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Beach Morphodynamic of the Serra Oil Field, Northeastern Brazil

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ABSTRACT

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Inserted on the meso-tidal North Coast of the Rio Grande do Norte State, the Serra Oil Field is under accelerated coastal erosion. On the Serra oil field are installed directional oil wells from PETROBRAS, nowadays located directly in the shoreline, under constant attacks of coastal processes (e.g. waves, tides and currents), which promote an intense morphodynamic variability of this sandy coast. A synthesis of results obtained over a period of 24 months from a study of beach dynamics is presented. The used methodology involved current techniques of beach profiles and hydrodynamical processes. The wind direction average 77ºAz (NE). The steepness of the berm and of the shoreface, as well as coastal current direction do not present significant changes, with an average of 36º for the steepness of the berma, 15º for the shoreface and 15º for the coastal current direction. This data set allow us to infer that the months of larger coastal erosion were november/2000 and april/2001, because of the largest wave parameter during this time. Places where the PETROBRAS oil wells are installed, were submitted to an erosion of until 15 meters during the monitored period. This work is intended to provide a general synthesis of recent results developed by GGEMMA Group from UFRN/Brazil, including the most recent developments in morphodynamic variability of this area in terms of environmental conditions.

ADDITIONAL INDEX WORDS: *Coastal erosion, beach profiles, hydrodynamic, environmental monitoring.*

INTRODUCTION

Beaches and their adjacent nearshore zones act as buffers to wave energy. Consequently they are sensitive to change, over timescales ranging from a few seconds to several years. The study of beach changes does assist in forecasting coastal erosion and marine flooding among other things (CARTER, 1988).

Wind, waves, and longshore currents are the driving forces behind coastal erosion. This removal and deposition of sand permanently changes beach shape and structure. Coastal erosion poses many problems to coastal communities in that valuable property is frequently lost to this dynamic beach-ocean system. Additionally, human activity may promulgate the process of coastal erosion through poor land use methods. Thus, issues of beach restoration and erosion control are at the forefront in coastal communities.

At present there is a worldwide tendency towards shoreline erosion (BIRD, 1985; BIRD, 1996, BIRD, 1999) and many solutions have been proposed, ranging from preventative, through curative to restorative. However, our understanding of the processes leading to coastal erosion is rudimentary. Without understanding the processes, prediction is difficult, if not impossible.

The Serra oil field, located near the Macau city in the northern coast of Rio Grande do Norte State (NE Brazil), is actually an area under intense erosive processes, natural or anthropics (Figure 1). This shore is a mesotidal, high-energy coast. The tides are semidiurnal with two nearly equal highs and lows each day. A longshore drift is predominant from the east to the west and together with the tidal currents promotes the transport of sediment in the nearshore.

This oil field is being explored through wells of directional surveys starting from two production areas, distant one from the other of about 700 meters. Nowadays it is located directly in the shoreline, under constant attacks of coastal processes (e.g. waves, tides and currents), which promote an intense morphodynamic variability of this sandy coast. Constant efforts were underway to protect this shoreline from erosion.

Recent studies (ALVES, 2001; SOUTO, 2002) evaluated the coastal dynamics of this area through products of remote sensing. However, systematic studies with collection of data in situ for evaluation of the coastal dynamics, essential before the implantation of any anthropic intervention, were never made.

Thus, the main objective of this paper is to describe the changes in beach morphology of this area. The dataset used here was obtained in a systematical monitoring during 24 months. These data are important to understand the causes of the erosion, as well as to quantify the changes in the coast line, as for the transport of sediments and its vulnerability. Furthermore, the data are been stored on the geo-referenced database of the projects MARPETRO and PETRORISCO, aiming to model the coastal and sea environment, susceptible to oil spills and their derivatives.

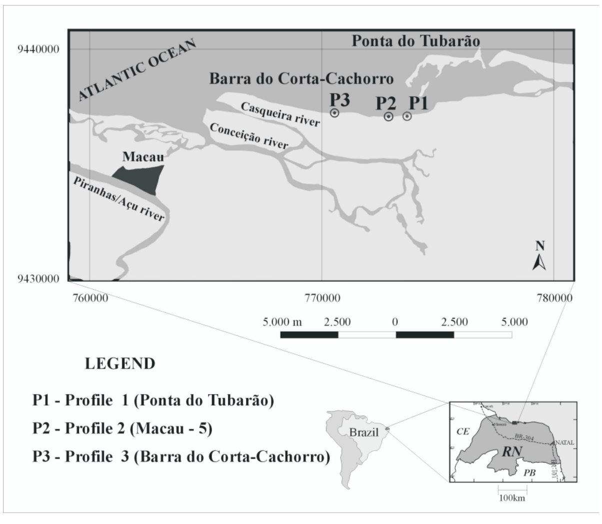

Figure 1. Location map of the studied area and profile station locations P1, P2 and P3.

