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The sedimentary record of the post-glacial transgression on the Gulf of Cadiz continental shelf (Southwest Spain)

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Abstract

Four seismic units (T_A to T_D) have been identified from the analysis and interpretation of high-resolution seismic profiles in a sector of the Gulf of Cádiz shelf. They constitute a composite seismic unit attributed to the transgressive systems tract (TST) of the last depositional sequence. The earliest transgressive unit was deposited on the outer shelf, and represents the distal facies of a coastal deposit. A process of shelf partitioning seems to have occurred during the formation of the three later transgressive parasequences. The shelf sector offshore from the Guadiana River mouth was a high-energy environment dominated by storm events. By contrast, the shelf sector offshore from the Doñana National Park was a low-gradient shelf, where large barrier island and lagoon systems were formed. The sparse occurrence of marine deposits within the TST is a consequence of the episodic nature of the sea-level rise.

The generation and preservation of these transgressive deposits results from the interaction of the following controlling processes: (1) Relative sea-level rise: The formation of coastal transgressive deposits is related to intervals of reduced sea-level rise or stillstands within a period of continuous sea-level rise. Those sea-level changes were probably driven by short-term periods of colder climate during the Late Pleistocene–Holocene deglaciation. The Younger Dryas interval is the most widely recognised climatic event of this type, but probably other events of similar characteristics had the same effect on the glacio-eustatic sea-level rise. (2) Sediment supply changes: Short-lived climatic events probably also involved changes in the sediment supply to the continental shelf due to changes in erosion rates and river regimes of the river basin hinterlands. (3) Effect of the paleophysiography/paleogeography: The sedimentary environments' differentiation processes are associated to the formation of an exposed coastal promontory offshore from the Guadiana River mouth and a semi-protected embayment offshore from Doñana National Park. This coastal configuration was controlled by previous tectonic evolution and influenced the non-uniform landward migration of the coastline.

Keywords: Gulf of Cadiz; Continental shelf; Seismic-sequence stratigraphy; Post-glacial transgression; Transgressive systems tract

1. Introduction

Transgressive deposits within the Quaternary sedimentary record are absent or show poor development because relative sea-level falls and lowstand periods prevailed during approximately 65% of that geological time span (Chiocci et al., 1997). Only the transgressive deposits related to the last major sea-level rise have been significantly preserved because

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of the higher amplitude of this rise compared with previous Late Quaternary rising intervals and because those deposits have not been eroded during subsequent lowstand periods (Gensous et al., 1993; Hernández-Molina et al., 1994; Trincardi et al., 1994). The generation of these transgressive deposits has been integrated into the context of the Late Pleistocene–Holocene sea-level rise, which occurred from the last glacial maximum, c. 18 ka BP (Fairbanks, 1989) when sea-level was approximately 120–125 m below the present, until 8–6.5 ka ago when the rate of rise decreased substantially and highstand conditions were established on the shelf (Stanley, 1995; Rohling et al., 2000).

A complete transgressive succession in a parasequence for temperate siliciclastic shelves would consist of two components bounded by a ravinement surface formed by wave and storm erosion (Carter et al., 1986; Saito, 1994): (1) lower component comprising different kinds of paralic depositional systems which overlay the transgressive surface (TS). The formation of this coastal component has been primarily attributed to periods of slow sea-level rise, stillstand or even brief periods of sea-level fall (Sager et al., 1992; Hernández-Molina et al., 1994). (2) Upper component of marine origin, formed as a consequence of the reworking of the lower component or the previous regressive deposits (Saito et al., 1989), and capped by maximum flooding surface (MFS). The occurrence of a continuous sea-level rise would enhance the formation of such reworking deposits (Carter et al., 1986). Therefore, the internal structure of the transgressive deposits and sedimentation processes are largely controlled by the nature of the sea-level rise, but other factors as variations of sediment supply and local paleogeography and paleotopography may also play a significant role (Chiocci et al., 1991; Correggiari et al., 1996).

Over the Gulf of Cadiz continental shelf, several deposits related to the post-glacial transgression have been identified. These deposits constitute a transgressive systems tract (TST), which comprises a backstepping succession of sedimentary units over the continental shelf (Hernández-Molina et al., 1994, 2000a; Somoza et al., 1997; Lobo, 1995; Roque, 1998; Rodero, 1999), whose formation has also been linked to periods of sea-level rise deceleration or short-lived sea-level stillstands (Hernández-Molina et al., 1994). However, until now, there was a lack of information on how the post-glacial transgression occurred and the nature of developed sedimentary environments. The present paper constitutes the first attempt to characterise the sedimentary history of a sector of the Gulf of Cadiz continental shelf during the post-glacial transgression by studying the sedimentary environments and their respective controlling factors, such as the relative sea-level rise, sediment supply changes, and paleo-geographic and paleo-oceanographic conditions related to post-glacial deposits.

2. Post-glacial climatic and glacio-eustatic changes

The details of the post-glacial sea-level rise are still a matter of controversy (Fairbanks, 1989; Stanley, 1995; Bard et al., 1996). Several cold climatic events involving ice sheets advance have been described in relation with this sea-level trend (Lowe and Walker, 1997):

(a) The Deglacial Onset at about 15 ka BP is related to a cold interval, sometimes referred to as the Oldest Dryas (Lézine and Denèfle, 1997; Lowe and Walker, 1997).

(b) A short-lived cold episode, the Older Dryas stadial (between 12–11.8 ka BP), divides the earlier Bölling Interstadial from the succeeding Allerød Interstadial (Williams et al., 1993; Lowe and Walker, 1997).

(c) Between 11 and 10 ka BP, the Younger Dryas stadial was a major cooling event linked to major oceanographic changes in the North Atlantic (Berger, 1990; Heusser and Morley, 1990; Kudrass et al., 1991). The Younger Dryas Event marks the transition between two steps of deglacial warming characterised by pulses of meltwater input (Bard et al., 1990): (a) the melt water pulse (MWP)-1A, centred at about 13–12 ka BP (14 000 cal yr BP), establishing the transition to the Older Dryas period through the Allerød Interstadial. (b) the MWP-1B, which occurred shortly after this cold event (Kallel et al., 1988; Berger, 1990).

(d) Recently, the study of North Atlantic ice-cores has given evidence of the occurrence of a dry and cold climatic event between 8.4–8 ka BP, with approximately half the amplitude of the Younger Dryas Event (Alley et al., 1997).

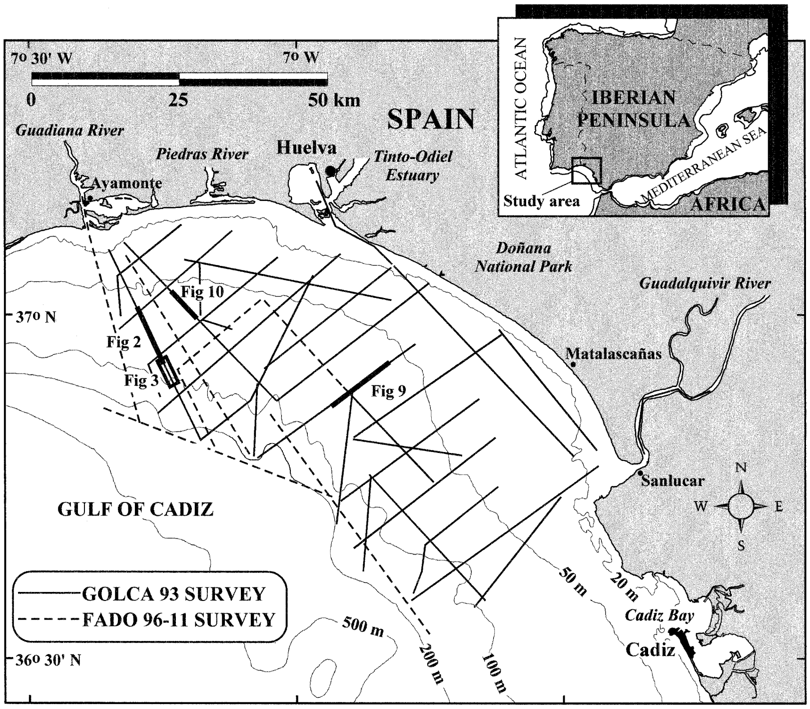

Fig. 1. Geographic setting of the study area and location of HR seismic reflection surveys.

The relationship between such cooling climatic events and the post-glacial sea-level changes is not well established yet. A growing body of evidence supports the idea that the post-glacial sea-level rise occurred episodically with small and rapid rises punctuated by stillstands or falls of sea-level (e.g. Carter and Johnson, 1986; Gensous et al., 1993; Gillespie et al., 1998; Buck et al., 1999). The most significant change on the general rising trend is related with the Younger Dryas Event, which appears to coincide with a period of reduced sea-level rise, from −75 to −60 m (Mayewski, 1994), or even a relative stillstand (Sager et al., 1992; Pirazzoli, 1996). The climatic change centred at about 8.2 ka BP is also related with a reduction in sea-level rise or even a small sea-level fall (Larcombe et al., 1995; Bard et al., 1996; Alley et al., 1997).

3. Study area

The study area is located in the Gulf of Cadiz continental shelf between mouths of the Guadiana and Guadalquivir Rivers (Southwestern Iberia) (Fig. 1). This coastal stretch receives fluvial supply from the Guadiana, Piedras, Tinto-Odiel and Guadalquivir rivers, from west to east. The Guadiana River's sediment contribution is especially significant for this sector of the Gulf of Cadiz shelf. Its mean annual water discharge between 1946 and 1990 has been estimated in about 4920 hm^3, although it shows a high variability (between 2280–13880 hm^3). Intraannual variations are also significant, influenced by climatic seasonality and the rainfall (Morales, 1993). Estimations of sediment supply of the Guadiana river over the last 44 years give values of 57.90×10^4 m^3/yr for the average suspended load and 43.96×10^4 m^3/yr for bedload (Morales, 1997). The average annual water discharge of the Guadalquivir River is about twice the amount of the Guadiana River discharge (Van Geen et al., 1997); however, most of its sediments are advected south-eastward of the study area by shelf hydrodynamics (Lobo, 1995; López-Galindo et al., 1999). In comparison, the contributions of the Tinto–Odiel system and the

Piedras river are small (average annual discharges <350 hm^3/yr) (Van Geen et al., 1997).

Dominant wave trains approach from the W and SW (approximately 50% of occurrences), although they are less energetic ($H_{1/3} = 0.40$ m, $T = 4.06$ s) than the SE waves ($H_{1/3} = 0.70$ m, $T = 5.08$ s), with ca. 25% of occurrences. These last waves are of particular relevance during winter storms, when significant wave heights may reach up to 3.80 m, (Morales, 1993). The estimated wave base level is 20 m for average conditions (Morales, 1993), but it is as high as 30–35 m during storm conditions on the Atlantic side of the Iberian Peninsula (Hernández-Molina et al., 1998, 2000b). General wave conditions generate a littoral drift towards east, which induces a potential sediment transport that has been estimated between 180×10^3 m^3/yr (Cuena, 1991) and 300×10^3 m^3/yr (CEEPYC, 1979).

