The quantification of coastal erosion processes in the South Atlantic Spanish coast: Methodology and preliminary results

Del Río, L.[1], Benavente, J.[1], Gracia, F.J.[1], Anfuso, G.[1], Martínez-del-Pozo, J.A.[1], Domínguez, L.[1], Rodríguez-Ramírez, A.[2], Flores, E.[2], Cáceres, L.[2], López-Aguayo, F.[1], & Rodríguez-Vidal, J.[2]

[1]*Coastal and Marine Geology Research Group. Dept. of Geology, CASEM. University of Cadiz, 11510 Puerto Real, Cadiz, Spain. E-mail: laura.delrio@uca.es*

[2]*Dept. of Geodynamics and Palaeontology, Campus El Carmen. University of Huelva, 21071 Huelva, Spain. E-mail: arodri@uhu.es*

Abstract

This work presents the first results of a research project about the erosion processes affecting beaches in SW Spain. Aerial photographs and historicaly records have been analyzed to reconstruct coastal evolution in the medium term, whereas the erosive processes acting in the short term have been studied by means of a field monitoring program. Both work techniques do not always provide the same results and they must be combined for a realistic knowledge of the erosional state of the coast. In the Gulf of Cadiz there are two main causes producing coastal erosion: the construction of dams in fluvial basins reduces sediment supply to the beaches, and the building of coastal engineering structures alters the coastal dynamics. In the Bay of Cadiz a map of morpho-erosive states has been made, based on the results of the beach monitoring program and the measurements on the aerial photographs.

1. INTRODUCTION

The study of present and recent rates of coastal retreat is of prime interest for a proper management and preservation of public coastal areas. This information must be complemented with data about physical processes involved in coastal erosion, since they can help in the design of coastal protective works adapted to the natural processes acting on the shore. The South Atlantic Spanish coast includes more than 300 km of low sandy coastlands periodically affected by westerly storms. About 750,000 people live in this coastal zone, involving many touristic, agricultural and industrial activities with great economic interest, often threatened by severe erosion processes (Gracia *et al.* 2000). However, very disperse and heterogeneous data exist about the topic in this portion of the Spanish coast. Usually, erosion processes are only indirectly considered and often as a part of wider regional studies (Guillemot & Palma 1987; Flor 1990).

The quantification of these processes and the unification of pre-existing data constitute the main objectives of the research project "Coastal Erosion Processes in the South Atlantic Spanish Coast", started in 1998 and performed by researchers from the universities of Cadiz and Huelva (SW Spain). It includes the compilation of historical data related to erosion processes and the application of several monitoring techniques in order to establish present retreating rates. These latter methods have been adapted to the prevailing coastal dynamics acting in this broadly homogeneous physiographic unit.

2. STUDY AREA

The Spanish coast of the Gulf of Cadiz can be divided in two main sectors (Fig. 1): the northwestern half (Huelva coast) is represented by an E-W to WNW-ESE sandy coast fed by several important rivers that drain the Neogene Guadalquivir Basin; the southeastern half (Cadiz coast) of the Gulf is represented by a NW-SE mixed sandy-rocky coast with several embayments occupied by sedimentary environments fed by short rivers draining the Western Betic Ranges.

In this mesotidal environment, prevailing waves, both at sea and swell conditions, come from the W and SW giving rise to a predominant littoral drift towards the E and SE. The changing coastline orientation in the Gulf influences the final wave approaching angle, which progressively diminishes towards the South. In the vicinity of the Gibraltar Strait littoral currents and tides achieve much less importance, and the coast exhibits a microtidal regime with a soft littoral drift. Fair weather (summer) waves usually present significant heights of 0.6 m, while storm waves reach average heights of 1.5 m (Benavente et al. 2000).

Sediments supplied to the coast are longitudinally transported by longshore currents, producing a set of littoral spits growing eastwards in Huelva and southeastwards in Cadiz. Their lengths vary notably alongshore, as a function of the contrasted sedimentary contributions of rivers to the coast and the gradually diminishing littoral drift.

