Morphological and sedimentary patterns of current-controlled sediment bodies and superimposed bedforms based on high-resolution seismic data from the continental shelf near the Strait of Gibraltar

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ABSTRACT: A previously unknown field of large-scale sedimentary bodies on the continental shelf off the Cape Trafalgar near the Strait of Gibraltar has been mapped and studied with particular emphasis on the relationship between large-scale sediment bodies and the superimposed bedforms. This study is based on a grid of 975 km of high-resolution seismic profiles collected at water depths ranging between 15 and 60 m. High variability of large-scale sedimentary bodies is attributed to the complex interaction of hydrodynamic agents. The most prominent sedimentary features indicate southwestward and southward sediment transport patterns. Relationships between superimposed bedforms (mostly very large dunes) and underlying sediment bodies vary across the study area. Most superimposed bedforms occur over the complex mosaic of sediment banks and sheets, suggesting that several high-energy currents with different directions interact in the area, making it hydrodynamically highly complex.

1 INTRODUCTION

On many continental shelves around the world, sand banks and ridges are 1st order morpho-stratigraphical elements in areas where strong uni- or bi-directional bottom flows impinge on the sea floor (Dyer and Huntley, 1999). They are laterally extensive deposits, tens of km long, several km wide and tens of m high. The term sand ridge refers to certain banks whose length is considerably higher than width whereas the term sand bank is more generic (Amos and King, 1984). As ridge axis are usually oriented nearly parallel or at a small oblique angle (up to 20º) in relation to the dominant current flow direction, their identification may provide information about bottom currents and their influence on shallow water sedimentary processes. In most cases, sand banks and ridges are associated with reciprocating tidal currents or with unidirectional storm-generated flows (Dyer and Huntley, 1999; Snedden and Dalrymple, 1999; Liu et al., 2007) that dominate the net bedload transport paths, and hence control the migration trends of those large-scale sediment bodies. One of the most distinctive characteristics of sand banks and ridges is the occurrence of smaller-scale bedforms superimposed on active larger bodies (Dyer and Huntley, 1999).

Previous studies in the Gulf of Cadiz shelf (NE Atlantic Ocean) have mapped submarine bedforms in an extensive area off Cape Trafalgar near the Strait of Gibraltar (Lobo et al., 2000). Recent oceanographic survey executed in this area revealed previously undocumented large-scale sediment bodies with dimensions equivalent to sand banks/ridges. These sediment bodies extend deeper into the subsurface and the submarine bedforms usually capture only their uppermost, currently active layer. This paper presents a detailed description and classification of this new field of large-scale sediment bodies, taking into account not only their modern development under dominant bottom current flows but also their spatial variability and relationship with preexisting subsurface physiography. We pay special attention to the relationship between large-scale sediment bodies and superimposed bedforms.

2 THE NORTHERN SHELF OF THE GULF OF CADIZ

The northern Gulf of Cadiz shelf extends off the coasts of southwestern Iberian Peninsula. The central sector between Guadiana and Guadalquivir rivers is fluvially dominated, as subsurface deposits mainly comprise widespread prodeltaic and other fluvially-related deposits. Fluvial influence decreases both towards the southern Portuguese shelf and towards the Strait of Gibraltar (Lobo et al., 2004). The study area is located on the continental shelf near the Strait of Gibraltar (Fig. 1), in an area where sediment supply from fuvial sources is minimal and where sedimentation processes are thought to be largely controlled by hydrodynamic processes.

General surface circulation in the Gulf of Cadiz is anticyclonic with short-term, meteorologically induced variations (Criado-Aldeanueva et al., 2006). Near the Strait of Gibraltar, the picture is further complicated by: a) strong winds with alternating directions; b) current reversals apparently linked to tidal cycles in the Strait of Gibraltar (Lobo et al., 2000); c) upwelling of cool waters offshore Cape Trafalgar (Vargas-Yáñez et al., 2002).

