Contourites along the Iberian continental margins: conceptual and economic implications

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Abstract:

This work uses seismic records to document and classify contourite features around the Iberian continental margin to determine their implications for depositional systems and petroleum exploration. Contourites include depositional features (separated, sheeted, plastered and confined drifts), erosional features (abraded surfaces, channels, furrows and moats) and mixed features (contourite terraces). Drifts generally show high to moderate amplitude reflectors, which are cyclically intercalated with transparent layers. Transparent layers may represent finer grained deposits, which can serve as seal rocks. High amplitude reflectors (HARs) likely represent sandier layers, which could form hydrocarbon reservoirs. HARs occur on erosive features (moats and channels) and are clearly developed on contourite terraces and overflow features. Most of the contourite features described here are influenced by Mediterranean water masses throughout their Pliocene and Quaternary history. They specifically record Mediterranean Outflow Water following its exit through the Gibraltar Strait. This work gives a detailed report on the variation of modern contourite deposits, which can help inform ancient contourite reservoir interpretation. Further research correlating 2D and 3D seismic anomalies with core and well logging data is needed to develop better diagnostic criteria for contourites. This can help clarify the role of contourites in petroleum systems.

Key words: *sandy contourites, high amplitude reflectors (HARs), water mass-seafloor interaction, hydrocarbon exploration, Iberian continental margin*

1. INTRODUCTION

The characterization of contourite features has been a critical area of research in marine geology over the past three decades due to their implications for stratigraphy, sedimentology, paleoceanography, paleoclimatology, sedimentary instability processes, and energy resources (Rebesco *et al.,* 2014). Studies have shown that contourites are common in deep marine environments, but remain poorly understood in terms of their composition, sedimentary processes, origin, sequence, lithology, seismic facies, petrophysical characteristics (porosity, permeability, etc.) and role in petroleum systems (Viana, 2008; Stow *et al.,* 2011a, b; Shanmugan, 2012; Brackenridge, 2014; among others). Advances in understanding of contourites have yielded a clearer picture of their lateral and temporal variability as well as their relations with along-slope processes. Previous work has helped formalize the terms Contourite Depositional System (CDS) and Contourite Depositional Complex (CDC) (Hernández-Molina *et al.,* 2003, 2008; Rebesco and Camerlenghi, 2008). Contourites however frequently occur interbedded or simultaneously deposited with sedimentary facies resulting from down-slope processes. These deposits represent mixed turbidite-contourite systems (Faugères *et al.,* 1999; Rebesco and Camerlenghi, 2008; Creaser *et al.,* 2017). Mixed systems are common along continental margins where bottom currents rework and/or redistribute pre-existing gravitational deposits (Marchès *et al.,* 2010; Mulder *et al.,* 2013; Brackenridge *et al.,* 2013). When down-slope processes dominate along-slope processes, gravitational deposits (such as turbidites) may overprint or inhibit the development of contourites. When strong along-slope currents dominate, turbidity currents may deviate and feed contourite drifts (e.g., Faugères *et al.,* 1999; Mulder *et al.,* 2003, 2006; Viana *et al.,* 2007).

This paper follows the contourite drift classification criteria of Faugères *et al.* (1999) and Rebesco (2005). Sediment drifts are commonly bounded by and/or associated with erosional contourite features (such as contourite channels or moats). Compared to depositional features, these latter erosional features have generally received less attention and their genetic relationships with oceanographic processes remain unclear (Nelson *et al.,* 1993, 1999; Stow and Mayall, 2000; Hernández-Molina *et al.,* 2006, 2008a, 2015a, 2015b; García *et al.,* 2009). Erosional contourite features are clearly identifiable in seismic reflection profiles allowing large-scale interpretation (Faugères *et al.,* 1999; Stow *et al.,* 2002; Hernández-Molina *et al.,* 2008, 2015c; Nielsen *et al.,* 2008; Brackenridge *et al.,* 2013; Llave *et al.,* 2015; Kuijpers and Nielsen, 2016; Calvin Campbell and Mosher, 2016; Delivet *et al.,* 2016; Gruetzner and Uenzelmann-Neben, 2016, among others). In the past, some contourite deposits have been considered as potential (hydrocarbon) source rocks, but ones less likely to form reservoirs than turbidites (Pickering *et al.,* 1989; Pickering and Hiscot, 2016). Sediments that make up such contourite drifts are typically muddy but can reach substantial local thickness and include well-sorted sands, that themselves are thick and laterally extensive enough play a role in deep-water petroleum systems. Recent studies have interpreted bottom currents as a crucial factor in hydrocarbon reservoir development because weak flows enable accumulation of mud-rich deposits (such as contourites). These can serve as both caprock (seals) or with deeper burial, as potential source rocks or shale-gas reservoirs when adequately enriched in organic matter (up to 2 wt.%). On the other hand, high velocity flows may represent a mechanism for “mature sand” accumulation in deep-water environments. These sands form excellent reservoir units (Enjorlas *et al.,* 1986; Colella, 1990; Mutti, 1992; Shanmugam *et al.,* 1993; Viana *et al.,* 1998; Stow and Faugères, 2008; Viana, 2008; Stow *et al.,* 2011b, 2013a; Shanmugam, 2006, 2012, 2013a, b; Mutti and Carminatti, 2012). Sandy contourites and related deposits with good lateral continuity and exposed to long-term effects of current winnowing may have greater textural maturity and better developed primary interstices than turbidites. Sandy contourites can thus present good petrophysical characteristics, including high values for porosity, permeability, and lateral and vertical transmissivity of fluids (Shanmugam, 2008; Viana, 2008).

