

RELATIONSHIP BETWEEN SHORELINE EVOLUTION AND SEDIMENT WEAR

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Abstract – Many factors can influence the shoreline retreat, such as: the maritime climate, anthropogenic actions like the construction of ports, dams, etc. To overcome this problem, it is necessary to understand the influence of each of the factors involved in beach erosion. This work tackles the problem of shoreline erosion from the study of the beach material, specifically sediment wear. The main objective is to establish a relationship between shoreline evolution and sediment wear. The study of diverse beaches (with different median sediment size, mineralogical composition, etc.) shows that the shoreline evolution trend is similar to of the results obtained by the accelerated particle wear test (APW). However, the relationship between the number of APW test cycles and the years of shoreline evolution is not clear. In Guardamar beach (Guardamar, Spain) the ratio (years/cycles) is 9.7, in Marineta Casiana beach (Denia, Spain) it is 5.6, and in Arenal beach (Calpe, Spain) it is 3. Differences may be due to the different mineralogical composition and morphology of the sand particles. Therefore, there is a relationship between sediment wear and shoreline evolution. However, more sediment tests (composition, morphology, fractures, etc.) are needed to determine the exact relationship between the number of APW cycles and the years of shoreline evolution.

Introduction

Coastal erosion is one of the most important problems worldwide [7]. Many actions have been undertaken to try to solve this problem, all of them based on two main aspects: the construction of protection structures and the supply or dumping of sediment [9, 38]. Periodic beach nourishment is considered to be the most acceptable method of protecting and stabilising beaches and restoring dunes [3, 14, 23]. However, to stop coastal erosion it is necessary to know the factors involved in the retreat of the shoreline, such as the waves, currents, the properties of the sediments, and the conditioning factors of the environment [6].

According to various authors, the intrinsic factors that control the stability of beaches are the profile of the beach and the characteristics (size, density and porosity) of the sediments [1, 29, 35]. Therefore, sediments are an important part of understanding coastal processes [12]. Many authors relate shoreline changes to sediment movements, specifically between the shoreline and the depth of closure [10, 13, 37], while others indicate that sediment wear is an important factor in shoreline evolution [8, 32, 33].

Sediment wear begins when the particles that constitute the sediment are set in motion, that is, when the instantaneous force of the fluid is greater than the resistance force of the grain [36]. Once the particles are in motion, wear can be caused by three phenomena [20]: i) particle shock. ii) Dissolution of carbonates. iii) Breakage and separation of mineral

fractions. Therefore, it is clear that the mineralogical composition of the sediment is an important factor to consider in wear [34]. However, according to several authors, the most influential factors in sediment wear are the morphology and fatigue of the material [21, 32]. Fatigue is understood as the breakage of the material when it is submitted to long-duration dynamic efforts, or the tendency to fail due to cyclic loads [4, 5]. Cyclic loads often cause failure in brittle materials, such as rocks, with stress levels below their strength under monotonous conditions [4, 11]. The existence of fractures and other microstructural aspects (microcracks, pores, etc.) in rocks significantly affect their fatigue strength [16, 18, 19].

Therefore, it is known that the sediment is worn by breakage when the particles collide with each other, by the dissolution of the mineral elements that compose it and by the fractures and micro-fissures of the particles [20, 21, 32]. However, the degree of influence that sediment wear has on beach erosion is not known. For this reason, this study will analyse the evolution of the shoreline, the maritime climate and the wear of sediment on 3 beaches to establish a relationship between beach erosion and sediment wear.

Materials and Methods

Shoreline evolution

The evolution of the shoreline was carried out by studying aerial images from 1956 to 2019. The non-georeferenced images (years 1956, 1977, 1981, 1986, 1990, 1992, 1994, 1996, 1998) were georeferenced using ArcGIS 10.1® software. Both non-georeferenced and orthophotos (years 2000, 2005, 2007, 2009, 2012, 2014) were obtained from the CNIG (Spanish National Centre of Geographic Information, www.cnig.es) under CC-BY 4.0 license.

