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Holocene sedimentary dynamics on the Iberian continental shelf of the Gulf of Cádiz (SW Spain)

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Abstract—The Holocene evolution of the Iberian continental shelf of the Gulf of Cádiz (SW Spain) has been elucidated from a study of the granulometric facies of surficial sediments and high-resolution seismic profiles. The relationship between different facies depends on eustatic events and oceanographic conditions associated with the North Atlantic Surficial Water (NASW) on the shelf. A Transgressive Systems Tract (TST) developed as a response to a transgression (14,000–6500 yr) and deposited a transgressive sand bed on the transgressive (or ravinement) surface. A backstepping para-sequence related to a brief stillstand period has produced an onlapping shelf-transgressive erosion surface. The change in eustatic regime from transgressive to highstand in the last 6500 years has resulted in the formation of a sedimentary wedge of a Highstand Systems Tract (HST), extending from the mouth of the Guadalquivir river towards the southeast because of NASW circulation. These prodeltaic mud deposits are prograding over the older transgressive sand. The present surficial sediment distribution has been influenced greatly, therefore, by the last eustatic rise of sea level and has been divided into three main areas: (a) the littoral area; (b) northern prodeltaic mud; and (c) a southern area of relict and palimpsest sand and muddy sand, generated in a high-energy littoral environment of the Late Pleistocene–Holocene shoreline transgression. Copyright © 1996 Elsevier Science Ltd

1. INTRODUCTION

The sedimentary dynamics of continental shelves has been influenced by the rise in sea level in the last eustatic hemicycle (18,000–6000 BP) during the Late Pleistocene–Holocene times, resulting from climatic warming and the melting of the ice sheets (Ruddiman and McIntyre, 1981; Aloïsi, 1986; Pirazzoli, 1992), as well as by the progressive establishment of a dynamic current systems on the shelf, synchronous with this rise (Abrantes, 1988; Caralp, 1992). The stabilization of sea level during the last 6500 yr has led to the formation of a sedimentary wedge on the shelf over the deposits of the previous transgressive sedimentary environments and the establishment of the present coastal environment (Swift *et al.*, 1991). In this way, the Late Pleistocene–Holocene sedimentary sequence may be related to the backstepping–forestepping of the sedimentary environment generated simultaneously by the rise and latter stabilization of the wave base level.

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However, the horizontal facies distribution is dependent on the current dynamics variability during each time interval.

In the Gulf of Cádiz, the sediment dynamics on the continental slope and continental rise have been studied in relation to processes generated by the interaction of the Mediterranean Outflow Water with the slope and rise topography (Heezen and Johnson, 1969; Kenyon and Belderson, 1973; Madelain, 1970; Melières, 1974; Nelson *et al.*, 1993) and the general dynamics of the suspended material (Palanques *et al.*, 1987). However, only a few studies dealt with the sedimentary aspects of the southern continental shelf of Gulf of Cádiz (Segado *et al.*, 1984; Gutierrez-Mas, 1992).

This paper deals with the study of the sediments of the continental shelf of the Gulf of Cádiz between the mouth of the Guadalquivir river (36°50′N) and Cape of Trafalgar (36°10′N) (SW Spain; Fig. 1). An integrated model of the evolution of the recent sediment dynamics is proposed, based on granulometric and mineralogic analysis of surficial samples of the sea floor (gravity cores) with an additional study of several high-resolution seismic profiles (3.5 kHz Uniboom).

2. GEOLOGIC SETTING AND PHYSIOGRAPHIC ASPECTS

The continental margin of the Gulf of Cádiz is a part of the Iberian Peninsula, located at the western region of the Alpine ranges of the Western Mediterranean (Betic-Rif ranges) on the intersection of the African and Euro-Asiatic plates. These tectonic terrains extend onto the shelf (Burke and Drake, 1974; Baldy *et al.*, 1977). The continental margin is formed on the front of the Betic–Rif olistostrome and the submarine prolongation of the Guadalquivir and the Tharb Neogene depressions. The sediments of the continental margin represent depositional sequences from the Miocene to the Quaternary (Roberts, 1970; Baldy *et al.*, 1977; Malod, 1982; Maldonado and Nelson, 1988; Maldonado *et al.*, 1989).

The continental margin of the Gulf of Cádiz shows a complex physiography as a result of the compressive tectonics during the Cenozoic and the subsequent depositional processes. In contrast to the remainder of the Atlantic margins, the NW–SE orientation of the margin has fault troughs on the shelf and diapiric ridges that are oblique to this trend. Both the NW–SE fault system and its accompanying conjugate system create a ridge and trough structural framework and morphology (Roberts, 1970; Benkehlil, 1976; Baldy *et al.*, 1977; Malod and Mougenot, 1979).

Between the mouth of the Guadalquivir river and Cape Trafalgar, the coast has a linear trend with a general NNW–SSE orientation and some inlets with a E–W direction [Fig. 1(B) and (C)]. On the northern seaboard, low coasts prevail with extensive beaches and some stretches of small cliffs alternating with estuaries and marine inlets. South of Cape Trafalgar, the Betic mountain range produces a cliffed coast and a narrow shelf. In the zone between 15 and 35–40 m depth, sub-horizontal outcrops of Pliocene–Quaternary deposits of "consolidated coquina" are frequent, in which reworked littoral abrasive platforms and scarps of 5–6 m in height have been cut parallel to the present coastline (Acosta, 1984; Gutierrez-Mas, 1992). The shelf has a gentle slope and a slight inclination towards the west, with an average width of 50 km and a shelf edge near 100 m depth [Fig. 1(C)]. The slope shows a ridge and valley morphology with an average gradient less than most slopes of the Atlantic margin; it is dissected by several submarine canyons perpendicular to the main direction of the continental margin shelf (Robert, 1970; Nelson *et al.*,