In spite of the potential role they play in deep-water petroleum systems and by extension, their economic significance, contourites and mixed-drift depositional systems are not well understood. In particular, the scientific literature on sandy contourites, including ancient analogues in outcrop is sparse. Mixed-drift systems do not yet enjoy the benefit of well-defined interpretive models. Both of these could help refine and direct turbidite exploration.

Published seismic and sedimentologic data from the Iberian continental margin have reported on the interrelations of turbidite and contourite depositional systems, especially contourites within mixed turbidite-contourite systems (Mulder *et al.*, 2003, 2006, 2008; Llave *et al.*, 2006; Marchès *et al.,* 2007; Hernández-Molina *et al.,* 2010;

García *et al.,* 2016). The Iberian margin is affected by several vigorous water masses interacting along upper and middle continental slopes and by weaker water masses moving along the lower slope and abyssal plains (Hernández-Molina *et al.,* 2011, 2016a) (Fig. 1). Each of these domains hosts extensive and complex contourite features of variable dimensions and sedimentary thicknesses that are often poorly understood in terms of their oceanographic / depositional contexts (Maestro *et al.,* 2013; Llave *et al.,* 2015). Along the Iberian margin, large volumes of sand have been efficiently transported, re-deposited or reworked by the persistent hydrodynamic regimes of the Gulf of Cadiz (Buitrago *et al.,* 2001; Habgood *et al.,* 2003; Llave *et al.,* 2005; Hernández-Molina *et al.,* 2006; Akhmetzhanov *et al.,* 2007; Brackenridge *et al.,* 2011, 2013). IODP Expedition 339 and and other cores from a number of cruises furthered understanding of sand-rich contourite deposits by presenting a facies model for sandy contourites (Expedition 339 Scientists, 2012; Hernández-Molina *et al.,* 2013; Stow *et al.,* 2013b, Brackenridge *et al.,* 2018). This research also considered contourites' potential role in deep-water petroleum systems. A thorough record of these features as they occur around the Iberian margin can further understanding of both their scientific significance and their economic potential (e.g., Rebesco and Camerlenghi, 2008; Hernández-Molina *et al.,* 2011 and references therein).

This study provides a regional review of along-slope processes and their sedimentary features around the Iberian continental margin based on 2D seismic profiles from published and unpublished sources. This work also discusses sandy contourites and how these features can be used to interpret ancient contourite deposits and explore for petroleum in deep-water settings.

2. DATA AND METHODOLOGY

This study interprets geophysical surveys of the Iberian continental margin. Surveys used acoustic techniques to develop a 2D vertical profile of the structure underlying the seafloor at water depths of 200 to 5000 m. This study primarily reviews contourite features as characterized by methods and nomenclature described in Faugères *et al.* (1999) and further developed by Rebesco and Stow (2001) and Nielsen *et al.* (2008). Contourite morphologies developed at different depths and under the influence of multiple water masses are defined as Contourite Features (CFs). Thickness is expressed in two way travel time seconds (s).

The dataset was collected by several Spanish and international research projects as well as by commercial petroleum exploration projects. Data were made available through the Geophysical Information System (Sistema de Información Geofísico - SIGEOF (http://cuarzo.igme.es/sigeco/default.htm), the Institut de Ciències del Mar-CSIC (http://www.icm.csic.es/geo/gma/SurveyMaps/) and the Instituto Portugues do Mar e da Atmosfera-IPMA (http:// www.ipma.pt). Data were obtained by various seismic reflection methods described here. Low resolution methods are commonly used for hydrocarbon exploration purposes. These methods record multi-channel seismic profiles penetrating several kilometers but provide comparatively low resolution (> 50 m) images. Moderate-resolution / penetration methods use air-guns (Uniboom and Sparker) that penetrate from 100 m to 2 km with a resolution of 1 and 10 m (respectively). High-resolution / low penetration seismic methods use 3.5 kHz echo sounders, TOPAS (topographic parametric sonar) and Parasound, which penetrate the upper few to tens of meters of the subsurface and record it at centimeter resolution. The various penetration depths and resolutions of these seismic survey systems record contourite features on different scales. Morphology and boundaries of the deposit are recorded at larger scales. The architecture of discrete internal depositional units is recorded at medium scales, and seismic facies are recorded at smaller scales. These features are referred to as first-, second- and third-order seismic elements in Nielsen *et al.* (2008).