Once the orthophotos of each year were obtained, the vectorization of the shoreline was performed. The criterion for digitizing the shoreline was the choice of the line of the last wet tide mark on the beach profile [28, 30]. Given the high resolution of the aerial images, the digitisation was conducted at a scale of 1:1000, which allows the shoreline to be obtained visually in detail. To obtain the width of the beach in each period, transects were created perpendicular to the shoreline every 100 m. The intersection of these transects with the shoreline allows obtaining the different beach widths.

To compare the results of the evolution of the shoreline with the wear of the sediment, the anthropic actions and the nourishment performed on the different beaches were considered. The beginning of the evolution of the shoreline was chosen as the year after the beach nourishment since this coincides with the material that was tested for wear.

Maritime climate

To exclude the influence of waves on the evolution of the shoreline, the maritime climate on each of the beaches was studied using data from the SIMAR nodes nearest to each of them. The data of the SIMAR series provided by Puertos del Estado (<http://www.puertos.es>), have been collected over 61 years, during the period 1958-2019, which constitutes the most complete database of the Mediterranean.

These data were treated using the AMEVA v1.4.3 software [15], obtaining for each of the study periods, the significant wave height and its corresponding periods, directions and probabilities of occurrence.

Sediment wear

The accelerated particle wear test (APW) proposed by López [20]. In this test, 75 g of sand from the beach and 500 ml of seawater from the study area are poured into a magnetic stirrer at 1600 rpm in 24-hour cycles. After each test cycle, the granulometry of the sand sample (UNE 103 101:1995, UNE 7050-2 and UNE 103 100) and the calcimetry of the water were performed using the Bernard calcimeter method (UNE 103200-93). The test is terminated when more than 50 % of the sample presents sizes smaller than 0.063 mm.

Finally, the Scanning Electron Microscopy (SEM) was used to perform elemental and morphological analysis of the sediments. This technique allows obtaining images of the sample, as well as the elemental composition of the sample and its possible changes [24].