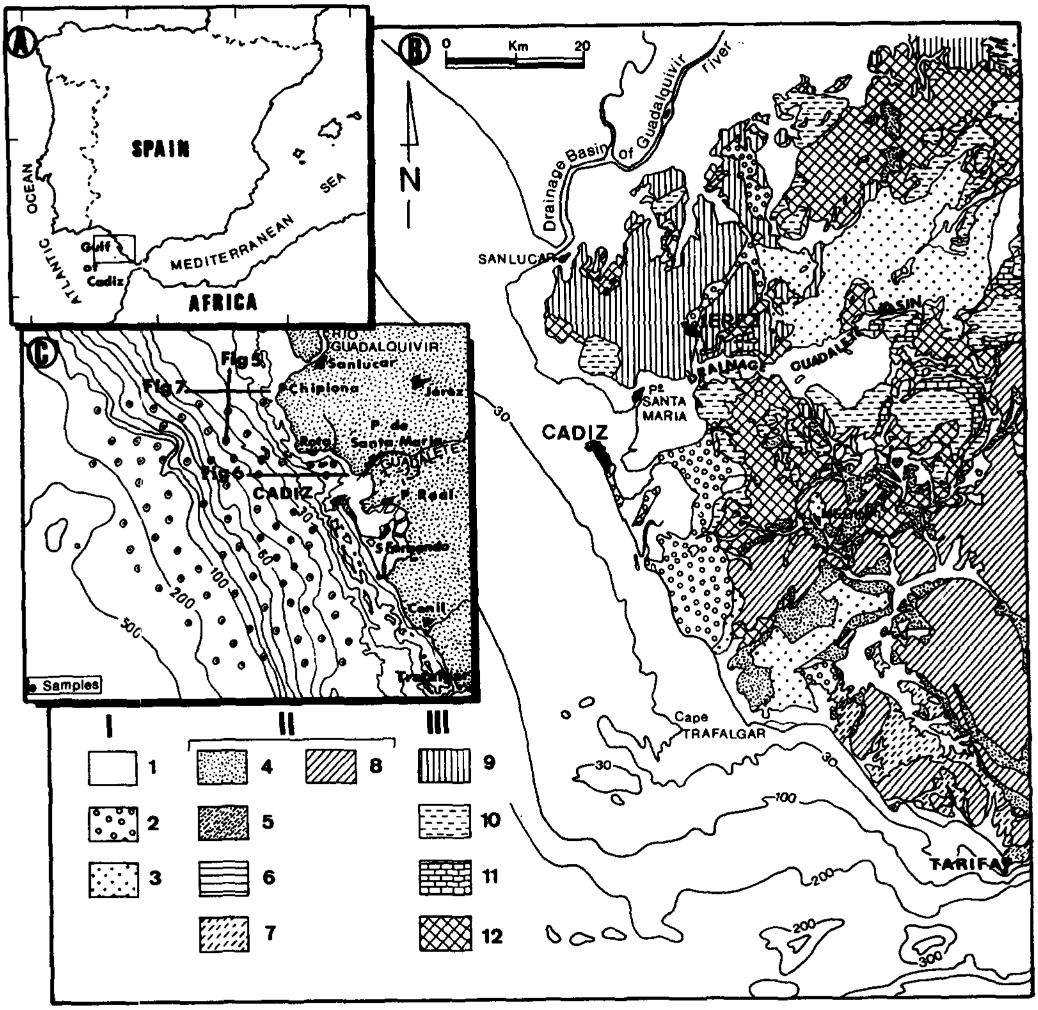

Fig. 1. (A) General study area of the continental shelf of the Gulf of Cádiz. (B) General geologic and bathymetric setting of the Gulf of Cádiz. (C) Geographical, bathymetric, sediment sample and seismic profile distribution of the study area. I: Post-orogenic sediments: (1) Quaternary, (2) Pliocene, (3) Miocene. II: Campo de Gibraltar Units: (4) Lower Miocene, (5) Algeciras unit (Cretaceus–Lower Miocene), (6) Aljibe unit (Eocene), (7) other units (Jurassic–Lower Miocene), (8) III: Middle Subbetic: (9) Moronites (Lower and Middle Miocene), (10) Cretaceus, (11) Jurassic, (12) Triassic (clays and gypsum).

1993). The transition to the continental rise is gentle and forms an extensive, slightly inclined slope passing into an abyssal plain at 4000 m (Melières, 1974).

3. HYDRODYNAMICS AND GENERAL ASSOCIATED SEDIMENTATION SETTING

The hydrodynamic regime in the Gulf of Cádiz has influenced the development of the sedimentary deposits, from the opening of the Strait of Gibraltar since the end of the

Messinian (Mulder and Parry, 1977; Nelson *et al.*, 1993). Nowadays, the water mass dynamics in the Gulf of Cádiz consist of: (a) North Atlantic Surficial Water (NASW) which flows eastward between depths of 0 and 300 m and moves towards the Strait of Gibraltar, winnowing the continental shelf sediment in a southeast direction (Stevenson, 1977; Ambar and Howe, 1979; Caralp, 1992); (b) Mediterranean Outflow Water (MOW), which flows towards the northwest below the NASW between 300 and 1200 m; it follows the continental slope contour (Heezen and Johnson, 1969; Madelain, 1970; Zenk, 1975; Ochoa and Bray, 1990) and does not affect either the shelf or depths shallower than 200 m (Melières, 1974; Villanueva and Gutierrez-Mas, 1994); and (c) North Atlantic Deep Water (NADW), which flows below 1200 m (Reid, 1979). The wave-generated littoral currents flow towards the east and southeast (Melières, 1974), due to the prevailing westerly storms and the orientation of the coastline.

The distribution of surficial sediment in the Gulf of Cádiz is known on a regional scale and shows the dynamic control of the currents on the sedimentary processes (Diaz *et al.*, 1985; Abrantes, 1990; Nelson *et al.*, 1993). The sediment input of the main rivers entering the Gulf of Cádiz (Guadiana, Tinto-Odiel, Guadalquivir and Guadalete, etc.; Fig. 1) is transported towards the east and southeast by the wave-induced and oceanographic currents and results in beaches and spits on the coast (Zazo *et al.*, 1994), and a shelf which is covered by mud and muddy sand (Segado *et al.*, 1984). The suspended load of the rivers becomes concentrated on the bottom as a nepheloid layer, which migrates towards the southeast and leaves the shelf by advection and diffusion processes (Palanques *et al.*, 1987). On the slope, sedimentation is controlled by suspension transport, mass gravitational processes (Faugères *et al.*, 1985) and Mediterranean Outflow Water (Kenyon and Belderson, 1973; Nelson *et al.*, 1993).

4. METHODS

Field-work was carried out over several years (1985–1992), by research vessels working between the parallels 36°50′N and that corresponding to the Trafalgar Cape (36°10′N), and between the meridians 7°W and that of the town of Cádiz (6°15′W). Bottom sampling was carried out using gravity cores and a "Shipek" grab. A total of 180 bottom samples was analysed, covering the area between the shallow water of the Bay of Cádiz (5 m) and the 300 m depth contour (Fig. 1).

The textural analyses have been accomplished by sieving the gravel–sand fractions, and by separation of the silt and clay fractions by decanting. The relationship between the depositional environment and the grain size in detrital deposits has been shown previously by several authors (Stewart, 1968; Friedman and Sanders, 1978; Visher, 1969; Sly, 1978; McManus, 1988). It is based on the fact that the sediments are formed not of one single grain population, but by a combination of sub-populations. The method of Visher (1969), based on cumulative grain size frequency curves applied on a regional scale, has made it possible to characterize the type of sedimentary environment and depositional conditions on the Cádiz continental shelf.

The study of the sand fraction components has been carried out with a binocular microscope with a ×40 magnification. The terrigenous, biogenous and autochthonous mineral percentages have been determined by counting 500 grains per sample. The carbonate percentage has been measured using Bernard's calcimeter. The mineralogical analyses have been performed using XRD on the total sample, the heavy minerals and the clay fractions.

The recent seismic units of the continental shelf have been defined by high-resolution seismic profile analysis (3.5 kHz Uniboom) taken during several oceanographic cruises (Instituto Geológico y Minero de España, 1973; Acosta, 1984; Gutierrez-Mas, 1992). Late Pleistocene–Holocene deposits have been analysed according to the geometry of their internal reflection patterns, their external morphology and their physiographic positions (Posamentier and Vail, 1988; Vail *et al.*, 1991). They are used as indicators of the variations in sea level over the past 20,000 yr. The results are compared to relative variations in sea level during the Late Pleistocene–Holocene, as determined by Hernández-Molina *et al.* (1994).

5. SEDIMENT CHARACTERISTICS

5.1. *Textural distribution*

The surficial sediments of the continental shelf near Cádiz are mainly siliciclastics with an average carbonate content of 20%, of bioclastic origin. The granulometric facies show a general NW–SE trend almost parallel to the coast (Fig. 2), which suggests active transport on the shelf towards the southeast, coinciding with the southeast littoral drift and the direction of the North Atlantic Surficial Water. Based on the granulometric distribution three sediment types and three extensive sedimentary areas can be differentiated, as outlined below.

(1) A sandy littoral zone that covers the Pliocene outcrops [Fig. 1(B)] with sediment of quartzose composition. These deposits contain abundant bioclasts, especially mollusc fragments and smaller quantities of echinoderms, bryozoa and benthonic foraminifera (Fig. 2).