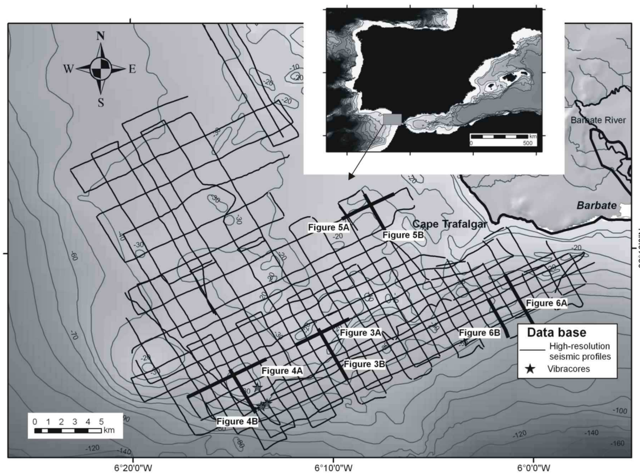

Figure 1: Geographical location of the study area and position of high-resolution geophysical records used in the study. Examples of seismic profiles shown in this work (figures 3 to 6) are indicated.

Morphology and sediments south of Guadalquivir River document a significant change from the fluvially-influenced Guadalquivir shelf, dominated by southeastward prograding muddy prodeltaic belt (López-Galindo et al., 1999; Nelson et al., 1999), to the southern shelf, dominated by coarse-grained facies consisting of relict reworked sediments with negligible fluvial input (López-Galindo et al., 1999). A large part of this sandy shelf is covered with extensive fields of bedforms showing diverse orientations and shapes (Lobo, 1995; Nelson et al., 1999; Lobo et al., 2000). In the study area, off the coast between Conil and Barbate towns, two main zones were detected where large dunes showed opposing asymmetries. Throughout the E-W oriented belt south of the Cape Trafalgar the majority of large dunes are asymmetric towards the west. However, further north in the inshore zone most of the bedforms are asymmetric towards the east (Lobo et al., 2000).

3 METHODOLOGY

Various data were collected during the BARBATE 2006 survey from 1-15 June 2006 off Cape Trafalgar. These data included multibeam bathymetry, side scan sonar imagery, high-resolution seismics, Acoustic Doppler Current Profiler (ADCP) data and sediment cores. For the purposes of this study, we have used a dense grid of high-resolution seismic profiles obtained using an Octopus 360™ seismic system based on a Geopulse™ boomer-type sound source (Fig. 1). Acquisition parameters were as follows: shooting interval of 400 ms, recording interval of 200 ms and the signal sampling frequency of 24 kHz. Recorded SEG-Y files were post-processed with Radexpro™ software. The processing sequence included the following steps: a) navigation processing; b) bandpass filtering; c) gain adjustment; d) mute corrections; and e) swell filtering.

A total length of 975 km of high-resolution seismic profiles was collected in two main directions: NNW-SSE and ENE-WSW, i.e. parallel and normal to the adjacent coastline near the Cape Trafalgar. Seismic profiles were collected at water depths ranging between 15 and 60 m. Lateral separation between seismic lines was between 1 and 2 km (Fig. 1).

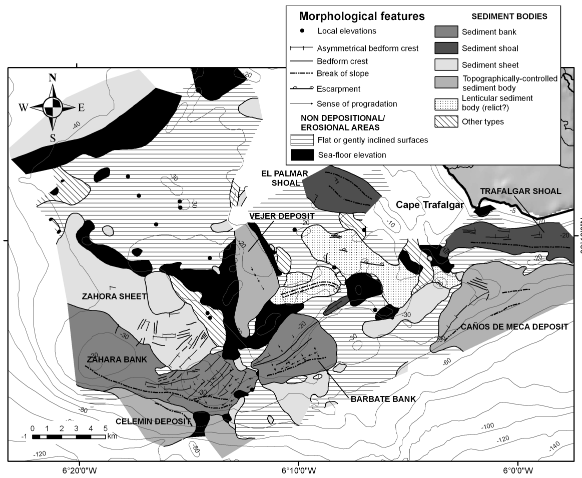

Figure 2: Morpho-sedimentary map of the study area highlighting major sedimentary bodies.

