment (Cooper and Jackson, 2010). During low energy event, gravity moves coarse sand to the lower steep sectors, decreasing the beach gradient. Conversely, with high-energy event, the uprush moves sediments to the upper beachface and so allows the increasing beach gradient (Hughes *et al*., 1997).

The morphology of the upper reflective beachface is more variable than the “low tide terrace” as noted by (Wright, 1980; Wright and Short, 1982). The beaches show high variabilities to energetic events. Some have been accreted like Fogeo, Kerver and Govelins beaches whereas the Suscinio embayed beach has been eroded, despite the relative protecting terrace to steep sectors (Miles and Russel, 2004). The existing rocky outcrops, headlands and platforms play an important role, by generating wave refraction and diffraction, accounting for the different morphodynamic behaviour between beaches as described by Jackson *et al.* (2005) and Jackson and Cooper (2010). In addition, more important bed return flow and infragravity band due to the embayement must occur in the Suscinio beach to account for the amount of sediment loss (Russel, 1993).

The deeply eroded eastern profile at Suscinio beach associated with a significant accreted western profile could arise from a longshore drift assimilated to a beach rotation between rocky headlands due to the local geological inheritance (Short, 2010) and accompanied by an updirft to the lower shoreface.

Each of these four beaches underwent a beach rotation but, at Suscinio, this was accompanied by a downdrift to the lower shoreface, accounting for the volume of sediment loss, whilst at the other beaches, the beach rotation was accompanied by an updrift to the upper shoreface accounting for the gain of sediment.

CONCLUSION

This work highlights the different morphodynamic behaviour of four pocket beaches located south of Rhuys penisula. These are located in the Quiberon bay and are not under the same hydrodynamic conditions. During high-energy wave conditions, three of them, located eastward of the studied area underwent accretion and only one, located westward, underwent massive erosion. These results underline the importance of geological settings responsible for different morphological responses observed for closely-spaced pocket beaches during high wave-energy conditions. The use of modelling to predict morphodynamic evolution of beaches behaviour must take into account the lower shoreface morphology as much as oceanographic parameters.

LITERATURE CITED

Aagaard, T. et al., 2005. Intertidal beach change during storm conditions; Egmond, The Netherlands. *Marine Geology*, 218(1-4), p.65–80.

Dehouck, A., Dupuis, H. & Sénéchal, N., 2009. Pocket beach hydrodynamics: The example of four macrotidal beaches, Brittany, France. *Marine Geology*, 266(1-4), p.1-17.

Hongshuai et al., 2010. The response of three main beach types to tropical storms in South China. *Marine Geology,* 275(1-4), p244-254.

Hughes et al., 1997. Flow velocity and sediment transport in the swash zone of a steep beach. *Marine geology,* 138(1-2), p91-103.

Jackson, D.W.T., Cooper J.A.G., del Rio L., 2005. Geological control of beach morphodynamic state. *Marine Geology*, 216(1-4), p.297-314.

Jackson D.W.T., Cooper J.A.G., 2010. Application of the equilibrium planform concept to natural beaches in Northern Ireland. *Marine Geology*, 57(1-2), p.112-123.

King, C.A.M., 1972. *Beaches and Coasts*. Edward Arnold, London.

Masselink G. and Hegges B., 1995. Morphodynamic of meso- and macrotidal beaches: examples from central Queensland, Australia. *Marine Geology*, 129(1-2), p.1-23.

Menier, D. Tessier, B. Proust, J.N. Baltzer, A. Sorrel, P. and Traini, C. 2010. The Holocene transgression as recorded by incised-valley infilling in a rocky coast context with low sediment supply (Southern Brittany, Western France). *Bull. Soc. géol. Fr*., 181(2), p.115-128.

Miles, J. and Russel, P., 2004. Dynamics of a reflective beach with a low tide terrace. *Continental Shelf Research*, 24, p.1219-1247.

Nordstrom, K.F., 1980. Cyclic and seasonal beach response: a comparison of oceanside and bayside beaches. *Physical Geography*, 1(2), p.177–196.

Pian, S., 2010. Analyse multiscalaire et multifactorielle de l'évolution et du comportement géomorphologique des systèmes côtiers sud bretons. France: University of Rennes2. Ph.D. thesis, 477p.

Quartel, S. Kroon, A. and Ruessink, B.G., 2008. Seasonal accretion and erosion patterns of a microtidal sandy beach. *Marine Geology*, 250(1-2), p.19–33.

Regnauld, H. and Louboutin, R., 2002. Variability of sediment transport in beach and coastal dune environments, Brittany, France. *Sedimentary Geology*, 150(1-2), p.17-29.

Regnauld, H. Pirazzoli, P.A. Morvan, G. and Ruz M., 2004. Impacts of storms and evolution of the coastline in western France. *Marine Geology*, 210(1-4), p.325–337.

Russell, P.E., 1993. Mechanisms for beach erosion during storms. *Continental Shelf Research*, 13(11), p.1243–1265.

Shih, S.-M. And P.D. Komar, 1994. Sediments, beach Morphology and Sea Cliff Erosion Within an Oregon coast Littoral Cell. *Journal of Coastal research* 10: 144-157.

Short, A.D., 2010. Role of geological inheritance in Australian beach morphodynamics. *Coastal Engineering*, 57(2), p.92–97.

Stépanian, A. and Levoy, F., 2003. Morphodynamical evolution sequences of intertidal bars on a macrotidal beach: case study of Omaha beach (Normandy, France). *Oceanologica Acta*, 26(2), p.167–177.

Wright L.D., 1980. Morphodynamics of reflective and dissipative beach and inshore systems: Southeastern Australia. *Marine Geology,* 37(3-4), p373-376.

Wright L.D. et al., 1982. Morphodynamics of a microtidal beach. *Marine Geology*, 50(1-2), p.97-127.

Wright, L.D. & Short, A.D., 1984. Morphodynamic variability of surf zones and beaches: a synthesis. *Marine Geology*, 56(1-4), p.93–118.