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MORPHOLOGICAL, HYDRODYNAMIC AND SEDIMENTARY CHARACTERISTICS OF THE NORTHEASTERN COAST OF CUBA

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ABSTRACT: The absence of the marine platform, the presence of emerged and submerged terraces with tide notches on its front face and the increase in the number of beaches constituted by terrigenous sands towards the east end of this coastal stretch are the main geomorphological features that characterize the northeastern coast of Cuba. The lower rocky terrace is the best represented type of coastline on the Northeastern coast, exposed to the direct action of ocean waves. Considering the inland coast, mangroves are the most abundant type of coast and occupy most of the bays on this coastal stretch. From the hydrodynamic point of view, the highest wave heights of the north coast of Cuba take place there. In addition, the biggest tidal range of the Cuban archipelago is recorded. From the sedimentary point of view, these beaches have a greater amount of fragments of mollusks and corals and fewer fragments of calcareous algae than the other beaches of the Cuban archipelago. These beaches, unlike the other beaches of Cuba, show cumulative processes at the end of winter and early spring, with a maximum accumulation in April, while eroding at the beginning of autumn, with maximum values in the months of September and October.

Keywords: Coastal characteristic, beach, genesis sand, Northeastern coast of Cuba.

RESUMO: *A ausência da plataforma marinha, a presença de terraços emersos e submersos com nichos de maré em sua face frontal, assim como o aumento do número de praias constituídas de areias aluviais em direção ao extremo oriental do litoral são os principais traços geomorfológicos que caracterizam a costa nordeste de Cuba. O terraço rochoso baixo é o tipo de costa melhor representado na costa nordeste, exposto à ação direta das ondas do oceano. Considerando a costa mais interior, os manguezais são o tipo de costa mais abundante e ocupam a maioria das baías desta costa. Do ponto de vista hidrodinâmico, apresentam as maiores alturas de onda da costa norte de Cuba e as maiores amplitudes de marés registradas no arquipélago cubano. Do ponto de vista sedimentar, as praias desta costa possuem maior quantidade de restos de moluscos e corais e menor quantidade de restos de algas calcárias, que as demais praias do arquipélago cubano. Estas praias, diferentes das demais praias de Cuba, apresentam processos de acumulação ao final do inverno e início da primavera, com uma máxima concentração no mês abril e erodem no início do outono, com valores máximos nos meses de setembro e outubro.*

Palavras-chave: *Característica costeira, praia, génesis de areia, costa Nordeste de Cuba.*

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1. INTRODUCTION

The Cuban island platform is considered as a single area divided into four regions, which are distinguished according to their geographical position with respect to the main island. These are the northwestern (Las Coloradas Archipelago), northeastern (Jardines del Rey Archipelago), southwestern (Los Canarreos Archipelago) and southeast (Jardines de la Reyna Archipelago) (Figure 1A). The Cuban island platform presents certain differences in its geomorphological development (Ramírez, 1989). These are associated with the tectonic behavior of the island of Cuba (Figure 1B), its geographical configuration, the rivers flow which do not contribute large volumes of sediments to the platform, the selective destruction of the carbonated coasts, and the peculiarities of the barrier reefs that surround it, among others.

In this context, the Northeastern coast of Cuba, from Punta Quemado, the easternmost tip of Cuba, to Punta Maternillo, in the Nuevitas Bay (Figure 1C), has the singularity of not being part of any of the four platform regions, which from the geomorphological point of view, the Cuban archipelago has been subdivided. Núñez Jiménez (1982) calls it the narrow platform region between the Bay of Nuevitas and Punta de Maisí. This characteristic, together with the behavior of the hydrodynamic regime and the sediments that make up the coast, imposes a group of peculiar features for this coastal stretch as well as the morphodynamic behavior of the biogenic beaches that exist there.

This coastal stretch has an extension of 474 km, exposed to the direct action of the oceanic waves. Beaches represent 26% of the coast and have fundamentally a marine origin (Rodríguez and Córdova, 2006). The absence of the insular platform determines that areas of production of marine sediments are very small. Consequently, beaches are of little extension and development; therefore, very fragile beaches linked its existence to the coral reef crests, which serve as elements of defense against the action of the greater waves.

In Cuba, during the twentieth century, coastal physical studies addressed fundamentally at the interpretation of coastal landforms and the clarification of their geological structure. Such are the cases of the studies conducted by Ionin *et al.* (1972, 1977); Shantzer *et al.* (1975); Ramírez (1989), with few references on current dynamic processes.

The most significant works were made by Juanes *et al.* (1984, 1985), Ramírez and Foyo (1987) and Juanes (1996), improving the understanding of the dynamic processes in the Hicacos Peninsula and the Eastern Beaches of La Habana respectively, and at the same time, contributing to a more complete picture on the erosion processes on Cuban beaches. However, the beaches of the northeastern coast of Cuba were left behind in these studies, until Rodríguez and Córdova (2006) undertook the problem of its erosion.

In order to mitigate erosion problems on Cuban beaches, beach nourishment has played a key role due to its advantages over other techniques (low environmental impacts, immediate results, and not foreign elements). However, the northeastern coast of Cuba has morphological, dynamic and sedimentary peculiarities, which differentiates it from the rest of the Cuban Archipelago. Consequently, the use of any numerical predictive model, as a theoretical basis for erosion control actions of its beaches has to consider these differences.

In concordance with the elements presented before, this paper aims to analyze the morphological, hydrodynamic and sedimentary peculiarities of the Northeastern coast of Cuba. This will contribute to a better understanding of the morphodynamic behavior and the processes responsible for the erosion on the beaches.