METHODS

Field data were collected monthly, during spring tide (new moon), from October 2000 to September 2002. Three stations were surveyed on the oil field shore. The stations, from east to west, were denominated P1 - Profile 1 (Ponta do Tubarão), P2 - Profile 2 (Macau5) and P3 - Profile 3 (Barra do Corta-Cachorro) (Figure 1). The measurements included detailed beach profiles, sediment samples, and quantitative data of tides, waves, currents, wind and temperature.

Topographic profiles of the beach normal to the coastline were measured using precision level, measuring tape and graduate sight. The survey was conducted on the three stations near the time of low tide to take advantage of maximum beach exposure. All elevation profiling is referenced to a datum stake, which is at a known elevation above mean spring low water (MSLW). Characterization of the beach environment (description and collection of sediments) were also performed during low tide.

Hydrodynamic data (wave height, wave period, wave breaking, speed and direction of the coastal current) were acquired during high tide on the stations P2 and P3. Measurements were taken with a scale staff, stopwatch and compass. Air temperature, wind velocity and air relative humidity were measured with a portable meteorological station, at 1,5 meters above the beach surface. To measure de wind direction was used a compass.

RESULTS

Characterization and Analysis of the Beach Profiles

The beach profiles give interesting information about the changing seasonal topography of the beach, which are described in this section.

Profile1 (P1) Ponta do Tubarão

On Profile P1, located in front off the Ponta do Tubarão island (Figure 1), we observe no significant change of beach morphology during the monitoring period. Its length, from datum stake until the shoreface, averages 178 meters (Figure 2A).

Although the berm scarp shown a steep slope it was only slightly eroded. The greater retreat occured during the month of June 2001. It was observed that the berm slop tended to decrease from November to October. The berm reaches their maximum steepness (33º) during the months of November and December 2000. Decreasing to 10º in the month of May 2002 and to 3º in the month of August of this same year. During the months of Setembro and October the berm was not formed. On the other hand, the shoreface slope was more stable (3º to 8o).

The sediments on the backshore and foreshore were composed of medium to fine sand, while the shoreface presents fine to very fine sand. The sands are moderately sorted in all units.

Profile2 (P2) Macau 5

This beach profile is located close to the fire burning of PETROBRÁS, where gases are frequently exhaled; and because of this its execution was some times difficulty, being necessary the use of protection mask to make it possible. The shore in this station is open to the sea. The profile length, from datum stake until the shoreface, averages 170 meters (Figure 2B).

Significant changes on the beach morphology occurred in this station. A retreat (around 10 m) of the berm scarp was observed. The berm was completely eroded in the beginning of the monitoring and no more was formed until their end. The foreshore presented constant slope (varying from 3º to 9º), staying practically unaltered along the studied period.

Beach cusps were present with a distance between them averaging 19 meters. We also observed that from one year to the other these distances tend to reduce 3 meters on average.

Moderately sorted fine sand was present along all the profile, from the backshore to shoreface.

Profile3 (P3) Barra do Corta-Cachorro

The profile P3, located just after the oil wells, was exposed to the more expressive erosion process. This was evident since the first year of monitoring (CHAVES and VITAL, 2001a). The profile length, from datum stake until the shoreface, averages 102 meters (Figure 2C).

During the 24 month monitored the berm scarp moves landwards around 15 meters decreasing the backshore. Due to this retreat, the location of the reference stake has been moved three times landward.

Despite the steepness of the berm scarp, whcich averages 37º, the foreshore slope has been slightly changed, with an average of 3º, maximal of 6º and minimal of 1º.

Beach cusps were observed only during the months of December 2000, April, June and September 2002. Along the studied period, the distance between the beach cusps was 31 meters on average, with maximal of 37 meters and minimal of 22 meters.

The sediments on the backshore and foreshore were composed of fine sand, while the shoreface presents very fine sand. The sands are moderately sorted in all units.

Characterization and Analysis of the Hydrodynamic Parameters

The tides along this period ranges from -0,3m to 0,7m (low tide) and from 2,5m to 3,1m (high tide).

Profile 1 (Ponta do Tubarão)

The presence of Ponta do Tubarão island in front of the station P1 promotes the wave reflection and diffraction, acting as a filter; in this way, the waves of large height or long period do not reached the shore. The type of breaking wave observed in almost all of the months monitored was the plunging wave. During four months (November 2001 and May/June/August of 2002), the sea was in the calm state.

