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The Role of Sediment Source in Beach Management. A Case Study from Cíes Islands (NW Spain)

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ABSTRACT

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Beach management and consequent beach understanding become necessary in coastal areas due to the high pressure that they are nowadays standing. Management plan objective is the protection of particular areas, coastal areas in this case. The three islands of the Cíes Archipelago, where we have developed this work, have been recently included in the Atlantic Islands National Park. Despite the detection of beach erosion problems, there is not a specific management plan to protect these fragile areas. This work deals with the identification of sediment sources, transport pathways, sinks and budgets in order to establish the basic knowledge to the future beach and shoreline management plan. Morphology of most important coastal sedimentary complexes developed at the Cíes Islands, as well as their sedimentary characterization were described. Results show that sediments consist of two major components: siliciclastic and biogenic material. First one is made up of well rounded quartzes concentrated at sand fraction, which is the main sediment component of the two northern islands. The other component consist of carbonate sands and gravels, being the main component at the southern island. Only the second component presents an active sediment source since siliciclastic supply is nowadays negligible. This fact makes more difficult management plan, specially in those cases affected by sand extractions.

ADDITIONAL INDEX WORDS: *National Park, relict quartzes, carbonate sands, grain size parameters, stranded marine deposits, erosion problems.*

INTRODUCTION

Beaches have attracted people to the coast and large numbers visit them at seaside resorts and tourist areas each year for holidays and recreation. Nevertheless, uses of a beach can be very different according to the interest of a group over a particular beach. In this way beaches can mainly have recreational or mining uses. Beaches have been of increasing importance to the economies of coastal regions, then beach management has become necessary to deal with a variety of problems, for example erosion problems. Beach management will be most effective if those concerned understand how their beach has taken shape, what changes are occurring and why, and what is likely to happen to it in the future.

Problems also arise from the diverse, sometimes conflicting, demands of the people who come to use the beach. Due to growing pressures for development and its associated problems, many nations have adopted plans for the management of their coastal zones. Examples of these initiatives are the Integrated Coastal Management in UK, Coastal Zone Management Act in United States, the Integrated Coastal Zone Management introduced in the developing island nations of the South Pacific, or the plan of Coastal Zone Management in Malaysia for 2001-2005.

Management seeks to maintain or improve a beach as a resource and a means of coast protection, while providing facilities that meet the needs and aspirations of those who use the beach. It includes the framing and policing of any necessary regulations, and decisions on the design and location of any structures needed to facility the use and enjoyment of the beach environment (BIRD, 1996). There are important concepts identified by SIMM *et al.* (1995), MICALLEF (1996), and WILLIANS and DAVIES (1999) that represent beach management: 1. Identification of local characteristics and/or problems, 2. Understanding of coastal processes including the identification of sediment sources, transport pathways, sinks and budgets, 3. Availability of data on coastal processes and sediment-related characteristics, 4. Use of sound management practice, and 5. Development of effective legislation and enforcement mechanisms.

Beach sediments are resources that need to be conserved and supplemented if beach environments and opportunities for beach recreation are to be maintained. Then management will have to understand sediment ways and found out sources and losses of sediment to the beach. Sources can be represented by erosion of nearby cliffs and foreshore outcrops, and supply from rivers or artificial nourishment. Losses of sediment from the beach take place through the washed or blown inland, drifting away alongshore or weathering and attrition (BIRD, 1996). There are many beaches that are still receiving sediment from one or more sources, some of them have become relict, and consist of deposits that accumulated in the past, but are now no longer arriving.

Along this paper we will present a study area located inside a National Park where erosion problems were registered and where there is not a beach management plan. The aim of this work is achieving of the understanding of coastal processes at the study area, in particular, the identification of sediment sources, transport pathways, sinks and budgets in order to establish the basic knowledge to beach and shoreline management. In order to reach this objective we will focus this paper on the identify the sediment components along the sedimentary complex of the Cíes Islands, as well as to establish relations between these components in order to find out beach nourishment.

ENVIRONMENTAL SETTING

Study area is located at the mouth of the Ría de Vigo, NW of Spain. This coastline, specifically, Ría de Vigo is characterized by winds that show seasonal behavior according with the analysis of a ten years temporal series (ALEJO, 1994). During winter (November to February) southern winds are the most frequents, while during summer (March to September) western-northwestern winds are the most frequents. Tidal regime is mesotidal, with a mean tidal range of 3 m. Swell conditions come into the Ría through the northern mouth, from NNW (R.O.M., 1991). On the other hand, sea conditions approach mainly from N direction (R.O.M., 1991). Storm waves reach study area from SW, most important erosive events at the study area are caused by these waves.

