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Utility of heavy minerals distribution and granulometric analyses in the study of coastal dynamics: Application to the littoral between Sanlúcar de Barrameda and Rota (Cadiz, southwest Iberian Peninsula)

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ABSTRACT

The present paper deals with grain size and heavy minerals distribution in the sandy coastal sediments of the littoral between the cities of Sanlúcar de Barrameda and Rota. We have related these distributions to the predominant southward littoral drift and the possible source contributions, mostly represented by the Guadalquivir and Guadalete Rivers. The littoral studied is composed of fine sand in the northern sector and medium sand in its central and southern sectors. Heavy minerals were identified using X-ray analysis: the most abundant in the study area are epidote and garnet. We found that their concentrations and sizes decrease from north to south according to the coastal drift, whereas the grain morphology and the mineralogical component generally remain constant.

Key words: Littoral dynamics, heavy minerals, longshore drift, source areas.

RESUMEN

Utilidad de la distribución de minerales pesados y de los análisis granulométricos en el estudio de la dinámica litoral: aplicación al tramo costero entre Sanlúcar de Barrameda y Rota (Cádiz, suroeste de la península Ibérica)

Este trabajo trata de las distribuciones granulométrica y de minerales pesados de los sedimentos arenosos del tramo de litoral comprendido entre las ciudades de Sanlúcar de Barrameda y Rota (suroeste de la península Ibérica). Se han relacionado dichas distribuciones con la deriva litoral predominante hacia el Sur y con las fuentes de aporte de sedimentos constituidas por los ríos Guadalquivir y Guadalete. El litoral estudiado se caracteriza por arena fina en su parte norte y arena media en su parte central y meridional. Los minerales pesados se han identificado mediante rayos X: los más abundantes en el área estudiada son epidota y granate. Se ha deducido cómo sus concentraciones y tamaños disminuyen de norte a sur de acuerdo con la deriva litoral, manteniéndose el conjunto mineralógico y la morfología de los granos constante.

Palabras clave: *Dinámica litoral, minerales pesados, transporte litoral, áreas fuente.*

INTRODUCTION

Much of the previous research on sediment origin and longshore transport has been carried out using heavy minerals, which are considered natural tracers because of their hydrodynamic behaviour and weathering resistance (King, 1972; Pettijohn, 1975; Frihy and Komar, 1993). Recently, this research has been complemented by the study of surface features. The present paper deals with grain size and heavy mineral trends in the sandy coastal sediments of the littoral between the Guadalquivir River's mouth and the city of Rota (southwest Iberian Peninsula). We also aim to relate these distributions with the local littoral drift and possible source contributions.

The coast studied (figure 1) has a total length of 16 km; the northern sector (Sanlúcar-Chipiona), northeast-southwest oriented, is constituted by beaches having a very broad intertidal zone with gentle slope, while the southern sector (Chipiona-Rota), northwest-southeast oriented, presents both small beaches with a steeper slope and rock platform facing beaches. The beaches studied are backed by dune ridges or plio-quaternary eroded cliffs constituted by clays, sands, sandstones and conglomerates (Mabesoone, 1963; Zazo *et al.*, 1977).

The main fluvial sources of sediment in this area are the Guadalquivir and Guadalete Rivers. The tide is semidiurnal and its average range is about 2 m, characterising the zone as a mesotidal one. The prevailing winds blow from the 2 and 4 quadrants, being the latter the one with the greatest impact on the littoral studied, due to its orientation.

The energetic wave regime is middle-low, with wave heights usually lower than 1 m. Wave fronts approach from the southeast and west; the latter is more frequent and generates an important littoral drift towards the southeast.