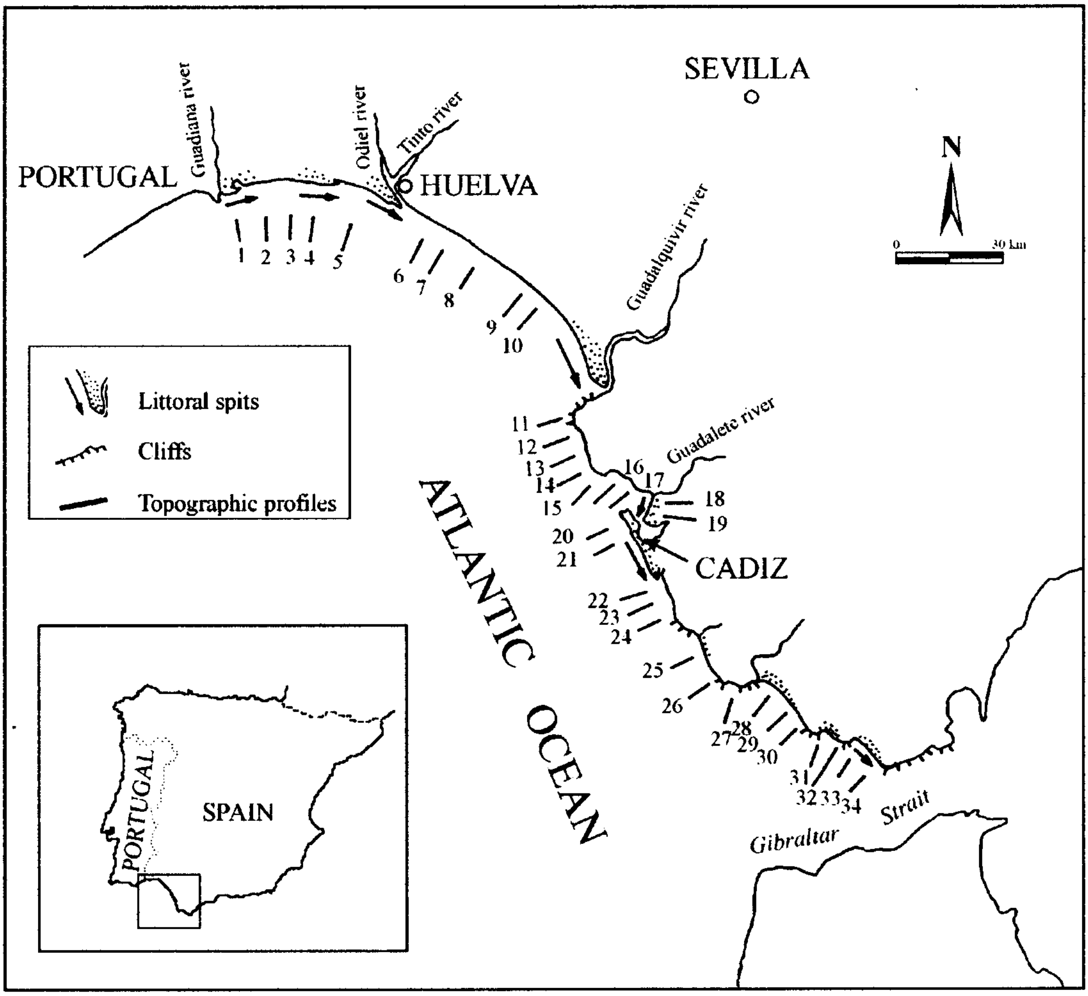

Figure 1: Study area and location of beach profiles.

The Huelva coast is characterized by well developed spits (Rodríguez-Ramírez *et al.* 2000b), with lengths greater than 14 km in some cases (El Rompido spit), and widths of up to 5 km (Doñana spit). This coastal configuration gives rise to alternating accreting/erosive zones, the former ones related to the spit free ends and the latter to the intervening zones (spit heads and some cliffs upon soft Neogene materials). The study of coastal erosion processes in Huelva coast is then greatly simplified, since it can be focused on the erosive zones. However, some Huelva spits present a clear recent tendency to grow eastwards, which impose a forced migration of erosive zones in this sense, sometimes distorted by human actuations on the coast (Rodríguez-Ramírez *et al.* 2000a).

In the Cadiz coast spits are less abundant, shorter and narrower. The main fluvial influx is represented by the Guadalete River, in Cadiz Bay (Fig. 1), where several spits of up to 7 km long were formed during the upper Holocene. The rest of this coast is represented by straight beaches backed by cliffs on resistant rocks. The southernmost beaches are restricted to small bays between headlands, and present different behaviours depending on local geomorphic factors. These features make the study of coastal erosion processes in Cadiz coast more complex, especially when human interventions at the coast interfere with the natural dynamics.