Cíes Islands archipelago is located between 42º 15' and 42º 11' North, and 8º 53' and 8º 55' West. The archipelago is made up of granite blocks with a very steep western side, and a gentle slope at the eastern side of the islands. Tectonics have given rise to three islands archipelago, Monteagudo Island, Faro Island and San Martiño Island, from North to South. These islands are part of the Atlantic Islands National Park.

Eastern slope of the islands is sheltered from the attack of the wave energy coming from the open ocean. Due to these hydrodynamics and morphological characteristics emerged sedimentary complexes, like beaches or dunes, are located at this side of the islands. These sedimentary complexes constitute the focus of this study. Figueiras, Rodas and San Martiño represent the main sedimentary complexes (Figure 1).

SEDIMENTARY COMPLEXES

Figueiras is a 300 m long beach located at the northern island is approximately oriented to the North direction (Figure 1), facing the waves coming into the Ría de Vigo from North and Northwest directions. Backshore border on an established foredune at the southern sector of the beach and on a low receding cliff at the northern one. Foredune reaches 12 m over the 0 local datum as maximum high. This beach was affected by the Prestige oil spill in December 2002. Nowadays dredging activities at nearshore are been carried out in order to remove oil that remains at this sector of the beach.

Rodas is a 1-km long beach, it is part of a sand barrier complex, which confines a lagoon (Figure 1). This sedimentary complex represents one of the most attractive natural resources of the National Park, due to its nice natural characteristics, sand whiteness, and ecological diversity. Sand barrier is bounded by south (Punta das Vellas Cape) and north (Punta Muxieiro Cape) headlands, resulting in a headland embayed beach linking northern island (Monteagudo) and central one (Faro). The northern one has a wide vegetated dune complex, Punta Muxieiro (Figure 1), which continues to Figueiras foredune connecting the sand barrier with Figueiras. Rodas beach is backed by a low foredune, 6 m height over the Hydrographic Zero Local Datum.

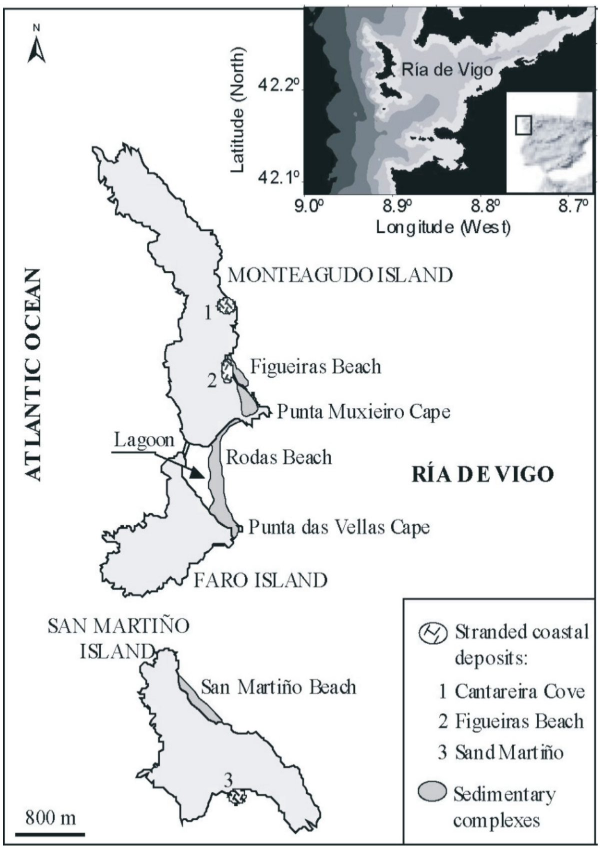

Figure 1. Sedimentary complexes studied locations at Cies Islands.

San Martiño is a 600 m long beach located at the southern island (Figure 1). There is a well developed and vegetated foredune at the backshore of the beach. There is not studies about the morphological evolution of this beach due to difficulties of transport to this island.

These systems are low energy beaches since they are sheltered from open ocean energy waves.