A digital bathymetric model obtained from Zitellini *et al.* (2009) and GEBCO (2003) served as the base map used in the study. The World Ocean Atlas 2012 provided source data for the selected vertical hydrographic profiles.

3. CONTOURITE FEATURES ALONG THE IBERIAN MARGIN

The water masses around Iberia control along-slope sedimentation and thus shape intermediate- and deep-water bathymetric features (Hernández-Molina *et al.,* 2011 and references therein) (Fig. 1 and Table I). In spite of many bottom current measurements, the Iberian margin lacks of long-term hydrodynamic records and has many areas with few or no measurements. Its mean recorded velocities are commonly low (5 to 15 cm/s), but certain water masses can travel across the seafloor at relatively high velocities, exceeding 80 cm/s and occasionally reaching almost 300 cm/s, for example within the Strait of Gibraltar (Mélières *et al.,* 1970; Madelain, 1970; Ambar and Howe, 1979; Iorga and Lozier, 1999; Candela, 2001). These water masses interact along the upper and middle continental slopes and with less intensity, along lower slope areas and the abyssal plain (Fig. 1).

Contourite features with large-scale dimensions and a range of sedimentary thicknesses occur at the following locations: the northeast Iberian margin, Alboran Sea, Gulf of Cadiz

CDS (well-studied), western Iberian margin, Galician margin, Ortegal Spur, and Le Danois Bank or “Cachucho”. These features are complex and poorly understood. The next section summarizes the main water masses shaping the Iberian margin and describes contourite features formed by their interaction with the seafloor.

3.1. Mediterranean Sea

3.1.A. Oceanographic setting

According to traditional definitions, the Mediterranean Sea hosts three main water masses (Fig. 1 and Table I): Atlantic Water, Levantine Intermediate Water and Western Mediterranean Deep Water.

Atlantic Water (AW) or Modified Atlantic Water (MAW) forms due to mixing of North Atlantic Surface Water, which enters through the Strait of Gibraltar at a velocity of approximately 1 m/s (Salat and Cruzado, 1981; Gascard and Richez, 1985). The MAW flows eastwards at a depth of 100-200 m and forms two anticyclonic gyres (Fig. 1), a quasi-permanent gyre in the western Alboran basin (Western Alboran Gyre; WAG) and a semi-permanent gyre in the eastern Alboran basin (Eastern Alboran Gyre; EAG) (e.g., Perkins *et al.,* 1990; Millot, 1999; Robinson *et al.,* 2001). The energy of the WAG may exert an effect down to water depths of approximately 500-700 m (Cheney and Doblar, 1982; Heburn and La Violette, 1990; Perkins *et al.,* 1990; Viúdez *et al.,* 1998).

Levantine Intermediate Water (LIW) originates in the Strait of Sicily and flows westwards into the Western Mediterranean at depths of 200-600 m. After emerging from the Strait of Sicily, the LIW flows along the Iberian margin and into the central part of the Alboran Sea at velocities of up to 14 cm/s (Fig. 1).

Western Mediterranean Deep Water (WMDW) forms locally in the Alboran basin and its surroundings during winter months and generally flows westwards at water depths down to 600 m, although it can also reach depths of 2000 m (Fig. 1). Certain WMDW pulses can travel at velocities as high as 22 cm/s (Gascard and Richez, 1985; Parrilla and Kinder, 1987; Millot, 1999; Fabres *et al.,* 2002).

In recent studies of the Strait of Gibraltar and nearby Alboran Sea, Millot (2009, 2014) proposed a more complex oceanographic structure and defined two additional water masses for this area: Western Intermediate Water (WIW; 100 to 300 m), situated between the AW and LIW, and Tyrrhenian Dense Water (TDW; variable water depth), situated between the LIW and WMDW (Fig. 1). Ercilla *et al.* (2016) categorized these five Alboran Sea water masses as light or intermediate water masses (Light Mediterranean Waters - LMW-; 100 to 600 m) and dense or deep-water masses (Dense Mediterranean Waters - DMW-; >275 m).

3.1.B. Contourite features (CFs)

The best-studied contourites in the Mediterranean Sea occur in the Alboran Sea. Evidence also indicates contourite deposition elsewhere along eastern margins of Iberia. Along the continental slope between Cap de Creus and Blanes Canyons (Fig. 2A, Table II), two mounded, upward-prograding stratified drifts reach thicknesses of approximately 1 s and widths of 5 km at water depths of 1000-2300 m (Barcelona CFs). One of these occurs just south of La Fonera Canyon at water depths of 1200-2300 m (Canals, 1985), and another is located between La Fonera and Blanes Canyons at depths of 1000-1300 m (Fig. 2B). This second drift has not been analysed for specific contourite features but is similar to the one studied by Canals (1985).