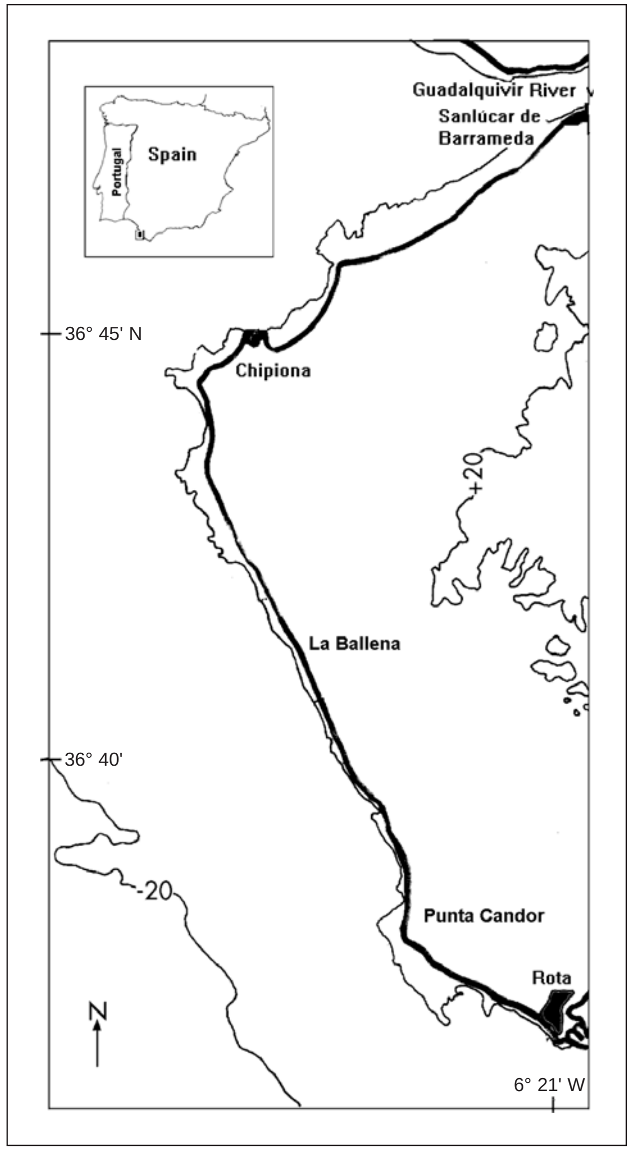

Figure 1. Location map

MATERIALS AND METHODS

Five representative profiles have been selected, and three samples (during autumn 1996) have been taken from each of them: one on the dry beach and the others in the lower and upper part of the nearshore area. Samples were sieved with a Ro-Tap machine and statistical parameters were obtained (Folk and Ward, 1957). After the elimination of carbonates, heavy minerals were separated from the fine sand fraction using the dense liquids technique, with bromoform (density greater than 2,8 g/cm^3). Mineralogy of light and heavy fractions was obtained by XRD, using a Philips PW 1710 diffractometer equipped with automatic slide and radiation CuK$_\alpha$. The data record was obtained applying the computer programs developed by Martín Ramos (1990). The behaviour of the different samples in relation to the heavy minerals was studied, as well, applying the statistic correspondence analysis. Finally, the surface features of the heavy mineral grains were explored with SEM, using a Jeol model JSM-820 microscope.

RESULTS

Statistical parameters, such as average grain size and sorting, reflect the energetic conditions of the environment (Visher, 1969; Sly, Thomas and Pelletier, 1983). Thus, the observed values enable us to divide the littoral into two different zones: the first, represented by the northern sector (Sanlúcar-Chipiona), is composed mainly by fine sand; the second (Chipiona-Rota) corresponds to exposed beaches composed by medium sand.

Figure 2 shows cumulative frequency distribution curves of the low nearshore zone samples, which best represent the variability of the granulometric characteristics of sediments.

The representative curve of the first sector (figure 2a) is a hyperbolic type and indicates transport by saltation and suspension –fine evolved materials whose sedimentation is due to an excess of the load fraction constitute sediments. However, the representative curves of the second sector (figure 2b) are logarithmic, and indicate an intermediate accumulation process of coarser and less-evolved material. Granulometric parameters have been calculated in order to characterise the different deposits and to facilitate the interpretation of the processes that have affected the sediments (table I).

Results of the mineralogical analysis of the light fraction show that quartz is the most important mineral (60 %), followed by feldspars (10 %) and carbonates (20 %); the latter present concentrations opposite to those of heavy minerals. The stereomicroscopic study confirms these mean values, according to those obtained by Gutiérrez Mas (1992) in Cadiz Bay.

The mineralogical analysis of the heavy minerals obtained from the sandy fraction of the lower intertidal samples provided the results summarised in table II.