The coast is a mesotidal (mean range 2 m) medium-energy coast. Tidal currents are weak in the littoral domain (0.3–0.4 m/s) but higher inside the estuaries (0.6–0.75 m/s) (Morales, 1997). The Atlantic Inflow Current moves south-eastwards over the continental shelf of the Gulf of Cadiz in a clockwise fashion at 10–15 cm/s (Nelson et al., 1999). These general oceanographic conditions have remained stable in this region since the last glacial maximum (Vergnaud-Grazzini et al., 1989).

The continental shelf of the study area has a slope of 0.32° off the Guadiana River mouth, decreasing eastwards to less than 0.2°. The shelf width increases from 20–25 km in the west off the Guadiana River mouth, to more than 30 km in its southern part. The shelf-break is located at water depths between 120 and 150 m.

4. Methodology

The present paper is based on a seismic stratigraphic analysis and interpretation of high-resolution (HR) seismic profiles, obtained with a Uniboom system (Geopulse) and a DGPS positioning during two oceanographic surveys (Fig. 1):

1. The Golca 93 survey was designed as a reconnaissance study (790 km of seismic profiles) covering the continental shelf and upper slope to a water depth of 200 m (Fig. 1). Spacing between two consecutive seismic profiles usually exceeds 7 km.
2. The Fado 96-11 survey was executed almost exclusively in the Portuguese continental shelf offshore from the Algarve coast, although 230 km of profiles were carried out over the Spanish continental shelf, in order to complete the information obtained during the previous survey (Fig. 1).

In this paper, we present the results of the analysis and interpretation of deposits placed overlying the most recent Pleistocene regressive wedge. The identification of reflector terminations has enabled us to characterise unconformity-bounded seismic units, following already established criteria for HR seismic stratigraphy analysis (e.g. Chiocci et al., 1991; Hernández-Molina et al., 1994, 2000a; Trincardi et al., 1994). For HR studies and under the absence of core data, the interpretation of depositional environments from the seismic facies analysis has proven to be a valuable tool giving information about the general conditions of sedimentary environments. In this sense, reflector termination and configuration give valuable information about paleoenvironments and mechanisms of sedimentary build-up because the good resolution of HR seismic profiles allows a precise identification of seismic facies (Berryhill, 1986; Canals et al., 1988; Cant, 1992; Selley, 1996). Furthermore, it is possible to obtain information about the depositional mechanisms leading to shelf sedimentation, and to reconstruct the most recent depositional evolution (Chiocci et al., 1991).

Each seismic unit has been correlated through the entire seismic grid, and the isopach maps have been expressed in two-way travel time (TWTT). To make the conversion into meters, the following velocity values have been used to determine depths and seismic unit thickness: 1500 m/s for the water column, and 1650 m/s for the recent sedimentary record.

5. Seismic facies analysis

Overlying the most recent Pleistocene regressive wedge, the composite seismic unit T, attributable to seismic unit 12 of Somoza et al. (1997) and Hernández-Molina et al. (2000a), comprises four backstepping seismic units (T_A to T_D from oldest to

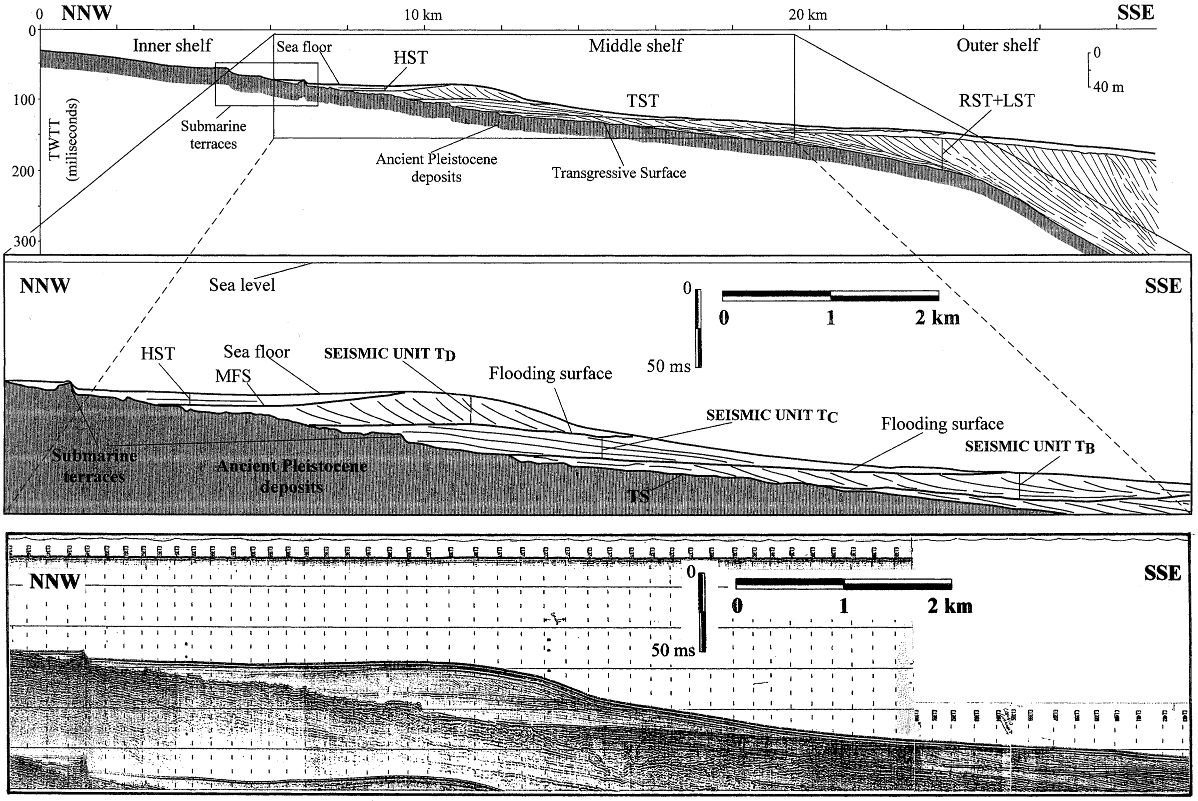

Fig. 2. Seismic profile section located offshore from the Guadiana River mouth (see Fig. 1 for location). The three most recent seismic units (T_B to T_D) are arranged in a backstepping pattern. RST + LST : regressive system tract + lowstand system tract, TST: transgressive system tract, HST: highstand system tract, MFS: maximum flooding surface, TS: transgressive surface, and TWTT: two-way travel time.

youngest) distributed over the continental shelf and upper slope of the study area. The stratigraphic relationship between the three most recent seismic units, located over the inner and/or middle shelf, is clear from seismic profiles (Fig. 2). The stratigraphic position of seismic unit T_A is less evident. It is usually located over the outer shelf and upper slope and detached from the other three more recent seismic units. However, in some seismic profiles, seismic unit T_B appears to be stratigraphically overlying seismic unit T_A (Fig. 3). Those seismic units have also been recognised on the adjacent Algarvian continental shelf (Roque, 1998; Lobo, 2000).

5.1. Distribution and characteristics of seismic discontinuities

The seismic units are defined by a number of seismic discontinuities, whose terminations are summarised in Table 1. The Lower Boundary of the composite seismic unit T is a stratigraphic surface that represents the upper boundary of the most recent Pleistocene regressive wedge (Hernández-Molina et al., 2000a). Offshore from the Doñana National Park, the Lower Boundary is a surface of low steepness (0.17°) (Fig. 4). Offshore from the Guadiana River mouth, three physiographic domains can be differentiated: (A) inner shelf, to the −50 ms isobath, displaying a mean slope of 0.3°; (B) middle shelf, between −50 and −130 ms isobaths, with a mean slope of 0.48°; (C) outer shelf, between the −130 ms isobath and the shelf-break, characterised by a smooth slope of 0.25°. The shelf–slope transition is defined by the −150 ms isobath (Fig. 4).

One of the most interesting stratigraphic characteristics of this surface is the presence of several

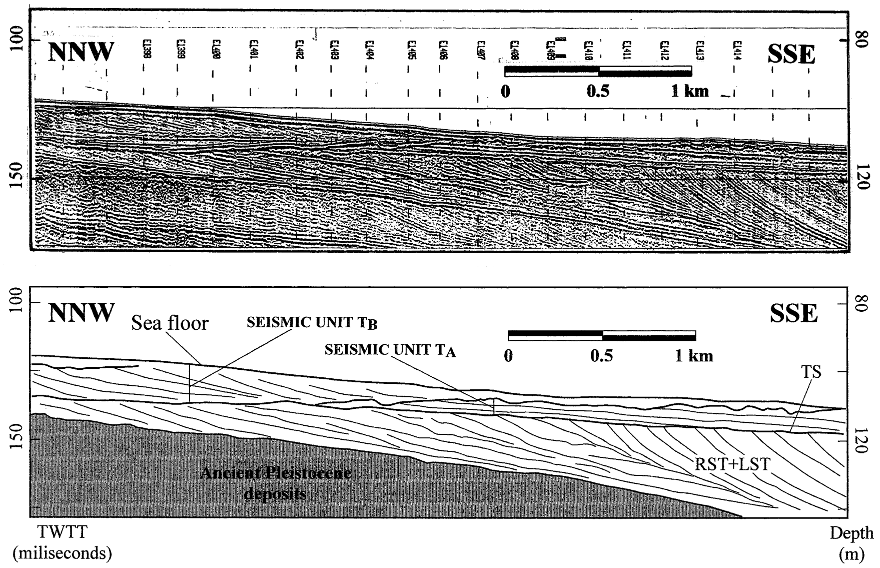

Fig. 3. Seismic profile section located offshore from the Guadiana River mouth (see Fig. 1 for location), which clearly shows the stratigraphic relationship between seismic units T_A and T_B. RST + LST : regressive system tract + lowstand system tract, TS: transgressive surface, and TWTT: two-way travel time.

4.5–7.5 m high terrace-like features at water depths ranging between 35 and 71 m, identified in a section normal to the continental shelf offshore the Guadiana river mouth (Fig. 2 and Table 2). These geomorphologic features do not show lateral continuity. The Lower Boundary shows several erosive features of moderate depths (several milliseconds) in specific zones on the mid-to-outer shelf.