Upslope, prograding, mounded, elongated and separated drifts (hereafter referred to simply as separated drifts) have been described from several localities. An isolated separated drift south Blanes Canyon reaches about 0.8 s thickness and 6 km width (Fig. 3A). A broad separated drift north of Menorca occurs on the lower slope at depths down to 2000 m. This drift is approximately 150 km long, 0.5 s thick, 25 km wide and reaches 100 m elevation above the seafloor (Menorca CFs) (Fig. 3B). This drift also exhibits sediment waves and a contourite moat (200 m deep, 5 km wide) along its seaward margin (Mauffret, 1979; Velasco *et al.*, 1996; Ercilla *et al.,* 2000). Sediment waves also occur along the Gulf of Valencia continental margin (Valencia CFs). One of these situated along the outer continental shelf exhibits wavelengths of 400-800 m and heights of 2-4 m. A second example at 250 to 850 m water depth exhibits wavelengths of 500 to 1000 m and wave amplitudes of 2 to 50 m (Ribó *et al.,* 2016). This latter field of sediment waves is developed along a possible prograding plastered drift approximately 0.5 s thick (Fig. 3C, Table II). Several separated drifts have also been identified developed locally around seamounts in this sector (Fig. 3D).

Several plastered drifts with upslope-prograding stacking pattern have also been reported. These include a 10-km-wide plastered drifts with thicknesses ranging from 1 to 0.5 s and developed at water depths of 400-800 m and 1100-1400 m (Barcelona CFs) (Fig. 4A) and mounded, plastered, shallow-water contourites (Mallorca CFs) in a slope canyon near western Cabrera Island (southwest of Mallorca) at water depths of 250-600 m (Fig. 4B, Table II). A field of sediment waves is also present at the surface (Vandorpe *et al.,* 2011; Lüdmann *et al.,* 2012). Several plastered drifts of approximate 0.5 s thickness also occur around seamounts in the Valencia Trough at depths between 500 m and > 1100 m (Valencia CFs), in the southern Ibiza Channel and along the SE Iberian margins between depths of 600 and 900 m (Murcia CFs) (Fig. 3D, Table II).

Contourites in the Alboran Sea display a great variety of both depositional and erosional features that range from a few to several tens of kilometres in length (Alboran CDS) (Fig. 5A). Their morphologic and sedimentary characteristics have recently been described by Ercilla *et al.* (2016) and Juan *et al.* (2016). Depositional features predominate and are categorized as different types of drifts (Ercilla *et al.,* 2002, 2012, 2016; Palomino *et al.,* 2011; Juan *et al.,* 2012, 2013, 2014, 2016). The largest drifts are plastered and sheeted types (Fig. 5B-C and 6A, Table II). *Plastered drifts* occur along the continental slopes of both the Iberian and African margins between water depths of 235 and 575-1000 m, respectively. These drifts appear in seismic images as upslope onlapping stratified facies that pinch out in both upslope and downslope directions (Fig. 5B and C). The *sheeted drifts* occur along the base of the central Iberian slope and in the western and southern Alboran basins at water depths below approximately 500 m. These appear as parallel-stratified seismic layers with a sub-tabular geometry beneath a relatively flat seafloor (Fig. 6A). Several small plastered and sheeted drifts occur locally along the flanks and tops of seamounts (Fig. 5C). Smaller drifts include separated (Fig. 5B and 6B), channel-related (Fig. 6C) and mounded, confined drifts (Fig. 6D) (Palomino *et al.,* 2010, 2011; Ercilla *et al.,* 2012, 2016; Juan *et al.,* 2012, 2013, 2014). Separated drifts occur along the westernmost upper and lower African slopes, and at the foot of structural seamounts and diapirs (Fig. 6B). In seismic images, they show onlapping stratified facies with internal discontinuities that display a mounded geometry. *Channel-related drifts* make up part of the seafloor within the Alboran Trough, appearing in the corridor between the Xauen bank and the African slope. Channel-related drifts consist of isolated irregular, stratified layers scattered within the channel floor (Fig. 6C). *Confined drifts*, situated between structural highs, display a mounded morphology, which consists of internally stratified layers (Fig. 6D).

The erosional contourite features are located primarily along the Alboran margin and consist of *moats, scarps* and *furrows* (Ercilla *et al.,* 2016, and Juan *et al.,* 2016). The *moats* are mostly associated with separated and confined drifts. A few incipient moats also occur along the walls of the structural highs, where the slope exhibits changes in bathymetric patterns (Fig. 5B and 6B). *Scarps* are narrow, steep erosional surfaces roughly parallel to the margin, which occur in association with landward flanks of terraces and other basal features along the slope. Scarps mark the transition between the basin's physiographic/oceanographic provinces. *Furrows* occur as linear features incised into steep, distal erosional escarpments of the African margin, near the Strait of Gibraltar. Extensive *terraces* represent mixed depositional and erosional features. These form the tops of plastered drifts along the continental slope. Terraces along the African margin are more pronounced (Fig. 5B). Terraces transition seaward into an onlapping, concordant surface.