In general, there is an evident decrease in the heavy minerals content from Sanlúcar to Rota, with a predominance of metamorphic minerals that had already been noted by Pérez-Mateos *et al.* (1982). Regarding heavy mineral content and association, there are differences among three coastal sections: the northernmost, Sanlúcar-Chipiona, with a pre-

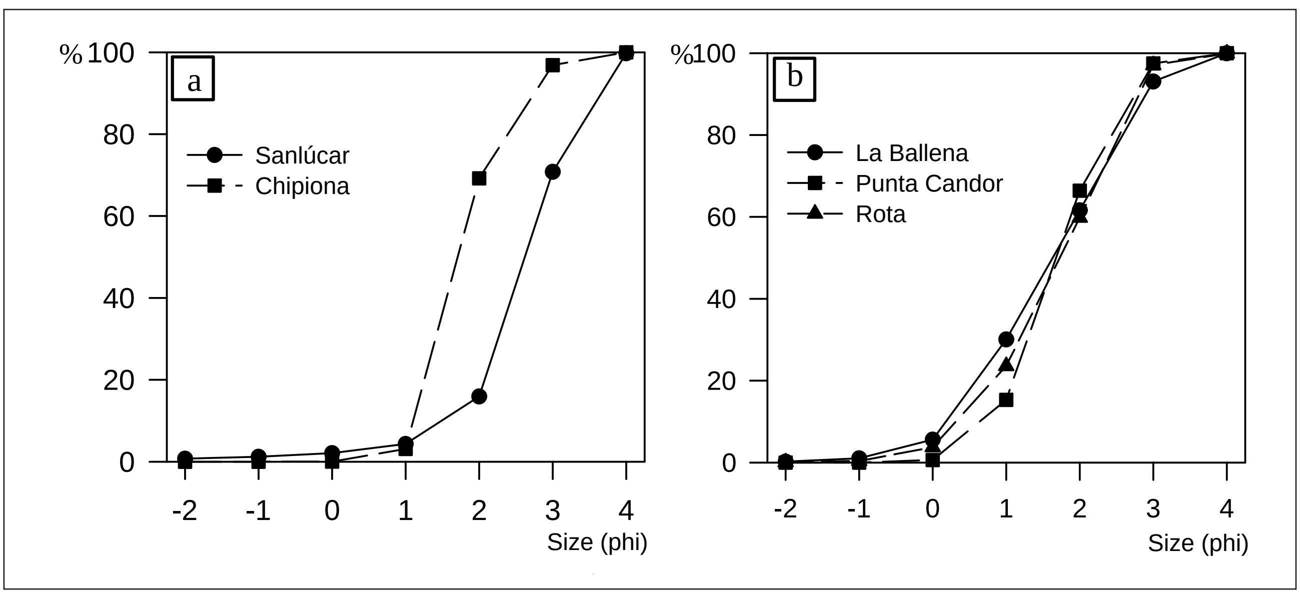

Figure 2. Cumulative frequency distribution curves

Table I. Statistical parameters

Location	Median	Mode	Sorting	Skewness	Kurtosis
Sanlúcar	2.62	Fine s.	0.78	0.02	1.19
Chipiona	1.71	Med. s.	0.62	0.28	0.94
La Ballena	1.63	Med. s.	1.00	–0.00	0.93
P. Candor	1.68	Med. s.	0.79	0.06	1.01
Rota	1.73	Fine s.	0.94	–0.11	0.88

Table II. Percentage distribution of heavy minerals of the low intertidal zone samples

Beach	Wt % Heavy min.	Garnet	Epidote	Andalucite	Ilmenite	Tourmaline	Hornblende
Sanlúcar	0.9	9	36	9	20	16	10
Chipiona	0.6	58	8	8	8	14	4
La Ballena	0.5	38	15	12	8	14	3
P. Candor	0.3	11	28	7	9	15	8
Rota	0.1	9	36	13	10	15	16

dominance of epidote-ilmenite and tourmaline; the Chipiona-La Ballena sector, with a predominance of the stable and ultrastable minerals garnet and tourmaline; and the coast between Punta Candor and Rota, where the epidote-andalucite set prevails. Treating the second and the third sectors together, it is striking how the garnet content falls from north to south, showing a distribution opposite to epidote, whereas hornblende increases its percentages. Furthermore, the remaining minerals show a quite constant distribution. Pérez-Mateos *et al.* (1982) indicate that the mineralogical association prevailing in the studied area is constituted by epidote and garnet, while the amphiboles, mainly green hornblende, increase their concentrations at the Guadalquivir River's mouth. The statistical correspondence analysis has indicated the differences between the samples of the northern and southern sectors and those of the central one, as well as the inverse garnet and epidote behaviour (figure 3).