3. METHODOLOGY

Two main sources of information were taken into account, comprising two different scales of actuation of erosive processes. First, recent historical records and aerial photographs give data about coastal evolution in the last decades. Second, the study and monitoring of active erosion processes gives an idea of the rate at which erosion takes place at present. With more detail, the techniques used were as follows:

In order to quantify the rates and total amount of coastal retreat during the last decades, aerial photointerpretation and accurate morphometric techniques were applied to several sets of flights, belonging to different years from 1976 to 2001. The definition of these shoreline positions was made by using control lines normal to the coast, and measuring changes in dune and cliff feet. Following this procedure, errors induced by the fluctuating sea level were avoided. This kind of measures were restricted to natural coasts, since in urbanized areas dunes and cliffs have been substituted by promenades and other constructions, and urban beaches have experienced changes controlled by human interventions (by-passing, nourishment works, etc.).

Field work was performed through a beach monitoring program carried out during two years, with a seasonal periodicity. 34 representative beach profiles were chosen along the Gulf coast (Fig. 1) for topographic measuring (by using theodolite and Total Station), starting from fixed points. Topographic data were ellaborated in order to obtain beach gradient and morphology. Beach sediment samples were seasonally collected from the intertidal zone and analysed by dry sieving. Wave data were obtained from two offshore buoys belonging to the Spanish Sea Wave Recording Network (REMRO), located in the central part of the Gulf. H_0 was calculated by considering the mean offshore wave height of the month prior to the beach profiling. This procedure is based on the natural rate of beach change, obtained from previous works (Benavente *et al.* 2000). Beach morphodynamic states were established by applying the classification and procedure proposed by Wright & Short (1984). For this purpose, the Surf Scaling Parameter (Guza & Inman 1975) was calculated for different zones and periods:

$$\varepsilon = 2\,\pi^2\,H_b\,/\,g\,T^2\tan^2\beta \qquad (1)$$

where H_b is the breaking wave height, T is the wave period and $\tan\beta$ is the beachface slope. Finally, systematic visual inspections of the coast were made during every winter season, in order to evaluate coastal changes and damages caused by the most important storms.

4. RESULTS AND DISCUSSION

4.1 Coastal erosion in the Gulf of Cadiz

Erosive tendencies and rates vary notably along the studied zone, depending on different causes. The information given by the study of aerial photographs and historical data, added to the beach monitoring program, helps to quantify erosion rates and estimate the main conditioning factors for beach erosion in each case.

Apart from the current sea-level rise tendency (Menanteau & Clemente 1977), the most important reason for beach erosion in the Gulf of Cadiz is the construction of dams and reservoirs in the fluvial basins draining this coast, which produce sediment trapping and an important diminution of sediment supply to the coast. Spanish hydraulic policy in the sixties and seventies led to the construction of tens of dams in the main fluvial catchments of the zone: Guadiana, Guadalquivir and Guadalete river basins. These actuations began in the late sixties and continued until the nineties. As a direct consequence, coastline retreat was initially slow in the seventies but progressively accelerated during the eighties, leading to a generalized erosion. The different amount of coastal retreat along this coast usually depends on local factors, like shoaling wave processes (Muñoz & Enríquez 1998; Anfuso *et al.* 2001b), human interventions, etc. In general, progradation trends are only restricted to small pocket beaches or to the accumulative sides of some jetties.

Many coastal areas, especially in the western and central zones of the Huelva coast (Fig. 1, profiles 1 to 8), have suffered frequent human interventions by means of jetties, groins and harbours, that have significantly altered the coastal dynamics, producing erosion (Ballesta *et al.* 1998). Near the Guadiana river mouth, González *et al.* (2000) recognized important coastline changes related to the construction of jetties. These structures led to sand starvation that resulted in a severe erosion of large salient parts of the coast between 1956 and 1994. Part of the eroded sand accumulated against other jetties and re-entrant portions located eastwards the Guadiana river mouth, resulting in a straightening of the coastline. One of the most spectacular examples of erosional effects of engineering structures is the 10 km long Juan Carlos-I groin, made in 1981 in Huelva town (Flores *et al.* 1997; Rodríguez-Ramírez *et al.* 1999). It completely blocks littoral currents, producing erosion along more than 25 km downdrift. In the 2000-2001 winter this structure led to a horizontal retreat of 10-20 m in profiles 8, 9 and 10 (Fig. 1). Mazagon beach (Fig. 2a, profile 7), protected in the shadow zone of the groin, exhibits little erosion and only suffers important retreating episodes during the most important storms, like the one in January 1996, that produced a set-back of 30 m in few days.