3.2. Gulf of Cadiz

3.2.A. Oceanographic setting

The modern hydrodynamic setting of the Gulf of Cadiz is dominated by the exchange of water between the Atlantic Ocean and Mediterranean Sea through the Strait of Gibraltar. This gateway allows egress of warm, saline Mediterranean Outflow Water (MOW), which flows into the Atlantic Ocean, and overlying inflow of the Atlantic Water into the Mediterranean Sea (Lacombe and Lizeray, 1959; Ochoa and Bray, 1991; Baringer and Price, 1999; Nelson *et al.,* 1999; Iorga and Lozier, 1999; Potter and Lozier, 2004; Lozier and Sindlinger, 2009) (Fig. 1 and Table I). The MOW is an intermediate water mass composed of waters originating in the Mediterranean Basin (Ambar and Howe, 1979; Bryden and Stommel, 1984; Bryden *et al.,* 1994; Millot *et al.,* 2006). The water mass accelerates through the narrow Strait of Gibraltar, reaching local velocities as high as 300 cm/s (Ambar and Howe, 1979; Mulder *et al.,* 2003) and moves northwestwards along the middle continental slope of the Gulf of Cadiz. This MOW flow occurs under the AIW and above the North Atlantic Deep Water (NADW). The AIW consists of the North Atlantic Superficial Water (NASW) from the surface down to a depth of approximately 100 m and the Eastern North Atlantic Central Water (ENACW), which flows between depths of 100 and 600 m. In the Gulf of Cadiz, the Modified Antarctic Intermediate Water (AAIW) (Louarn and Morin, 2011) circulates above the MOW (Hernández-Molina *et al.,* 2014b). The underlying NADW flows southwards from the Greenland-Norwegian Sea region at depths greater than 1500 m (Baringer and Price, 1999; Ambar *et al.,* 1999; Serra *et al.,* 2005).

In the Gulf of Cadiz, the MOW flow is controlled by the complex morphology of the continental slope. Flow is locally enhanced where salt tectonics have created diapiric ridges oblique to the MOW flow direction (Fig. 1). These ridges are partially responsible for splitting the MOW into numerous distinctive cores (Fig. 1), although vertical layering within the main MOW core has also been proposed as an alternative controlling mechanism (Sannino *et al.,* 2007; Millot, 2009; Copard *et al.,* 2011). The main water cores are the Mediterranean Upper Core (MU) and the Mediterranean Lower Core (ML), each of whose branches displays unique salinity, temperature and average velocity (Madelain, 1970; Zenk, 1975; Ambar and Howe, 1979; Gründlingh, 1981; Börenas *et al.,* 2002; Serra *et al.,* 2005) (Fig. 1). The MU flows along-slope along the southwestern Iberian margin at depths of 500-800 m, and part of its flow is captured by Portimão Canyon along the Algarve margin (Marchès *et al.,* 2007). The ML generally flows northwestwards at an average velocity of 20-30 cm/s (Llave *at al.,* 2007) with the major part of flow concentrated west of 7° W (Madelain, 1970). At this longitude, a branch detaches from the south side of the ML and flows southwest. At approximately 7° 20’ W, the ML divides into three distinct branches that generally flow northwest: the Southern Branch (SB), the Principal Branch (PB) and the Intermediate Branch (IB) (Fig. 1). Portimão Canyon and Cape St. Vincent also create a series of eddies, referred to as meddies due to their MOW origins (Ambar *et al.,* 2002, 2008; Serra *et al.,* 2005).

3.2.B. Contourite features

Erosional features are common in the Strait of Gibraltar, where high bottom current velocities prevent deposition (Kelling and Stanley, 1972; Stanley *et al.,* 1975; Serrano *et al.,* 2005). Esteras *et al.,* (2000) identified several large channels likely associated with MOW circulation as the dominant contourite features. A few isolated plastered drifts also occur along the northern continental slope (Fig. 7A and B).

