Heavy Mineral Placer Formation: an Example From Algarve, Portugal

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ABSTRACT


Since June 2001 Faro beach (Algarve, Portugal) has been studied in the scope of a scientific project that aims the study of cross-shore processes. During several field experiments, sand layers rich in heavy minerals were observed in the beach face. The presence of these layers at beach face is generally accepted as a consequence of a marked erosion period when the intensity of the swash is adequate to promote hydraulic grain sorting processes that lead to the enhancement in heavy mineral particles. The main objective of this work is to establish a relationship between the oceanographic and morphologic conditions and the development of rich heavy mineral laminations in the beach face. Throughout one observational period the changing in physical processes intensity (wave and wind regime) promoted sensitive morphological changes on beach profile causing significant erosion at upper beach face. These changes allowed the development of the heavy mineral rich layers. The formation of these layers is related with an initial phase of the profile growth, just after the maximum erosion period.

INTRODUCTION

The frequent occurrence of black sand layers in beach faces is due to the presence of high quantities of heavy minerals. The heavy mineral enrichment process takes place at the upper beach face (in some cases at the foot of a scarp), where the intensity of the swash is adequate to promote hydraulic grain sorting processes that lead to the enhancement in heavy particles (KOMAR and WANG, 1984; KOMAR, 1989; HAMILTON and COLLINS, 1998; HUGHES, KEENE and JOSEPH, 2000). Despite the prevailing sorting mechanism, the formation of the black sand layers is accepted as a consequence of storm periods which cause erosion of the beach profile (RAO, 1957; KOMAR and WANG, 1984; PETERSON, KOMAR and SCHEIDEGGER, 1986). These authors believe that during storms the longer-period swash motions provide the ideal conditions in the beach face for the transport of light minerals leaving behind the heavies as a lag deposit. Nevertheless, observations made by WOOLSEY, HENRY and HUNT, (1975), suggested that the selective process may have limited action during storm peaks because during that phase high energy causes a high degree of homogenisation and mass transport of sand.

The main objective of this work is to establish a relationship between the oceanographic and morphological conditions with the development of rich heavy mineral laminations at the beach face. This paper explores the results of the field work that has been developed at Faro beach for more than three years, in order to propose a conceptual model that can explain the heavy mineral concentration process. Results presented here describe a series of comprehensive intra-tidal beach profile observations, particularly detailed in the swash zone were the sorting between light and heavy minerals occurs.

METHODS

Since June 2001, the Faro beach (Southern Portugal) (Figure 1) has been studied in the scope of a scientific project that aims at the study of cross-shore processes. This beach is an open sandy beach located in the west part of the Ria Formosa barrier island system in Algarve (South of Portugal) (Figure 1). This coastal zone is under the influence of a semi-diurnal mesotidal regime, with the maximum spring tidal regime reaching about 3.5 m.

The field experience took place in Faro beach on July 2nd, 2003 between 11h and 20h. In the beginning of the field work the beach profile had a typical summer configuration with two well developed berms, a beach face with an average slope of 0.14 and a tidal terrace with an average slope of 0.01.

A meteorological station installed on the site of the experiment, enable the acquisition of wind speed and direction. Wind data was logged at 1 Hz. The wave was measured using pressure transducers sensors placed at the base of the beach face. An additional sensor was positioned at the beach berm to correct readings for the atmospheric pressure. The transducers outputs were logged at 4 Hz and spectral analysis was performed, using the procedure outlined in EARLE and BISHOP, (1994) using the Matlab software package, to provide summary statistics and energy density spectra.

Inter-tidal beach morphological changes were monitored in a cross-shore profile using 1.0 m long rods driven into the sand. During the field work a total of 8 samples were collected. They represent the upper 0.5 cm thickness of the sand at each sample location. All the samples were first washed and oven dried. After that they were sieved at 0.5 (phi units) intervals in order to obtain the entire grain-size sand distribution and respective parameters. Six grain-size classes (medium sand to finer sand) were used in the separation of the light and heavy minerals using bromoform (density 2.82).

RESULTS

Physical Processes

The tide regime during the field work of July, 2nd 2003 was characterized by a low tide of 0.9 m (at 10h 43m) and a high tide of 3.2 m (at 17h 06m).

Wind data collected at Faro beach during the day of the experiment is represented in figure 2. Wind direction changed from nearly west direction (about 280°) to almost a northwest direction (about 330°). During the day, wind speed showed a significant increment from about 2 m/s to almost 9 m/s (with higher peaks of 10 m/s), decreasing again in the late afternoon.

During the period of measurement, the wave regime reflected the wind changes and undergone considerable modifications. Wave height increased from 0.3 m to a maximum of about 0.5 m.
at high tide (17h 06m) followed by a decline to a value of 0.25 m (at 19h 30m) (figure 3).

During the rising tide, the wave energy was related to the action of long period waves with T of about 10 s (figure 4). Near the high tide the swell was still present but higher frequency waves (T = 4 s) had increased in energy (17:07 line - figure 4). At late afternoon, the long period swell dominated the signal while the high frequency waves decreased again (18:50 line - figure 4).

**Morphological Changes**

At the beginning of the field the beach was in dynamic equilibrium with a presence of a smooth beach face. During rising tide the changing wave conditions imprint marked erosion in upper beach face. The incident wave promoted an intense backwash force which induces a transport of large quantities of sediment to the foreshore. As a consequence the beach acquires a new profile showing marked erosion in the upper beach face. After the high tide, and following the changes in wind velocity, the wave regime weakness and the beach profile showed a tendency to reacquire the initial dynamic equilibrium (figure 5). These changes were measured with a great detail by the rods that were distributed across the beach profile. After low tide (occurred at 10h 43m with 0.9 m) the first measures of the rods heights show a slight accretion at the lower profile (about 2 cm between 59 and 62 m). Around 13h 00m the erosion begun to take place at distance 60 to 65 m from the baseline, with an average of 3 cm. With the rising tide and increasing sea conditions, the erosion strengthened at the upper beach face (30 cm between 45 and 51 m). The maximum erosion was at high tide (17h 06m-3.2 m) with values of about 35 cm from 47 to 51 m. After this period the profile enters in a slight accretion phase, which allows recuperation of about 2 to 7 cm.