Dune ridges usually lessen the erosive effects of storms. When they are destroyed for urbanization purposes, associated beaches erode more easily and sedimentary budget becomes negative (Fig. 2c, profile 16). This type of actuation produces significant variations in the retreating behaviour of beaches, even if they are near to each other: a comparison can be made between profiles 22

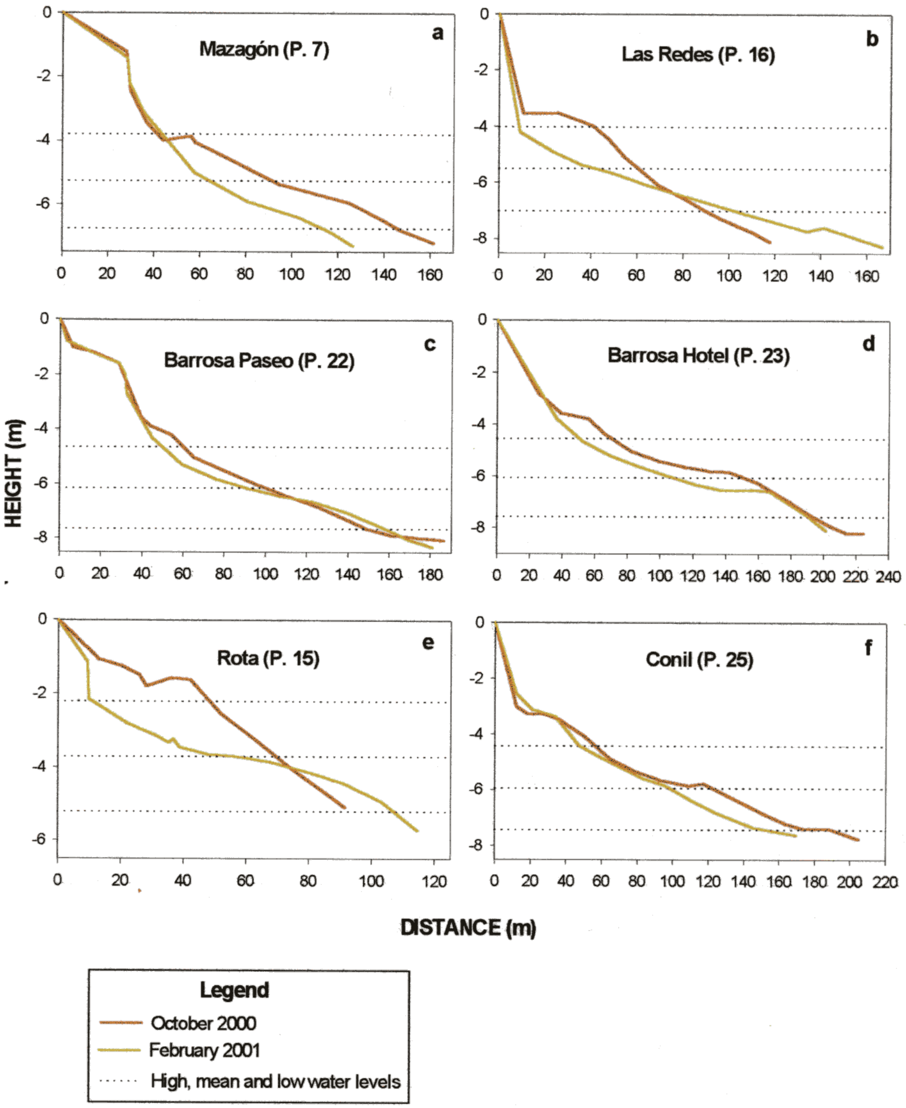

Figure 2: Examples of beach profile changes before and after a medium-energy winter period. Beach location in Fig. 1.

(Fig. 2d, with dunes artificially removed) and 23 (Fig. 2e, with well preserved natural dunes).

The need for enough sand on beaches of touristic interest makes continuous nourishment works on them necessary (Muñoz & Gutiérrez 1999; Muñoz *et al.* 2001). The resultant artificial profiles are more sensitive to wave action (Fig. 2b, profile 15) and after winter storms natural recoveries become slower and less effective (Benavente *et al.* 1997; Anfuso *et al.* 2001a).

Finally, exposed natural beaches present very different behaviours during the actuation of a single energetic event (Reyes *et al.* 1999). This is due to the relative quantity of sand existing in the coastal system. Some beaches contain an amount of sand big enough for attaining different morphodynamic states along the year, well adapted to the changing energetic conditions. In these cases beaches usually experience small retreats during winter energetic periods (Benavente *et al.* 2002). Erosion processes produce a certain beach flattening, and profiles assume quite dissipative designs (Fig. 2f, profile 25). During fair weather sedimentary recovery in these beaches is faster and almost complete, by the progressive arrival of subtidal bars and the acquisition of intermediate to reflective profiles. The western beaches of Huelva coast follow this behaviour (profiles 1 to 4). In contrast, other beaches lacking enough sand for a change in the morphodynamic state, have not this autodefensive response and suffer more intense erosive processes. The most characteristic examples can be found in the Bay of Cadiz.