Beyond where the MOW exits the Strait of Gibraltar, its interaction with the middle slope of the southwestern Iberian margin has produced one of the most extensive and complex contourite depositional systems ever described. This feature is referred to as the Gulf of Cadiz CDS (Fig. 7, Table II) (e.g., Madelain, 1970; Kenyon and Belderson, 1973; Gonthier *et al.,* 1984; Nelson *et al.,* 1999; Llave *et al.,* 2015; Stow *et al.,* 2002a, 2002b, 2002c; Habgood *et al.,* 2003; Hernández-Molina *et al.,* 2006; Mulder *et al*., 2006; Hanquiez *et al*., 2007; Marchès *et al*., 2007; Roque *et al.,* 2012; Brackenridge *et al.,* 2013 and references therein). The main depositional features are sediment wave fields, sediment lobes, mixed drifts, plastered drifts, separated drifts and sheeted drifts. The major erosional features are contourite channels, furrows, marginal valleys and moats (García *et al.,* 2009). All of these features occur at specific locations along the margin, and their distributions correspond to five morphosedimentary sectors within the CDS. Sector 1 includes proximal scours and ribbons. Sector 2 includes overflow sediment lobes. Sector 3 includes channels and ridges. Sector 4 includes contourite deposition and Sector 5 includes submarine canyons (Hernández-Molina *et al.,* 2003, 2006; Llave *et al.,* 2007). The development of each of these five sectors through time is related to an overall systematic deceleration of the MOW along the margin, with localised acceleration due to its interaction with irregularities along the seafloor. The middle slope of the Gulf of Cadiz is a bathymetrically complex area composed of mixed contourite features. This slope hosts four relatively flat contourite *terraces* with gradients of less than 0.5º at average depths of 500, 675, 750 and 850 m (García *et al.,* 2009; Hernández-Molina *et al.,* 2012, 2014b). These terraces are bounded by relatively steep risers with gradients of 1.5-3º. Terraces form by both depositional and erosional processes.

Four sets of separated drifts have been described at water depths of 500 to 700 m along the Algarve margin: the Faro-Albufeira, Portimão, Lagos and Sagres drifts (Table II). The Faro-Albufeira drifts are the most extensive and best developed. The Álvarez Cabral moat restricts these features to the upper slope. The drifts display asymmetric shapes and sigmoidal-oblique, prograding stacking patterns (Fig. 7C). These drifts rise 150-200 m above the adjacent moat axis and surrounding deposits, and grade southwards into the Faro and the Bartolomeu Dias sheeted drifts, where the seafloor is smooth and almost flat (Fig. 7D). The Portimão and Lagos drifts extend approximately 50 km from Portimão Canyon but are separated by Lagos Canyon. These display a smooth mounded morphology and categorize as sheeted drifts (Hernández-Molina *et al.,* 2003; Marchès *et al.,* 2007, 2010). However, Roque *et al.* (2012) reported that the Lagos drift grades from a sheeted drift near Lagos Canyon to a plastered drift near the San Vicente high and finally to a separated drift. The Sagres drift occurs at the transition between the southern and western Portuguese margins.

Sheeted drifts, with an aggrading stacking pattern and gentle morphology, occur between water depths of 600 and 1600 m in the contourite depositional and submarine canyons sectors (Vanney and Mougenot, 1981). These were deposited across hundreds of kilometres, over which they are crossed by diapiric ridges, deformed and eroded by large contouritic channels of Sector 3 (channels and ridges sector) (Fig. 8A-C) (García, 2002; Mulder *et al.,* 2002, 2003; Habgood *et al.,* 2003; Hernández-Molina *et al.,* 2003, 2006; Llave, 2003; Llave *et al.,* 2007).

Extensive bedforms include ripple marks, sand ribbons and sediment waves (Fig. 8D). Longitudinal mounded drifts (Fig. 9A) are well developed in a NW-SE direction in Sector 1 (proximal scours and ribbons sector) and in Sector 2 (overflow sediment lobes sector) (Hernández-Molina *et al.,* 2006; Llave *et al.,* 2007).

Composite erosional features occur along the Guadalquivir Bank. Along with numerous diapiric highs (isolated and ridge-form), these include four types of submarine valleys (moats, channels, marginal valleys and furrows) in Sector 3 (García, 2002; Hernández-Molina *et al.,* 2003, 2006; García *et al.,* 2009) (Fig. 9). The main erosional features along the middle slope of the central Gulf of Cadiz (Sector 3) include five major contourite channels (Fig. 8A-C). These occur along the southern flanks of the diapiric ridges and the Guadalquivir Bank. They include (from north to south) the Diego Cao, Huelva, Gusano, Guadalquivir and Cadiz Contourite channels (García *et al.,* 2009). Different channels assume different dimensions but all display sinuous trends in the down-slope to along-slope directions. The Cadiz and Guadalquivir channels (Fig. 8A) represent the largest features (1 and 12 km wide, respectively, more than 100 km long, up to 130 m deep). Marginal valleys are unique erosional features located along northwest sides of the diapiric ridges and isolated diapirs within the channels and ridges sector (Fig. 9E). These features exhibit irregular orientations but a locally sinuous morphology with a predominantly NE-SW trend

(García *et al.,* 2009). Their incision depths can exceed 250 m at some localities. The most prominent example of these features in the Gulf of Cadiz is the Alvarez Cabral contourite moat (Fig. 7C), which is associated with the Faro-Albufeira mounded drifts (Sector 4) (Gonthier *et al.,* 1984; Llave *et al.,* 2001; García, 2002; Stow *et al.,* 2002c; Hernández-Molina *et al.,* 2003, 2006; Marchès *et al.,* 2007). This moat (80 km long, 3.5-11 km wide) incises the base of the Algarve margin's upper slope and trends WSW, parallel to the slope.