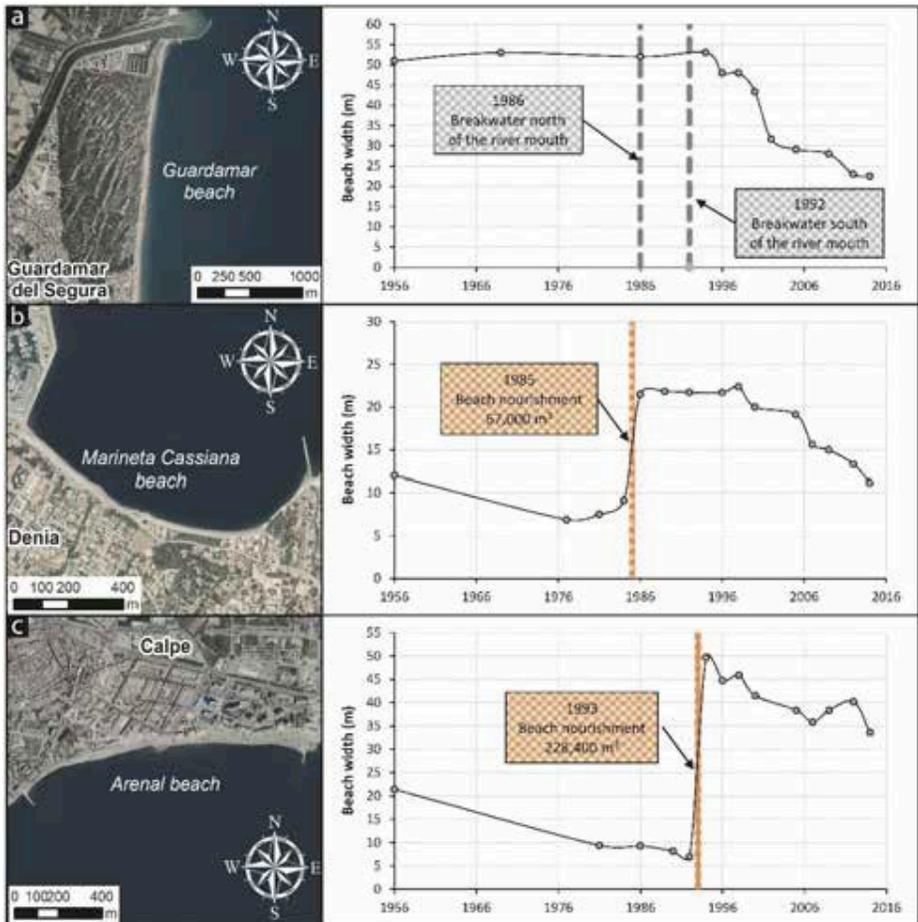


Figure 1 - Location of study beaches and evolution of the mean beach width. a) Guardamar. b) Marineta Casiana. c) Arenal.

Thus, it was possible to know the microstructure and morphology of the particles with their possible fracture faces and heterogeneity. For crystallographic analysis, X-ray diffraction (XRD) was used to determine their mineralogical composition.

Results

Figure 1 shows the evolution of the mean width of the beaches since 1956. All three beaches show clear erosion. Erosion on Guardamar beach began just after the construction of the groins at the mouth of the Segura river. Since then, more than 30 m were lost in 20 years (58 % of the beach). In Marineta Casiana and Arenal, beach nourishments were performed in 1985 and 1993, respectively. The nourishment at Marineta Casiana with 67 000 m³ of sand produced an increase in beach width of 12.4 m. And the nourishment in the Arenal with 228 400 m³ produced an increase of 42.8 m in width. Erosion on these two beaches continued after the nourishment, with a rate of -0.37 m/year at Marineta Casiana and -0.8 m/year at Arenal. Due to the nourishment conducted, for this study data on the evolution of the coast since 1956 in Guardamar, 1986 in Marineta Casiana, and 1994 in the Arenal are used. This is done so that the material tested in the APW test is related to the existing material on the beach.

To justify that the increase in erosion in recent years, especially on the beaches of Guardamar and Marineta Casiana, is not related to the waves, Figure 2 shows the evolution of the average wave height (Hm) and its associated period (Tm) on each of the beaches under study. Thus, in Guardamar, the mean wave height remains constant at an average of 0.6 m and a period of 5.3 s. At Marineta Casiana, due to its orientation (NNE), the mean wave height at the beach is higher than at the other beaches, but although the height is greater, the mean height is also constant, with an average of 0.76 m and a period of 6.2 s. The Arenal beach is where the lowest wave height occurs because it has a south orientation. The mean wave height is 0.55 m and a period of 5 s. On this beach, a small increase in the mean wave height is observed in the years 2013 and 2014, with wave height values of 0.7 m and 0.65 m, respectively.

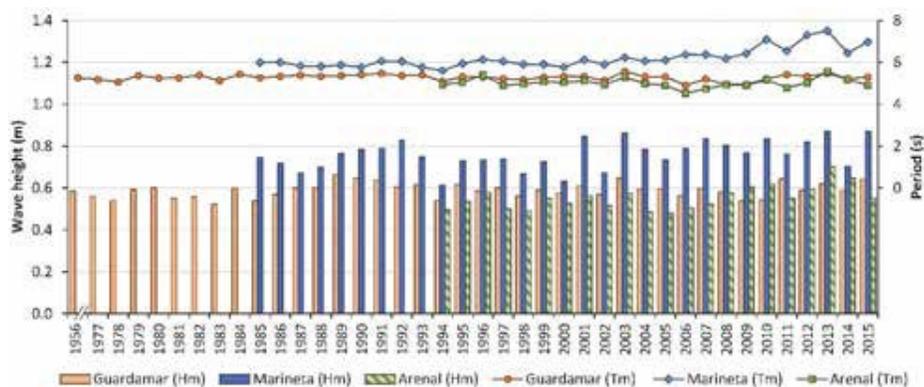


Figure 2 - Evolution of mean wave height and its associated period on each of the study beaches.