To explain the low garnet concentration in Sanlúcar compared with the high one observed in

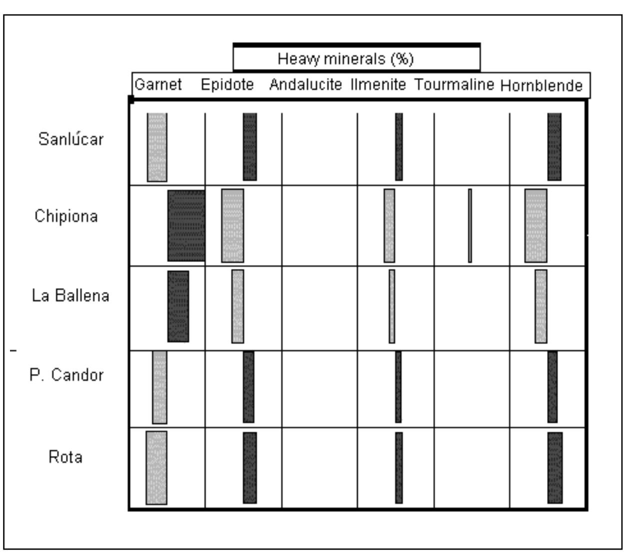

Figure 3. Correspondence statistical analysis: associations diagram. Minerals that have a good correlation present similar filling patterns, the thickness of the shaded areas is proportional to the percentage of each of them

Chipiona, we separated the heavy minerals in the different granulometric fractions of the Sanlúcar sample. We found that garnet is more abundant in the coarsest fractions, whereas epidote is accumulated in the fine fraction, generally more rich in heavy minerals, according to Veenstra and Winkelmolen (1976). We should also note that, according to Davis (1985), heavy mineral content increases in the high part of the beach due to the accumulation favoured by winter storms. In particular, on La Ballena, where the dry beach is very small, the content of heavy minerals reaches 1.2 % of the sample.

In order to assess the influence on littoral sediments of the artificial nourishment of a small beach located at Rota, a sample of the injected sand has been analysed. The results show that heavy minerals reach the value of 0.5 % in weight, and tourmaline is the most important component. This confirms the slight influence of artificial nourishment on nearby beaches, in agreement with the findings of Eitner and Ragutzki (1994) in the North Sea.

The textural analysis has provided information regarding surface features and morphological characteristics of the main heavy mineral grains (figure 4), which presented similar characteristics to those described by Moral *et al.* (1996) for Cadiz Bay.

Epidote: presents xenomorphic morphology with rounded forms in the north (figure 4a) and subrounded-subangular (figure 4b) in the extreme south. The chemical texture (oriented etch and solution pits) are common for both morphologies, while the conchoidal fractures prevail in the latter.

Garnet: xenomorphic morphology is common to the entire littoral studied. It presents very rounded forms (Sanlúcar eolic grain, figure 4c) with a chemically reworked mechanical texture, as well as very angular forms (figure 4d, Rota) with fresh conchoidal fractures and polished surfaces.

Tourmaline: presents two common morphologies in the study area. These are: idiomorphic morphologies (Rota, figure 4e) with mechanical fea-