For the purposes of classification of the sedimentary bodies identified in the study area, we distinguish between the large-scale sediment bodies and superimposed bedforms. Large-scale sediment bodies have been classified based on their distribution and dimensions (in plan-form as well as cross-sectional), internal structure, absence/presence of superimposed bedforms and relationship with underlying and/or adjacent bathymetry. Superimposed bedforms are classified as subaqueous dunes according to the classification of Ashley (1990). Thickness values are given in milliseconds (ms).

4 RESULTS: LARGE-SCALE SEDIMENT BODIES AND SUPERIMPOSED BEDFORMS

Sea-floor morphological types distinguished in the study area were classified as: a) elevations: local or regional; b) planes: either flat or inclined; c) sediment bodies, further classified as: sediment banks, sediment shoals, sediment sheets, topographically controlled sediment bodies, lenticular sediment bodies and other, unspecified sediment bodies; d) superimposed bedform fields indicative of modern, active sediment bodies

In this paper, we focus on modern sedimentary bodies. Local names have been assigned to the most prominent sediment bodies in order to facilitate the discussion (Fig. 2).

4.1 *Sediment banks*

Two major sediment banks are recognised in the study area:

a) Barbate Bank is a compound sediment body in up to 40 m water depth at approximately 13 km southwestward of the Cape Trafalgar (Fig. 2). It is NE-SW elongated and over 5 km long, although it is nearly as wide in the NE part (c. 4.5 km in a NNW-SSE direction). In the SW part the bank is less than 2 km wide in a NNW-SSE direction. Cross-sectional profiles display a bank shape with a slight break of slope running ENE-WSW near the southern boundary of the bank.

Thickness of the Barbate Bank is variable, although values higher than 20 ms are common in the centre of the body. Locally, where superimposed bedforms occur, maximum thicknesses exceed 30 ms. Internal structure of the bank shows prograding reflections dipping towards the SSW (Fig. 3).

Two very large dunes are superimposed on the Barbate Bank (Fig. 3). They exhibit NE-SW oriented crests running parallel to the bank main direction for several km. The northern dune is larger than the southern one and shows in places an asymmetric profile oriented towards the S, whereas the southern dune shows a dominantly symmetric profile.

b) Zahara Bank is a compound sediment body located west of the Barbate Bank, at water depths up to 50 m. It extends WNW-ESE for more than 12 km. In NNE-SSW direction its maximum extent ranges between 2 and 5 km (Fig. 2).

Cross-sectional profiles show an asymmetrical profile with the SSW side being steeper than the NNE side (Fig. 4). The break of slope between the two sides runs approximately parallel to the main orientation of the bank. According to the strongly elongated pattern and the asymmetrical cross-section, this sediment body could be classified as a sediment ridge.

Maximum thickness occurs close to the break of slope, where thickness values higher than 35 ms have been locally measured (Fig. 4A). Thicknesses are also higher than 30 ms in local bedform depressions. The internal layering shows dominantly progradational structure, with reflectors dipping toward the SW (Fig. 4). Westward, the internal reflectors become less distinct.

Numerous very large dunes are superimposed on the Zahara Bank, especially in its eastern part (Fig. 2). Most dunes exhibit NE-SW oriented crests, and tend to be asymmetric towards the NNW. In the western part of the bank, the orientation of the crests is mainly E-W and the asymmetry of the dunes is more variable.

4.2 *Sediment shoals*

Sediment shoals exhibit similar morphology but have smaller dimensions as contrasted to sediment banks. Several shoals are identified in the study area:

a) El Palmar Shoal occurs at water depths ranging between 10 and 20 m, at about 5 km off El Palmar town, in an area of predominantly plane sea floor. Although our data only enabled us to identify landward and seaward boundaries, the bank seems to extend for at least 5 km oblique to the coastline with mainly WNW-ESE orientation. It extends for more than 3 km in a cross-shelf direction (Fig. 2).