The Upper Boundary of the composite seismic unit T merges with the present-day sea floor where the most recent seismic unit (15) is not developed. The distribution of sea-floor gradients of the

Table 1
Main stratigraphic characteristics of seismic discontinuities studied in the present work, in relation with the upper and lower seismic units

	Underlying reflectors		**Overlying reflectors**	
	Inner–middle shelf	*Middle–outer shelf*	*Inner–middle shelf*	*Middle–outer shelf*
Lower boundary	Concordance	Erosional truncation	Onlap	Downlap
Boundary between T_A and T_B	Toplap		Downlap	
Boundary between T_B and T_C	*Inner–middle shelf*	*Middle–outer shelf*	Variable (downlap, onlap, concordance)	
	Concordance	Toplap/erosional truncation		
Boundary between T_C and T_D	Concordance to toplap		*Inner shelf*	*Middle shelf*
			Concordance	Downlap
	Inner shelf	*Middle–outer shelf*	Downlap is dominat, also onlap and concordance	
Upper boundary	Concordance	Toplap/erosional truncation		

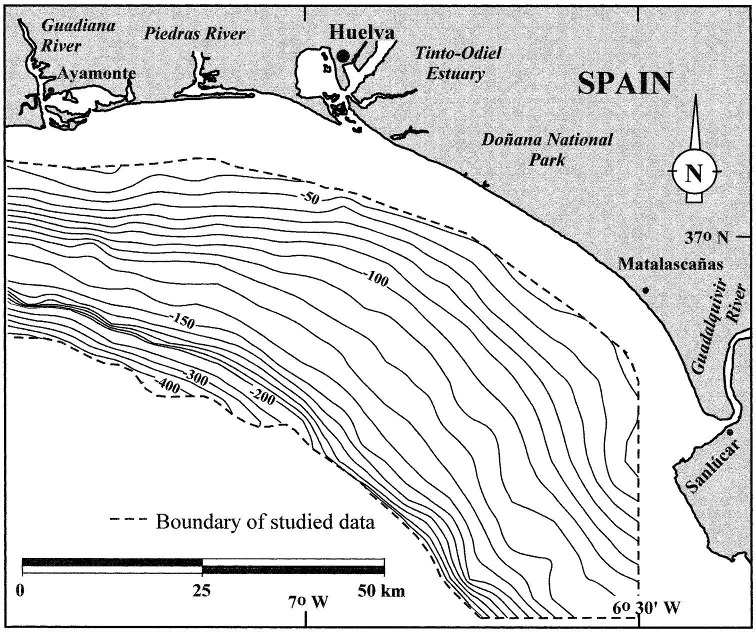

Fig. 4. Distribution map of the lower boundary (TS) of composite seismic unit T, expressed in milliseconds.

discontinuities between seismic units is fairly similar, and two main sectors can be differentiated (Fig. 5): (1) the shelf offshore the Guadiana river mouth, where three physiographic domains are distinguished. The inner domain corresponds with a morphostructural feature named the Guadiana-Tavira High (Lobo, 2000), and is characterised by average slopes <0.2°. The middle domain presents a higher slope ranging between 0.4–0.5°, whereas in the outer shelf, the average slope decreases again to values around 0.2°. (2) The shelf offshore the Doñana National Park, which displays average gradients of about 0.15° and the isobaths tend to be closer to the present-day coastline. An increase in the seafloor gradient can be seen towards the outer shelf in the shallowest discontinuities (T_C–T_D and Upper Boundary), where it may attain values >0.3°. The shelf–slope transition is determined by the −160 ms isobath (Fig. 5).

5.2. Distribution, stacking patterns and seismic facies of the seismic units

The isopach map of the composite seismic unit T shows a widespread distribution over the shelf and upper slope and an irregular distribution of depocenters (Fig. 6). Its landward termination can only be determined westwards of the Piedras River, where it is located on the inner shelf at distances of 5–15 km

Table 2
Main morphological characteristics of submarine terraces and associated seismic units identified in the study area, considering the division into two sectors: sector A (offshore Guadiana river mouth), where the terraces have been identified, and sector B (Doñana National Park shelf)

Estimated height (m) of terraces	Water depth (m) of the top surface of the terraces	Height (m) between terraces and top surfaces of associated seismic units	Estimated depth (m) of top surface of seismic units (sector A)	Estimated depth (m) of top surface of seismic units (sector B)
4.5 (terrace B)	71 (terrace B)	11–12 (above seismic unit T_B)	82–83 (seismic unit T_B)	69–70 (seismic unit T_B)
6 (terrace C)	49 (terrace C)	15 (above seismic unit T_C)	64–65 (seismic unit T_C)	45–50 (seismic unit T_C)
7.5 (terrace D)	35 (terrace D)	20 (above seismic unit T_D)	55 (seismic unit T_D)	33–35 (seismic unit T_D)

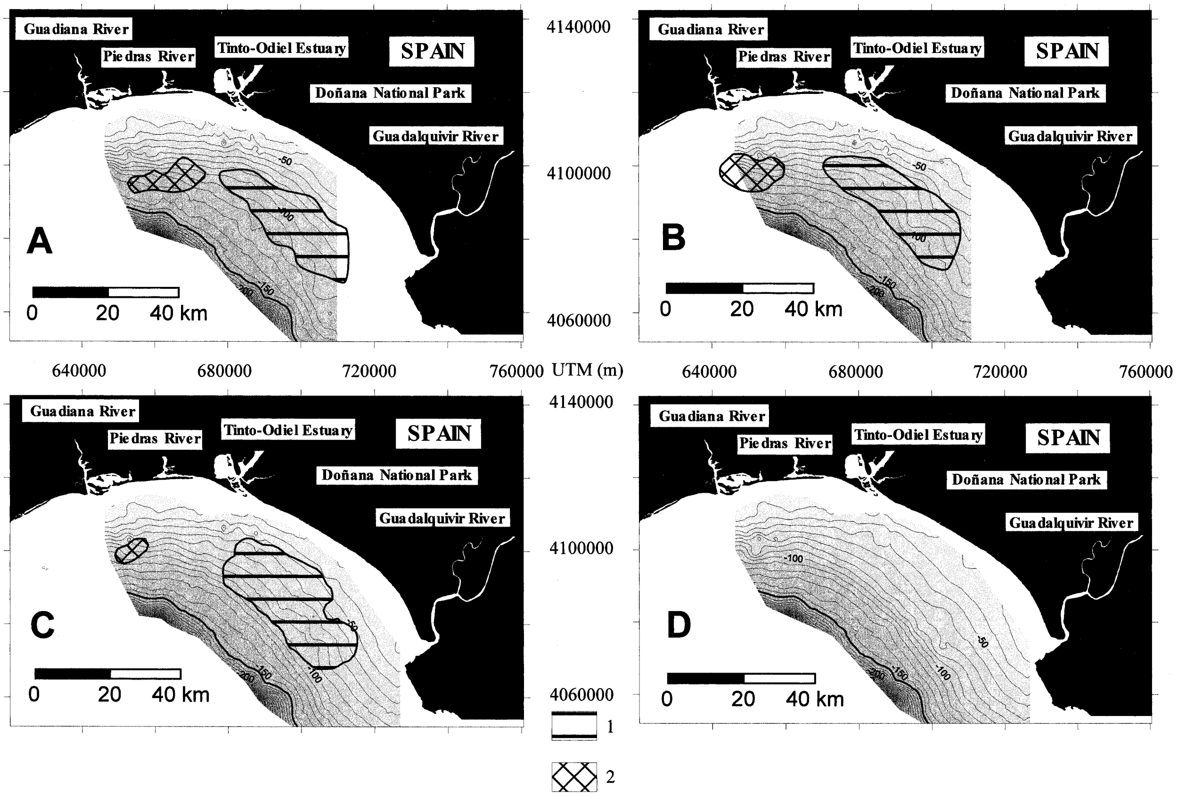

Fig. 5. Distribution map of seismic discontinuities (expressed in milliseconds) between seismic units T_A to T_D, showing the relationships between main depocenters of seismic units T_B, T_C and T_D and their lower boundaries (1 and 2 correspond to Doñana National Park and Guadiana shelf depocenters, respectively). Legend: (A) Boundary between seismic units T_A and T_B. (B) Boundary between seismic units T_B and T_C. (C) Boundary between seismic units T_C and T_D. (D) Upper boundary of seismic unit T_D.

from the coastline. The main NW–SE orientated depocenter is located on the Doñana National Park shelf eastward from the Tinto–Odiel estuary. It is 50 km long and more than 20 km wide, and is bounded by the 15 ms isopach, although maximum thickness can reach more than 35 ms (about 30 m) on the middle shelf. This depocenter extends westwards with an E–W orientation to the longitude of the Guadiana River, developing a maximum accumulation of 20 ms. Another significant depocenter (>50 ms) is located over the upper slope offshore from the Guadiana River mouth. On the other zones (inner shelf between the Guadiana River and the Tinto–Odiel estuary, and the outer shelf), sediment thickness is <10 ms (Fig. 6).

Seismic unit T_A is distributed over the outer shelf and upper slope (Figs. 3 and 7A). Its landward termination is found at an approximate water depth of 110 m. This seismic unit develops two main depocenters (Fig. 7A). The first one is a NW–SE elongated depocenter located over the outer shelf between the Guadiana River and the Tinto–Odiel estuary, where it reaches a maximum thickness of 10 ms. The second one is located at the upper slope seaward of the Guadiana River, where it is locally up to 40 ms thick. Seismic facies are characterised by a low-angle parallel-oblique configuration (<0.5°) for the outer shelf depocenter, and by a divergent configuration for the upper slope depocenter (Figs. 3 and 8A).

The distribution of the seismic units T_B, T_C and T_D shows two sectors:

1. Sector A, offshore from the Guadiana River mouth: T_B, T_C and T_D are located over the middle shelf at water depths of 55–90 m (Table 2), where they are set out in a progressively landward set

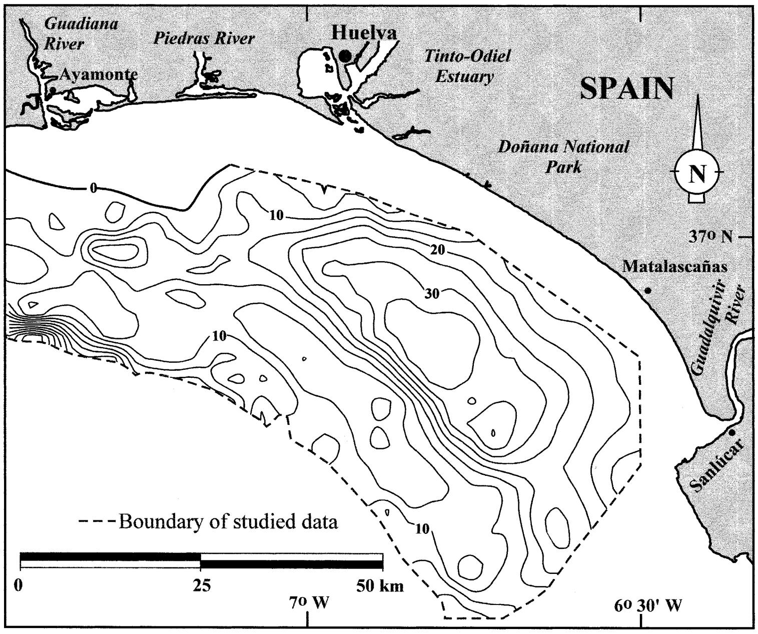

Fig. 6. Isopach map expressed in milliseconds of composite seismic unit T.

backstepping pattern (Fig. 2). Isopach maps show E–W trending depocenters continuing to the east but not to the west, except in the case of seismic unit T_B (Fig. 7B–D). Maximum thickness of depocenters in this sector range between 10 and 12 ms. Seismic unit T_B partially offlaps seismic unit T_A, presents a lensoidal external shape and locally may reach more than 8 ms. Internally, it is characterised by an oblique-tangential configuration, with downlap and toplap terminations. Dip angles decreases from 2–3° for the foresets to <1° for the bottomsets. Seismic unit T_C is a lensoidal body with a maximum thickness of 12 ms. It shows a low-angle (<1°) to sigmoid internal configuration, downlapping the lower boundary and showing a concordant relationship with the upper boundary. Seismic unit T_D is the most landward of the three seismic units, and offlaps seismic unit T_C. It displays the following seismic attributes: lensoidal external shape, thickness of 12 ms and oblique-tangential configuration, with dip angles of 1–2° in the foresets and <1° in the bottomsets (Figs. 2 and 8D).