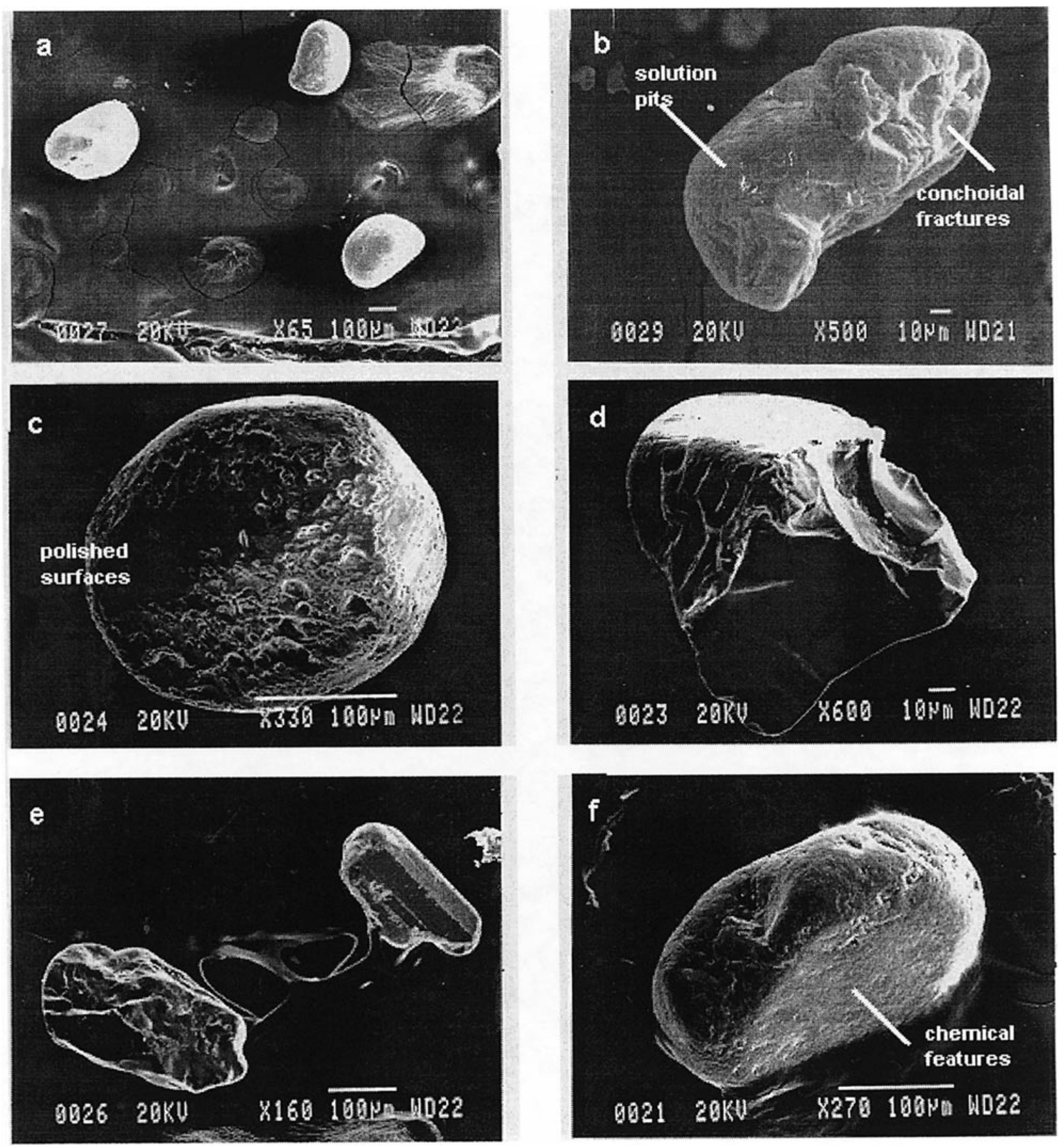

Figure 4. SEM microphotographs of some heavy minerals: epidote (a, b), garnet (c, d) and tourmaline (e, f)

tures (angular conchoidal fractures and grooves) as well as chemical marks, and xenomorphic morphology with rounded (Rota aeolic grain, figure 4f) and subangular-subrounded forms, with fractures and chemical features developed on mechanical marks.

Andalucite: subidiomorphic and xenomorphic morphologies are common to the entire coast. The former presents prismatic forms with mechanical (arcuate steps) and chemical features (solution pits and hollows). The latter presents subrounded forms with substantially chemical features.