4.2 Coastal erosion in the Bay of Cadiz

The Bay of Cadiz, located in the central sector of the studied coast (profiles 16 to 21), constitutes a good example for the comparison of long- and short-term erosional data. The zone has an additional interest due to its high socioeconomic and naturalistic importance.

Fig. 3 shows the general morphodynamic classification of beaches in the Bay of Cadiz and surrounding zones. The application of the Surf Scaling Parameter to the beaches shows typical dissipative values, with intermediate prevalent states in the northern Cadiz beaches, between Chipiona and Rota (Benavente *et al.* 2002). The Valdelagrana littoral spit, in the center of the Bay, reaches very high values and a general behaviour resembling the ultradissipative beach state described by Masselink & Short (1993). A discrimination has been made in Fig. 3 between beaches exhibiting the same morphodynamic state during the whole year, and those showing a seasonal behaviour, alternating quite different states depending on the changing energetic conditions. As indicated earlier, the latter present a significantly lower susceptibility to erosion during storm periods.

Photointerpretation analysis of the Bay of Cadiz shows a general tendency to the coastal retreat, often supported by field evidences and indicators. The highest erosion rate was measured in the free end of Valdelagrana spit, with some important set-back episodes occuring in the last 25 years; average annual values range between 6 and 84 m (Martínez-del-Pozo *et al.* 2001). In this case these episodes are very clearly related to periods of construction and enlargement of the jetties that confine the Guadalete river mouth (Fig. 3). These structures produce an injection of the sediment supplied by the Guadalete river to the outer Bay, and substantially reduce the amount of sand redistributed by littoral currents along the spit. The important decrease in the sedimentary charge of currents and waves approaching the southern end of the spit results in a rapid erosion of the beach at this point. In this sense, the morphology of Valdelagrana spit has demonstrated to be very sensitive to variations in the sedimentary budget and is a very useful indicator of slight changes in the sediment supply to the Bay (Martínez-del-Pozo *et al.* 2001).

In the rest of the coast recent erosion was less important. Punta Candor, in the northern Cadiz coast, suffered a retreating rate of up to 3 m/year. Lower but significant values were recorded at Peginas and Fuentebravia beaches (Fig. 3).

Punta Candor and Peginas constitute two cuspate headlands where wave energy concentrates. Moreover, the substantial diminution in the sedimentary supply by the Guadalquivir river in recent years has contributed for the recorded erosion in this zone.

Fuentebravia beach is affected by the jetties of the Rota NATO Military Zone. These structures are located upstream from predominant littoral drift, and after their construction in the fifties they led to the disappearance of a small beach placed immediately downdrift. Moreover, the whole-year-dissipative behaviour of Fuentebravia beach increases its susceptibility to erosion.

As mentioned above, the consequences of these erosive processes are often observable due to the existence of morphological and anthropic indicators. Several bunkers were constructed in the thirties on dune ridges and are today fallen and tilted in the intertidal zone (Fig. 4). The most outstanding morphologies associated to coastal erosion are the collapses of the Plioquaternary cliff in Aguadulce beach, and the dune scarpments existing in Punta Candor, Vistahermosa, Valdelagrana and Camposoto beaches. Moreover, substratum outcrops (either rocky-shore platforms or ancient marshes) appear after the arrival of winter storms on the areas that suffer more intense erosive processes. In Sancti-Petri spit former marsh levels outcropping at the intertidal zone on Camposoto beach, and washover fans existing on the dune ridge, indicate a coastline retreat and the landward migration of the beach-dune system.