Profile2 (Macau5)

The waves arriving on the shore are blocked by shallow waters sandbanks , modifying the intensity of the energy and the direction of the incident waves. Little changes on the dominant longshore currents directions can be observed. The water temperature averages 28,7ºC (minimum of 25ºC in June 2001 and a maximum of 31ºC in February and May 2001).

The wave height averages 0,3 meters, with a minimum of 0,1 meters in June 2001 and a maximum of 0,7 meters in November 2001. The wave period was on average 4,70 seconds, with minimum of 0,336 seconds, in May 2001, and maximum of 7,496 seconds, in June 2002.

Predominant breaking waves observed during the monitoring were plunging waves; however, during the months of June and July 2001 it changes to spilling waves, and in May 2002 no waves were formed.

The shoreline presented a direction with average of 280ºAz, and the waves reaches the shore with an angle around 8º. Together with persistent trade winds from NE they generate a longshore current from east to west with maximum speed of 0,71 m/s (November 2001) and a minimum of 0,11 m/s (April 2001). The longshore current was stationary during the months of June and August 2001 and February, March and August 2002). Secondary winds come from SE (CHAVES *et al*., 2003).

Profile3 (Barra do Corta-Cachorro)

On this station the shoreline direction averages 285ºAz, paleo-mangroves are exposed on the beach and no sandy banks

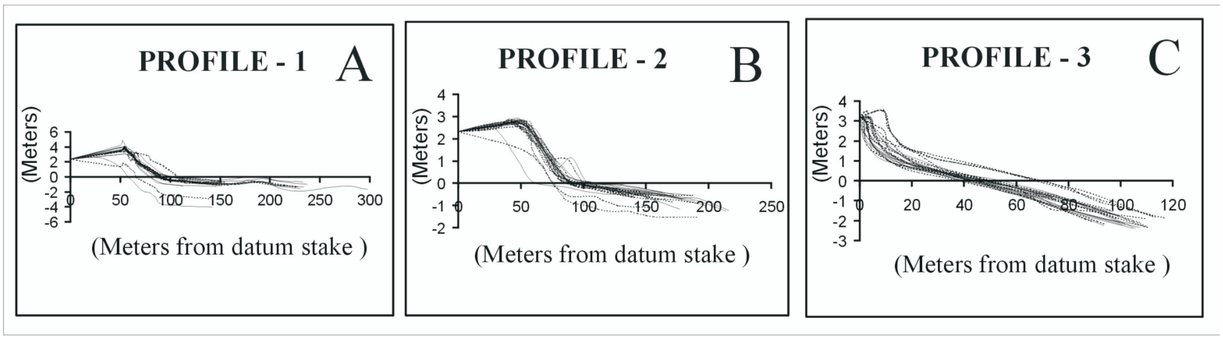

Figure 2. Beach profiles of profile 1 (A), profile 2 (B) and profile 3 (C), in the period of october 2000 at september 2002, MacauRN.

monitoring averages 29ºC, with a minimum of 26,5ºC and a maximum of 34ºC.

The wave height averages 0,4 meters (minimum of 0,13 meters in June 2001 and maximum of 0,7 meters in November 2000). The wave period averages 5,041 seconds (minimum of 3,256 seconds in May 2001 and maximum of 8,007 seconds in April 2001). Plunging waves were dominant during all the monitored period.

The propagation waves direction range from 260ºAz to 343ºAz, with average of 297ºAz. The waves reaches the coast with an average incidence angle 13º. The prevailing trade winds direction is from northeast, averaging 77ºAz, and the secondary winds are from southeast (CHAVES *et al*., 2003). Minimum wind speed was measured in June 2002 (1,5 m/s), and the maximum speed 17,8 m/s in August 2002. The longshore current averages 0,6 m/s, but ranges from 0,1 m/s (April 2002) to 1,8 m/s (September 2002).

The air temperature averages 29,6ºC, ranging from a minimum of 26ºC (August 2002) to a maximum of 31,9th (June of 2002). The air relative humidity averages 64%, with a minimum of 44% (June 2002) and maximum of 91% (May 2002).

DISCUSSIONS

The obtained results show that the environmental impact in this area, by the presence of the oil base of the Field Macau-5 to be located in the foreshore, causing interference in the deposition of the sediments and altering the speed of the coastal current. It is important to point out that, when these wells were installed, the shoreline was more than 500 meters seawards.