2. Sector B, offshore from Doñana National Park: T_B, T_C and T_D share similar stratigraphic characteristics, being persistent in a shore-parallel direction and showing highly variable seismic facies in a shore-normal direction (Fig. 9). They appear from the middle shelf between the Guadiana River and the Tinto–Odiel estuary to the inner shelf, and even to the outer shelf southward of the Doñana National Park shelf (Fig. 7B–D). Their landward termination cannot be determined east of the Tinto–Odiel estuary. They are vertically arranged in an aggradational stacking pattern, and bounded by low-angle (<0.2°) erosion surfaces, whose estimated depths are summarised in Table 2. The thickness of these seismic units is moderate and varies between 6 and 20 ms. Depocenters are mainly NW–SE orientated, with secondary NE–SW axes. The seaward termination of depocenters is quite abrupt, except for the seaward termination of seismic unit T_D, which is smoother. They are characterised by sheet-like external shapes, but pinch out towards the outer shelf (Fig. 7B–D). In the landward proximal zones, they usually show mainly parallel oblique prograding configurations (1–2°) with very high reflectivity. They evolve towards middle shelf zones to subparallel and semi-transparent configurations. Locally landward progradational foresets can be observed (Fig. 8B–D). Finally, they distally

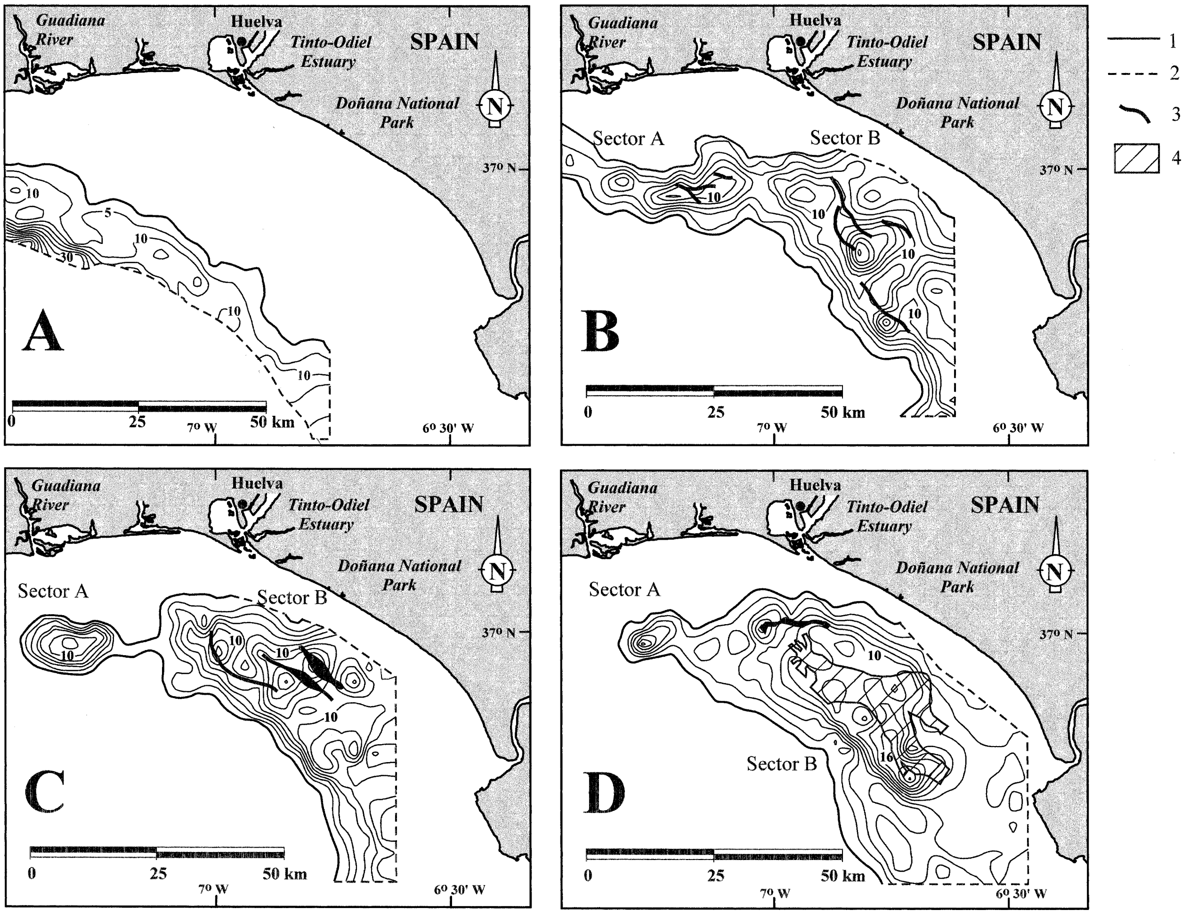

Fig. 7. Isopach maps, in milliseconds, of each seismic unit: (A) seismic unit T_A, (B) seismic unit T_B, (C) seismic unit T_C, (D) seismic unit T_D. Legend: (1) zero isopach, (2) boundary of studied data, (3) erosive channels of local distribution at the top boundary, (4) erosive channels of wider distribution.

present highly reflective parallel oblique configurations (1–2°). Here, low-angle configurations (<1°) onlapping high-reflectivity seismic facies can be observed occasionally.

The seismic units T_B, T_C and T_D are affected by mainly NW–SE orientated erosive channels with transparent infills at their upper boundaries (Fig. 7B–D). These seem to be quite wide in the middle zones (several kilometers), but are very reduced in the distal zones (hundred of meters). The depth of the channels is also variable, but normally their depth does not exceed 5 m. Most of these channels are located on the middle shelf east of the Tinto–Odiel estuary, although they can also occur to the west. They can be continued laterally over large distances, normally between 20 and 30 km.

Between sectors A and B, seismic units show an intermediate character because they increase their extension progressively from W to E over the shelf domain, and thus, they lose their backstepping pattern. In this transitional area, large paleochannels located on the inner shelf erode older Pleistocene deposits (Fig. 10). The most significant of these features shows a complex infilling, and it is located landward of composite seismic unit T. The analysis of seismic profiles has enabled us to identify three paleochannels, which show a dominant NW–SE orientation (Fig. 10). Those features are probably ancient courses

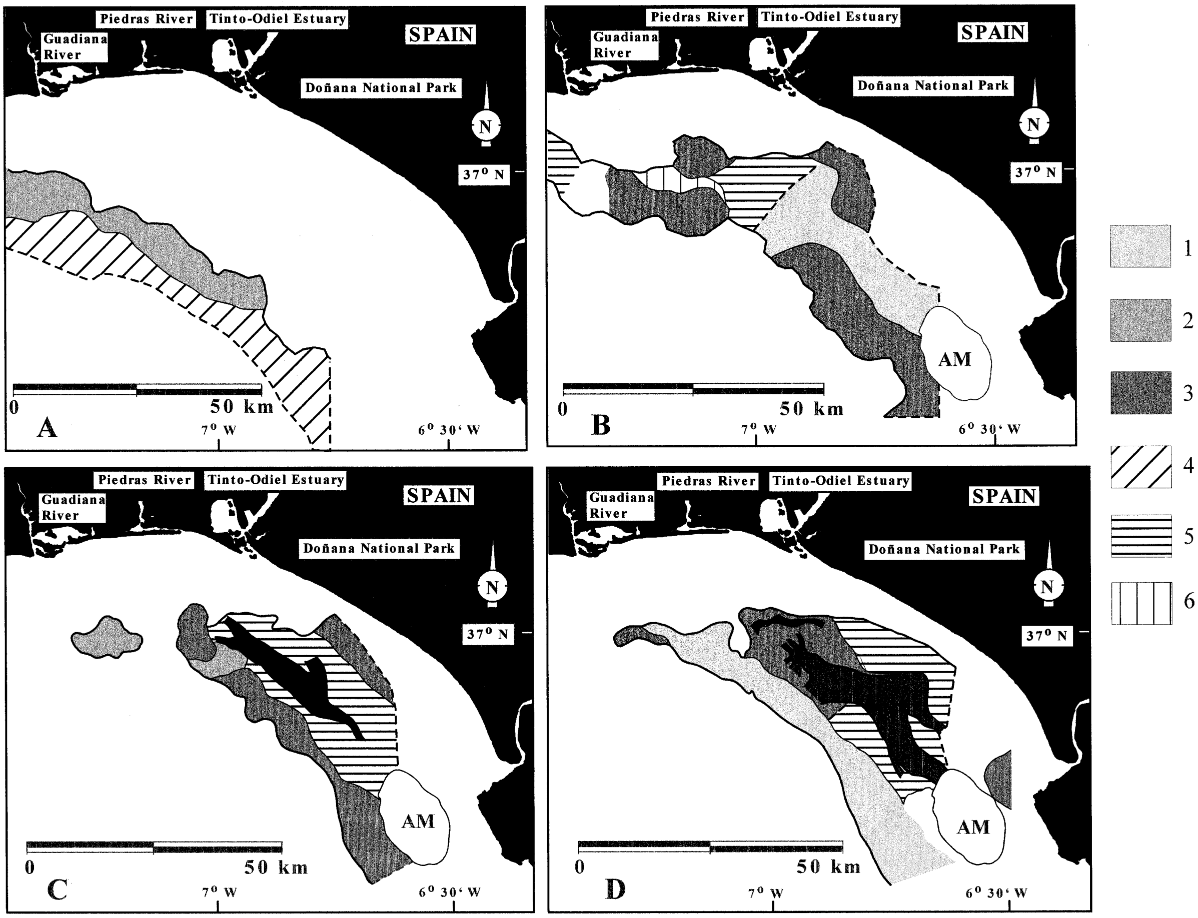

Fig. 8. Seismic facies of the seismic unit that compose the composite seismic unit T: (A) seismic unit T_A, (B) seismic unit T_B, (C) seismic unit T_C, (D) seismic unit T_D. Legend: (1) Semi-transparent configurations, (2) low-angle parallel-oblique configurations, (3) high-angle parallel-oblique configurations, usually highly reflective, (4) divergent configuration, (5) subparallel configurations, (6) landward progradations and acoustic masking (AM).

of the Guadiana River, recording a westward migration of the river as they erode younger units in that direction. From the analysis of seismic profiles alone, it is not possible to find a correlation between channel migration and the identified seismic units.

A younger unit overlying seismic units T_B, T_C and T_D has also been identified. This is the uppermost seismic unit of this continental shelf's sedimentary record, and correlates with the seismic unit 13 of Somoza et al. (1997) and Hernández-Molina et al. (2000a), which has been associated to the Highstand Systems Tract of the Late-Quaternary depositional sequence.