2. MATERIALS AND METHODS

2.1 Study area

The northeastern coast of Cuba, from Punta Quemado (74°W, 20°N), the most Eastern tip of Cuba, to Punta Maternillo (77°W, 21°N), in Nuevitas Bay, has an extension of 1402 km, including the inner coasts of the numerous bays existing. Of these, 474 km are exposed to the wave direct effects from the Atlantic Ocean and represent 8.2% of the outer coasts of the island of Cuba (Figures 1A, 1B, 1C).

The geological features of the Cuban archipelago are the result of a very complex history, represented by a series of sequences and structures closely related to the evolution of the Western Caribbean (Cotilla *et al.*, 1996). With a volcanic origin, nowadays it constitutes a folded belt accreted to the southern margin of the North American Plate (Cotilla *et al.*, 1996). The proximity to the plate boundary of Oriente fault, along with other factors, has created conditions for the formation and continued seismic activity (Pérez *et al.*, 2001) being the south of Sierra Maestra, in the Oriente fault, the zone where greater seismicity occurs (Arango *et al.*, 2015). Almost parallel to and close to

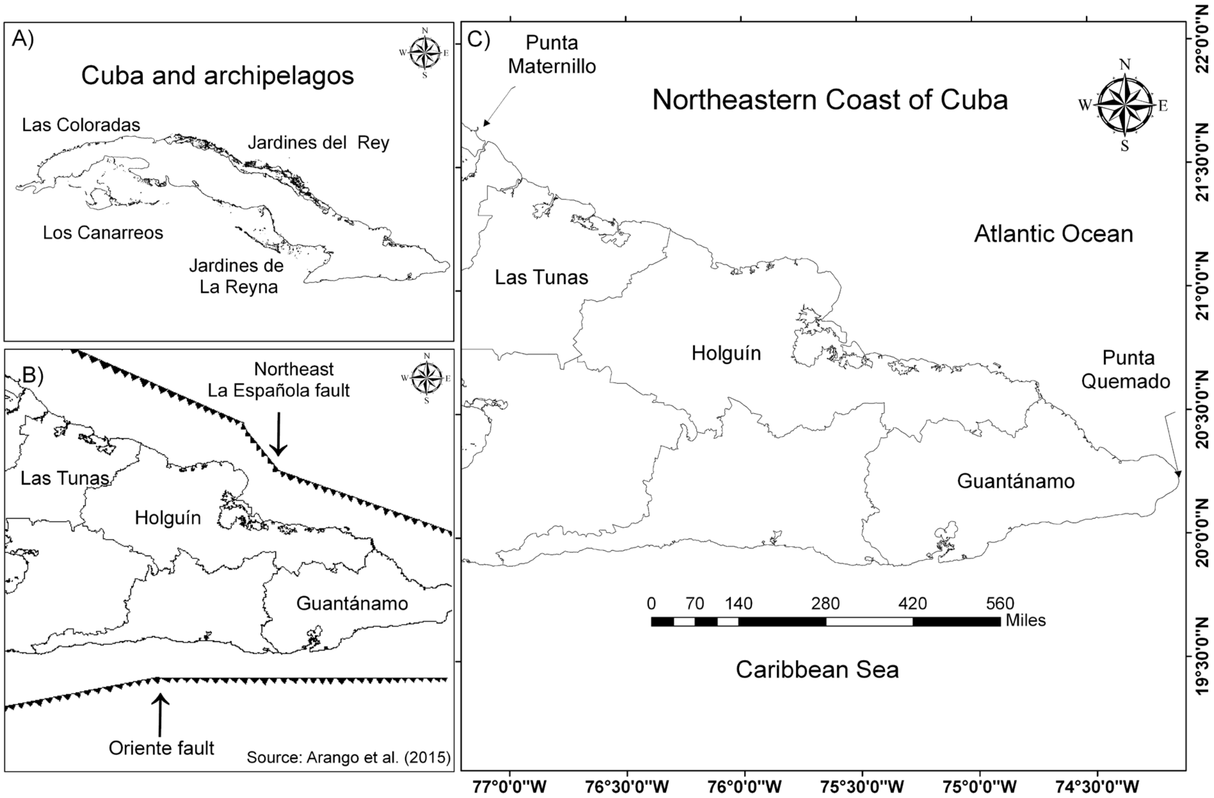

Figure 1. Geographical context of the study area. A: Cuban archipelagos; B: Fault position; C: Limits of the northeastern coast of Cuba.

the Northeastern coast of Cuba is the continuity of the island of Hispaniola Northern fault (Arango *et al*., 2015) and further west the Sabana fault (Orbera, 1989), separating Cuba from the Bahamas basin, by the fracture of the Old Channel of Bahamas (Ionin *et al*., 1977).

Jaminaitas formation (Jai.) of Pleistocene age, parallel to the shoreline, constitutes the main lithology of this coastal stretch. It is composed of massive, reef-shaped, and usually karstic and calcarenite bio-limestone, on which sand deposits of the Varadero Formation (Va.), appears. Underlying to the Jaimanitas Formation appears the Formation Júcaro (Jc.) composed by marls, bream loams, limestones usually argillaceous, calcarenites. In general, they are carbonate sediments of sublittoral facies of yellow and cream colors, which by the weathering become red and violaceous (Orbera, 1989).

Cuban climate is moderate subtropical, with two distinct seasons. According to the Institute of Meteorology of Cuba (INSMET, 2017), the most important changes are linked to the presence of disturbances in the tropical circulation, causing the arrival of waves from the East and tropical cyclones. Data from the Meteorological Center of Holguín (2016) show that every 17 months, the study area is affected by extreme hydro-meteorological events (northern frontal systems, extratropical falls, and hurricanes), which generate waves higher than 2.5 m.