The analysis of the beach profiles in Station P2 (Macau5) showed that the erosive process is increasing; it can be evidenced by the decrease of the berm scarp in more than 10 meters, as well as for the decrease of the backshore extension landwards, in the 24 months of monitoring. In the same way the beach profiles analysis of the Station P3 (Barra do Corta Cachorro), show us that there was a retreat landwards of the berm scarp in more than 15 meters during the months of February 2001 to February of 2002 and its slope was reduced in more than 40º, what evidences a continuous erosion.

Beach erosion results in coastal land loss due to three major factors: (1) sea level changes, (2) unbalanced sediment budgets, and (3) human activities. It is well known that coastal erosion is triggered by rising sea level, but it can also occur on coastlines where the sea level is stable or even falling, especially where a deficit has developed in the availability of sediment to maintain or enlarge the coastline (BIRD, 1996).

The sea level curves available for this area shown that it is not under rising sea level (CALDAS, 2002). According to DOMINGUEZ and BITTENCOURT (1996) sediment budget is the main factor governing the coastal erosion in northeastern Brazil. VITAL *et al*. (2002) outline that coastal erosion on the northern coast of Rio Grande do Norte State seems to be a consequence of unbalanced sediment budget, mainly due to the lack of continuous longshore sediment supply, as well as due to the lack of sediment from the land side. These authors concluded that, this is finally caused by neotectonic movements. Human impact is imposed mainly by the oils wells on the intertidal zone. However coastal erosion is reported to this area before the implantation of the oil Firma.

The bottom morphology in the septentrional platform of Rio Grande do Norte seems to interfere directly in the erosive and depositional processes through their effects on the wave refraction (VITAL *et al*., 2001; TABOSA *et al*., 2001; TABOSA, 2002; TABOSA *et al*., 2002). The pattern of refraction of the waves generated by the morphology of the platform adjacent to São Bento and Caiçara do Norte, apparently influenced by the local tectonics and associate to the pattern of currents (CALDAS, 2002), results in erosion and/or beach deposition, affecting all this coast until Macau, including the area of installation of the Guamaré Oil Pole (SILVEIRA, 2002) and the Serra oil field (VITAL *et al*., 2003).

In agreement with CHAVES and VITAL (2001b) and CHAVES *et al*. (2003), the months of worse coastal erosion in the Serra oil field, are related with the increasing wavy energy. This in turn, seems to be related to seasonal climatic variations, with the wave energy and tide currents speed increasing during months of minor precipitations (June to January).

The results obtained during this 24 months monitoring confirms us a situation of accentuated erosion, mainly in Profile 3, where the wave height, wave period, and coastal current speed are always larger than the values found in Profile2.

Probably these values are more expressive in Profile3, for this do not present any natural structure of protection to the wave impact, as reefs, islands or sand banks. The transport of the sediments occurs from East to West, and the accumulation of sands is more pronounced towards Profile3. The speed of the tidal currents, on the other hand, are more accentuated in the Profile 2 (SANTOS *et al*., 2003; SANTOS, 2003). SANTOS (2003) emphasizes that in the Ponta do Tubarão the tidal currents presented preferential direction for NE in periods of flood currents and for NW in period of ebb current, while in Barra do Corta-Cachorro the direction of the currents were predominantly for NW, independent of the tide phase, coinciding with the preferential direction of the longshore current. This inversion of the currents in the Ponta do Tubarão is explained by this author, by the presence of the Ponta do Tubarão island barrier and by the communication channel of the lagoon with the sea.

With the exposed we can affirm that the more active natural factors in this area, are the currents, followed by the tides and the winds. The anthropic factors are exclusively local and punctual (Macau and Serra Oil Field). This is an area of high coastal vulnerability, due to high environmental fragility of this beach how was observed by the morphological changes between October 2000 and September 2002.

CONCLUSIONS

This study described the general behaviour of the northern shore of Rio Grande do Norte State relating beach profile morphology with hydrodynamic and sedimentological parameters.

The area is subjected to accenctuated erosion processes, due to environmental fragility of the area. The main environmental impact is due the base of the oil wells of the Macau/Serra field be located in the foreshore under direct attack of the waves and currents.

The months of worse coastal erosion were the ones of September and November, when the largest wave parameters and the largest speed currents are measured in the area. Since these months are included on the period of minor precipitations, we related the coastal erosion to seasonal climatic variations.

The tide currents are better observed in protected areas, as in the Ponta do Tubarão, when they present inversion in their direction in agreement with the flood and ebb tide. In open areas, as in Barra do Corta-Cachorro, the tide currents are overprinted by the longshore currents.

Taking in account the economic importance of the area, as well as the intensity of coastal processes acting on this shore, it is important a continuity of the monthly environmental monitoring looking for variations on longer-period cycles

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