5.3. Relationship between seismic units and discontinuities

The seismic units T_B, T_C and T_D display two main depocenters (Fig. 5): (1) The most significant are located on the shelf offshore the Doñana National Park, showing a significant extension and with a main NW–SE trend. Those depocenters are located in a sector, where the underlying discontinuities are characterised by low-seafloor gradients, generally <0.2°, and eastward of the protuberance located offshore the Guadiana river mouth. (2) Another depocenter, although less important in thickness

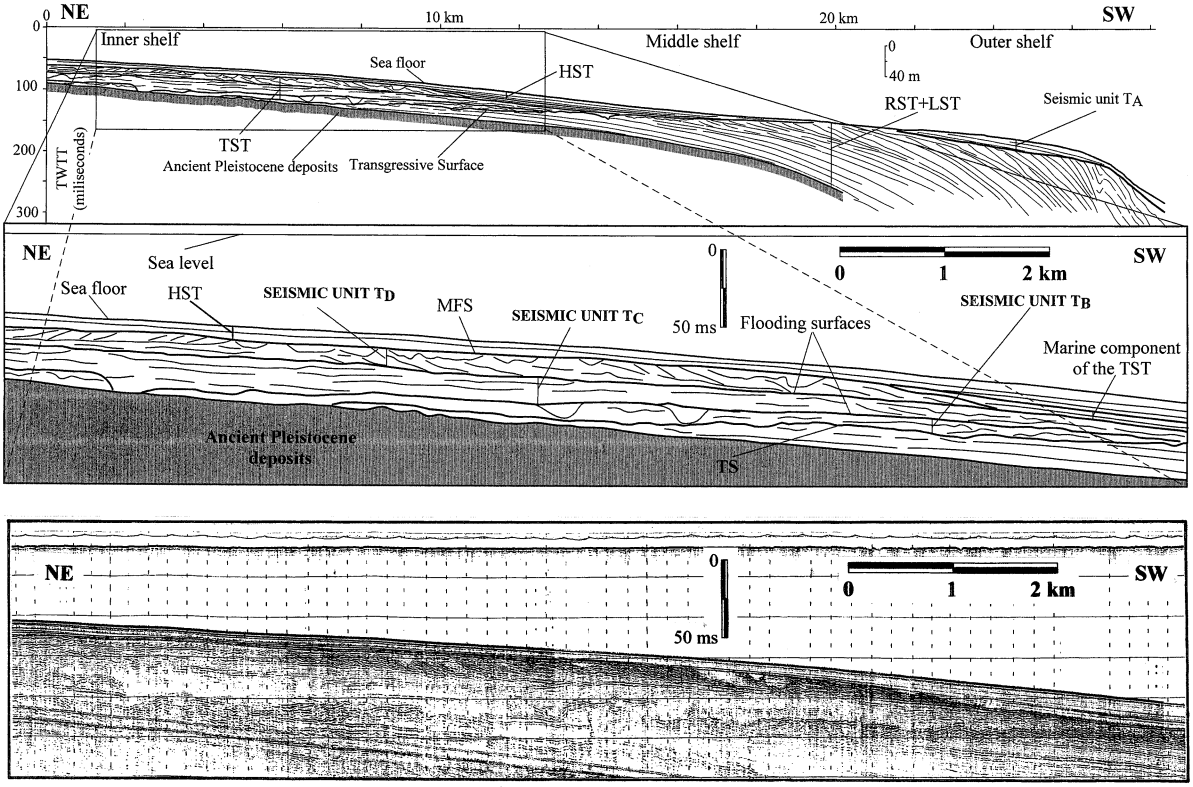

Fig. 9. Seismic profile section located offshore from Doñana National Park (see Fig. 1 for location). The three most recent seismic units (T_B to T_D) are arranged in an aggradational pattern. RST + LST : regressive system tract + lowstand system tract, TS: transgressive surface, and TWTT: two-way travel time.

and distribution, is located between the Guadiana River mouth and the Piedras River mouth, normally over the middle shelf characterised by a relatively high-seafloor gradient (0.4–0.5°). Possibly pre-existing physiographical features played a major role in determining the location of depocenters of those seismic units.

Another interesting point to consider is the difference of water depths between the three main terrace-like features identified offshore the Guadiana River mouth and the three youngest seismic units (T_B, T_C and T_D). These values range approximately between 12–20 m, but they increase progressively from the deepest to the shallowest one (Table 2). This increase in the difference of water depths is proportional to the increase in the height of the terrace-like features.

6. Discussion

The most recent Pleistocene regressive wedge is composed of two seismic units (10 and 11). Seismic unit 10 represents the forced regressive wedge systems tract associated to the sea-level fall during the transition between isotopic stages 3 and 2. Seismic unit 11 is considered as the lowstand systems tract, related to the low sea-level interval during isotopic stage 2 (Somoza et al., 1997; Hernández-Molina et al., 2000a). The composite seismic unit T is stratigraphically located above the seismic units 10 and 11, and is considered as a TST from the last depositional sequence (Late Pleistocene–Holocene). This TST was developed between the last glacial maximum (c. 18 ka BP), when sea-level dropped to −120 m, to the present highstand 6.8–6 ka BP, dated with ^{14}C on

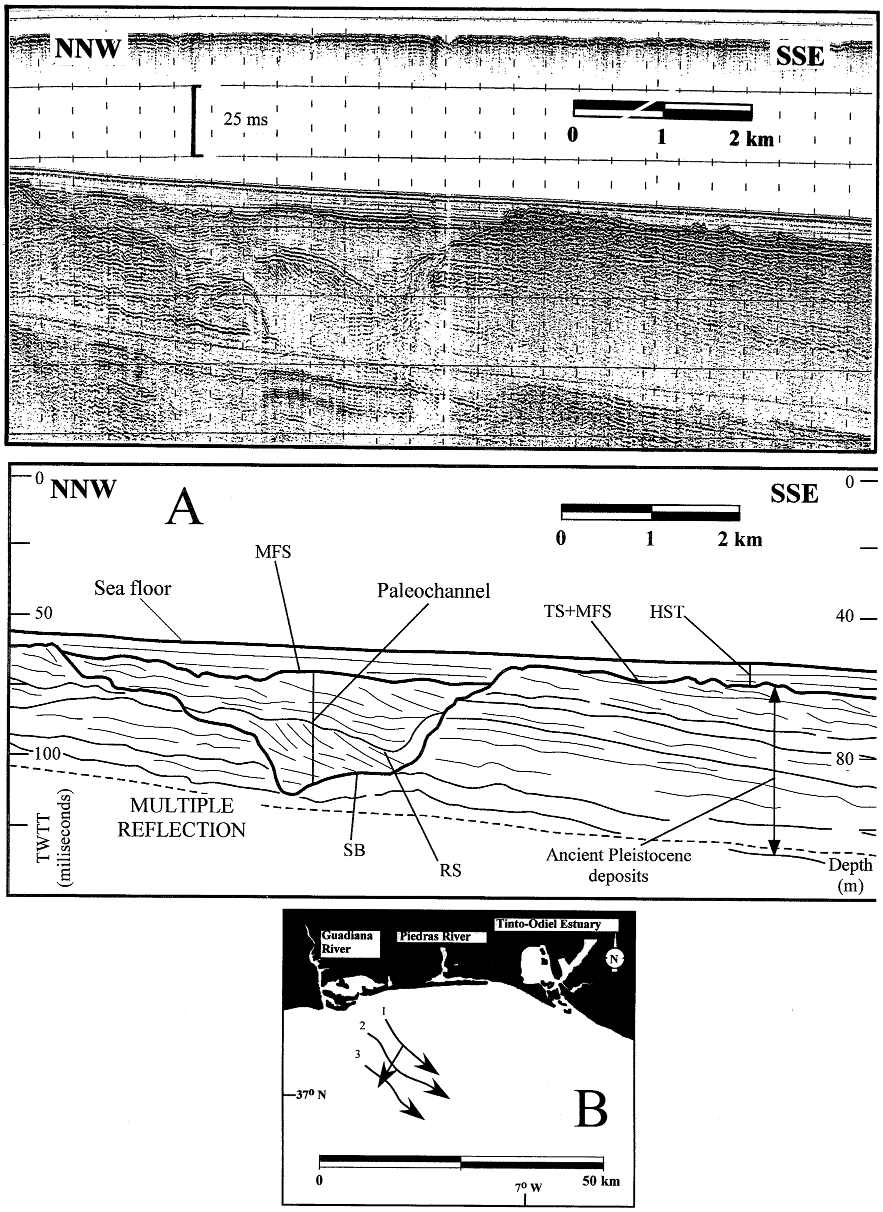

Fig. 10. Characterisation of the Guadiana palaeovalley: (A) seismic profile section located on the inner-to-middle shelf offshore from the Piedras River (see Fig. 1 for location) and where a large palaeochannel located landward of the studied seismic units can be seen. This palaeochannel is buried by highstand deposits. HST: highstand system tract, MFS: maximum flooding surface, TS: transgressive surface, SB: sequence boundary, RS: ravinement surface and TWTT: two-way travel time. (B) Lateral migration of the paleovalley of the Guadiana river, inferred from the analysis of HR seismic profiles.

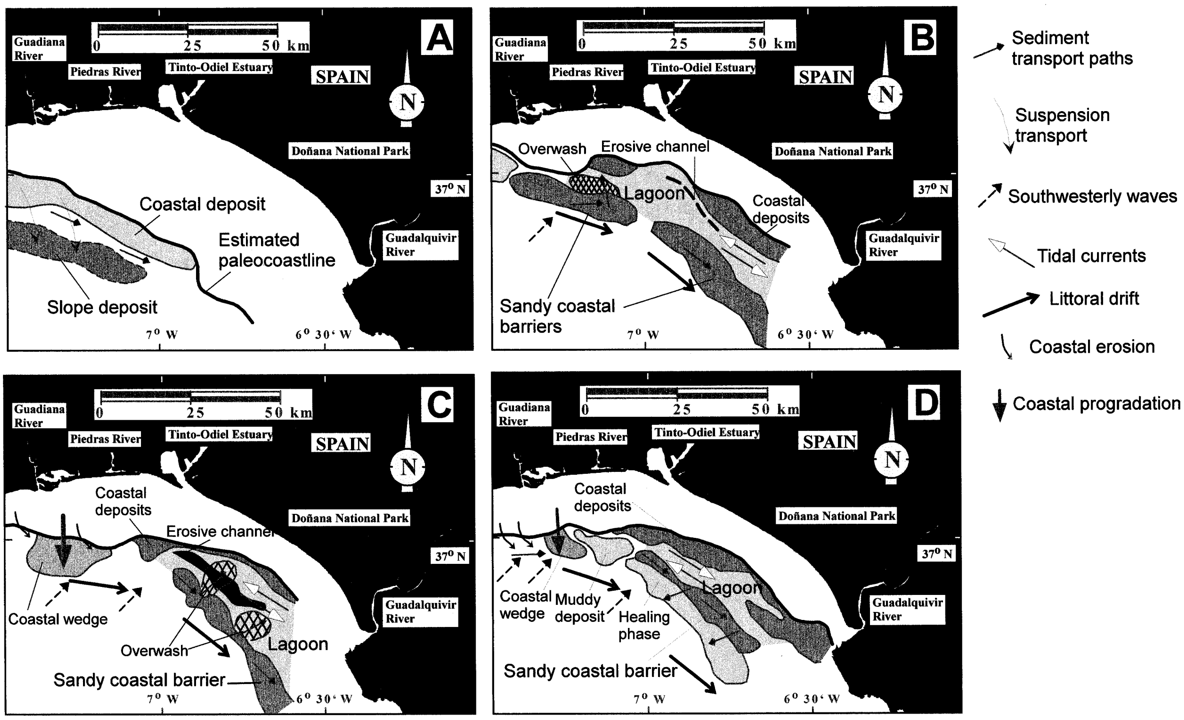

Fig. 11. Inferred depositional systems related to transgressive seismic units. Legend: (A) Seismic unit T_A; (B) Seismic unit T_B; (C) Seismic unit T_C; (D) Seismic unit T_D.

emerged coastal deposits (Zazo et al., 1994; Somoza et al., 1997; Dabrio et al., 2000; Hernández-Molina et al., 2000a; Rohling et al., 2000). The Lower Boundary of composite seismic unit T can be considered as a TS overlying the last regressive and lowstand systems tract. It was formed during the sea-level rise following the last lowstand related to isotopic stage 2 (Hernández-Molina et al., 2000a). Each individual seismic unit constitutes a parasequence of the TST, separated by successive intervals of continental shelf flooding. Those flooding events are represented by the seismic discontinuities establishing the internal boundaries between seismic units, whereas the Upper Boundary of composite seismic unit T is considered as an MFS that establishes the boundary with the highstand systems tract.