Rainfalls are distributed during the months of June, May, November, and October, according to the order of their historical averages, closely associated in October and November with extensive precipitation areas associated with hurricanes and tropical storms. In Cuba, the average precipitation is 1234 mm, although in the littoral study area does not exceed 800 mm (INSMET, 2017).

2.2 Methodology

2.2.1 Geomorphology

The geomorphological characterization of the northeastern coast of Cuba was made considering the lithological composition, presenting relief forms, coastal processes, as well as the classification of the coasts of Cuba (Ramírez and Sosa, 1989), collected in the Nuevo Atlas Nacional de Cuba (1989). Fundamentally, it considers the four types of coastal landforms, of interest to the management of the coastal zone (cliffs, low terraces, beaches, and mangroves) which appear in the Act 212/2000 of Coastal Zone Management.

The analysis was carried out taking as reference the studies and observations made by the author for more than 20 years covering the whole study region (Rodríguez and Córdova, 2005a, 2006, 2010), including three very low altitude helicopter travels (1999, 2005, 2012), several expeditions by sea (1993 - 2013), as well as numerous land expeditions (1993 - 2016). In addition, topographic maps at 1:25000 and 1:50000 scales of the Republic of Cuba were analyzed and interpreted.

2.2.2 Hydrodynamics

The hydrodynamic characteristics were determined considering information about wind, historical waves, tides, and littoral currents. A wind dataset of 50 years was analyzed (1963-2013), provided by the Institute of Meteorology of Cuba (INSMET), which contains information about wind velocity, direction and frequency from Lucrecia meteorological station (75° 37' W, 21° 04' N), located in the center of the study coastal area, and therefore representative of the same area.

Wave data is referred on the grid 32 of the Global Wave Statistics, which provides information on significant wave height and period, very close to the study area. This is a wave database published by the Royal British Navy in which the seas and oceans of the world were divided into 104 areas. The prevailing directions of the waves of the Global Wave Statistics coincide with the wind regime reported from the Lucrecia meteorological station. A database of 50 years (1960-2010) was used.

The information about tides was obtained from twelve tide gauge stations which cover the coastal study area, whose information appears in the publications of the Intergovernmental Oceanographic Commission of UNESCO, and in the tide tables of the Republic of Cuba. These tide gauge stations are: Nuevitas (77° 7' W, 21° 38' N); Manatí (76° 49' W, 21° 21' N); Puerto Padre (76° 33' W, 21° 14' N); Gibara (76° 7' W, 21° 7' N); Banes (75° 42' W, 20° 55' N); Felton (75° 35' W, 20° 44' N); Nipe (75° 34 W, 20° 47' N); Levisa (75° 33' W, 20° 42' N); Tánamo (75° 19' W, 20° 43' N); Moa (74° 54' W, 20° 39' N); Baracoa (74° 30' W, 20° 21' N) and Maisí (74° 8' W, 20° 15' N).

2.2.3. Sediments

For the sedimentological study, the genetic composition of 35 sandy beaches was used. Those are in the northeastern coast of Cuba, according to the inventory and characterization made by Rodríguez (2004) and upgraded by the same author in 2015 and 2016. The beaches selected for the study represent 44% of the total, and their selection took into account their geographical location, extension, shoreline configuration and exposure to the usual waves. The analysis of the sand genetic composition was performed with a stereoscopic microscope and the genetic determination of 200 grains sand beach of fractions between 0.25 and 2.0 mm of average diameter size of the 35 sandy beaches. Three fractions (0.25 - 0.425; 0.425 - 0.84, 0.84 - 2.00 mm) of each sand beach sample were averaged for the definition of the genetic composition of the sands of each beach.

3. RESULTS AND DISCUSSION

3.1. Geomorphology

The most characteristic feature on the northeastern coast of Cuba is the narrowness or absence of a marine platform. At the central position of the territory, the platform does not exceed a nautical mile in width and almost disappears to the eastern end, contrary to what happens in the rest of the north coast of Cuba, where the platform has an extension of several miles of width. Núñez Jiménez (1982) denominates it a region of the narrow platform between Nuevitas bay and Maisí tip.

The morphological features at the northeastern coast of Cuba are conditioned by tectonic activity, geostatic changes in sea level and the effect of the fluvial network, although with a spatial differentiation. According to Rodríguez and Córdova (2005a), there is a predominance of coasts exposed to erosive processes (60.5%), while cumulative coasts occupy 39.5%, in both cases for the coast exposed to waves.

The biggest part of the coastal consists of a low rocky terrace, which does not exceed 2.0 m of height above mean sea level, with limestone and karst forms development. This low rocky terrace stretches along 211.5 km, occupying 46.3% of the northeastern coast of Cuba. It is largely covered by deposits of coral fragments (coastal ridge or *seboruco costero*) (Figure 2A). These deposits constitute remains of a frontal coral reef that is exposed after the descent of 3 or 4 m of the sea level, which occurred subsequently to the Flandrian transgression (Cabrera, 2011); and not as a consequence of materials carried thrown by storms as suggested by Núñez Jiménez (1982). Cabrera (2011) classifies them as old ridges of early Holocene age, probably correlated with the Flandrian Transgression. In large sectors, the coastal ridges were removed and used as construction material.

In the northeastern coast of Cuba, there are cliffs of low height, forming small sectors, such as in the area between Naranjo bay and Samá bay and to the east of the Yumurí River in Maisí, occupying 14% of the coastal stretch. On the other hand, the beaches extend along 123 km, representing 26%, whereas the mangroves extend along 57 km, representing only 12%, in all cases the outer coasts (Table 1). The behavior is different if the inland coast is considered, due to the predominance of biogenic processes and the mangrove present in the bays.

Table 1.Coastal types at the northeastern coast of Cuba.