In cross-section, the bank shows a relatively plane upper surface, bounded by two breaks of slope running approximately NW-SE that laterally delimit two sides of the shoal. The maximum thickness is typically less than 15 ms, and values around 10 ms are common. The internal structure is not distinct, although locally offshore progradation is apparent (Fig. 5).

Some large dunes of low lateral continuity are superimposed on the El Palmar Shoal. In addition, several very large dunes are not superimposed, but coalesce laterally with the shoal (Fig. 5). The asymmetry seems to be variable, but the highest dune is migrating towards the NW.

b) Trafalgar Shoal occurs south of Cape Trafalgar, at water depths less than 20 m. This shoal is E-W elongated and over 8 km long, although its lateral extent is not exactly known. Width of the Trafalgar Shoal in N-S direction is less than 2 km (Fig. 2).

In cross- section, a slight break of slope runs E-W for several kilometers. Thickness of the Trafalgar Shoal does not commonly exceed 10 ms. The internal structure is not clearly defined. In the middle part, the shoal is constituted by the coalescence of several smaller-scale bedforms that are asymmetrically oriented towards the N.

c) A nearly 2 km long and several hundreds of meters wide NE-SW elongated sediment shoal is identified at approximately 10 km southwest of the Cape Trafalgar, (Fig. 2). This sediment shoal is symmetrical or locally very slightly asymmetrical towards the N.

4.3 *Sediment sheets*

Sediment sheets are sediment bodies with relatively constant thickness over extensive areas and without distinctive sloping of the upper surfaces. According to thickness distribution, we distinguish two main types:

a) Thick sediment sheets are deposits with lateral extent in the order of several kilometres and with variable sediment thickness typically exceeding 10 ms. Thick sediment sheets are found in three main areas (Fig. 2):

On the shelf southwest of the Cape Trafalgar at least two sheets with mainly ENE-WSW orientation are recognized. They extend laterally for several km. Thickness of the sheets is around 5 ms, reaching locally up to 10 ms.

North of the Zahara Bank, a major thick sediment sheet is named the Zahora Sheet. It is elongated in a NW-SE direction, extending for more than 10 km, whereas the width in a NE-SW direction is generally less than 5 km (Fig. 2). Cross-sectional data indicate constant thickness over extensive areas and commonly less than 15 ms. However, zones of reduced thickness in the middle part suggest that the Zahora Sheet comprises several sedimentary lobes. The internal structure is not clearly discernible. Numerous very large dunes cover the Zahora Sheet in the southeastern part of the sediment body (Fig. 2). Crests of the dunes seem to show two main orientations: NE-SW and E-W. These orientations are not conclusive, however, as lateral correlation of single dunes across consecutive profiles in this area is somewhat uncertain. Most of the dunes are asymmetric towards the S or SE, although symmetrical dunes are also observed.

In the northern part of the study area, another thick sheet is identified. It is truncated by a NE-SW oriented morphological elevation at its southern limit. The location of this sediment body suggests a genetic link with the Guadalquivir River.

b) Thin sediment sheets occur scattered across the entire study area. Their lateral extents are less than 1 km and thicknesses below 5 ms are common.

4.4 *Topographically-controlled sediment bodies*

This category includes deposits whose development seems to be influenced by preexisting physiography. Two main types could be distinguished:

a) A confined sediment body over 13 km from the coastline in the middle part of the study area, northwest of the Barbate Bank, is named Vejer Deposit. In plan view, the Vejer Bank is over 7 km long, elongated N-S with maximum width of less than 3 km in the E-W direction (Fig. 2). The Vejer Deposit is bounded by morphological elevations that are particularly continuous along the western and southern boundaries.