(2) Muds with less than a 2% sand content prevail on the north and northwest shelf. Most of these sediments form a progradational wedge which extends southward from the mouth of the Guadalquivir river on the shelf and reaches the latitude of the town of Cádiz. Some of these sediments are transported from the shelf towards the upper slope (Fig. 2).

(3) Sand and quartzose muddy sand are present to the south and southwest of Cádiz with reworked bioclastics consisting of mollusc fragments and tests of echinoderms and bryozoa, also foraminifers (planktonic and benthonic) (Fig. 2).

5.2. *Granulometric populations and depositional environments*

Following the method of Visher (1969), the muddy sediments in the northern sector are attributed to low-energy environments of the prodelta type. These sediments are located seaward of the main fluvial mouths in the north of the study area, in particular the Guadalquivir river. The bioclastic sands of the southern sector show characteristics of high-energy environments affected by wave action and these are relict–palimpsest sediments [Fig. 3(A) and (B)]. A third group of samples, which are dispersed over the shelf and the periphery of the Bay of Cádiz, suggest a depositional environment which (according to method of Visher, 1969) can be attributed to turbidity currents. However, these samples are thought not to be true turbidite deposits, but to be due to the materials

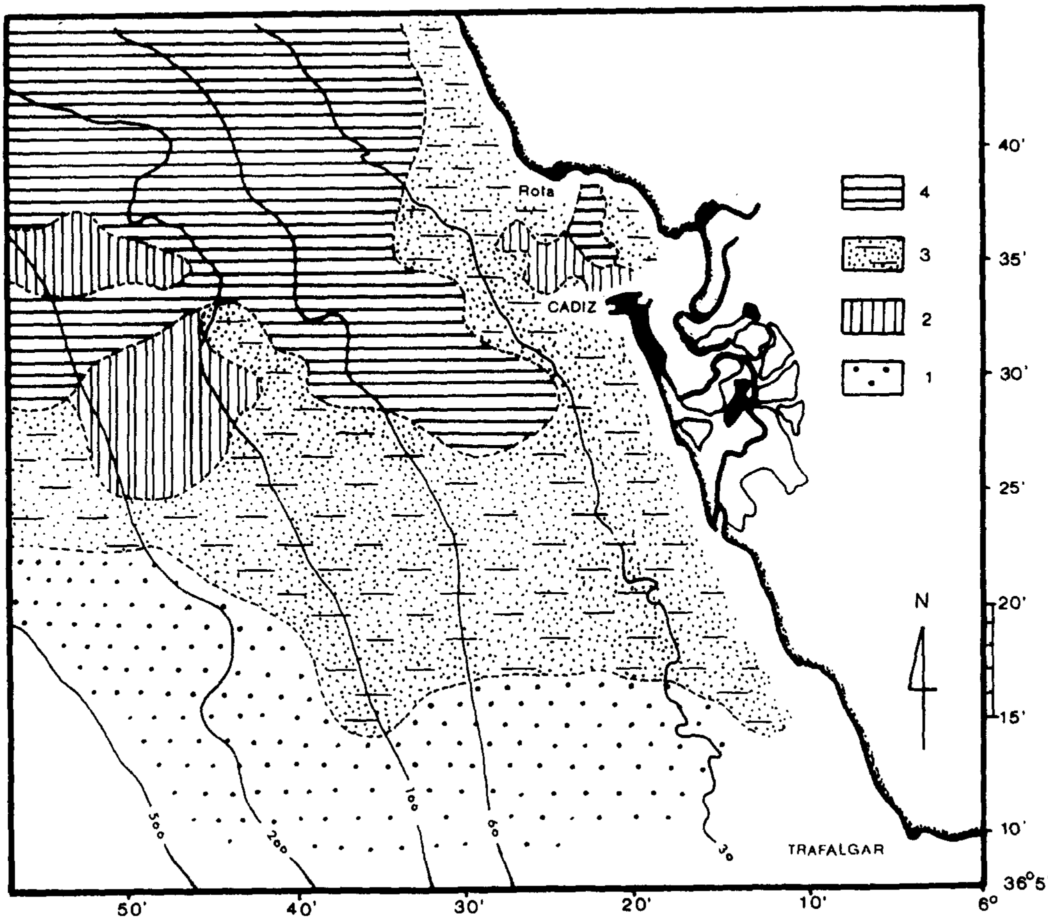

Fig. 2. Map showing the present granulometric distribution of surficial sediments. (1) sand, (2) sandy silt, (3) clayey sand, (4) clayey mud.

which have been dredged from nearby harbours and dumped in these locations [Fig. 3(A) and (B)].

5.3. *Mineralogical composition*

The prevailing mineralogical association in the total sample is quartz–calcite which predominates in the sandy sediments (Fig. 4), followed by phylosilicates–calcite–quartz, associated with clayey-mud deposits. The areal distribution of the mineral components is similar to the textural distribution due to strong control of the latter on the mineral components in the sediments. In the clay fraction the dominant association is ilite–kaolinite ($I \gg K$). The heavy mineral fraction is formed by the association epidote, garnet and rutile ($E > G > R$), with the ultrastable minerals predominating in sandy sediments of the southern shelf and the metastable minerals prevailing on the northern shelf (Fig. 4).

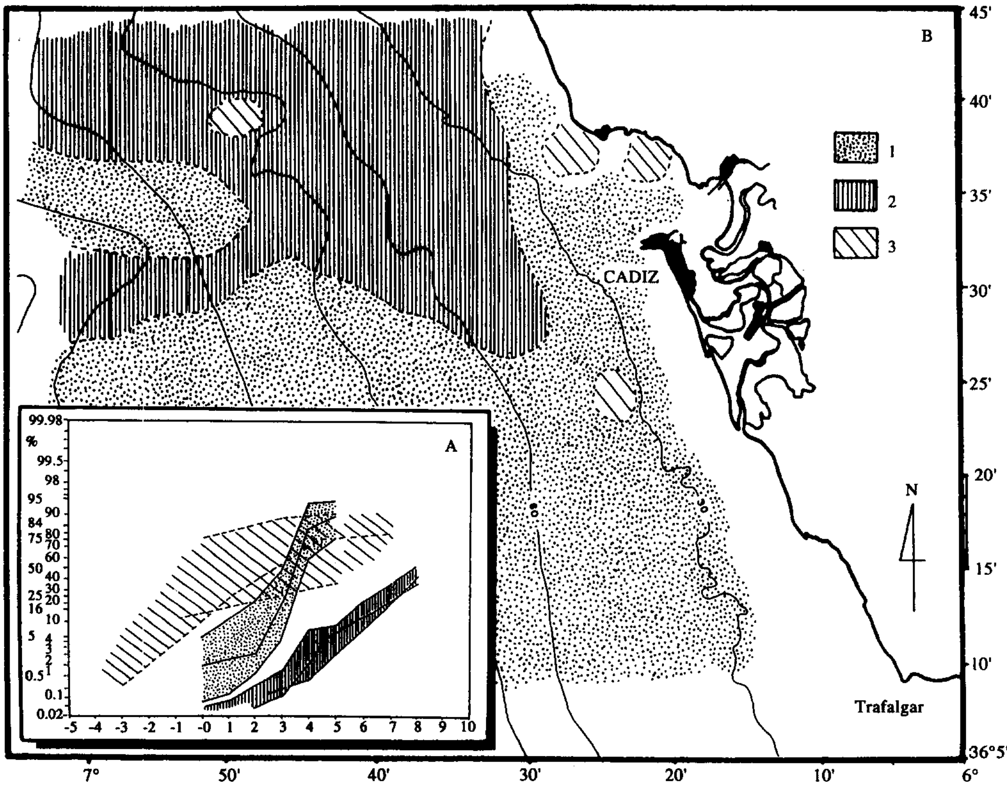

Fig. 3. (A) Families of granulometric curves obtained for samples of the Cádiz shelf. (B) Type of sedimentary environment and conditions on the continental shelf of Cádiz deduced from the curves shown in (A) [according to the Visher (1969) interpretation]. (1) High-energy environments in inlets affected by wave action (transgressive sands); (2) low-energy environments of the prodelta submarine (prodeltaic mud); and (3) sediments attributed to dredged material and linked to turbidity depositional processes.