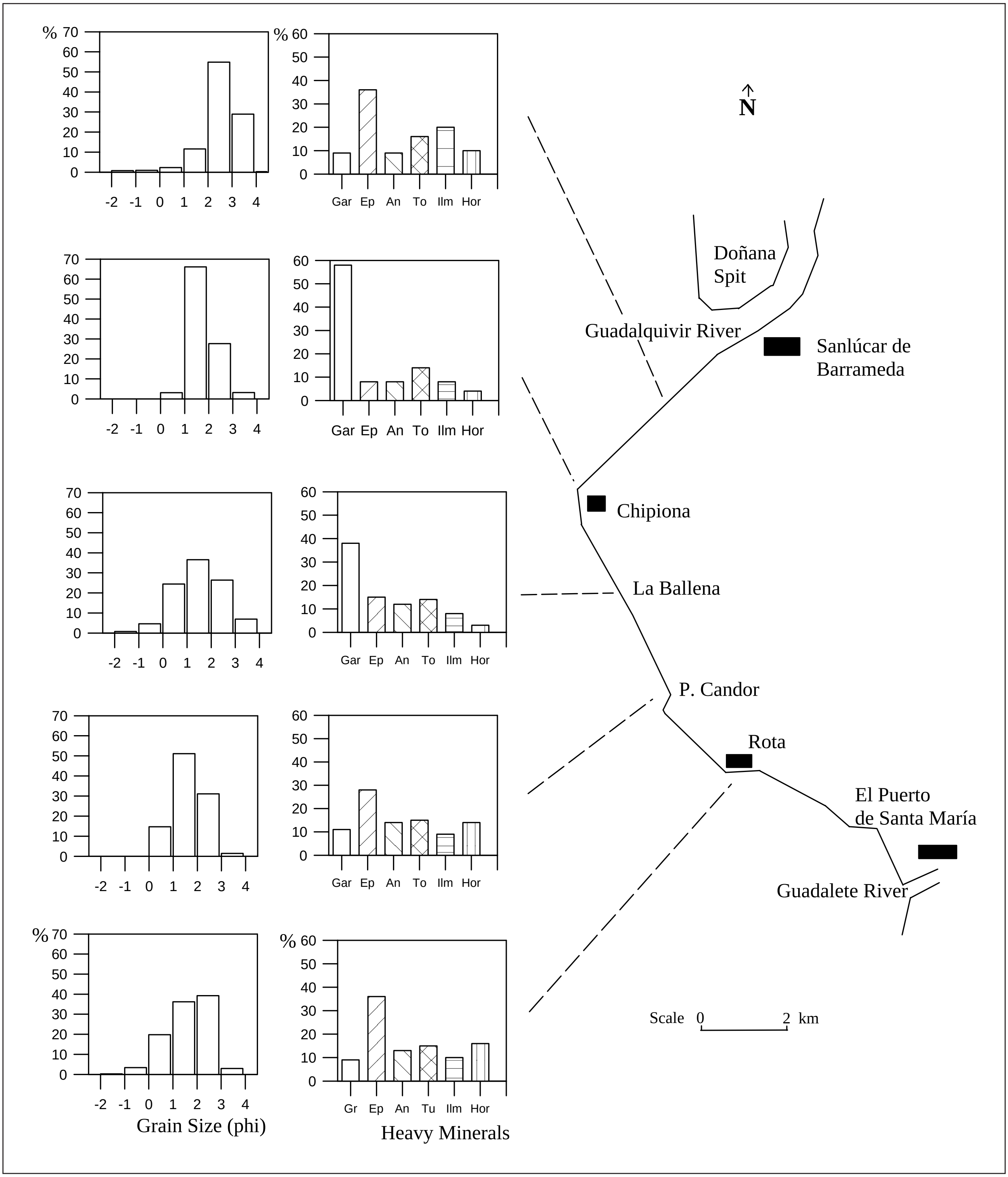

Figure 5. Histograms of grain size and heavy minerals distributions along the littoral studied

DISCUSSION

The granulometric parameters obtained indicate that the Sanlúcar sample presents moderate sorting, symmetrical skewness, a fine-sand mode, and a leptocurtic trend. All these characteristics are typical of the deposits of sheltered zones. The sedimentary system is constituted by Guadalquivir

River supplies, which originate a submerged delta lengthened towards the northwest, in which, close to the littoral, there is a deposit of medium sand on the right margin (Doñana Park) and fine sand on the left (Sanlúcar-Chipiona). This deposit pattern is in accordance with the hydrodynamic model of the well-mixed estuaries in the Northern Hemisphere (Bearman, 1989). The other samples (Chipiona-La Ballena) correspond to homogeneous deposits composed by medium sand, with quite symmetrical curves of a mesocurtic type. The latter deposits indicate that the Guadalquivir River supplies have been reworked by marine currents and then deposited on beaches exposed to wave action (Gutiérrez-Mas, Hernández-Molina and López-Aguayo, 1996). Finally, the southern sector (Rota), with a new increase of the fine fraction, corresponds to a littoral deposit partially influenced by supplies from the Guadalete River (Parrado Román, Gutiérrez Mas and Achab, 1996).