Stranded coastal deposits (beaches or dunes) have been found (Figure 1). Their age is still unknown. COSTAS (2002) pointed out a hypothesis that suggests that Figueiras deposits had been formed during a sea-level highstand, which could be during the 5e interestadial. These ancient deposits are located at the backshore and below Figueiras Beach, and Cantareira Cove. These deposits show a high cementation degree that could be related to the water table. We have related this deposits to the development of beach systems at past due to their position and sedimentary characteristics. The other deposit, at San Martiño Island, could be identified as a dune system due to the internal structure, sedimentary characteristics and mainly due to its position. It is raised from the actual sea level (4-5 m), and was developed in the top of a colluvion deposit. It shows a lower cementation degree than the other deposits since the water table does not affect it. This one faces the South, which is the approach direction of winter storms. Nowadays a rounded boulder beach is developed at this zone, which is part of a tombolo. This stranded dune would be developed during a lowstand.

Uses and Problems

Cíes Islands have attracted people from fifties decade. It is due to their nice beaches and high water quality. Particular characteristics of beach sands whetted the interest of construction companies that have been extracting sand as cement component for two decades, from fifties to seventies (COSTAS *et al*., 2002). Actually this practice is not allowed by the national authorities, with special emphasis at protected zones, as a National Park.

Nowadays islands only receive tourists from June to September, although human press during these months is very high due to the low area where tourist is allowed, as well as the large number of visits. Press is concentrated on beaches, dunes and lagoon areas with recreational aims.

Rodas Beach showed important erosion problems near to the walk path that travels around the northern and central islands (COSTAS *et al*., 2002), where dune has disappeared and consequently erosion problems are affecting walk path conditions. Erosion problems are also located at the southern area of the sand barrier, where the authors have registered destruction of the Punta das Vellas foredune, as well as a quick retreat of the southern sector of this sand barrier.

The lagoon, where there are important *Zostera marina* communities (KERSTING *et al*., 2001), is also suffering important problems. In this case, it is registering an accelerated infilling process since sixties (COSTAS *et al*., 2002). This decrease in depth promotes the *Zostera* proliferation due that these communities are developed on sand and shallow substrates (KERSTING *et al*., 2001). Other problem, related to the human activities and lagoon evolution, is an increase of species diversity (mainly fishes). The communication with the open ocean shows natural restriction, it is not an open channel since the basement is just bellow the water: covered during high tide, and exposed during low tide. Due to this fact, fishes could come into the lagoon during high tide, when the lagoon has lower water level than open ocean. However during ebb tide, water level into the lagoon is higher and there is not a flow connection with open ocean. This communication have become more limited since the construction of an artificial path connecting the two islands.

SEDIMENTARY CHARACTERIZATION

A total of thirty surface sediment samples were collected at the three beaches, as well as at adjacent offshore areas, and stranded coastal deposits. Grain-size distributions were determined at 0.5 phi units (phi = $-\log_2 d$, where d is the grain diameter in mm) intervals over a range 4 to 4 phi using dry sieving. Graphic method (FOLK and WARD, 1957) was applied to calculate grain size parameters. Carbonate percentage was determined by Bernard Calcimeter (WIESMANN and NEHRING, 1951). Mineralogical composition was analyzed by X-ray diffraction. Grain shape was determined at each phi interval using a visual comparison chart that combines measures of roundness and sphericity (POWERS, 1982).

Table 1 summarizes results from mean grain size, mode, roundness of the mode fraction, sorting of sediment, and carbonate percentage.

A Kruskal-Wallis test was used to test for differences in grain size parameters along the profile (dune, backshore, foreshore and shoreface sectors) where samples were collected. This test is advisable for small data sets, it is a non-parametric equivalent to one-way ANOVA. The null hypothesis is that all samples were drawn from population with identical medians. Significance level for statistical analysis was $P < 0.05$.

Figueiras Beach

Nine sediment samples were collected at Figueiras Beach to characterize sediment components along the beach profile (dune, backshore, foreshore and shoreface), and from North to South along the beach.

Grain size parameters showed an important homogeneity, except for sample colleted at the northern shoreface, which showed high heterogeneity due to the accumulation of around 9 cm quartzite boulders (Table 1). In spite of the high homogeneity of the sediment samples(except for shoreface), it was possible to identify an increase in the mean grain size and mode towards southern sector of the beach. Sorting analysis resulted well sorted samples, sorting improves towards northern sector (Table 1).