In cross section, it shows a lenticular shape. Internal structure seems to be complex, but the sedimentary architecture of the uppermost part shows a component of southward progradation. No significant superimposed bedforms are recognized in this area.

b) Sediment bodies developed over inclined surfaces. Two major deposits fall within this category:

A sediment wedge that is located south of the Trafalgar Shoal, nearly 4 km from the coastline. This large-scale sediment body is called Caños de Meca Deposit. The deposit seems to be elongated in NE-SW direction and can be followed for more than 10 km, although the southward termination could not be determined (Fig. 2).

The deposit is wedge-shaped in NNW-SSE cross-sections lying on a sloping surface (Fig. 6). Its thickness decreases towards the NNW. On the ENE-WSW cross-sections, this deposit shows a bank or lenticular shape with a major axis running in a WNW-ESE to W-E direction. Maximum thicknesses of locally more than 20 ms are observed along the major axis. Thicknesses over 15 ms are common on the gently sloping surface.

A very large NW asymmetric dune with NE-SW orientation of the crest-line is identified over the Caños de Meca Deposit (Fig. 6). Other smaller superimposed bedforms are also recognized.

Another major sediment body is recognized on a sloping surface south of Zahara Bank. It seems to follow a main NNW-SSE orientation, although the boundaries of the body are poorly defined. We named this deposit a Celemin Deposit (Fig. 2). Cross-sectional profiles indicate a sheet or lenticular shape, with maximum thickness exceeding 20 ms. The internal structure is mixed and does not exhibit a clear pattern.

4.5 *Lenticular bodies*

Two major lenticular bodies occur on the shelf southwest of the Cape Trafalgar. The one closer to the shore in a shallower water has NW-SE orientation whereas the one farther offshore in the deeper water has ENE-WSW orientation (Fig. 2). Maximum thickness exceeds 20 ms in their middle parts.

Those deposits exhibit numerous scarps and other erosive features. In some places, they are overlain by more recent deposits, suggesting that they are relict deposits. No appreciable bedforms are observed in these two areas.

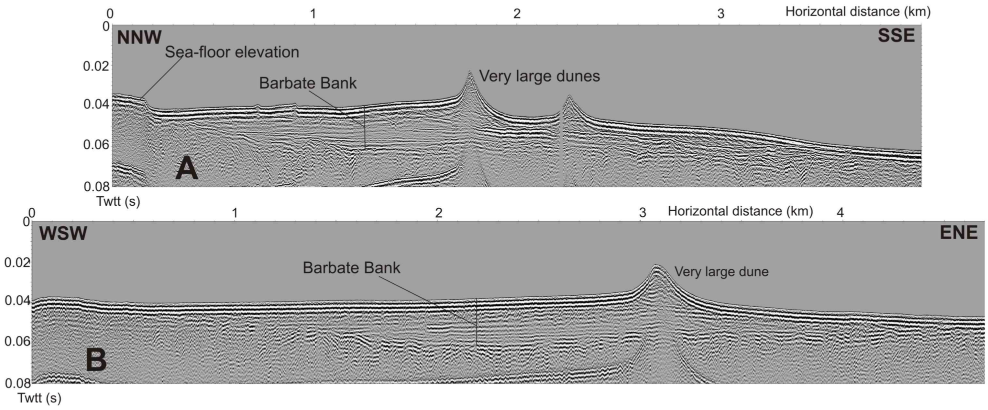

Figure 3: Examples of seismic records of the Barbate Bank. Two very large dunes are superimposed on the bank.