6.1. Differentiation of depositional environments and shelf partitioning

Depositional environments result from the analysis and regional distribution of seismic facies associations inside each individual seismic unit (Fig. 11). The low-angle facies of unit T_A is regarded as the distal part of a coastal depositional system on the outer shelf (Lobo et al., 1999). The better development of this deposit between the Guadiana River and the Tinto–Odiel estuary suggests the influence of the Guadiana's sediment supply and lateral redistribution by the eastward littoral drift. The slope depocenter is attributed to the accumulation of fine-grained sediments transported seaward from the coastal domain to relatively deep water (Fig. 11A). By contrast, during the formation of the three most recent transgressive deposits, the continental shelf was partitioned as it was characterised by two main depositional environments (Figs. 11B–D and 12).

In sector A (continental shelf of the Guadiana River), the toplap/erosional truncations at the upper boundary and the poor development of transgressive deposits indicate shoreface erosion processes (Evans et al., 1992; Saito, 1994), associated with a limited

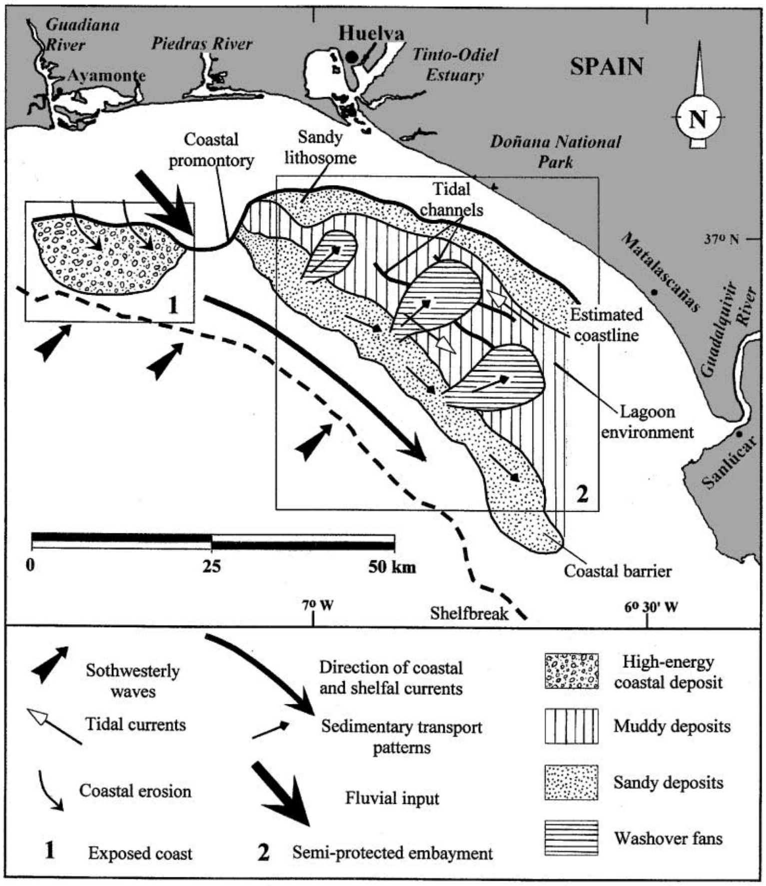

Fig. 12. Synthetic picture showing the differentiation of sedimentary environments and shelf partitioning process during the formation of seismic units T_B, T_C and T_D. Two main sedimentary environments are differentiated: (1) sector A, and (2) sector B.

sediment supply and an effective action of littoral drift, which led to an eastward transference of the Guadiana input. Those deposits are small coastal lithosomes in which the proximal facies have not been preserved (Tortora, 1996). They can be interpreted in the following ways:

(A) Prodeltaic deposits, developing at fluvial mouths during stillstands or periods of decreasing rate of sea-level rise. The location of deposits offshore from the Guadiana River mouth would support this hypothesis, but significant paleochannel systems have not been identified landward of these sedimentary bodies. In contrast, our data suggest that the Guadiana River was probably located eastward of the present-day Guadiana River mouth during most of the transgressive period (Fig. 10).

(B) Beach deposits associated with wave-cut terraces landward of these deposits. However, their potential preservation is assumed to be low during transgressive intervals as they tend to be eroded during the coastline retreat (Heward, 1981). In addition, we did not find evidence of reworked deposits on top of them.

(C) Infralittoral prograding wedges (IPW) 10–15 m thick are interpreted as storm deposits (Chiocci and Orlando, 1996; Hernández-Molina et al., 1998, 2000b; Pomar and Tropeano, in press). They are made up of coarse-grained sediments deposited in the infralittoral domain by storm-surge currents directed offshore. The generation of these wedges

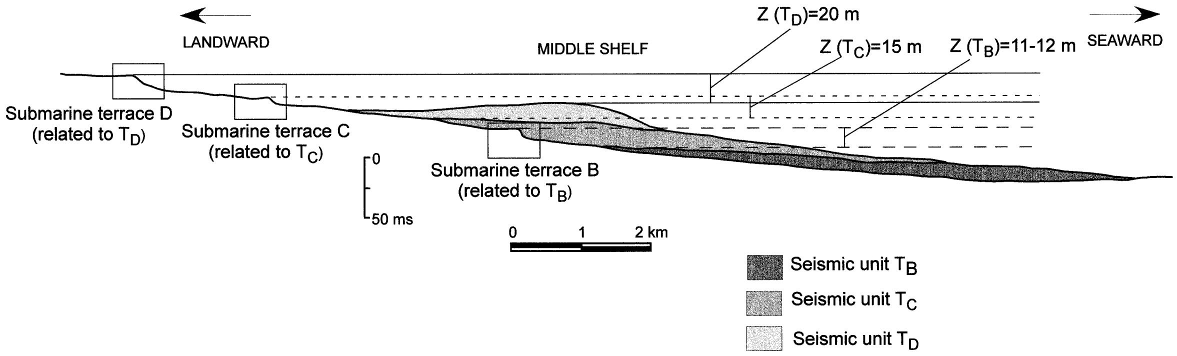

Fig. 13. Schematic profile showing the relationships between the submarine terraces and the seismic units T_B, T_C and T_D, and indicating the main morphological characteristics of submarine terraces. Note that the water depth between the terrace and the related seismic unit increases from older to younger units.

has been related to (1) Last glacial maximum lowstand of sea-level, when the littoral domain was characterised by very high-seafloor gradients because the shoreline was located at the shelf-break (Chiocci and Orlando, 1996) and (2) Late Holocene highstand sea-level, characterised in inner-shelf settings by low-fluvial input (Hernández-Molina et al., 1998, 2000b).

We propose that this sector's transgressive lithosomes represent high-energy deposits for the following reasons:

1. The deposits developed in an exposed sector in relation to the more protected eastward environment. The relatively steep seafloor (0.4–0.5°) would have favoured the piling of water when storm events occurred, and the deposition of storm-surge deposits near the coast.
2. The presence of concave foresets characteristic of oblique-tangential configurations has been used as an indicator of dominance of deposition during storm cycles (Browne, 1994).
3. The difference in water depth (10–20 m) between wave-cut terraces and transgressive deposits would give a rough estimate of the storm-wave base level in this region (Fig. 13). If they formed below this level, their potential preservation would also be high because they would not be significantly affected by reworking processes during the subsequent sea-level rise. Terrace height increases from the oldest one (related to seismic unit T_B) to the youngest one (related to seismic unit T_D), and concurrently an increase in water depth between the terraces and the related seismic units is evidenced (Fig. 13, Table 2). This relationship suggests that the effect of storms has increased over time, promoting the development of larger wave-cut terraces and the deepening of the wave base level until approaching the present-day base level. This effect has been associated to progressive increase of wave energy and oceanographic circulation due to shelf widening during the transgression (Trincardi et al., 1994).

However, we believe that core data and oceanographic information about waves, tides and currents are necessary to confirm this assumption, and at present, we only can conclude that they are relatively high-energy deposits formed under conditions of moderate-to-reduced sediment supply (Fig. 12).