Beach sediments consist mainly of quartz (91 %), secondary component is made up of biogenic carbonate (3-6 %). Rest of the sediment composition is made up of heavy minerals (garnets, estaurolite, magnetite and glauconite). Increase in the percentage of heavy minerals is related to washed process, eolian deflation or water currents. Mode fraction is made mainly up of quartz.

Mode grain shape is well rounded and very spherical. On the other hand, shell fragments, are angular and prismoidal grains due to the breaking processes that affect these grains.

Table 1. *Grain size parameters, shape analysis and carbonate content for the samples located at the studied sites.*

SAMPLED SITES	ZONE	SECTOR	NUMBER OF SAMPLES	MODE	SECOND MODE	MODE ROUNDNESS	MEAN (phi)	SORTING	% CARBONATE
FIGUEIRAS	North	Backshore	1	1.747		Well rounded	1.534	0.330	4.01
FIGUEIRAS	North	Foreshore	2	1.747		Well rounded	1.673	0.375	4.85
FIGUEIRAS	North	Shoreface	1	-4.731	1.747	Well rounded	-2.308	0.753	3.20
FIGUEIRAS	South	Dune	1	1.247		Well rounded	1.466	0.392	3.42
FIGUEIRAS	South	Backshore	1	1.247		Well rounded	1.253	0.345	5.00
FIGUEIRAS	South	Foreshore	2	1.247		Well rounded	1.413	0.350	4.00
FIGUEIRAS	South	Shoreface	1	1.247		Well rounded	1.187	0.722	6.23
RODAS	North	Dune	1	1.747		Well rounded	1.570	0.315	6.01
RODAS	North	Backshore	1	1.247		Well rounded	1.208	0.350	4.00
RODAS	North	Foreshore	2	1.247		Well rounded	1.270	0.348	11.88
RODAS	North	Shoreface	1	1.247		Well rounded	1.025	0.409	11.78
RODAS	Center	Dune	1	1.247		Well rounded	1.482	0.394	5.55
RODAS	Center	Backshore	1	1.247		Well rounded	1.058	0.866	8.92
RODAS	Center	Foreshore	2	1.247		Well rounded	1.287	0.350	10.80
RODAS	Center	Shoreface	1	0.747	-2.743	Sub-rounded	-0.543	1.790	27.95
RODAS	South	Dune	1	1.247		Well rounded	1.067	0.487	14.83
RODAS	South	Backshore	1	1.247		Well rounded	1.242	0.429	16.41
RODAS	South	Foreshore	2	1.247		Well rounded	1.337	0.354	36.08
RODAS	South	Shoreface	1	0.747	-4.731	Sub-rounded	-0.478	1.589	39.02
RODAS		Adjacent offshore	1	1.247		Rounded	1.090	1.063	31.89
SAN MARTIÑO		Foreshore	1	0.747	-1.743	Angular	-0.430	1.790	96.50
SAN MARTIÑO		Adjacent offshore	1	0.747		Angular	0.180	1.070	88.60
STRANDED FIGUEIRAS	North		2	1.247		Well Rounded	1.470	0.490	0.00
STRANDED SAN MARTIÑO			1	1.247		Rounded	1.320	0.720	0.00

Rodas Beach

Fifteen samples were collected along the beach profile (dune, backshore, foreshore and shoreface sectors), as well as along the northern, central and southern sectors.

Transversal and longitudinal heterogeneity is related to presence of gravel shell fragments. Concentration of this fraction happened owing to the closeness to the shoreface (Table 1), where there is high shellfish productivity. Highest concentrations are related to washed process that happen at the beach step due to the incidence of waves and the action of a backwash vortex.

Mean grain size increases towards southern sector of the sand barrier (Table 1), where there are a higher presence of shell fragments. This fact shows that this area receives a higher sediment contribution from the nearby areas. Due to its orientation deflation processes are more important at this area, contributing to the shell fragments concentration. Sorting repeats mean grain size pattern improving towards North, showing a slight mean size increase at the backshore of the central sector. This fact could be related to eolian deflation processes and consequent concentration of gravel fraction (shells). Mode variations along the beach were not registered, except for center and southern shoreface samples, which showed a bimodal distribution with first mode different from beach mode.

Beach sediments consist mainly of quartz (70-95 %), secondary component is made up of biogenic carbonate (4-39 %). Heavy minerals concentration is lower than at Figueiras Beach.

Mode at this beach also consists of very rounded quartz grains. Tails of the grain size distribution are made up of shell fragments, grains with textural immaturity.