Comparing granulometric curves obtained in the present paper with those proposed by Visher (1969), it is possible to conclude that they are characteristic of the foreshore sands, indicating a prevailing saltation transport. In particular, the curves of the Rota, Punta Candor and La Ballena deposits would indicate a traction transport for grains larger than ∅0, and a suspension transport for grains smaller than ∅4. The curves of the Chipiona sediments would indicate traction for grains up to ∅1, and suspension for grains smaller than ∅4. Furthermore, the Sanlúcar curve presents a population of sorted coarse-bed sediments, which would be transported in traction until ∅0.5, and in suspension for grains larger than ∅3, due to the greater energy of the environment related to the Guadalquivir River.

The granulometric data obtained have been also represented in a median/first percentile diagram (Passega, 1964). The sediments of La Ballena, Punta Candor and Rota would have been transported mainly as bedload, those of Sanlúcar as suspension load and those of Chipiona intermediately.

Regarding heavy mineral trends, it is noteworthy that their sizes and concentrations decrease from north to south, according to the littoral drift; a similar trend has been observed by Komar *et al.* (1989) on the Nile Delta beaches. However, the mineralogical components (figure 5) and grain morphology (with the exception of epidote, which presents rounded forms in the northern part and subrounded-subangular in the southern part) are nearly constant, being the Guadalquivir and Guadalete Rivers the main source contributors, according to the results obtained by Gutiérrez Mas *et al.* (1997).

Heavy minerals are concentrated especially in the fine sand fraction, in which epidote is more abundant, whereas garnet prevails in the median sand fraction (figure 6).

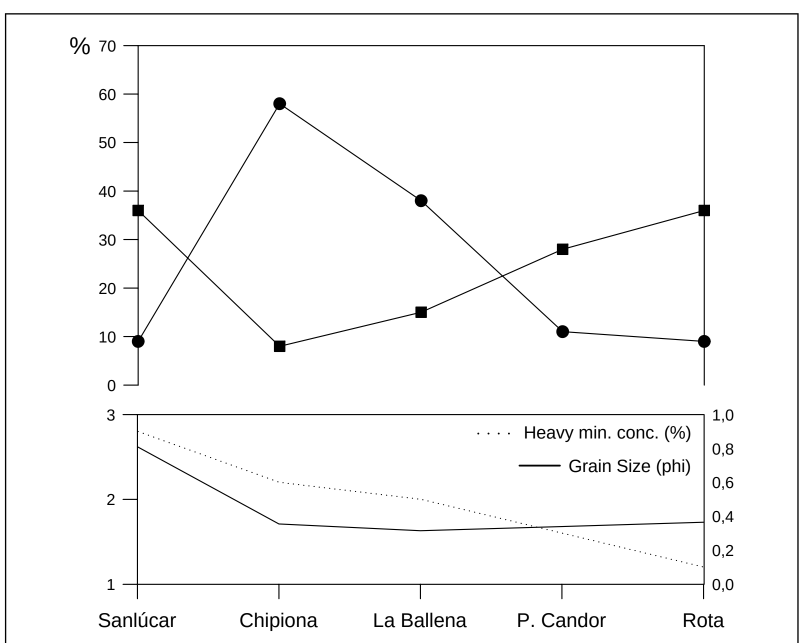

Figure 6. Epidote and garnet distributions and their relationships with heavy minerals and grain-size trends

These results explain both the abundance of garnet in Chipiona (where the sediment is composed by medium sand) and its drop in percentage (compared with epidote's behaviour) southwards, according to the grain-size decrease. The enrichment of epidote southward and its morphological changes are probably related to the local supplies from the Guadalete River (Zazo *et al.*, 1977; Mabesoone, 1963), which are transported to Rota by ebb-tidal currents (Parrado Román, Gutiérrez Mas and Achab, 1996).

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