Type of coast	Exposed to oceanic wave		Including bays	
Terraces	211456 m	45 %	448215 m	32 %
Beaches	122979 m	26 %	142267 m	10 %
Rifts	64840 m	14 %	205632 m	15 %
Mangroves	57280 m	12 %	588370 m	42 %
Outlets	17270 m	3 %	17270 m	1%
Total	473825 m	100 %	1402054 m	100 %

Although this littoral represents only 8.2% of the outer coast of the island of Cuba, more than 60% of Cuban bays are located there, including the biggest bays in the Cuban archipelago (Nipe, Malagueta, Levisa, Chaparra-Puerto Padre and Tánamo bays). They penetrate several kilometers inland, many with narrow and sinuous channels, where strong currents associated with the tides take place. In many of them, it is possible to appreciate the paleo-channel river cutting the insular platform.

At the eastern half of the territory, there is a dense river network, which has given rise to the development of some marshy areas, such as those created by the Mayarí River in the interior of the Nipe bay and a great number of coves, creeks and other coastal irregularities. The accumulation of sand in many of these irregularities, closing the river outlet giving rise to numerous estuaries of barrier (tibaracón). Due to the large number, those from the Baracoa city are the best known (Figure 2B). This estuary has the peculiarity of being constituted by sediments coming from sources both, terrigenous sand from the river flow and organogenic sands from the marine bottom.

A distinctive feature of this littoral is the absence of cays and bottom lows, except those inside some bays and another very close to the coast, like Guincho, Burro, Bariay, Moa, del Medio and the ones of Jaraguá in Baracoa. These last ones constitute, according to Rodríguez (2008), the most eastern of the Cuban archipelago and not Cayo del Medio as referred by Núñez Jiménez (1984).

Another characteristic feature of this littoral is the presence of emerging terraces, where six levels of emerged surfaces are clearly observed (Figure 2C), being Maisí the most known for their height and number. Here it is possible to count more than 15 levels of terraces up to 400 m of heights.

The presence of marine terraces, more frequently emerged than submerged, with tide notches worked in its base and frontal area, constitute evidence of the Quaternary fluctuations of sea level and of its importance in the configuration of the Cuban archipelago and of this coastal sector in particular.

In the insular platform, the bottom descends in an abrupt way, with terraces in the levels of 5 - 6 m, 10 - 12 m, 18 - 20 m, 26 - 35 m, then it stops to descend again until the 50 m, and finally to descend until more than 200 m (Figure 3). Although the traces of Holocene transgression are quite clearly observed on Cuba's marine platform, in all sectors it is not possible to clearly appreciate the abrasive surfaces of the first, second, third and fourth terraces, located at depths between 5 - 6 m, 10 - 12 m, 18 - 20 m and 26 - 35 m respectively, reaching a total of nine levels of sea terraces (Ionin *et al*., 1977).

Figure 2. Coastal landforms. A: Coastal ridge on the low terrace; B: Barrier estuary (tibaracón) of Nibujón River; C: Emerged marine terraces in Baracoa.