6. LATE PLEISTOCENE–HOLOCENE SEDIMENTATION

Using seismic stratigraphy analysis of high-resolution seismic profiles three sedimentary systems tracts have been determined, as described below.

(1) A Lowstand System Tract (LST) has not been identified on the inner shelf but, instead, the lowstand sea level has expressed itself simultaneously as both an erosion surface and incised river channels (Fig. 5). Alonso *et al.* (1988) have recognized lowstand wedge deposits associated with the last low sea level position on the shelf edge of Cádiz.

(2) The existence of retrogradational parasequences generated on a transgressive erosion surface makes it possible to determine a Transgressive Systems Tract (TST). The retrograding units are shown in the seismic profiles as weak transparent seismic units, with lobate morphology (Fig. 6). They are well developed in sectors near the mouth of the Guadalquivir river but they diminish, and even disappear, southward (Fig. 6), giving way laterally to terraces and submarine cliffs.

(3) The Highstand Systems Tract (HST) shows prograding sigmoidal reflection patterns which downlap over the transgressive deposits, to generate the Downlap Surface

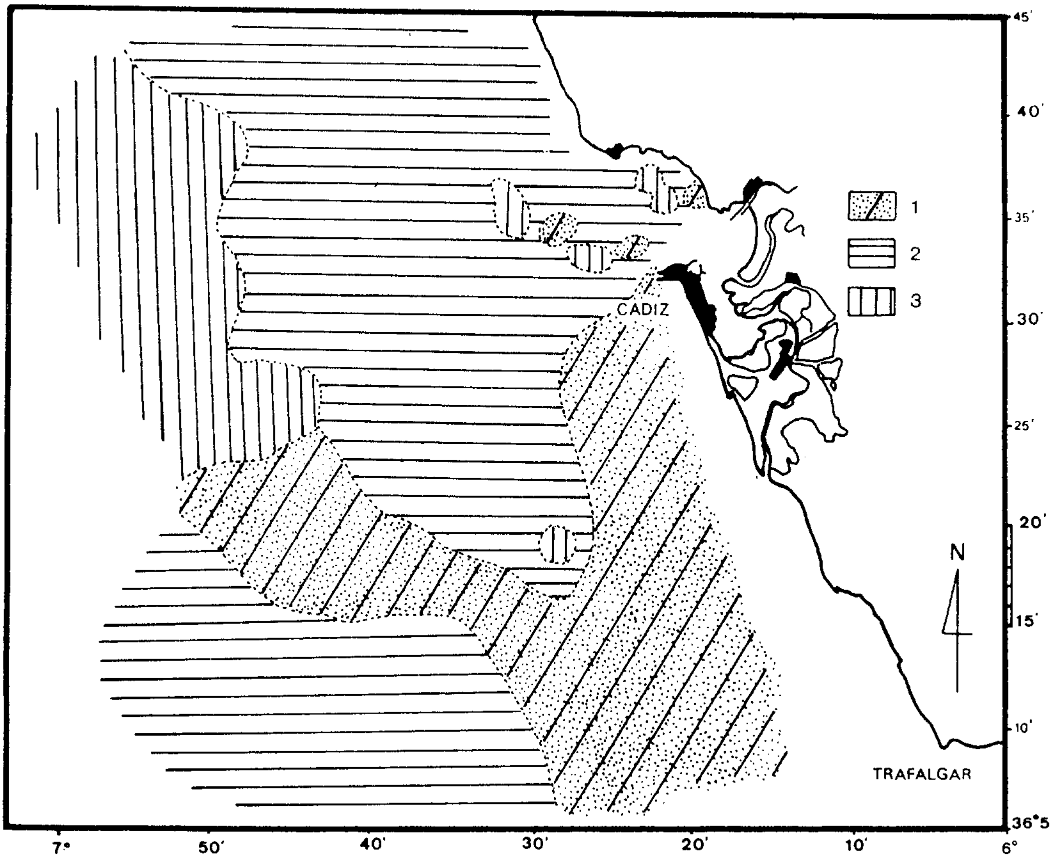

Fig. 4. Map showing the distribution of heavy mineral (ultrastable and metastable ratio). (1) Met/Ult = >1%; (2) Met/Ult = 0.5–1%; and (3) Met/Ult < 0.5%.

(DLS, Figs 6 and 7). This surface cannot be identified near the mouth of the Guadalquivir river because of the existence of acoustic masking. Such acoustic masking, due to its seismic characteristics and according to the criteria of Davis (1992), is attributable to the presence of gas in the sediment. During the evolution of the Highstand Systems Tract a prograding sedimentary wedge is generated and extends from the mouth of the Guadalquivir river, towards the southeast. This wedge has more defined reflections (in the 3.5 kHz profiles) in proximal regions with differentiated internal units, but a more transparent response in more distal regions because of the presence of muddier sediment (Figs 6 and 7).

7. DISCUSSION

7.1. *Shelf sedimentary dynamics of the Gulf of Cádiz*

The sedimentary facies on the continental shelf of Cádiz shows no correspondence between the grain size distribution, the oceanographic setting and the present-day sea