The next step is to compare in the APW test and the percentage of beach width lost from, as indicated above, the year of origin of the data (Guardamar) or from the nourishments conducted on the beach (Marineta Casiana and Arenal). As shown in Figure 3, the results of the APW test are completely different on the three beaches. Guardamar beach takes 6 cycles to lose 50 % of its mass, while Marineta Casiana beach takes 5 cycles and Arenal beach 7 cycles. Nor the mode of wear is the same, while the Arenal wears continuously and linearly, the beaches of Guardamar and Marineta Casiana have continuous wear until a cycle in which they lose material abruptly. This behaviour is similar to the behaviour of the evolution of the average beach width. However, the relationship between the number of years and the number of cycles in the APW test is completely different between the three beaches. For Guardamar beach the ratio (years/cycles) is 9.7, in Marineta Casiana it is 5.6, and in Arenal it is 3. This difference in sediment behaviour compared to the APW test and in the years/cycles ratio could be due to the different mineralogical composition and morphology of the particles (Figure 4).

The mineralogical composition of the sediment is similar on the beaches of Marineta Casiana and the Arenal, where the main component is quartz (> 60%) and the next mineral is Calcite. However, the composition at Guardamar beach is mainly distributed in Quartz, Calcite and Dolomite. The morphology of the particles on the three beaches is also different. Particles from Guardamar beach present angular shapes at the edges, foliation planes and a large number of fissures, while the particles from Marineta Casiana and Arenal show more rounded edges. Besides, the Marineta Casiana particles show Calcium and Silicon clusters.

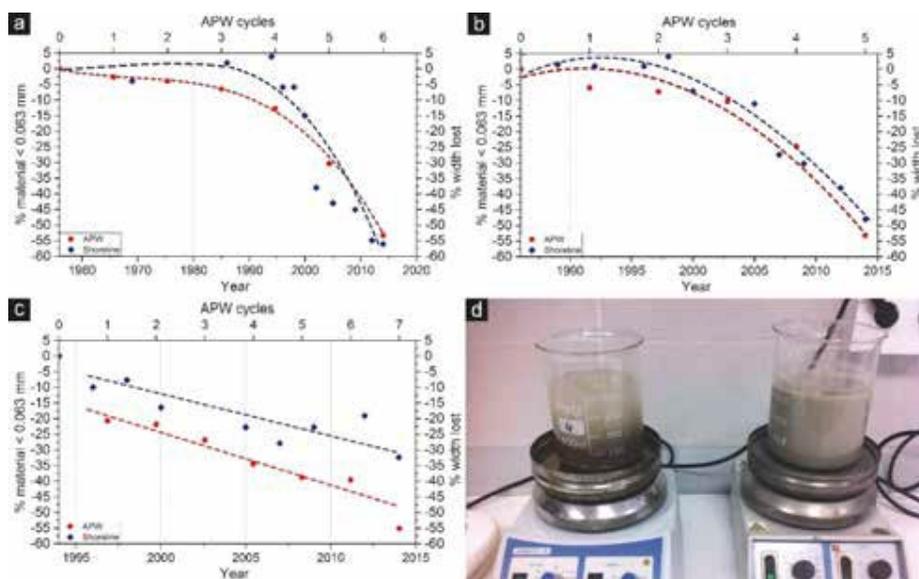


Figure 3 - Percentage of material less than 0.063 mm at the end of each cycle and percentage of mean width lost. a) Guardamar. b) Marineta Casiana. c) Arenal. d) APW test.