In sector B (continental shelf of the Doñana National Park), a barrier island-lagoon sedimentary environment developed under conditions of moderate oceanographic regime and relatively high-sediment supply (Fig. 12), resembling the present-day situation in the semi-protected environments of the Gulf of Cadiz coast (Morales, 1997; Borrego et al., 1999). Proximal highly reflective seismic facies represents sandy coastal plain deposits, evolving over the middle shelf to lagoonal facies and tidal flats, indicative of a semi-protected embayment where deposition of fine-grained sediments took place, as evidenced by semi-transparent and aggrading configurations (Ashley et

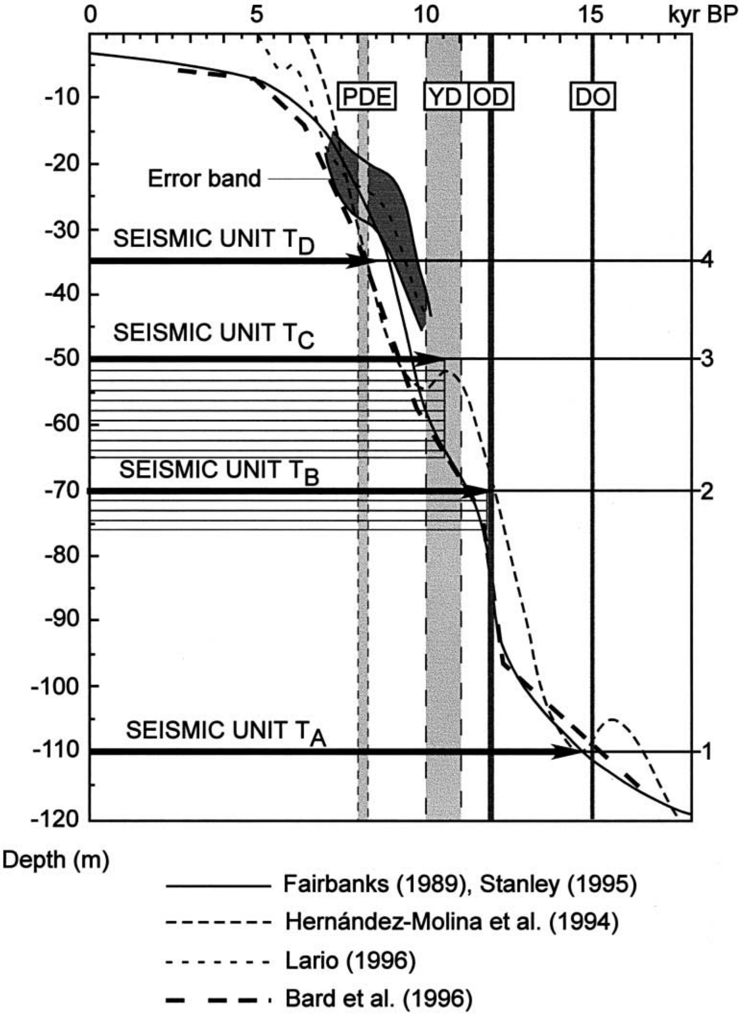

Fig. 14. Proposed chronostratigraphic framework of transgressive deposits of the Gulf of Cadiz continental shelf, based on the correlation between seismic units: (A) Correlation between seismic units and climatic changes and several post-glacial sea-level curves. DO: Deglacial Onset; OD: Older Dryas; YD: Younger Dryas; PDE: Post-Dryas Event. The arrows (1–4) indicate the most possible sea-level stabilisations, deduced from estimated depths of seismic unit T_A (1) and from estimated depths of submarine terraces for seismic units T_B, T_C and T_D (2–4). In the case of seismic units T_B and T_C, the striped pattern indicates the range of depth between the submarine terrace and associated seismic unit.

al., 1991; Tortora, 1996; Lee and Yoon, 1997). The highly reflective prograding facies on the mid-to-outer shelf are attributable to sandy barrier shoreface environments protecting the lagoon environment (Ashley et al., 1991). These NW–SE oriented sandy barriers were probably formed in relation with the lateral transport driven by littoral drift. Landward-dipping foresets related to NE–SE trending depocenters are interpreted as washover fans or flood deltas (Fig. 12). The reduced dimensions and general parallel orientation of erosive channels in relation to the coastline lead us to interpret them as tidal channels (Ashley et al., 1991; Browne, 1994).

The resulting architecture of transgressive deposits and internal surfaces in the study area is related to a mechanism of in-place drowning through the formation of the deposits, characterised by a low effectiveness of reworking processes during sea-level rises and by a high-sediment supply during sea-level stabilisation (Tortora, 1996). Such a mechanism was probably at work in sector B, where the good preservation of high-reflectivity prograding facies and back-barrier deposits implies that shoreface erosion should have been limited to the upper parts of beach and barrier systems (Browne, 1994; Saito, 1994; Tortora, 1996). Also, the reduced gradients of TSs probably conditioned sudden coastline translations during each flooding interval. Those stratigraphic surfaces are considered to be mixed surfaces because they are flooding surfaces as well as ravinement surfaces (Trincardi et al., 1994). Marine deposits represented by the low-angle seismic facies of unit T_D on the mid-to-outer shelf seem to have been generated only during the last period of accelerated sea-level rise (Fig. 8D). This last sea-level rise led to the flooding of the most recent transgressive deposit and to the formation of the MFS, which is represented by the Upper Boundary. In sector A, interlittoral (foreshore and shoreface) deposits would have developed poorly, and therefore, the available material for reworking was very low.

6.2. Proposed chronostratigraphic framework

Due to the absence of age control, a correlation between the transgressive seismic units and associated coastal features and the post-glacial climatic/sea-level changes was attempted (Fig. 14). The estimated depths of submarine terraces associated to seismic units in sector A were tentatively correlated with known sea-level positions, a useful criterium well documented in several shelves and used by a number of authors (Dias, 1987; Suter et al., 1987; Hernández-Molina et al., 1994; Savoye and Piper, 1993; Chiocci and Orlando, 1996). These submarine terraces in sector A show a good correlation with the estimated depths of the top surfaces of seismic units in the inner shelf of sector B (See Table 2), and therefore, they can be considered as representatives for the entire study area. This assumption implies that coastal terraces should be considered more reliable indicators of ancient shorelines than their associated deposits. As a consequence, numerous sea-level positions should be reinterpreted as they were inferred from coastal deposits that probably were generated below storm wave base-level (Hernández-Molina et al., 2000b).

The most significant post-glacial climatic events and several global and regional sea-level curves have been considered to establish the correlation. Global curves were dated by ^{14}C and Th/U on emerged corals (Fairbanks, 1989; Stanley, 1995; Bard et al., 1996). Regional curves are based on the correlation of sedimentary bodies from the Spanish shelves with well-known sea-level positions (Hernández-Molina et al., 1994), or based on the sequence stratigraphy of Gulf of Cádiz estuaries (Lario, 1996).

Under the absence of significant geomorphologic features, the landward termination of seismic unit T_A has been estimated as its associated coastline (Lobo et al., 1999). The formation of this seismic unit is related with a period of reduced sea-level rise or even with a small sea-level fall according to Hernández-Molina et al. (1994) (Fig. 14). Depositional bodies and/or topographic features have been identified on nearby shelves at equivalent water depths of 100–110 m, such as the Portuguese shelf (Dias, 1987; Rodrigues and Dias, 1989; Roque, 1998) and the Alboran Sea shelf (Hernández-Molina et al., 1994), and were reported also on other shelves (Sager et al., 1992; Gensous and Tesson, 1998). They have been related with a stillstand/slow sea-level rise that occurred during the Deglacial Onset. For this reason, we presume that the formation of seismic unit T_A was related with a climatic change during the Deglacial Onset that probably involved changes in the rate of glacio-eustatic sea-level rise (Fig. 14).

For seismic units T_B and T_C, we have represented the water depth of their associated terraces and the ranges in water depth between the terraces and the seismic units. The correlation shows that those ranges of water depths are bounded by the curve of Hernández-Molina et al. (1994) and the global sea-level curves, suggesting that the real curve is probably located between them. That sea-level curve was probably characterised by reduced sea-level rises, during which the formation of those deposits took place moderately. Those sea-level rises culminated with sea-level stillstands leading to the formation of the terraces and the bulk of seismic units (Fig. 14).

Seismic unit T_B and its associated terrace correlate with the sea-level position at the time of the Older Dryas event. The existence of submarine terraces at water depths of 65–70 m on the nearby Algarvian shelf (Roque, 1998) would indicate the regional character of this episode. However, this correlation remains hypothetical because the Older Dryas period has been evidenced in continental Europe, but not on continental margins. Its influence on the sea-level curve has not been demonstrated, although that event has recently been recorded in the Alboran Sea (Nebout et al., 1999).

Seismic unit T_C correlates with the reduced sea-level rise evidenced in the global curves and the stillstand/sea-level fall proposed by Hernández-Molina et al. (1994), which coincides with the Younger Dryas Event (Davies et al., 1992). Coastal deposits or shorelines related to this cold event has also been evidenced in nearby locations, such as the Portuguese shelf (Dias, 1987; Rodrigues and Dias, 1989) and other sectors of the Spanish shelf (Hernández-Molina et al., 1994), as well as in other more distant shelf settings at water depths between 40 and 55 m (Carter et al., 1986; Correggiari et al., 1996; Gensous and Tesson, 1998; Roque, 1998). Due to its regional persistence, this record is considered as one of greater significance than other recognised post-glacial sea-level markers (Carter et al., 1986).

Another alternative interpretation would relate the formation of both seismic units T_B and T_C to the Younger Dryas Event in relation to inflection points of the sea-level curve, the first one at the beginning of the sea-level rise reduction and the second one at the end. Thus, some works relate reef-like mounds to a slow sea-level rise during the Younger Dryas Event at water depths of 74–82 m (Sager et al., 1992), which are similar to the estimated depth for the paleoshoreline of seismic unit T_B. Besides, in the adjacent sectors of the Gulf of Cádiz continental shelf, the bulk of submarine terraces are located between water depths of 55–80 m (Lobo, 1995; Roque, 1998), corresponding to the estimated paleo-shorelines for seismic units T_B and T_C. Those data support the idea that the formation of these seismic units would be linked to a period of reduced sea-level rise, probably punctuated by small-scale sea-level stillstands.

The water depth of the submarine terrace associated to seismic unit T_D coincides with the curves of Hernández-Molina et al. (1994) and Bard et al. (1996) at the timing of the cold event centred at 8.2 ka BP (Fig. 14). The reduction of sea-level rise associated to this event is evidenced in the curve of Lario (1996), but at lower water depths. However, there is a significant rate of uncertainty with this curve because of the existence of different precision and calibrations of the radiocarbon data, and also a time lag in the response of estuarine systems to new dynamic conditions (Lario, 1996). On the nearby Spanish shelf, a significant level of submarine terraces at about 30 m of water depth also would be related with this event (Lobo, 1995).

One of the main indicators of the existence of periods of stillstand or reduced sea-level rise during the post-glacial sea-level rise is the identification of deposits associated to sea-level markers (Carter et al., 1986; Larcombe and Carter, 1998). Our data suggest that the formation of seismic units during the post-glacial transgressive interval was related to climatic changes that determined periods of reduced sea-level rise. However, during periods of accelerated sea-level rise, flooding and/or ravinement surfaces were preferentially developed and the lateral migration of main courses was probably favoured. Consequently, the stratigraphic record of the post-glacial transgression on the Gulf of Cadiz shelf represents the sedimentary response of this continental shelf to sudden and short-lived climatic events, which imposed its signature on the sea-level curve. Those events may not be recorded on post-glacial sea-level curves obtained from coastal deposits because they probably do not register small periods of reduced sea-level rise/stillstands.

6.3. The role of sediment supply

The significance of sediment supply changes to the studied shelf is difficult to evaluate, considering the scarcity of data about river-derived sediment yields and marine sediment transport. However, we have tried to make an approach to the influence of sediment supply changes and its relationship with climatic and induced sea-level changes, basing our considerations on the following points:

We only consider the contributions of the Guadiana River because it is the most important river in terms of sediment supply to the studied area. These data are estimates of sediment supply from the water discharge data through a series of theoretic calculations, and give an annual amount of about

10.2×10^5 m^3 for the last 44 years, including the suspended material and bedload, and considering the influence of dam construction. The value is probably too low because it is based on monthly averaged discharges, and peak values of daily values are not considered (Morales, 1993).

There is no data on sedimentary input from marine sources during the post-glacial sea-level-rise, and therefore, we consider the present-day data of sediment transport by littoral drift as an approximation. Also, we may speculate that most of the sedimentary input was accumulated on the study area due to the generation of a semi-protected environment.