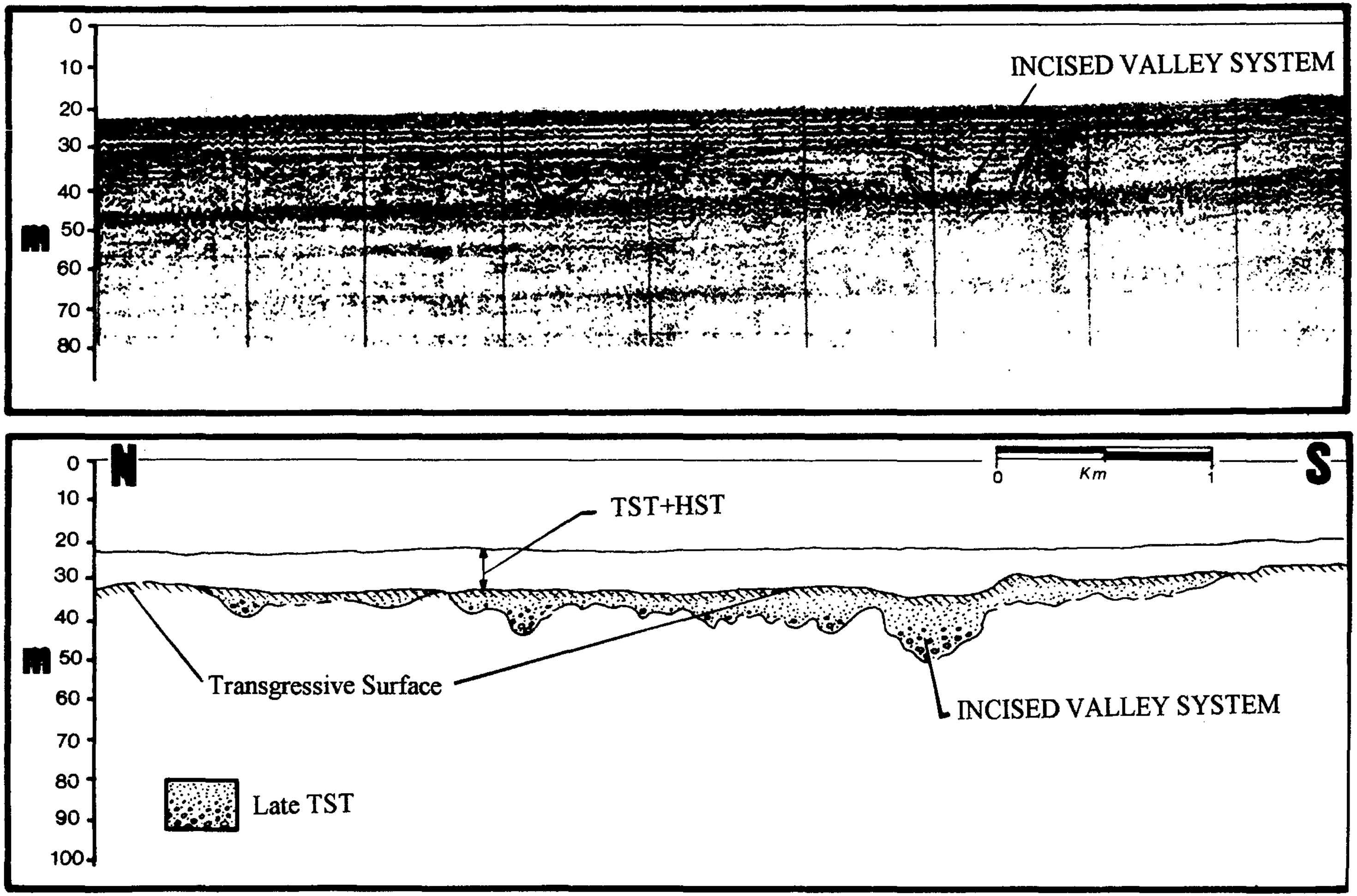

Fig. 5. High-resolution seismic profiles from the Gulf of Cádiz showing the incised valley system and transgressive surface of erosion. (Uniboom profile, modified after IGME, 1973.) TST: Transgressive Systems Tract; HST: Highstand Systems Tract. See location profile in Fig. 1.

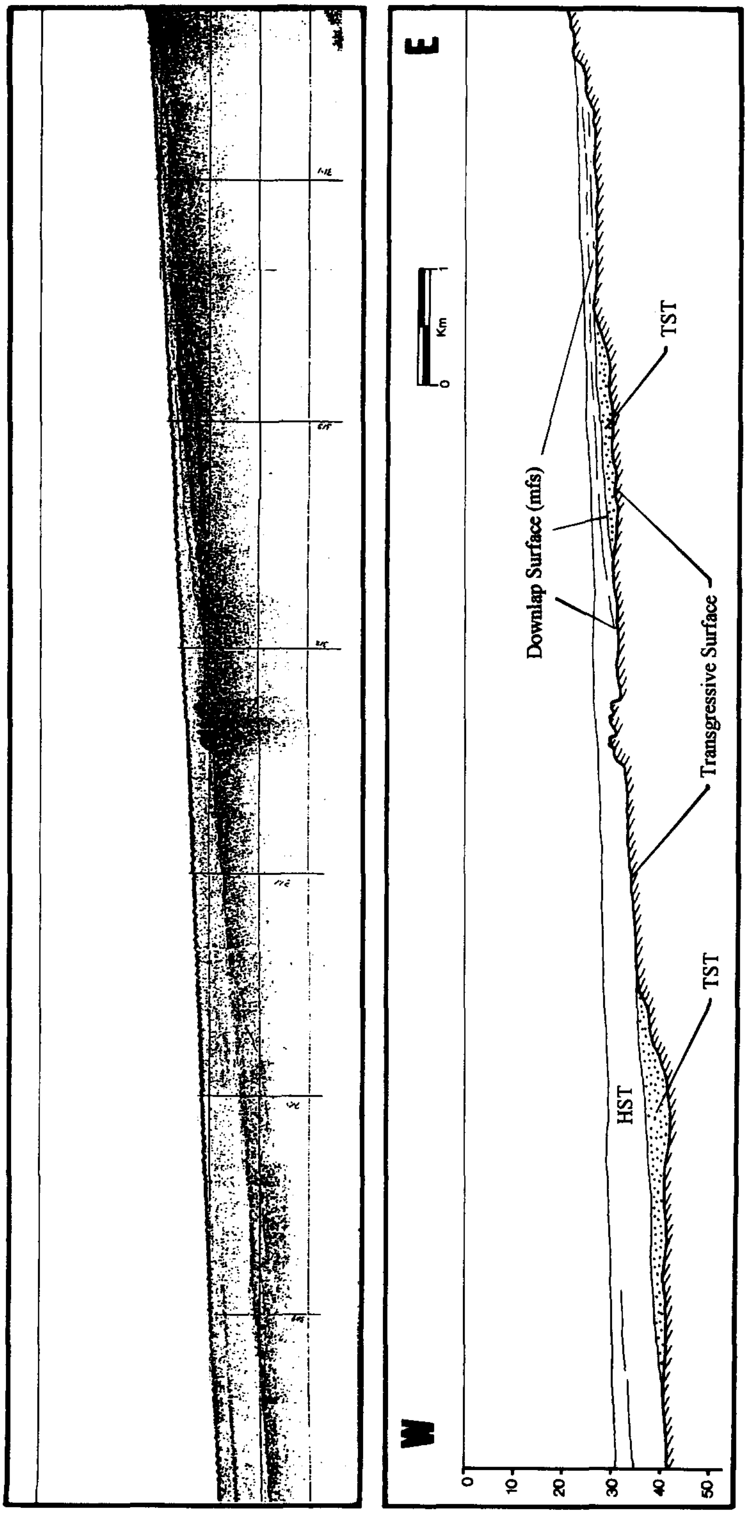

Fig. 6. 3.5 kHz seismic profile (Gutierrez-Mas, 1992). Note the episodic sedimentary bodies in the Transgressive Systems Tract (TST) characterized by weak seismic units with lobate morphology of Transgressive Systems Tract, and the Holocene sedimentary wedge of Highstand Systems Tract (HST). See location profile in Fig. 1.