A sample was collected at the inner offshore (11.95 m depth) in order to relate this one with beach sediment. Mode sample coincides with mode along the beach. Mean grain size was higher than sizes for the beach, and this sample resulted more negative skewness, as well as poorly sorted (Table 1). Carbonate material presents at this sample shows an increase compared with beach samples, except for the higher concentration registered at shoreface (31.89 %).

San Martiño Beach

One sample from the foreshore was collected to characterize sediment of this beach. Results showed that it is different from the other beaches analyzed.

Grain size distribution is bimodal, first mode is located at coarse sand (0.75 phi, Table 1) second one is located at granule fraction (-1.74 phi). Sediment was poorly sorted.

Beach sediment consist of carbonate (96 %), and granite fragments as secondary component. Characteristics of this sediment show that it has low textural maturity.

Sample collected at adjacent offshore area (11 m depth) showed an unimodal distribution. Mode coincided with the main one at beach sediments (Table 1). Mean grain size showed a decrease towards this area, while sorting resulted slightly better than beach sediments. Carbonate percentage analysis showed that this sample consist of 88 % of biogenic material. Rounded quartzes were detected as trace material at this sample.

Stranded Coastal Deposits

Three samples were collected to characterize ancient deposits, beach and dune. Figueiras stranded beach sediment was described by two samples selected from the outcrop, one from the lower part and the other 1 m above this one (Figure 2). The third one was collected at the south of San Martiño Island (Figure 1).

Grain size parameters for these samples showed a high homogeneity (Table 1). Sorting was the most variable parameter due to the higher dispersion of this sediment towards finer fractions with regard to actual beaches. This fact could be related to the mixture of grains from the original deposit, and sediment product of alteration that would take place during fossilization processes. Finer fractions consist mainly of iron oxides, which could come from washed of slope deposits. An increase in mean grain size at San Martiño deposit is related to the higher presence of granite alteration products, as a component.

Biogenic carbonate has been removed from the ancient deposits. This fact has been introduced by ALONSO and PAGÉS (2000) when they described others ancient beaches deposits developed at Galiza Coast. They attribute the carbonate dissolution to the common acidity of Galiza soils.

Statistical Analysis

Kruskal-Wallis test to twenty eight samples showed significant differences in grain size parameters, mean grain size and sorting of sediment between the defined classes. On the other hand, the same analysis did not show significant differences in skewness, kurtosis and mode.

However, test performed for a total of twenty three samples did not show significant differences when shoreface class was not included (Table 2).

DISCUSSIONS

According with the results introduced above, samples collected at Rodas and Figueiras have a high homogeneity as regards grain size distribution and composition, on the other hand, San Martiño Beach sediment showed differences in both features, since this one is made up of biogenic carbonate.

Kruskal-Wallis test showed that do not exist significant differences in size grain parameters between dune, backshore and foreshore at the three beaches. Differences appeared when we introduced shoreface profile sector. This fact was related to the presence of biogenic carbonate at higher fractions (> 1 mm) at Rodas and to the presence of siliciclastic boulders at Figueiras.

Mode fraction at Rodas, Figueiras, and ancient deposits coincide. It is made up of very well rounded quartz grains and was considered as the major component at this sedimentary complexes. Second component at Rodas and Figueiras is composed of biogenic carbonate, whereas it is the major component at San Martiño Beach.

Identification of two major components inside the National

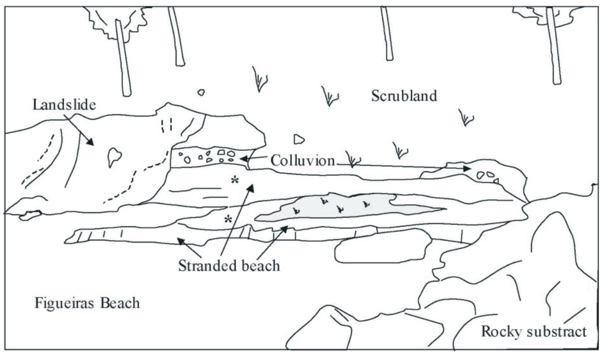

Figure 2. Picture and diagram showing Figueiras stranded beach location, as well as samples collection sites (*).