In this respect two different scales of study can be taken into account. On one hand, considering a historical scale, from the above mentioned indicators it can be inferred that Sancti-Petri spit has been suffering a set-back at least since Roman times (Gracia *et al.* 1999), probably due to the combination of several factors like energetic storm events, sea level rise, diminution of sediment supply and contouring conditions (i. e. the shape of a submerged rocky platform located about 500 m offshore). On the other hand, con-

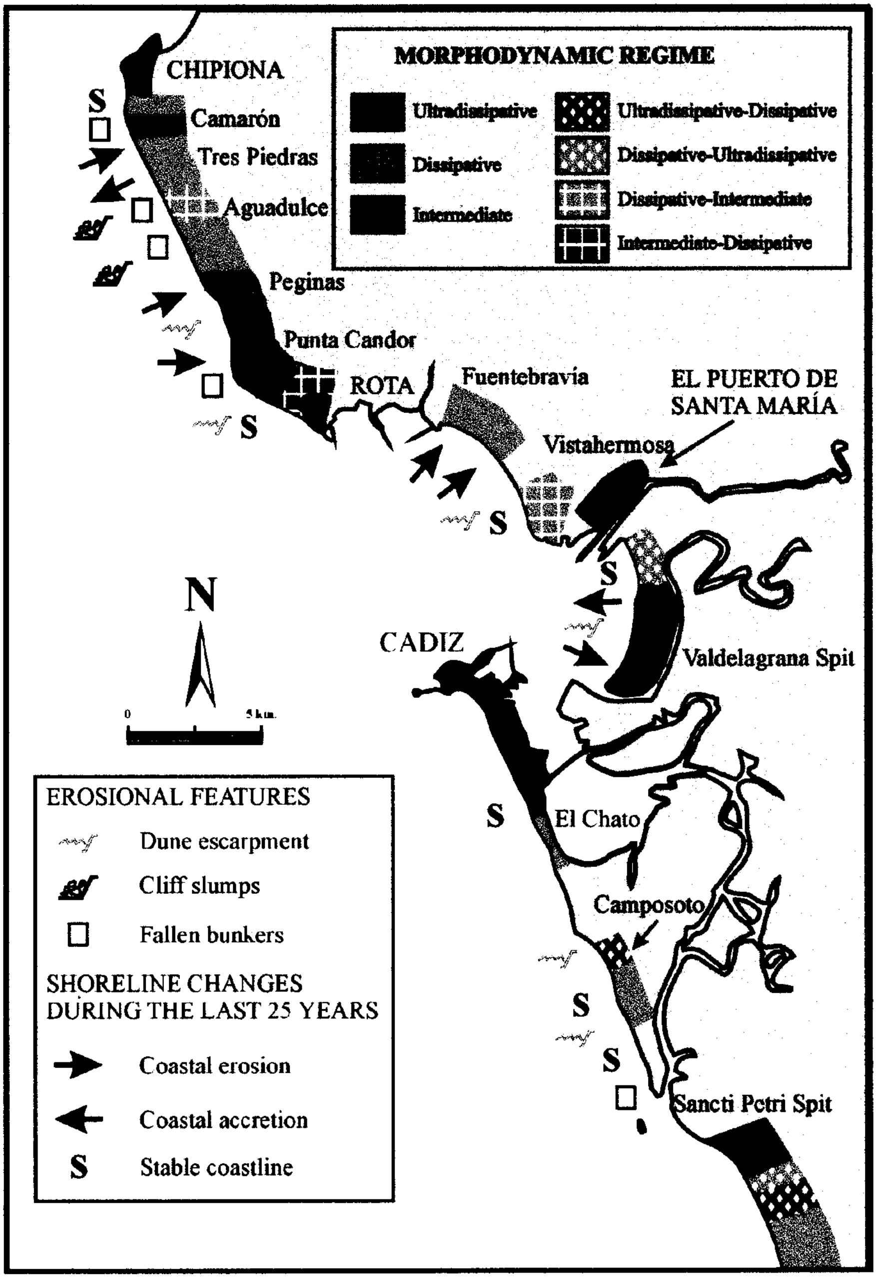

Figure 3: Map of morpho-erosional beach states in the Bay of Cádiz.

sidering a scale of decades, the analysis of aerial photographs show relative coastline stability in this zone.

So, apart from the general regressive trend existing in the study area, there are several relatively stable coastal stretches: Camposoto beach, El Chato beach and the southern portions of Aguadulce and Vistahermosa beaches show a rate of progradation or retreat lower than 1 m/year. Littoral stability in these areas is mainly related to the protection provided by intertidal or subtidal rocky platforms existing in some coastal sections (Muñoz & Enríquez 1998), as well as to the well-

Figure 4: Bunker initially installed upon former dune ridges, today fallen on the intertidal zone of Malandar Beach (Doñana National Park).

conserved dune ridges existing in others. Finally, there are very few zones in the Bay of Cadiz that present a clear coastline progradation trend, generally related to local conditions or to the existence of littoral cells.