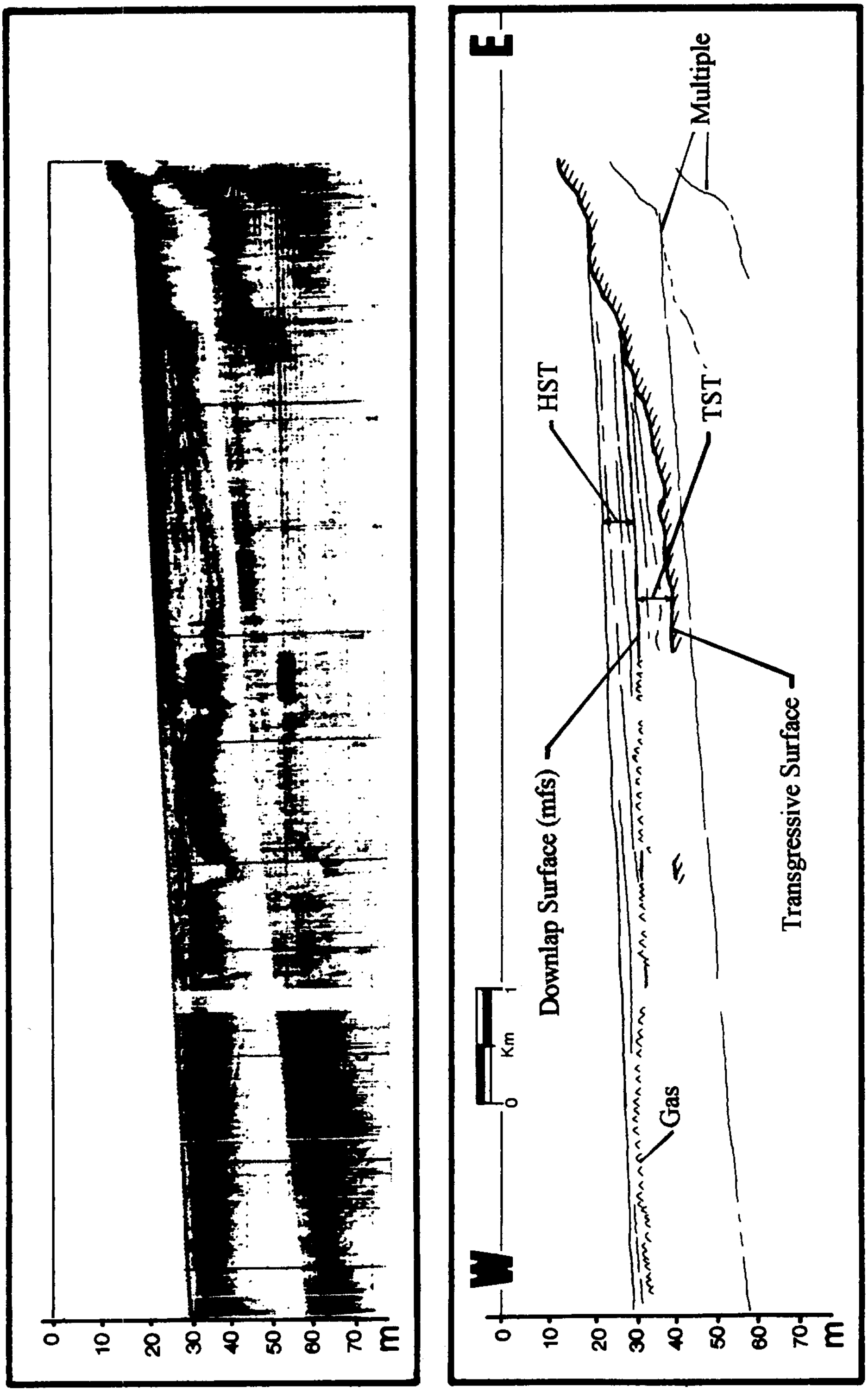

Fig. 7. 3.5 kHz profile (modified after Instituto Geológico y Minero de España, 1973). Note the acoustic masking due to the presence of gas in the sediment. TST: Transgressive System Tract; HST: Highstand System Tract. See location profile in Fig. 1.

level. The southern region is covered with coarse quartziferous–bioclastic sands which do not correspond with the present oceanographic conditions. However, near the Strait of Gibraltar there are reworked sand deposits due to the Mediterranean Outflow. These deposits are located only on the continental slope, indicating that this flow does not affect the continental shelf (Kenyon and Belderson, 1973; Melières, 1974; Ochoa and Bray, 1990). In contrast, the deposits of the northern region—fine prodeltaic clay and silty clay—are in equilibrium with the present oceanographic conditions. These conclusions agree with those of Swift *et al.* (1991) who claim that the lithological characteristics of the shelf deposit may be utilized as indicators of eustatic events, in such a way that the vertical fluctuations are related to lateral distribution of grain size facies and different sedimentary environments.

The evolution of the Holocene sedimentary dynamics can be deduced by chronologically comparing the systems tract with the present facies data of the Gulf of Cádiz developed, between the eustatic minimum of 18,000 yr BP (Caralp, 1992) and the maximum at 6500 yr BP according to Zazo *et al.* (1994).

Owing to the global eustatic fall during the last glacial maximum (Pirazzoli, 1992), the continental shelf was emergent favouring subaerial erosion, and fluvial valley incision with marine sedimentation developed on the outer shelf (LST) slope and in the adjacent deep basin.

The subsequent Flandrian transgression (14,000–6500 yr BP: Fairbridge, 1961; Aloïsi, 1986; Saito, 1991) generated a transgressive surface of erosion on the shelf; it also generated a quartzose–bioclastic sand sheet by the erosional retreat of the coastline and the reworking of the littoral facies. The development of small prograding bodies of lobate morphology, terraces and small cliffs—in backstepping formation (TST)—is attributed to ancient beach crestlines [Fig. 8(A)], related to successive periods of stillstand during the eustatic rise. Similar periods of stillstand during the last transgression have been described by other authors on numerous continental shelves (Mörner, 1971; Chronis *et al.*, 1991; Swift *et al.*, 1991; Hernández-Molina *et al.*, 1994).

From approximately 6500 years ago until the present, a Highstand Systems Tract (HST) has developed in the inner shelf and it is related to the stabilization of the eustatic rise in the northern hemisphere (Fairbridge, 1961; Thom and Roy, 1985; Aloïsi, 1986; Saito, 1991) and has been shown by various authors in the Gulf of Cádiz and Alboran Sea (Hoffman, 1988; Zazo *et al.*, 1994). During the last eustatic maximum, sea level is considered to have reached 2 m above the present level, leading to the formation of estuaries and sea inlets [Fig. 8(B)], which persisted in the Gulf of Cádiz until Roman times (Mabesoone, 1963a,b; Zazo *et al.*, 1994). This ancient coastline is expressed as cliffs and ancient abrasive platforms above the present sea level (Zazo, 1980; Zazo and Goy, 1991). From the transgressive maximum until the present (Zazo *et al.*, 1994), a sediment wedge derived mainly from the mouth of the Guadalquivir river prograded onto the shelf [Fig. 8(C)]. At the beginning, the prodelta wedge had a aggradational configuration until the accommodation space was filled. At the same time, the sediments forming this wedge were deflected both to the southeast by the action of the North Atlantic Surficial Water, where they prograded over the sandy deposits of the previous transgressive interval [Fig. 8(C)], and seaward to reach the slope. Nevertheless, in zones with a low sedimentary input as in the south and southeast of the study area, the action of the geostrophic currents produced winnowing and reworking of relict sands; these, together with wave action, generated palimpsest sediments. The inlets of the main rivers (Guadalquivir, Guadalete, Barbate,