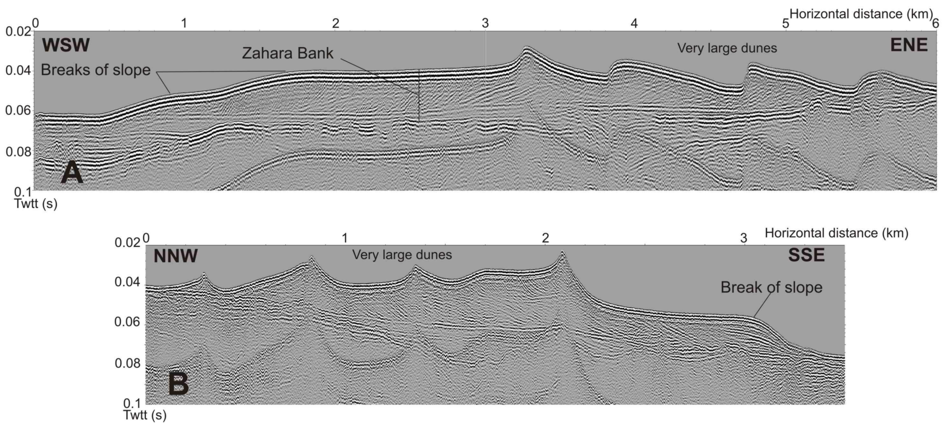

Figure 4: Examples of seismic records of the Zahara Bank, characterised by an asymmetrical pattern and numerous superimposed very large dunes.

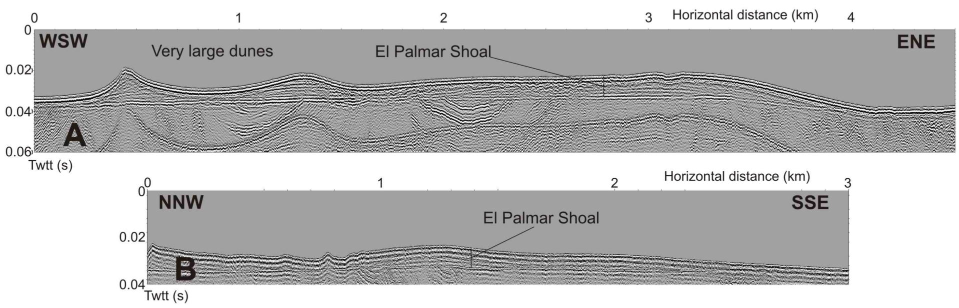

Figure 5: Examples of seismic records of the El Palmar Shoal, coalescing laterally with very large dunes.

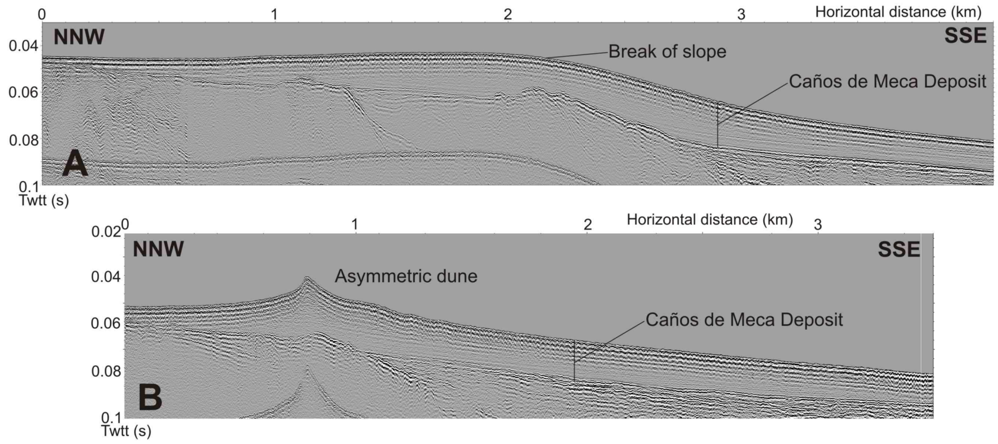

Figure 6: Examples of seismic records of the Caños de Meca Deposit covering a gently sloping surface.

4.6 *Other types*

In this category we include other sediment bodies with distinct shapes and/or lateral extent: numerous sediment infills and an attached wedge (Fig. 2). Sediment infills occur in different places in the study area, particularly around lenticular bodies. They do not generate a significant relief, and therefore are not considered to have been produced by modern regional hydrodynamics.