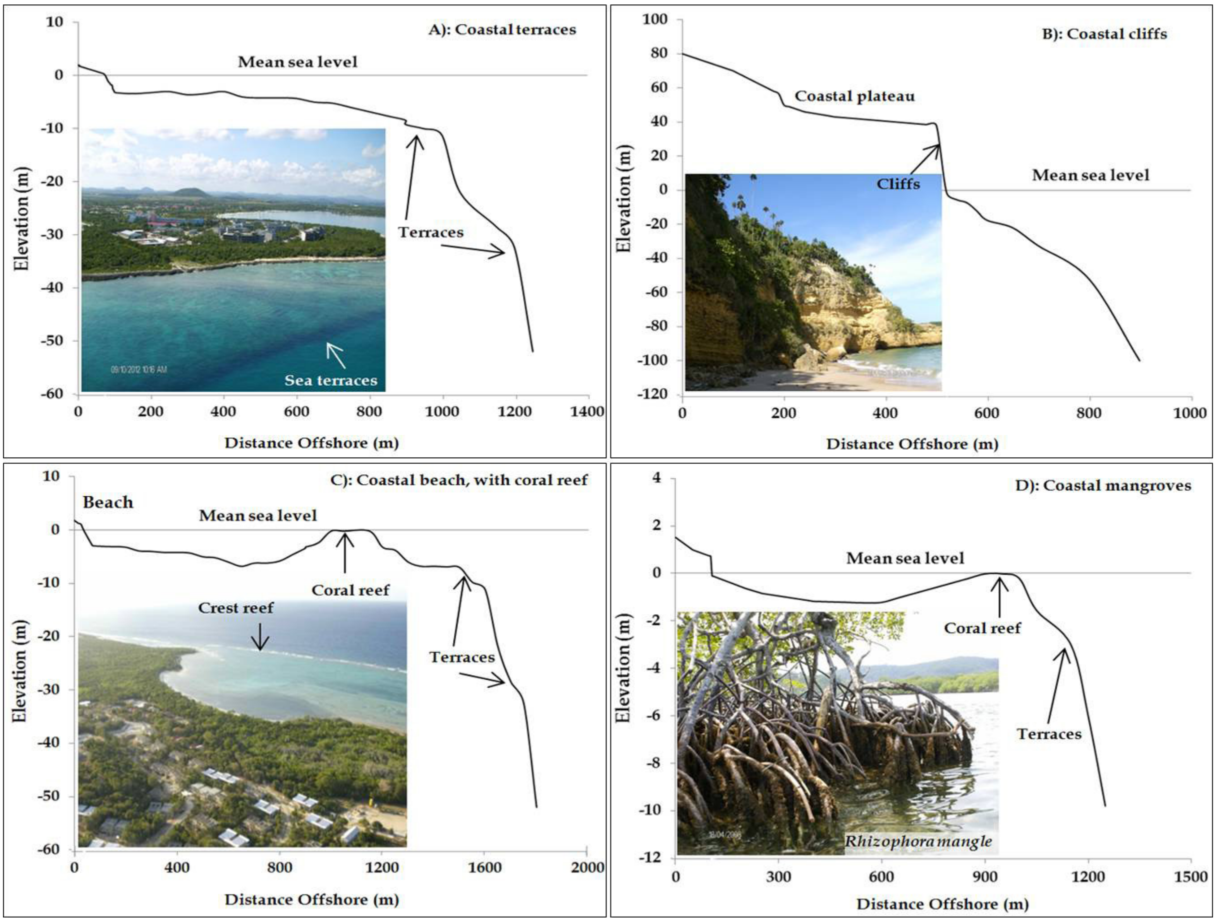

Figure 3. Scheme of characteristic profiles in the marine platform at the northeastern coast of Cuba. A: Coastal terraces (picture show sea terraces border), B: Coastal cliffs with collapse of blocks, C: Coastal beach (picture show coral reef crest), D: Coastal mangroves with Rhizophora mangle trees.

In some beach sectors, reefs limit their depths in the inner lagoon to lower depths of 6 m and then descend abruptly again. The existence and dynamic stability of these beaches are linked to the reefs, because those are the main source supply for their sediments and the same time serve as protection for the effects of the waves, particularly during the action of hurricanes and tropical storms.

Figure 4 shows there is a significant increase in the beaches constituted by terrigenous sands towards the eastern end of the study region (Guantánamo Province). This is due to the abundance of river currents to this part of the territory, which during the rainy season carry large amounts of sediments, favored by the mountainous condition of the relief and the great rainfall that takes place there. Tropical hurricanes have a considerable influence on the hydrological regime of these rivers since they bring abundant and heavy rainfall, mainly between the months of August to November.

Additionally, this is the area of the northeastern coast of Cuba with the smaller presence of coastal reefs and the biggest narrowness of the insular platform. This results in the lack of large areas of sediment production by marine organisms, particularly calcareous algae, as in the rest of the Cuban archipelago. Consequently, there are no large deposits of marine sand and beaches are of small extension and width.

3.2. Hydrodynamics

The northeastern coast of Cuba is characterized by being exposed to the persistent action of waves (heights than 1.0 m) throughout the year. During the summer has predominant directions from the I and II quadrants of the wind rose and during the winter with directions of the I and IV quadrants. These characteristics are determined by the wind regime (25 - 30 km/h) affecting the region and by the narrowness of its platform, which rarely exceeds one nautical mile wide.

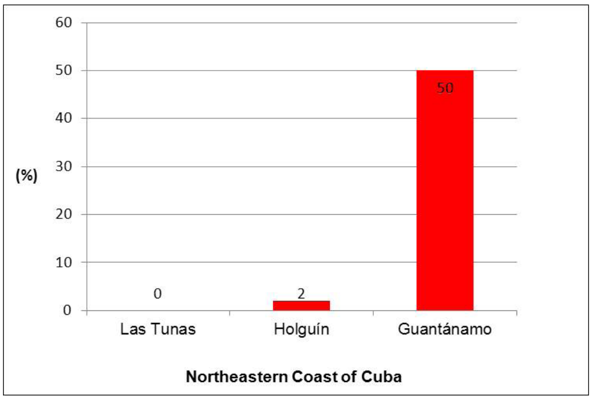

Figure 4. Distribution of terrigenous beaches by province.

Winds of the I and II quadrants of the wind rose, have a frequency greater than 75%, mainly from the East (53.09%), Northeast (9.75%), North (5.48%) and South East (8.94%). This is because Cuba and the northeast coast are more notably affected, almost all the year, by the Alisios winds, due to the nearly permanent presence of the anticyclone of the North Atlantic over the Azores Islands. This determines that the directions of incident waves in the study area and, therefore, those that define the behavior of the hydrodynamic regime in the northeastern coast of Cuba are North, Northeast, East, Northwest, and Southeast. The rest has no influence in the study area or their influence is very low, therefore its time of action can be considered as calms time.

Table 2 shows that the frequency of occurrence by direction increases from Northwest to East: 4.93%, 9.82%, 18.19% and 29.28% for the Northwest, North, Northeast and East directions respectively. The waves from the Southeast sector have 19.42%, therefore, it can be stated that the waves of the I quadrant are predominant.

However, the highest mean significant wave heights correspond to the North and Northwest directions: 2.00 m and 1.99 m, respectively (Table 3), which is related to the cold fronts and the strong winds that accompany it. This shows that although there is a predominance of the I quadrant waves of the wind rose, those of the IV quadrant are more energetic and therefore have a strong influence in the coastal processes.

Table 2. Annual frequency distribution of high and direction of waves in %, in the northeastern coast of Cuba.

Wave height (m)	Directions								Total
	IV quadrant		I quadrant		II quadrant		III quadrant		
	NW	N	NE	E	SE	S	SW	W	
Calm time	-	-	-	-	-	-	-	-	1.80
0-1	1.66	3.33	6.86	10.41	7.37	4.27	1.97	1.66	37.60
1-2	0.98	3.37	6.74	12.14	8.11	3.71	1.07	0.98	37.72
2-3	0.40	1.78	3.03	4.82	2.96	1.32	0.31	0.40	15.49
3-4	0.16	0.78	1.05	1.40	0.75	0.37	0.09	0.16	5.02
4-5	0.06	0.31	0.34	0.38	0.17	0.10	0.02	0.06	1.56
5-6	0.02	0.14	0.11	0.11	0.03	0.03	0.01	0.02	0.53
6-7	0.01	0.11	0.06	0.02	0.02	0.01	-	0.01	0.24
Total	**4.93**	**9.82**	**18.19**	**29.28**	**19.42**	**9.81**	**3.47**	**3.29**	**100.0**

Source: Based on data from the Global Waves Statistics (1960-2010).