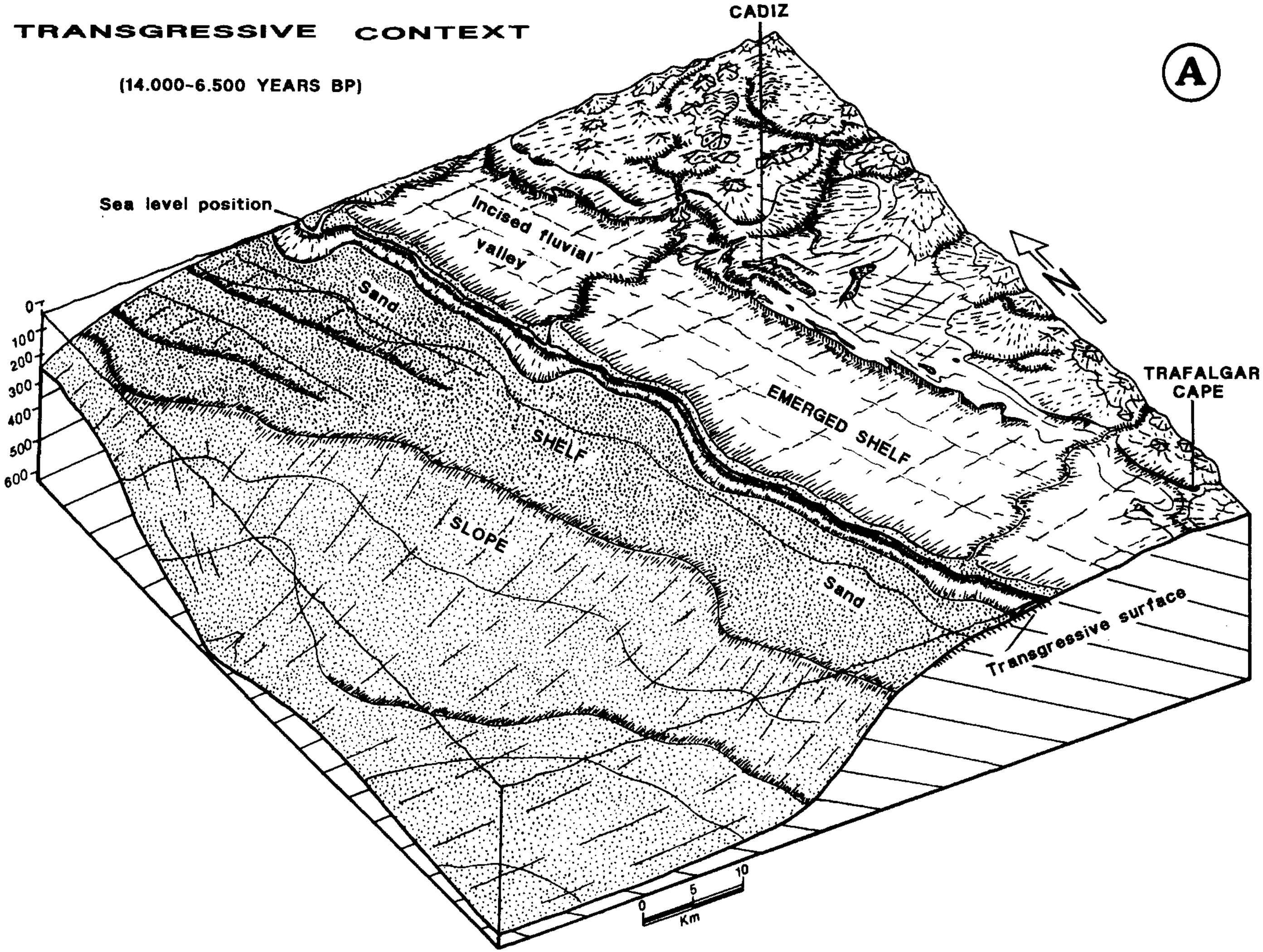

Fig. 8. Theoretical sketch of recent sedimentary evolution and present sediment facies distribution. (A) Sketch of TST, the sea level stillstand situation and the generation of ancient beach crestlines.

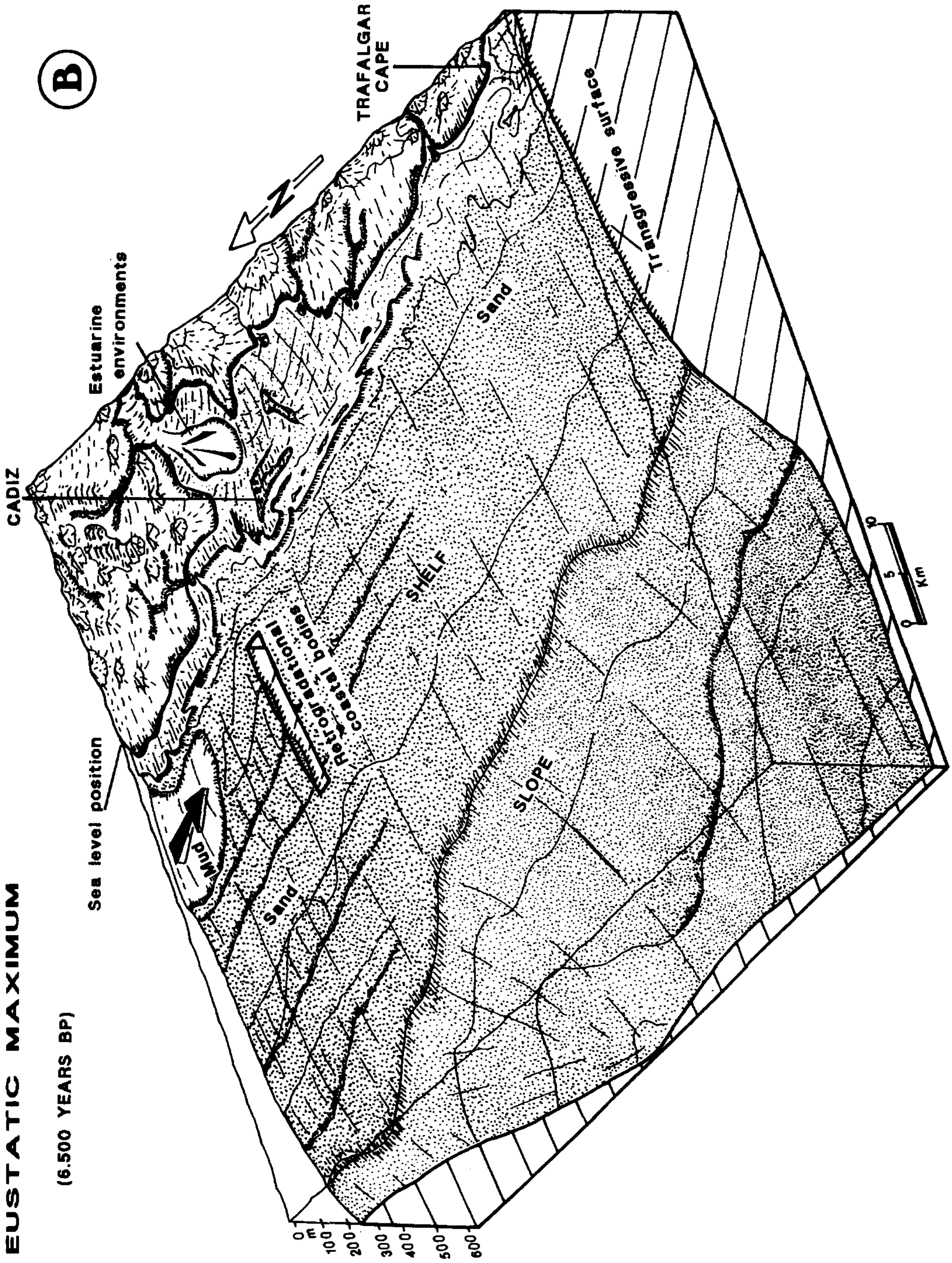

Fig. 8. (B) Sketch of the eustatic maximum situation (6500 yr BP). The sea level was 2 m above the present level, leading to the formation of estuaries and sea inlets.