**DISCUSSIONS**

Several studies focusing on heavy mineral placer formation point to the importance of beach erosion or a short episode of recession as a necessary condition to the placer formation. During beach erosion the swash zone processes are capable of promoting the selective winnowing of lower-density quartz and feldspars, leaving denser minerals behind. The association of the beach erosion phase with the heavy mineral concentration is clearly assumed by some authors (RAO, 1957; KOMAR and WANG, 1984; PETERSON, KOMAR and SCHEIDEGGER, 1986), who suggest that the conditions that prevail during this phase are ideal for the maximum development of the sorting processes. In fact, the observations carried out during the field work that has been developed at Faro beach, have shown that the thickness of the heavy mineral layers seems to be proportional to the segment of beach erosion. It was only after major erosion events that heavy mineral layers developed on the beach face. For example, on a field work at April 1st, 2003 a heavy mineral heavy rich layer was found in a trench that intercepts the base of a buried scarp related with previous storm conditions that occurred at March 29th, 2003 (Hs 4 m). The
Figure 6 represents one cross-shore trench revealing the sedimentary infilling that occurred after the storm. In this figure the layer A has more than 40% of weight in heavy minerals whereas the layer B contain less then 3% in these minerals. 

However, when the beach face is undergoing erosion during a storm episode this means that there is an offshore transport tendency of all sand particles. This means that the intense erosion phase may not be the ideal moment for the development of the sorting mechanisms and therefore the heavy mineral placer is not produced.

There is an apparent contradiction between the association of heavy mineral layers with storm episodes and the fact that the transport cannot be selective when the beach is experiencing erosion and therefore does not allow the development of a heavy mineral lag deposit. The in situ observation of the development of a heavy mineral layer carried out in this study allowed the correct understanding of formation of these deposits and the harmonizing of those views.

During tide rising (from 10h 43m to 17h 06m) the overall effect of the wave regime causes upper beach face erosion. Probably the high frequency waves present in the wave spectra of figure 4 (17:07 line) are responsible for this erosion. The changing of the wave regime corresponds to the appearance of plunging waves breaking directly onto the beach face with shorter periods and considerable energy. It is likely that this change of the wave regime of high frequency wave energy was caused by the increment of the local wind speed. In fact, at 9h 39m the wind speed was about 3 m/s and 7 hours later the speed it had increased to almost 9 m/s (Figure 2).

The high energy/frequency wave regime induced considerable transformations in the profile causing significant erosion attested by the measured values obtained in the rods. The maximum absolute erosion value measured was 35.5 cm in Rod 47 m at 17h30m. It is noticeable that at this exact time all the rods situated from 45 m to 51 m registered the maximum erosion values. Probably, at 17h 30m is likely to be considered the instant of maximum erosion. After that time the profile went on accretion phase.

It was precisely at the beginning of the accretion phase that the deposition of the heavy mineral layer occurred. In fact, the sample showing the higher concentration in these minerals (12 %) was collected at point 45 m at 17h40m, when at this position the profile was in the beginning of an accretion phase (Figure 7). In fact, from 17h 30m to 18h 00m the point 45 showed a slight accretion of 2 cm. So, heavy mineral concentration is expected to be contemporaneous of the initial profile growth phase.

The thickness of activated sand was measured by plug holes with marked sand and by placing a loose-fitting washer on rods. The layer enriched in heavy minerals appeared just above the upper limit of the marked sand and above of the washer. This observation attests that the heavy rich layer formation occurs just after the erosion phase and this lower limit marks the mixing depth maximum.

The figure 8 illustrates the conceptual model of heavy mineral layer formation process. The process responsible for the heavy mineral concentration may work according to the following description.

Profile A in figure 8 represents the profile initial stage. First, the erosion phase takes place promoted by the wave swash. Sand grains are winnowed and carried back down the beach face. This phase can be characterized by intense erosion, high offshore transport rate and no substantial grain sorting (figure 8, profile B).

After maximum erosion phase the profile begins to growth and the swash hydrodynamic conditions promote the...

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Figure 5. Beach profile evolution during July 2nd, 2003. 

Figure 6. Cross-shore trench in upper beach face showing the heavy mineral layer that was formed in the sequence of the March 29th, 2003 storm (results obtained during field campaign ofApril 1st, 2003).

Figure 7. Intra tidal elevation changes at point 45 and correspondent log.

Figure 8. Conceptual model of heavy mineral layer formation process.
generation of the upper beach face deposits enriched in heavy minerals. The grain sorting is intense and very efficient (figure 8, profile C). After this phase the profile develops into a high-speed growth and the conditions of sorting between light and heavy minerals are again weaker (figure 8, profile D).

**CONCLUSIONS**

This study is concerned about the relationship between the physical processes acting on the beach face and the development of sand layers enriched in heavy minerals. During the fieldwork at the Faro beach wind and wave conditions underwent a substantial change that deeply marked the upper beach face. During rising tide, the progressive increasing of the wave energy promoted the erosion of the upper beach face creating an incipient scarp. After the erosion maximum, swash conditions allowed intense grain sorting which promoted the heavy mineral layer formation at the upper beach face. This layer, formed just above the marked sand and washer, marks the beginning of an accretion phase.

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**LITERATURE CITED**