Table 3. Mean height of the significant waves at northeastern coast of Cuba.

Directions	Wave height (m) by direction of incidence								Global Average
	W	NW	N	NE	E	SE	S	SW	
Northeastern coast	1.75	1.99	2.00	1.92	1.73	1.43	1.33	1.35	1.69

Source: Based on data from the Global Waves Statistics (1960-2010).

This explains the fact that sand retention rates are higher during winter than during the summer, as reported by Rodríguez and Córdova (2005b, 2010) during the work of the Estero Ciego and Don Lino beach nourishment. For this reason, the cold fronts have an important role in returning, each year, to their origin positions the sands permanently transported in the West direction. As the cold fronts are less frequent and intense nowadays, the sands do not return to their origin sector during the winter season, and that why rocky appear in the east sectors of some beaches.

Although wave characteristics are similar for the north coast of Cuba (Figure 5), the wave height is highest in the northeast coast since it receives the direct action of the oceanic waves due to the narrowing of the platform and by the wind regime, as discussed previously. In the case of the south coast, the characteristics are very different. Here the highest mean significant wave heights correspond to the Northeast and East directions (Table 3): 2.06 m and 2.04 m, respectively, as determined by the wind and wave patterns of the Caribbean Sea.

Due to the shoreline orientation and this wave regime, beaches of the northeastern coast of Cuba shown an accumulative process at the end of winter and at the begin of the spring. Maximum accumulation appears in the month of April while eroding happen beginning of autumn, with maximum values in the months of September and October (Rodríguez, 1992; Rodríguez and Córdova, 2005a, 2006, 2010).

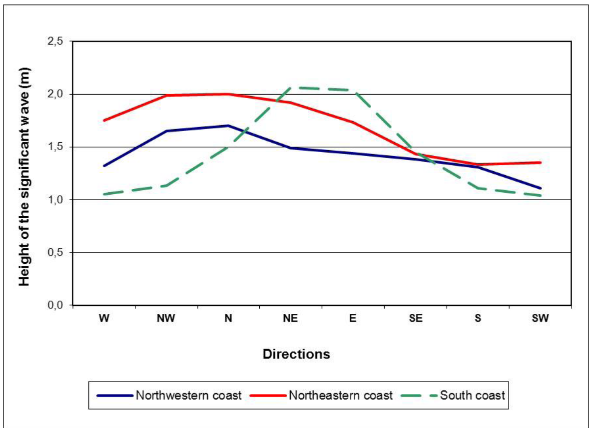

Figure 5. Characteristics of the typical wave conditions on the Cuban coast. Source: Based on data from the Global Waves Statistics (1960-2010).

However, the analysis of the morphodynamic behavior of the beach profile, in several sectors at the North coast of Cuba, shows that there is no defined trend of erosion and accumulation cycles. The normal periods where deposition and erosion processes predominate are irregular, although in general a tendency to accumulate in summer and to erode in winter may be observed (Juanes *et al*., 1984, 1985, Ramírez and Foyo, 1987; García, 2005; Sosa *et al*., 2005; Zúñiga, 2009).

The fact that beaches at the northeastern coast shown erosional processes at the beginning of autumn (September and October) is due to the increase in the frequency of the more energetic waves, mainly during the action of extreme events (hurricanes and tropical storms). These are mainly formed during summer and autumn (June to November), with the seasonal change of the atmospheric circulation, characterized by abundant and intense rainfalls, high-speed winds and coastal flooding. The waves produced by these phenomena cause erosive escarp, which at certain times appear in the berm and first dunes of the beaches.

The northeastern coast of Cuba presents semidiurnal mixed tides. It has the singularity of registering the greatest tidal range of the Cuban archipelago, with an average range higher than 0.50 m, but maintaining the condition of micro-tidal tides (Figure 6).

These tides generate currents, which become strong at the entrance of the bay, direction West-northwest during the tide flow and East-southeast, during the tide reflux. In fact, tidal currents may reach an average magnitude of 13.8 cm/s. Drift currents also take place, with a West-northwest direction, due to the high persistence of the Alisios winds of the Eastern sector and the shoreline orientation and configuration.

3.3. Sediments

Rodríguez and Córdova (2006) reported that 78.8% of the beaches at the northeastern coast of Cuba are constituted by biogenic sands, 14.1% of terrigenous sand, and 7.1% of mixed genesis sands (Figure 7). They used a sample of 99 beaches and considered biogenic beaches those constituted by more than 70% of elements coming from marine organisms. In their composition, mollusks, foraminifera, corals and calcareous algae highlight.

This shoreline is characterized by the absence of oolitic sediments (geochemical) as shown in Figure 7. The geological constitution has a big influence on it, along with the geochemical processes involved in its formation, the activity of marine organisms, and other factors (temperature, wave conditions). The predominance of volcanic rocks determines a poor contribution to the sea of calcium carbonate ($CaCO_3$), which together with the dynamic activity of the coastal zone, permanently affected by oceanic waves, and the strong slope on the marine platform, do not create favorable conditions for their formation and deposition.