5. CONCLUSIONS

The current research project "Coastal Erosion Processes in the South Atlantic Spanish Coast", performed by researchers from the universities of Cadiz and Huelva (SW Spain), has demonstrated the utility of applying different temporal scales in the study of coastal erosion. As a first conclusion, it can be stated that historical erosive trends recorded in the shoreline during the last centuries or even decades do not always agree with the short-term retreating trends monitored in the field. The combination of both type of techniques is essential for a proper and realistic knowledge of the erosional state of a coast. This procedure contrasts with other more traditional studies in which local data obtained from very definite time periods have often been oversimplified and inadequately extrapolated in time and space.

In the Gulf of Cadiz the most important causes producing coastal erosion are:

- In the short term (months, several years), coastal engineering structures have produced local although intense erosion processes. The construction of groins, jetties and harbours induce a rapid coastal retreat at some points. Nevertheless, a re-equilibrium is usually attained after some time.
- In the medium term (decades), dams and reservoirs installed on fluvial basins give rise to sediment retention. The decrease in the fluvial sedimentary supply also contributes to coastal erosion. At a similar temporal scale, the destruction of dune ridges for coastal urbanization purposes introduce important transformations on the littoral sedimentary budget. The resulting evolution commonly consists in a long-lasting tendency towards the sand loss.
- Finally, in the long term evolution, the current sea level rise would worsen all these effects. In this way, future climatic changes could produce fluctuations in the frequency and/or cyclicity of storm occurrence.

Future works on this subject can be focused on the relative role played by local and regional geomorphologic and dynamic factors in the different coastal erosion rates recorded along the Gulf coast. These include the longitudinal tidal range variability, the effects of submerged topography in the wave shoaling processes, etc.

ACKNOWLEDGEMENTS

The authors would like to thank J. Roman, M. Navarro, N. Ruiz, I. Ares, M. Romero and M.L. Garcia for field and laboratory support.

This is a contribution to Spanish D.G.E.S. project PB98-0581.

REFERENCES

Anfuso, G., Benavente, J. & Gracia, F.J. 2001a. "Morphodynamic responses of nourished beaches in SW Spain", *Journal of Coastal Conservation*, 7, 71-80.

Anfuso, G., Martínez-del-Pozo, J.A., Gracia, F.J. & López-Aguayo, F. 2001b. "Longshore distribution of morphodynamic beach states in a homogeneous coast in SW Spain", in E. Ozhan (ed.): *Proc. 5th Intern. Conf. on Mediterranean Coastal Environment, MEDCOAST'01*, Hammamet, Tunisia, 1381-1392.

Ballesta, M., Morales, J.A. & Acosta, E.A. 1998. "Efecto erosivo de los temporales del invierno 1995-1996 sobre la playa de Mazagón (Huelva, SO España): influencia de las construcciones costeras", *Revista de la Sociedad Geológica de España*, 11(3-4), 285-296.

Benavente, J., Del Río, L., Anfuso, G., Gracia, F.J. & Reyes, J.L. 2002. "Utility of morphodynamic characterization in the prediction of beach damage by storms", *Journal of Coastal Research*, SI 36 (in press).

Benavente, J., Gracia, F.J. & López-Aguayo, F. 2000. "Empirical model of morphodynamic beachface behaviour for low-energy mesotidal environments", *Marine Geology*, 167, 375-390.

Benavente, J., Reyes, J.L., Anfuso, G., Gracia, F.J. & López-Aguayo, F. 1997. "Respuesta diferencial de playas regeneradas en la Bahía de Cádiz", *IV Jornadas Españolas de Ingeniería de Puertos y Costas*, Serv. Publ. Univ. Valencia, vol. III, 803-813.

Flor, G. 1990. "Tipología de dunas eólicas. Procesos de erosión-sedimentación costera y evolución litoral de la provincia de Huelva (Golfo de Cádiz occidental, Sur de España)", *Estudios Geológicos*, 46, 99-109.

Flores, E., Rodríguez-Vidal, J., Ballesta, M., Rodríguez, A. & Cáceres, L.M. 1997. "Cambios morfológicos actuales en la playa de Mazagón (Huelva)", in J. Rodríguez-Vidal (ed.): *Cuaternario Ibérico*, AEQUA, Huelva, 154-156.

González, R., Dias, J.M.A. & Ferreira, O. 2000. "Altering the natural balance of sedimentation and its consequences: recent evolution of the Guadiana Delta (SW Iberian Peninsula)", *3º Simposio sobre a Margem Ibérica Atlántica*, Univ. do Algarve, Faro, Portugal, 125-126.