Sector 1, located at water depths of between 500 and 1000 m, is where the majority of the erosional features occur. This locality hosts abrasive surfaces (Fig. 9B) and several NW-SE-trending erosional scours (Fig. 9C) formed across an extensive area (90 km long and 30 km wide) (Kenyon and Belderson, 1973; Habgood, 2002; Hernández-Molina *et al.,* 2003, 2006). This sector also hosts two main channels (Fig. 9A) (Hernández-Molina *et al.,* 2012, 2014b). The southern channel forms due to WSW-trending erosion from the Camarinal Sill and at 3-4 km width, represents the most significant erosional feature near the Strait of Gibraltar. The northern channel is obscured by infill near the Strait but becomes more distinct towards the northwest, where it joins the Cadiz and Guadalquivir contourite channels (Hernández-Molina *et al.,* 2014b). Both southern and northern channels host an associated mounded drift along the seaward side of the channel and numerous small oblique furrows (Fig. 9A) (Hernández-Molina *et al.,* 2014b). Several reports have interpreted furrows in the overflow sedimentary lobe sector (Sector 2) as erosional features related MOW dynamics and gravitational processes (Habgood *et al.,* 2003; Mulder *et al.,* 2003; Hanquiez *et al.,* 2007; García *et al.,* 2009). The best-developed furrow is the Gil Eanes furrow (Fig. 9D), situated at water depths between 900 and 1200 m. Kenyon and Belderson (1973) first described this feature while Habgood *et al.* (2003), Hanquiez *et al.* (2007) and García *et al.* (2009) published subsequent descriptions. The furrow is approximately 50 km long and has a width of 0.8-1.7 km, a sinuous trend, and erosional incision of up 90 m.

3.3. West Iberia

3.3.A. Oceanographic setting

Four main water masses flow along the western Iberian margin at different depths (Fig. 1 and Table I). As the main shallow currents, (1) the Portugal Current (PC) flows southward while the Portugal Coastal Current (PCC) flows towards the north (Fiúza *et al.,* 1998; Pérez *et al.,* 2001; Martins *et al.,* 2002; Peliz *et al.,* 2005; Varela *et al.,* 2005). The ENACW (2) of subtropical origin extends down to water depths of 600 m (McCartney and Talley, 1982; Fiúza, 1984; Pollard and Pu, 1985; Ambar and Fiúza, 1994; Fiúza *et al.,* 1998; Perez *et al.,* 2001) and moves north from about 200-300 m. A component of ENACW of subpolar origin moves south from about 300-400 m (Ambar and Fiuza, 1994; Fiúza *et al.,* 1998). After exiting the Gulf of Cadiz, the MOW (3) splits into three principal branches: a main branch flowing northwards, a second branch flowing westwards and a third branch flowing southwards towards the Canary Islands before veering westwards (Ambar and Howe, 1979; Iorga and Lozier, 1999; Slater, 2003). The northern branch flows along the middle slope of the Portuguese margin towards the Galician margin and the Bay of Biscay. This branch includes two distinct cores centred at water depths of 800 m and nearly 1200 m. Along the Oporto continental slope, the MOW mixes with the ENACW flowing at depths between 250 and 540 m. At approximately 42°N, the MOW bifurcates intermittently into two branches (Mazé *et al.,* 1997). Of these, one branch flows west of the Galicia Bank plateau and the other flows north along the continental slope of the Iberian Peninsula (Iorga and Lozier, 1999; González-Pola, 2006). The deep-water masses (below 2000-m water depth) of the western Iberian margin consist of the southwards-flowing NADW and northwards-flowing Lower Deep Water (LDW) (4) (van Aken, 2000). This LDW forms primarily from the mixing of the deep Antarctic Bottom Water (AABW) and the Labrador Deep Water (LADW) (Le Floch, 1969; Botas *et al.,* 1989; Haynes and Barton, 1990; McCartney, 1992; Pingree and Le Cann, 1990; Van Aken, 2000; McCave *et al.,* 2001; Valencia *et al.,* 2004).

3.3.B. Contourite features

The Sines drift (a separated drift) represents the main contourite depositional feature of western Iberia. Mougenot (1989) first identified this feature as a contourite based on its general mounded morphology and wavy seismic patterns (Fig. 10A and B, Table II). The Sines drift is bounded by two of the Portuguese margin's major canyons: Setúbal Canyon to the north and San Vicente Canyon to the south (Fig. 10A). Formed by MOW circulation, the drift is an elongated, plastered sedimentary body formed below 750 m water depth along the gentle (~0.5°) N-S trending continental slope of the Alentejo margin (AM) (Fig. 10B). Roque *et al.,* (2015) recently discovered an extensive area (approximately 52 km long and 34 km wide) of the Sines drift affected by slope failure and mass wasting.