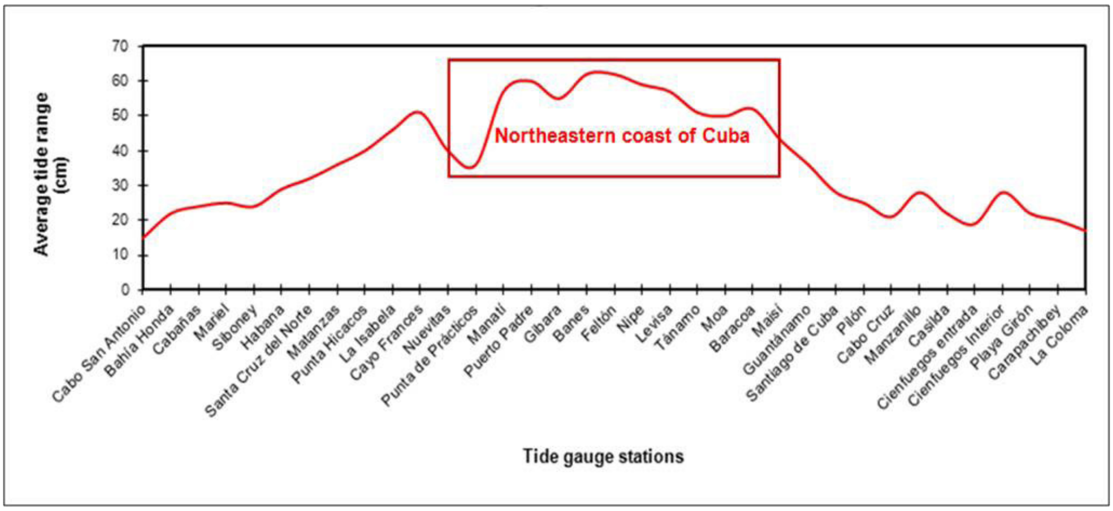

Figure 6. Average tidal range in the Cuban archipelago and northeastern coast of Cuba. Source: Based on data from tide tables of the Republic of Cuba (2017).

The study of the genetic composition of 35 representative beaches of this littoral indicates the predominance of mollusk remains in the genetic composition, followed by fragments of corals, foraminifera, and calcareous algae. The remains of minerals appear in proportions not exceeding 10%, denoting the predominance, almost absolute, of organic remains and the marine genesis of their sediments.

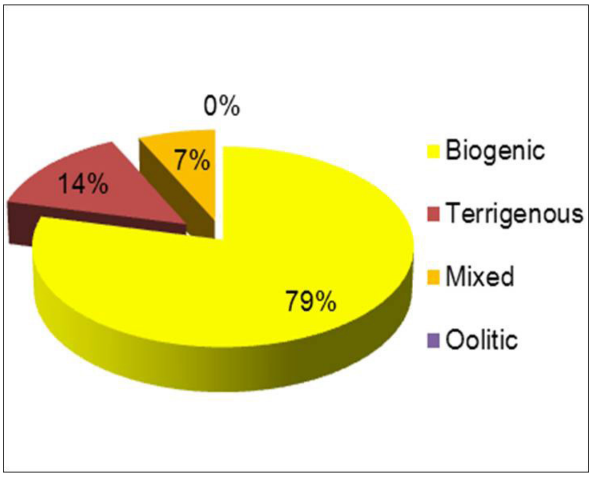

Figure 7. Genesis of the beach grain sand at northeastern coast of Cuba.

Figure 8 shows a comparative analysis of beaches of other regions of the Cuban archipelago. It is possible to observe that beaches at the northeastern coast of Cuba have a greater amount of remains of mollusks and corals, and much less remains of calcareous algae than the other beaches of the Cuban archipelago taken as reference in this study.

This is due to the differences between the northeastern coast of Cuba and other regions of the Cuban archipelago, in particular, the small extent of the insular platform, which limits the presence of large areas of sediments production by calcareous algae and marine organisms in general. This confirms the importance of the coral reef and the reef lagoon in the sediments formation feeding the beaches of this littoral.

Scuba diving exploration in numerous beaches does not show the formation of large sandbars that would evidence the presence of abundant sediments in the submarine slope. Therefore, the zone of production of sediments must be located between the shoreline and the limits towards the sea of the coral reefs that exist in front of the beaches. When surpassing the rift crests, the depth increases abruptly and the sediments become scarcer, being unable to cross the obstacle that constitutes the presence of a compact crest of coral reefs (reef crest) and the gravity force effects.

Figure 9 shows the main characteristics at the northeastern coast of Cuba. It shows the orientation of the shoreline, the arrangement of the coral reefs, coastal processes and characteristic profiles of the different coast types, among other aspects.

Due to the predominance of coastal relief forms conditioned by ascent movements in the northeastern coast of Cuba (Ionin

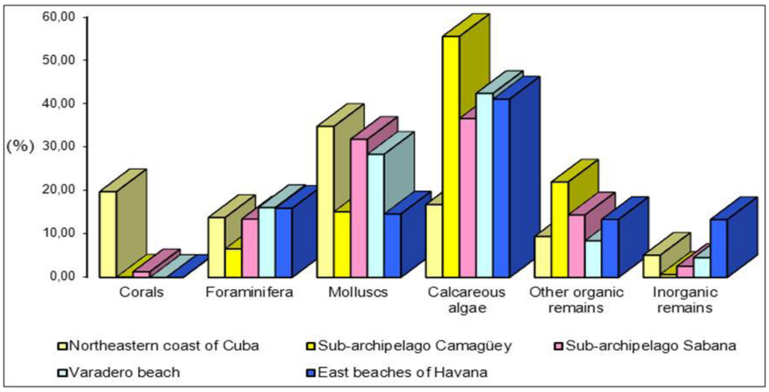

Figure 8. Genetic composition of the biogenic beach sands at northeastern coast of Cuba and other beaches of the Cuban archipelago (Ramírez and Álvarez, 1990; Garcia, 2005); Monitoreo Station of Caibarien (CESAM, 2009; Zúñiga, 2009; Rodríguez *et al.*, 2009).