Gracia, F.J., Alonso, C., Gallardo, M., Giles, F., Rodríguez, J., Benavente, J. & López-Aguayo, F. 1999. "Aplicación de la geoarqueología al estudio de cambios costeros postflandrienses en la Bahía de Cádiz", in V. Rosselló (ed.): *Geoarqueologia i Quaternari Litoral. Memorial M.P. Fumanal*, Univ. Valencia, 357-366.

Gracia, F.J., Anfuso, G., Macías, A., Benavente, J., Ferreira, O. & López-Aguayo, F. 2000. "Towards a sustainable coastal management of the Cádiz Gulf (SW Spain and Portugal)", *Intern. Conf. on Integrated Coastal Area Management & Marine Sciences*, San Petersburgo, IOC-UNESCO, 119.

Guillemot, E. & Palma, M. 1987. "Diagnóstico de cambios recientes ocurridos en la Bahía de Cádiz (1956-1984)", in F. Fourneau & J. Garrido (dir.): *Bahía de Cádiz*, Junta de Andalucía and Casa de Velázquez, 23-47.

Guza, R.T. & Inman, D.L. 1975. "Edge waves and beach cusps", *Journal of Geophysical Research*, 80, 2997-3012.

Martínez-del-Pozo, J.A., Anfuso, G. & Gracia, F.J. 2001. "Recent evolution of a tidal delta in Cadiz Bay (SW Spain) due to human interventions", in E. Özhan (ed.): *Proc. 5th Intern. Conf. on Mediterranean Coastal Environment, MEDCOAST'01*, Hammamet, Tunisia, 1425-1433.

Masselink, G. & Short, A.D. 1993. "The effect of tide range on beach morphodynamics and morphology: a conceptual beach model", *Journal of Coastal Research*, 9 (3), 785-800.

Menanteau, L. & Clemente, L. 1977. "Nuevos datos sobre las relaciones entre la erosión costera y el ascenso del nivel marino en el sector Mazagón (Huelva)-Chipiona (Cádiz). Papel de la tectónica", in M.T. Alberdi, J. Gallardo, T. Aleixandre & M. Santonja (eds.): *Actas de la 2ª Reun. Nac. Grupo Español de Trabajo del Cuaternario*, Jaca, Trabajos Neógeno-Cuaternario CSIC, 6, 177-185.

Muñoz, J.J. & Enríquez, J. 1998. "Dinámica litoral de una unidad fisiográfica completa: Sanlúcar-Rota", *Revista de Obras Públicas*, 3.375, 35-44.

Muñoz, J.J. & Gutiérrez, J.M. 1999. "Tipología y eficacia de los espigones de escollera construidos para la mejora de la estabilidad de las playas del litoral atlántico de la provincia de Cádiz", *Boletín Geológico y Minero*, 110-1, 53-66.

Muñoz, J.J., López, B., Gutiérrez, J.M., Moreno, L. & Cuena, G.J. 2001. "Cost of beach maintenance in the Gulf of Cádiz (SW Spain)", *Coastal Engineering*, 42, 143-153.

Reyes, J.L., Martins, J.T., Benavente, J., Ferreira, O., Gracia, F.J., Alveirinho-Dias, J. & López-Aguayo, F. 1999. "Gulf of Cádiz beaches: A comparative response to storm events", *Boletín Instituto Español de Oceanografía*, 15 (1-4), 221-228.

Rodríguez-Ramírez, A., Cáceres, L.M., Rodríguez Vidal, J. & Flores, E. 1999. "Modificación antropogénica de la dinámica marina en la costa de Mazagón (Huelva)", in L. Pallí & C. Roqué (eds.): *Avances en el estudio del Cuaternario español*, X Reun. Nac. Cuat., AEQUA and Univ. Girona, 43-48.

Rodríguez-Ramírez, A., Cáceres, L., Rodríguez-Vidal, J. & Cantano, M. 2000a. "Relación entre clima y génesis de crestas/surcos de playa en los últimos cuarenta años (Huelva, Golfo de Cádiz)", *Cuaternario y Geomorfología*, 14 (3-4), 109-113.

Rodríguez-Ramírez, A., Cáceres, L.M. & Rodríguez-Vidal, J. 2000b. "Dinámica y evolución de flechas litorales: el litoral onubense (SO España)", in J.R. de Andrés & F.J. Gracia (eds.): *Geomorfología litoral. Procesos activos*, Monografías SEG 7, ITGE and Univ. Cádiz, 101-113.

Wright, L.D. & Short, A.D. 1984. "Morphodynamic variability of surf zones and beaches: a synthesis", *Marine Geology*, 56, 93-118.