An attached wedge occurs in the eastern termination of the Zahora Sheet, attached to a NNW-SSE oriented morphological elevation. It is elongated in that direction for more than 6 km. In cross-sections, it generates a SW oriented sloping surface.

5 DISCUSSION

Three main points are considered in the discussion: a) the variability of large-scale sediment bodies developed under changing conditions of bottom flows in the study area; b) the controlling effect exerted by sea-floor elevations and ramps on the bottom currents and consequently on the generation of sediment bodies; c) the generation of superimposed bedforms on the various underlying sediment bodies.

5.1 *Spatial variability of sediment banks and other large-scale sediment bodies*

Sediment banks are the best developed large-scale sediment bodies identified in the study area, and their overall morphology and internal structures are indicative of the long-term direction of sediment body migration, which is compatible with the major influence of westward-directed bottom flows, interacting with southward flowing bottom currents. Lateral variability of the banks suggests complex interaction between westward and southward-directed flows. The formation of the asymmetrical Zahara Bank located offshore of the Barbate Bank could probably be explained by the dominant influence of currents resulting from regional wind patterns, as suggested in other shallow-water settings (Daniell and Hughes, 2007).

Development of the sediment shoals in shallower water is apparently limited by the reduced accommodation space controlled by the local wave climate. Bedforms in these areas indicate mainly northward sediment transport.

Sediment sheets are found in areas of particular hydrodynamic conditions, typically where progressive decrease in current velocity occurs as, for instance in the Taiwan Strait (Liao et al., in press).

5.2 *Influence of preexisting physiography*

Recent studies have highlighted the influence of bedrock topography on sand bank development (Bastos et al., 2003). In the study area, a significant number of major sediment bodies seem to be controlled by preexisting physiographic features, such as sea-floor elevations with two main orientations (NW-SE and ENE-WSW), and steep slopes (Fig. 2). These features are thought to control the original current patterns, generating specific morphologies and modifications to sediment transport trends. The physiographic control is two-fold:

a) Some sediment bodies on gently sloping underlying surfaces are laterally elongated suggesting that their genesis is related to the changes in the near-bottom flow direction and speed induced by the submarine morphology.

b) Distribution of some deposits is limited within local depressions surrounded by elevations. In most cases, the absence of superimposed bedforms and/or the prevalence of erosional features in these areas indicate that those deposits are essentially relict.

5.3 *Relationships between superimposed bedforms and underlying sediment bodies*

Relationships between superimposed bedforms and underlying sediment bodies are complex across the study area. Most bedforms occur over the composite mosaic of sediment banks and sheets composed of Barbate and Zahara banks and Zahora Sheet (Fig. 2) suggesting that this area is hydrodynamically complex due to the interaction of several high-energy currents. Long-term migration trends deduced from the bedform structure and distribution reflect the combined influence of spatially varying unidirectional currents.

However, bedforms also occur in other places, such as sediment shoals and the Caños de Meca Deposit. In these areas, the orientation and asymmetry of the superimposed bedforms is different from that of the large-scale sediment bodies. Both sets of bedforms, however suggest the influence of relatively unidirectional flows.

6 CONCLUSIONS

The high variability of large-scale sediment bodies found in the study area is attributed to a complex interaction of hydrodynamic agents, in which both, reversing tidal currents as well as wind-driven currents are probably involved. The most prominent morphological and sedimentary features indicate southwestward and southward sediment transport patterns, possibly as a result of combined influence of both westward and southward-directed currents.

Beform distribution and asymmetry seems to reflect the short-term current patterns, apparently normal to the long-term net sediment transport pattern and large-scale bedform migration. This inference is particularly evident in the areas where currents with different directions interact.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

Amos, C.L. & King, E.L. 1984. Bedforms of the Canadian eastern seaboard: A comparison with global occurrences. Marine Geology, 57(1-4): 167-208.