Table 2. *Kruskal-Wallis test results for dune, backshore and foreshore classes.*

	Chi-square	Significance Levels
MEAN	2.216	0.529
SORTING	4.181	0.243
SKEWNESS	3.616	0.306
KURTOSIS	2.803	0.423
MODE	0.064	0.996

Park seems point out to the presence of two different sediment sources. One would consist of very well rounded quartz with a high textural maturity, which, along with its presence into the ancient deposits, show that this component is made up of relict grains. This component could be making up of all of the sedimentary complexes at the Cíes Islands Archipelago at past, including landforms developed at San Martiño Island. According with these we could assume that this component was transported towards the islands in the past and it has stayed trapped at sites, where it has could be fossilized. Actual sedimentary complexes have taken this component through the erosion of ancient ones. We suggest that sediment source of this component is nowadays negligible since it has not an active external source as would be in the past.

The other component, biogenic carbonate, comes from adjacent benthic communities that live at the adjacent offshore areas. In this sense, we have detected an increase towards these areas of carbonate percentage according with the results showed for the two samples collected at these areas, as well as Ría de Vigo sediments in the vicinity of the study area (Vilas *et al*., 1995). This component presents an active source of sediment towards the beaches. It shows a high textural immaturity due to the considerable modification via fragmentation, abrasion and process filtering over a comparatively short time span, as pointed out CARTER (1982).

Comparison between the samples collected at Figueiras and Rodas was carried out in order to establish transport patterns between north and central islands due to the described similarity, and due to both beaches share the same principal component. Changes in grain size parameters have been used to speculate on the direction of sediment transport with field transport direction observations.

Several methods using grain-size parameters of surface sediments have been employed over the last three decades to establish their transport pattern (MCLAREN and BOWLES, 1985; GAO and COLLINS, 1992 or LE ROUX *et al*., 2002). We have compared the trend of those samples with the four dominant trend types that these authors have concluded for speculate on the direction of transport. Authors relate distributions of sediment in transport to their source by a sediment transfer function. According with the reported grain size distribution changes, we have interpreted that sediment transport direction at Rodas and Figueiras is towards the North. Along this direction sediments become finer, better sorted and more negative skewed, in accordance with the case B defined by MCLAREN and BOWLES (1985), or case 1 defined by GAO and COLLINS (1992). Both were defined, together with case C and 2 trend types respectively, as the most suitable to determine grain size transport pathways (GAO *et al*., 1994). In this sense Rodas and Figueiras could be defined as relict beaches, in agreement with the definition proposed by BIRD (1996). According with this author, beaches continually reworked by wave action can become very well sorted, or develop lateral grading in grain size in relation to incident wave regimes. This author pointed out that such adjustments are impeded where there is a continuing supply of fresh sediment. Even though both beaches have the same sediment transport pathway, we suggest that Rodas and Figueiras constitute independent hydrodynamic cells, since they are separate by Punta Muxieiro Cape. Nevertheless, this cape and the dune complex developed behind, acts as an eolian sediment connection between these beaches. Wind transports sediment from South to North during winter, while during summer this pattern reverses.

These cells would consist of a main component, relict quartz grains, reworked along the time. This fact becomes very important when a natural or artificial process removes sediment from the system. In this sense we emphasized on the erosion problems at Rodas (COSTAS *et al*., 2002) due to exhaustive mining activities, as well as possible future erosion problems at Figueiras Beach due to the nowadays dredging activities that are carrying out to remove oil remains. These activities could promote the loss of sediment, which, as we have pointed out before, has not an actual sediment source.

CONCLUSIONS

Sedimentary complexes developed at Cíes Islands are mainly made up of two components. First one consists of well rounded quartzes as principal component of Rodas, Figueiras Beaches and stranded coastal deposits. This component was transported to the islands in the past and it is considered as relict sediments. The second component consist of biogenic carbonate. This one is present at Rodas and Figueiras as a secondary component, however is the main one at San Martiño Beach, developed at the southern island of this National Park. On the other hand, we considered that San Martiño Sedimentary Complex is not related to the other beaches sediment budget and sources. Biogenic carbonate is an immature component, since is continuously added to actual beaches. This component is not present at stranded coastal deposits due to dissolution processes that occur during fossilization.

These sedimentary environments are included into a National Park, therefore they need a specific management plan. Requirements for this ought to bear in mind the special sediment characteristic of the main component, which consist of relict sediments, whose source is nowadays negligible. Human activities developed at study area can promote lost of sediment and consequently irreversible erosion problems at these environments.

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