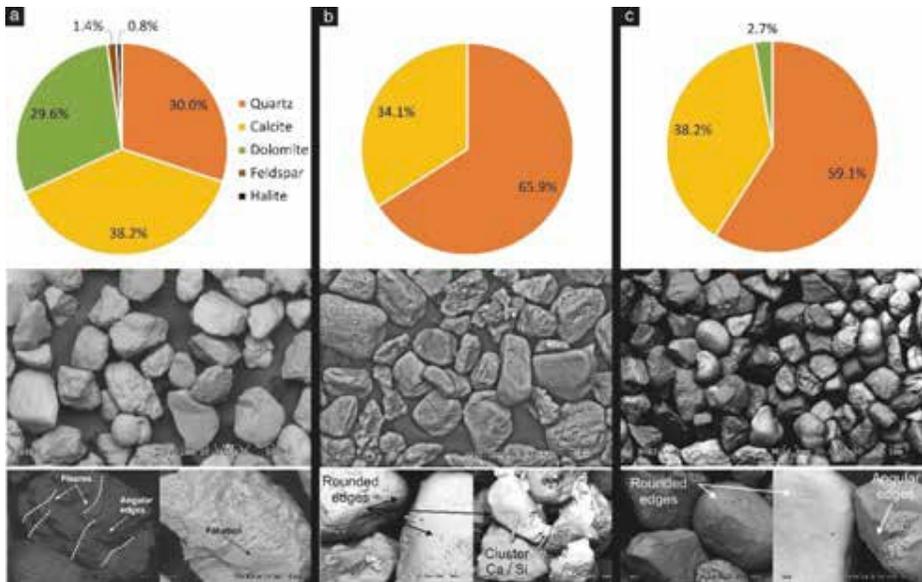


Figure 4 - Mineralogical composition and morphology. a) Guardamar. b) Marineta Casiana. c) Arenal.

Discussion

Coastal erosion is a major problem that has worsened in recent years. One element that could explain this increase in erosion is that wave energy and frequency have increased in recent years due to climate change [27]. However, as shown in Figure 2, wave conditions in the study areas have hardly changed, which coincides with those observed by other authors in the same or nearby areas [8, 31-33]. So why is erosion increasing? According to several authors, this increase could be due to the durability (ageing) of the beach material [22, 25].

In this sense, the durability of the material would be related to its mineralogical composition and the morphology of its particles. From the images obtained from microscopy, it can be seen that there is an important difference in the number of rounded and homogeneous particles. Thus, Marineta Casiana presents clusters of Silicon and Calcium, that is, weak unions between the minerals which could lead to the separation of the two mineral phases and the consequent loss of size [20]. Guardamar beach, however, with a large number of fissures and exfoliation planes, is the one which lasts the longest if the number of years it has been on the beach is considered (since 1956). This could be explained by the presence of dolomite which presents greater resistance to minerals such as quartz or calcite [17]. Thus, it is clear that the durability of materials is completely different depending on their composition and therefore they behave differently to the atmospheric conditions, which on a beach leads to different behaviours in the evolution of the shoreline [32]. And so, by accepting the hypothesis of the durability of beach sediment, the acceleration of beach erosion in recent decades can be explained since the amount of natural contributions to the

sea (and consequently to the beach) has been reduced due to the construction of dams and channels [2, 26].

The aforementioned implies that there is a relationship between sediment wear and the erosion of the shoreline. It is also shown that, as explained by other authors [8, 22, 32, 33] sediment wear is mainly influenced by the mineralogical composition and the morphology of the particles. These latter factors need to be studied in more detail to finally determine the relationship between the number of cycles in the APW test and the years of coastal erosion.

Conclusion

There is a relationship between sediment wear and the shoreline evolution. However, more sediment tests (composition, morphology, fractures, etc.) are needed to determine the exact relationship between the number of APW cycles and the years of shoreline evolution.

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