Ashley, G.M. 1990. Classification of large-scale subaqueous bedforms: a new look at an old problem. Journal of Sedimentary Petrology, 60(1): 160-172.

Bastos, A.C., Collins, M. & Kenyon, N.H. 2003. Morphology and internal structure of sand shoals and sandbanks off the Dorset coast, English Channel. Sedimentology, 50(6): 1105-1122.

Criado-Aldeanueva, F., Garcia-Lafuente, J., Vargas, J.M., Del Rio, J., Sanchez, A., Delgado, J. & Sanchez, J.C. 2006. Wind induced variability of hydrographic features and water masses distribution in the Gulf of Cadiz (SW Iberia) from in situ data. Journal of Marine Systems, 63(3-4): 130-140.

Daniell, J.J. & Hughes, M. 2007. The morphology of barchan-shaped sand banks from western Torres Strait, northern Australia. Sedimentary Geology, 202(4): 638-652.

Dyer, K.R. & Huntley, D.A. 1999. The origin, classification and modelling of sand banks and ridges. Continental Shelf Research, 19(10): 1285-1330.

Liao, H.-R., Yu, H.-S. & Su, C.-C. in press. Morphology and Sedimentation of Sand bodies in the Tidal Shelf Sea of eastern Taiwan Strait. Marine Geology

Liu, Z., Berne, S., Saito, Y., Yu, H., Trentesaux, A., Uehara, K., Yin, P., Liu, J.P., Li, C., Hu, G. & Wang, X. 2007. Internal architecture and mobility of tidal sand ridges in the East China Sea. Continental Shelf Research, 27(13): 1820-1834.

Lobo, F.J. 1995. Estructuración y evolución morfosedimentaria de un sector del margen continental septentrional del Golfo de Cádiz durante el Cuaternario Terminal. Dissertation Thesis, Cádiz, Puerto Real (Cádiz, España), 200 pp.

Lobo, F.J., Hernandez-Molina, F. J., Somoza, L., Rodero, J., Maldonado, A. & Barnolas, A. 2000. Patterns of bottom current flow deduced from dune asymmetries over the Gulf of Cadiz shelf (southwest Spain). Marine Geology, 164(3-4): 91-117.

Lobo, F.J., Sanchez, R., Gonzalez, R., Dias, J. M. A., Hernandez-Molina, F. J., Fernandez-Salas, L. M., Diaz del Rio, V. & Mendes, I. 2004. Contrasting styles of the Holocene highstand sedimentation and sediment dispersal systems in the northern shelf of the Gulf of Cadiz. Continental Shelf Research, 24(4-5): 461-482.

Lopez-Galindo, A., Rodero, J. & Maldonado, A. 1999. Surface facies and sediment dispersal patterns: southeastern Gulf of Cadiz, Spanish continental margin. Marine Geology, 155(1-2): 83-98.

Nelson, C.H., Baraza, J., Maldonado, A., Rodero, J., Escutia, C. & Barber, J.H. 1999. Influence of the Atlantic inflow and Mediterranean outflow currents on Late Quaternary sedimentary facies of the Gulf of Cadiz continental margin. Marine Geology, 155(1-2): 99-129.

Snedden, J.W. & Dalrymple, R.W. 1999. Modern shelf sand ridges: from historical perspective to a unified hydrodynamic and evolutionary model. In: K.M. Bergman and J.W. Snedden (Editors), Isolated Shallow Marine Sand Bodies: Sequence Stratigraphic Analysis and Sedimentologic Interpretation, SEPM Special Publication, vol. 64, pp. 13-28.

Vargas-Yáñez, M., Viola, T.S., Jorge, F.P., Rubín, J.P. & García-Martínez, M.C. 2002. The influence of tide-topography interaction on low-frequency heat and nutrient fluxes. Application to Cape Trafalgar. Continental Shelf Research, 22(1): 115-139.