We have calculated the volumes of the seismic units in order to obtain a rough estimate of the total amount of sediment accumulated during the post-glacial sea-level rise on the studied shelf: seismic unit T_A (14.5 km^3), seismic unit T_B (8.7 km^3), seismic unit T_C (8.6 km^3), and seismic unit T_D (8.4 km^3). The value obtained for seismic unit T_A is unreliable because the slope depocenter is not well covered by the seismic grid. However, for the three more recent units, the calculations can be considered as fairly good estimations of the original volumes as they are preserved in a significant way. We also estimate that those deposits are mainly fluvial because the significance of deposits of different origins (as storm-related deposits in sector A) is small volumetrically.

The great sameness of the volumes of the three most recent seismic units, all of them about 8.5 km^3, suggest that their formation would be linked to climatically induced processes of similar magnitude. Annual sediment supply to the shelf is estimated at 13.19×10^5 m^3, considering the present-day Guadiana and littoral drift inputs. Consequently, about 6.5 ka would be necessary for the generation of each transgressive parasequence if we assume the present-day value as an approximation. This result is incompatible with the estimated durations of the transgressive cooling events (the longest one was the Younger Dryas, which lasted approximately 1000 years). This discrepancy suggests that, apart from the fact that the present-day data are considered underestimations (Morales, 1993), the periods of reduced sea-level rises may have been characterised by higher rates of terrigenous supply to the shelf than the recent and present-day situation, or else the duration of those periods is underestimated. The role of sediment supply seems to be of special significance because the periods of slow sea-level rise during the post-glacial transgression linked to climatic changes probably were coupled with increased sediment flux to the shelf (Correggiari et al., 1996; Trincardi et al., 1996a; Larcombe and Carter, 1998). Particularly in Europe, relatively cold conditions during the last glacial–interglacial transition, topically during the Younger Dryas Event but also other short-lived events, would have modified vegetation patterns and erosion processes (Trincardi et al., 1996a, b; Lowe and Walker, 1997). Lower temperatures increased aridity, reduced the vegetation cover (Roberts, 1998), and favoured its replacement by taxa indicative of disturbed and moving soils (Lowe and Walker, 1997). The protection offered to the soil against erosion was affected, increasing the erosional activity (Walker, 1995). As a result, the amount of sediment washing into the streams must have been altered (Williams et al., 1993) because the increase in erosion rates would have enhanced sediment flux. Eventually, the increase in river discharge rates in relation to melt-water times and the adjustment of river equilibrium profiles would result in a shedding increase in bedload to the shelf (Trincardi et al., 1996a, b).

6.4. Physiographic and tectonic controls

The relatively homogeneous character of the first transgressive deposit suggests that during its generation, the paleogeographic situation was quite similar in the study area because the low-shelf slope of the outer shelf conditioned a similar shoreline migration. The process of differentiation of sedimentary environments during the formation of the three later transgressive deposits can be related to the influence of the shelf geomorphology. Thus, the higher slope of sector A's middle shelf conditioned a slower coastline migration and a greater erosive capability in the coastal domain (Tortora, 1996). During the generation of each transgressive unit, a coastal promontory exposed to the action of waves and storm events would have formed in sector A, and the Guadiana River would have been displaced eastward (Fig. 12). Under these conditions, only small coastal deposits would have been developed in this sector. In contrast, in sector B a wide, shallow shelf developed prior to the formation of the deposits

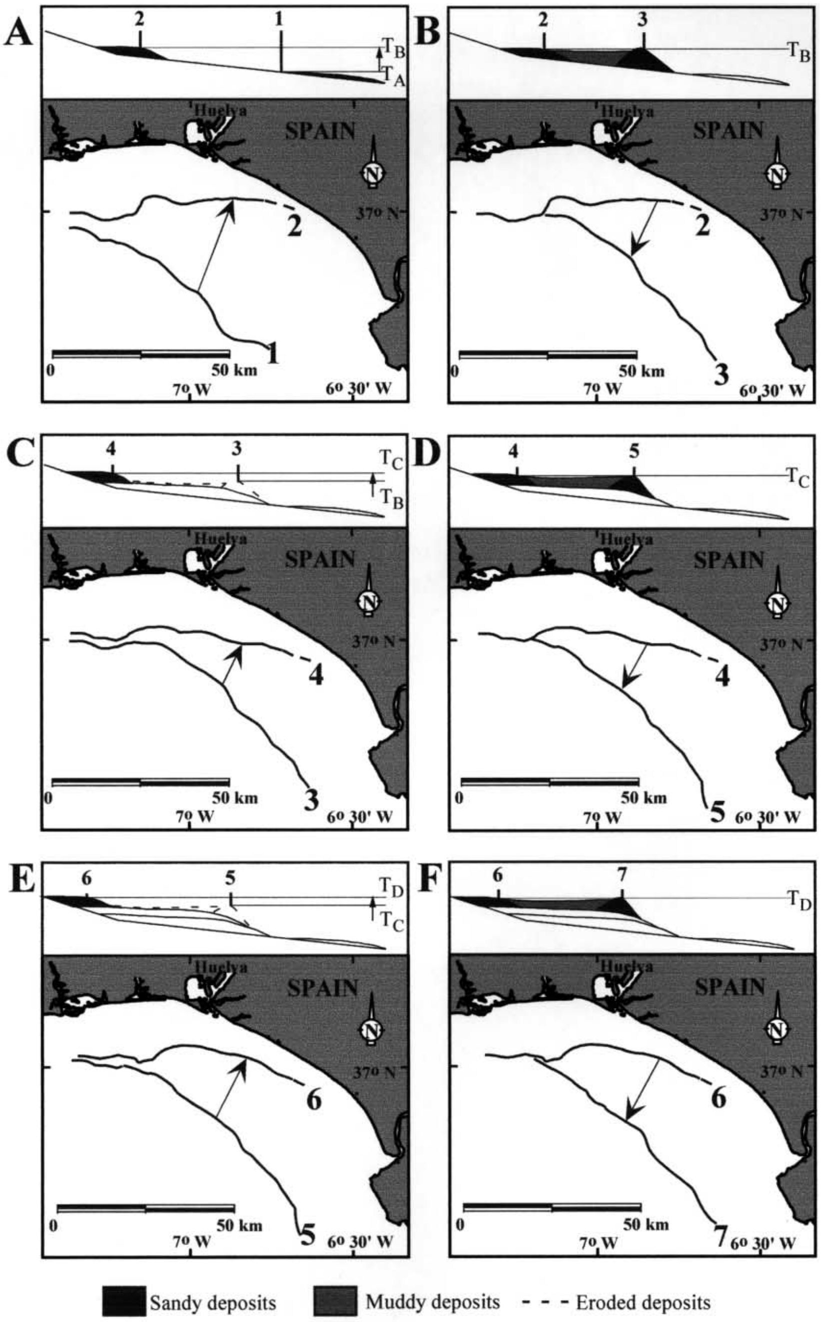

Fig. 15. Estimated coastline changes during the post-glacial transgression in the study area. Each stillstand or period of reduced sea-level rise is characterised by the name of the transgressive deposit formed during that period. (A) Transgression between T_A and T_B, (B) regression during T_B, (C) transgression between T_B and T_C, (D) regression during T_C, (E) transgression between T_C and T_D, and (F) regression during T_D. The vertical schemes mainly refer to what occurred in sector B because the coastline variation history in sector A is presumed to be simpler.

because the lower sea-floor gradient conditioned larger coastline translations and consequently rapid shelf inundation. The shallow depth permitted the relatively rapid progradation of the coastal barriers, which in conjunction with the promontory in sector A protected the coastal realm from the erosive action of marine agents, creating semi-enclosed embayments. This physiographic configuration of the shelf was determined by its recent tectonic evolution (Lobo, 2000). Sector A can be considered as a relatively stable sector, from which significant progradation took place mainly during falling and low sea-levels; in contrast, sector B is considered as a subsiding area in relation to sector A. Therefore, the existence of this process of differential subsidence on this shelf has controlled the alternation of promontories and semi-protected environments.

The slope of the flooded shelf also controlled the pattern of coastline migration during the general sea-level rise. Thus, in sector A, we can discern a sequence of progressive shoreline landward migration (Fig. 15). However, in sector B, the transgressions during each interval of accelerated sea-level rise were more significant than in sector A due to the lower shelf gradient. Besides, during the three later periods of reduced sea-level rise and stillstand (T_B, T_C and T_D), the coastline appears to have been stationary in sector A, whereas in sector B, it seems to have undergone regression. This is attributable to the existence of a relatively high-sediment supply over a shallow shelf, which favoured the rapid seaward coastline migration. Surprisingly, the landward and seaward positions reached by the coastlines in sector B are fairly similar during the T_B, T_C and T_D stillstands (Fig. 15). To explain this evidence, it is necessary to consider an increase in the sea-floor gradient landward of the inner shelf, resulting in a similar landward position of the coastline, and also a similar duration for each period.

7. Conclusions

A composite seismic unit (T) determined on the continental shelf of the Gulf of Cadiz has been attributed to the TST developed during the post-glacial transgression. It comprises four seismic units (T_A to T_D) that are considered parasequences bounded by flooding surfaces and capped by a MFS. Two well-defined depositional environments have been generated on this shelf during the post-glacial transgression: (A) The continental shelf offshore from the Guadiana River (sector A) is characterised by the development of small high-energy coastal deposits; (B) The continental shelf offshore from Doñana National Park (sector B) is characterised by large barrier island-lagoons environments. The poor development of the marine component within these transgressive deposits is attributable to a low effectiveness of reworking processes. The resultant transgressive architecture has been determined by a number of controlling factors:

1. The formation of transgressive deposits and associated coastal features was favoured during short-lived cool episodes, such as the Younger Dryas Event. Probably, other events of similar characteristics although of less amplitude would have led to the generation of significant sedimentary bodies due to their influence on the rate of sea-level rise. Therefore, the transgressive sedimentary deposits of this continental shelf would represent the record of short-term climatic events that influenced the pattern of the post-glacial sea-level rise. In relation with this point, it is worth mentioning that the determination of former sea-level positions from paleo-water depths of coastal bodies should be made with caution, especially if they are IPW because probably most of them were generated well below mean sea-level. The assignment of ancient sea-level positions to easily recognisable coastal features as wave-cut terraces seems to be more reliable.
2. The short-lived climatic events seem to have influenced the rates of sediment supply to the continental shelf. As a result, transgressive deposits results from a combination of reduced rates of sea-level rise and increased sediment yields to the shelf, probably higher than the present-day situation. However, in order to adequately evaluate the role of the sediment supply factor, it seems necessary to obtain more reliable estimates on sediment supply from the rivers, and also to assess the significance of dispersal processes in coastal and shelf systems.
3. The previous paleogeography and paleophysiography of the seafloor controlled the shelf partitioning process and the landward coastline migration. In

sector A, the relatively high slope of the middle shelf conditioned the formation of an exposed coastal promontory. In sector B, the low-gradient lower surface favoured the development of a wide shallow shelf with a moderate hydrodynamic regime. There is stratigraphic evidence of the occurrence of regressive events during the post-glacial sea-level rise.

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