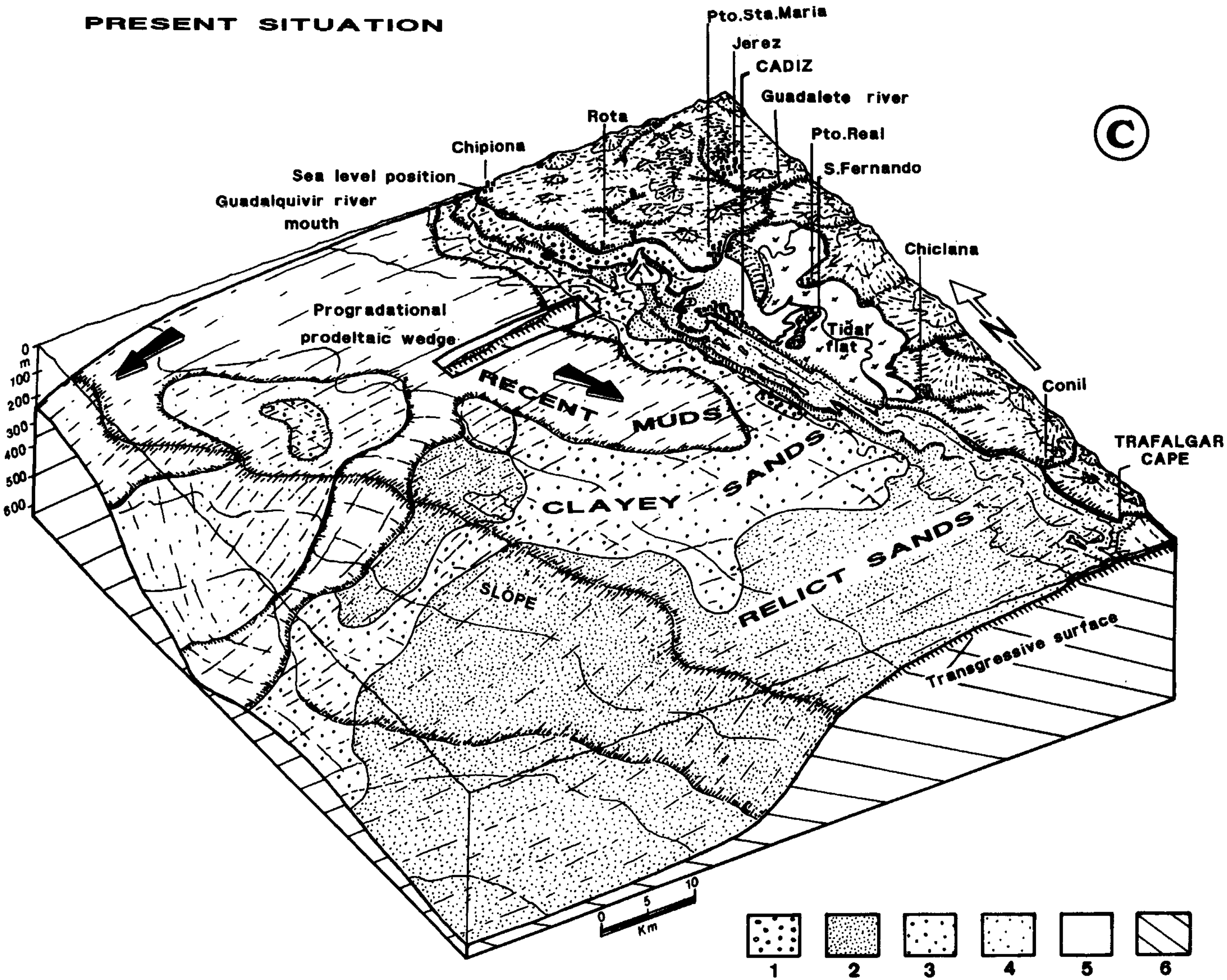

Fig. 8. (C) Present sedimentary facies distribution. Note how the sediments that form the Guadalquivir wedge are deflected towards the southeast by the action of the North Atlantic Surficial Water, to cover the sandy deposits of the previous transgressive interval. (1) Gravel, (2) sand, (3) muddy sand, (4) sandy mud, (5) mud (silt-clay), and (6) Pre-Holocene deposits.

etc.) and the longitudinal profile of the coastline have been generated during the last slight sea level fall, to its present position.

Both the HST progradation of the deposits that form the Holocene sedimentary wedge and the surficial sediment distribution show the persistence of the current dynamic system over at least the last 6500 years. The presence of well-developed mud deposits on the southern sector of the shelf occurs because the previously deposited bioclastic sands have not yet been covered by the progradation of sedimentary mud originating from the Guadalquivir river. Also, there is an absence of fluvial inputs in this sector, because the Guadalete river, the only important stream, has deposited the major part of its load within the protected Bay of Cádiz (Gavala, 1927, 1959; Mabesoone, 1963a,b,c, 1966).

7.2. *Sediment source areas*

Sediment composition suggests that mainly igneous and metamorphic terrains are the source of shelf siliciclastic sands. The presence of quartz grains and heavy minerals with traces of reworking (Gutierrez-Mas, 1992) and the predominance of ultrastable minerals over a wide region (Fig. 3), however, show the existence of source areas with abundant rocks of sedimentary origin. Similarly, the dominant association in the mud fraction (illite>>kaolinite), is similar to the association found in Pliocene and Quaternary materials (Fig. 1) near the Bay of Cádiz (Zazo, 1980; Viguier, 1974; Mabesoone, 1963c). In the heavy mineral fraction, the association epidote>garnet>rutile correlates generally with what Mabesoone (1963c, 1966) defined as the "Petrographic Province of Jerez". This province is defined by an epidote>garnet>andalucite association, which is present in alluvial materials of the Guadalete basin (Fig. 1) and in beaches near the Bay of Cádiz (Mabesoone, 1963c, 1966; Viguier, 1874; Pérez-Mateos *et al.*, 1982). The source area of this mineralogical association (epidote>garnet>andalucite) is found in the Sierra Morena (Iberian Massif, Central Spain) and in Subbetic Zones (Cordillera Bética).

According to these data, the shelf sediments originate from the north (Sierra Morena; Iberian Massif) and from the east [Internal Zones of the Cordillera Bética, Fig. 1(C)]. These source areas supply slightly reworked sorted minerals, which reach the northern region of the shelf through the Guadalquivir river. Other sources are the western units of the Cordillera Bética (Middle Subbetic and units from the "Campo de Gibraltar"), especially the "Aljibe sandstones" (Areniscas del Aljibe) [Fig. 1(C)] drained by the tributaries of the left side of the Guadalete river; this supplies mature sediments characterized by reworked quartz grains. Additional sources consist of reworked Neogene sediments from the Guadalquivir Depression, which is drained by the Guadalquivir and Guadalete rivers. The basin sediment consists partly of sediments derived from the zones described above.

8. CONCLUSIONS

(1) The surficial sediment on the continental shelf of Cádiz is divided into three general regions: (a) a sandy littoral region; (b) an area of prodeltaic material, in the northern and central shelf region of low energy; and (c) an area of transgressive littoral sands in the south. The latter two deposits show a lack of correspondence between the grain size distribution and the present sea level and current system.

(2) Analysis of the seismic profiles defines a Transgressive Systems Tract (TST)

characterized by surficial erosion, quartzitic–bioclastic sands and retrograding parasequences development during periods of stillstand. An early Highstand Systems Tract (HST) has prograded, with sigmoidal clinoforms, on the regional downlap surface of the TST. During the HST a muddy sedimentary wedge has prograded southward because of the deflection of sediment from the mouth of the Guadalquivir river by NASW over the earlier transgressive sands.

(3) Both the southward progradation of the muddy sedimentary wedge during the high sea level and the present granulometric facies distribution on the shelf indicate the persistence of this dynamic system on the shelf, during the last 6500 yr.

(4) The shelf sediment was derived from igneous and metamorphic sources to the north in the Sierra Morena (Iberian Massif) Mountain and to the east in the Internal Zones of the Betic Cordillera. Sediments were transported to the shelf by the Guadalquivir river. Other source areas are the Neogene deposits from the depression of the Guadalquivir river and the western units of the Betic Cordillera (Middle Subbetic and units from the Campo de Gibraltar) drained by the Guadalete river.

(5) The recent sedimentary dynamics of the continental shelf of Gulf of Cádiz has been controlled mainly by: (1) the eustatic changes which controlled the general sea level trend and periods of stillstand which resulted in deposition of retrogradational sedimentary bodies; (2) the sediment supply, with a differential sedimentation rate between the northern and southern sectors; (3) the North Atlantic Surficial Water current systems, responsible for the transport of the prograding Guadalquivir sediments towards the southeast; and (4) the tectonic structure which determined the orientation of the coast, fluvial streams, bottom morphology, troughs and ridges.

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