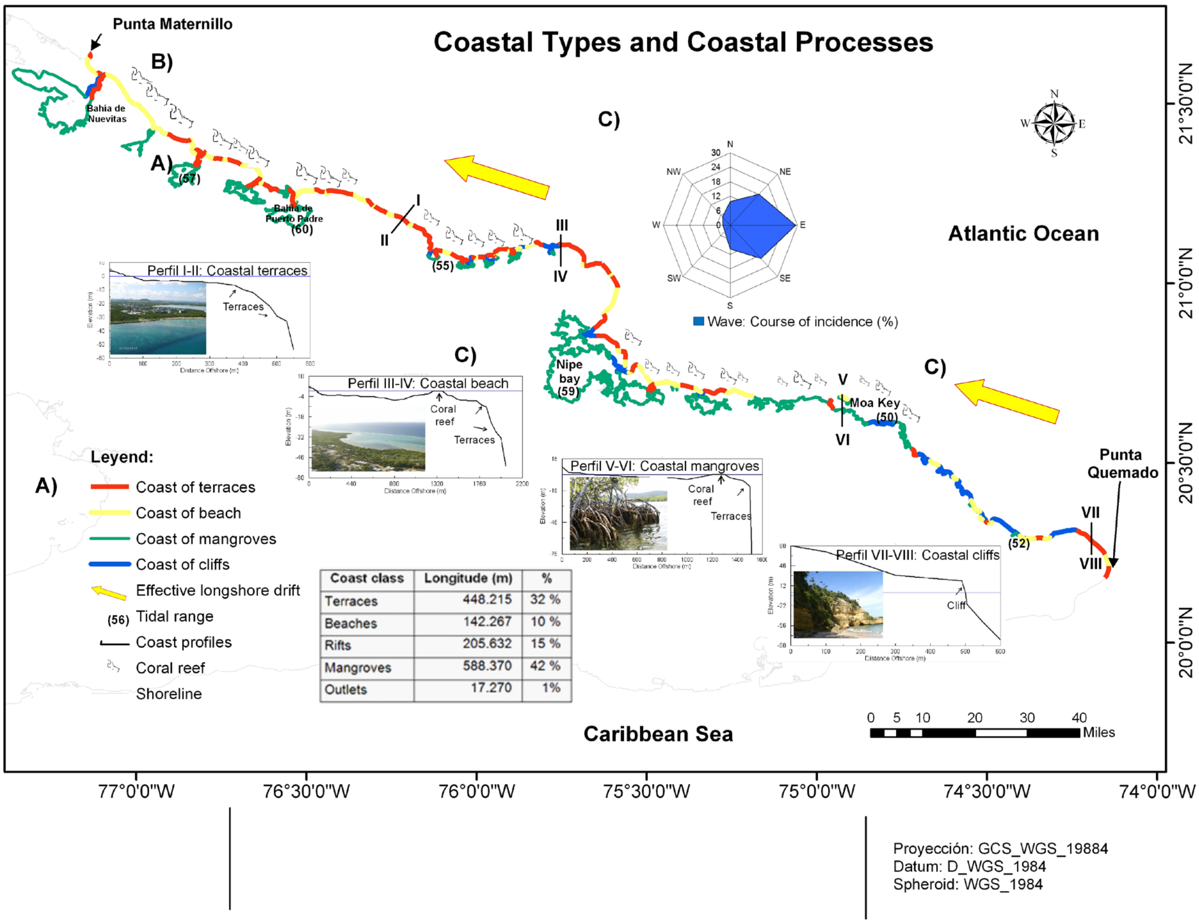

Figura 9. Coastal types and coastal processes at the northeastern coast of Cuba. A: Coastal type and orientation of the coastline, B: Arrangement of the coral reefs, C: Coastal processes and characteristic profile of different types of coast.

et al., 1977; Nunez Jimenez, 1982), sea level rise could have a lower impact in this littoral than in the rest of the Cuban archipelago, particularly in cays and lowlands. Preliminary studies on the impacts of climate change up to the year 2100 in Cuba anticipate a sea level rise between 0.27 and 0.85 m, which will lead to the loss of 6% (6628 km^2) of the surface area (AMA, 2014).

Given the peculiarities found at the northeastern coast of Cuba, the beach equilibrium profiles must have a behavior different from those predicted by the theoretical models developed for the continental coasts and applied to some sectors of the west coast and center of Cuba. This is because beach equilibrium profiles are determined by the hydrodynamic characteristics of the coastal zone where they are located and the characteristics of the sediments that compose it, including its genesis and grain size.

4. CONCLUSIONS

The northeastern coast of Cuba has a group of geomorphological, hydrodynamic and sedimentary features that distinguishes it from the rest of Cuba's archipelago. The existence of these singular features requires the definition of predictive numerical models of beach equilibrium profile, adjusted to the beach characteristics presented. Among the characteristic features are:

- The absence or narrowness of the insular platform. This most characteristic geomorphological feature on the northeast coast of Cuba determines the existence of coastal profiles of abrupt slope in the platform and the absence of large areas of detritus production by marine organisms;
- The low rocky terrace is the best represented type of coastline on the Northeastern coast, exposed to the direct action of ocean waves. Considering the inland coast, mangroves are the most abundant type of coast and occupy most of the bays on this littoral;
- There is a significant increase of beaches constituted by terrigenous sands towards the eastern end of the coast, conditioned by the abundant drainage network existing in the area;
- The highest wave heights of the north coast of Cuba take place there. In addition, the biggest tidal range of the Cuban archipelago is recorded;
- Beaches contain remains of mollusks and corals in their sediments, in higher proportions than in the rest of the Cuban archipelago, and a much smaller quantity of remains of calcareous algae.

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