Recent reports have documented additional local contourite features occurring around structural highs and topographic irregularities associated with the circulation of either the MOW (300-2000-m water depth) or LDW (>2000-m water depth). Roque *et al.* (2015) recently identified a new separated drift offshore of Aveiro on the continental rise at a water depths of approximately 2500 m (Fig. 10C, Table II. Neves *et al.* (2009) reported evidence of a contourite between water depths of 2300 and 3000 m reaching approximately 1.5 s thickness and 2.5 km width. This contourite drift is separated from a structural high by a moat (Fig. 10C). Large-scale sediment waves also appear in high-resolution seismic reflection data (Fig. 10D), along with localised synsedimentary deformation and primary faulting within contourite drift strata (Alves *et al.,* 2000, 2003).

Clear examples of both depositional (plastered drift, separated drift, sediment waves) and erosional (terraces, moats, furrows) features occur along the Galician continental margin and rise (Galicia Bank CFs) (Ercilla *et al.,* 2006, 2008a, 2009, 2011; Bender *et al.,* 2012; Hanebuth *et al.,* 2015; Llave *et al.,* 2018; Collart *et al.,* 2018). The plastered drifts occur as low-relief mounds of a few kilometres in length, and tens to a few hundred metres in thickness. Their internal structure as revealed by high to very high amplitude acoustic reflections highlights well-stratified, aggradational-progadational seismic features of good lateral continuity (Fig. 10E, Table II). Plastered drifts along the continental slope occur: i) on the northwestern flank (2100 m water depth), ii) along the northern scarp (1600 m water depth), iii) at the base of certain structural highs (between 1500 and 4980 m deep) within the Galicia Bank plateau (Ercilla *et al.,* 2011) and iv) along the distal part of the Ortegal marginal platform (OMP) between water depths of 700 and 1100 m (Fig. 10E) (Jané *et al.,* 2012; Llave *et al.,* 2013, 2018). These drifts display smooth and terraced morphology (*Ortegal CDS*), a morphology which contrasts the numerous adjacent submarine canyons incised into the seafloor.

Major separated drifts occur at four locations. The first location lies along the lower continental slope of the western Galician continental margin, specifically at the foot of and near highs reaching approximately 2000 m water depth (Ercilla *et al.,* 2006; Bender *et al.,* 2012). Sediment waves contour the surface of this drift. The second drift occurs in the Transitional Zone (TZ: 1600 to 2500 m) (Ercilla *et al.,* 2011). A third occurs along the Galicia Bank plateau (GB: 700-800-m water depth), where several moats and associated drifts (15 to 250 m tall from the moat axis to the top of the drift crest and 1-5 km wide) are developed at its foot and around the numerous highs (Fig. 11A). Elongated separated drifts have formed on one flank adjacent to three of the aforementioned highs while local plastered drifts form on the other flank (Ercilla *et al.,* 2008a, 2011a). As such, these separated drifts form part of the Galicia Bank CFs*.* The fourth separated drift locality occurs at the heads of Ferrol and A Coruña canyons at water depths of 500 and 700 m, and as part of the Pardo Bazán marginal platform at a depth of 1600 m in the Ortegal CFs (Fig. 11B). These drifts exhibit mounded shapes and are 5-22 km long, 2-10 km wide and average 50 m in thickness (Jané *et al.,* 2012; Llave *et al.,* 2013, 2018; Collart *et al.,* 2018). A separated drift occurs at the foot of the highs across the lower slope of the western Galician continental margin (Bender *et al.,* 2012). Several of these drifts host sediment waves, which are also developed at the heads of Ferrol and A Coruña canyons (Jané *et al.,* 2012; Llave *et al.,* 2018; Collart *et al.,* 2018).

Abraded surfaces are tens of metres in relief and several hundreds of metres long. Seismic images show reflectors for these features terminating against eroded seafloor surfaces that form large-scale contourite terraces. The main abraded surfaces occur along the Ortegal, Pardo Bazán and Castro marginal platforms (OMP, PBMP and CMP respectively) where they form three contourite terraces at water depths of 200-600 m, 900-1800 m, and 2000-3500 m, respectively (Ortegal CDS) (Fig. 11C) (Jane *et al.,* 2012; Llave *et al.,* 2018). These represent structural highs (Fig. 11D) (Ercilla *et al.,* 2008a, 2011). The Ortegal terrace is the most extensive of these highs, spanning approximately 150 km in length, up to 70 km in width to the north and approximately 20 km width in the south (Llave *et al.,* 2013, 2018). Moats are erosional features that typically occur at the foot of structural scarps and highs (Fig. 11A). These can represent tens of metres (depth) and hundreds of metres (width) of erosional incision. Their asymmetric, V-shaped cross-sections exhibit steeper eastern margins (Ercilla *et al.,* 2011). Several moats occur on the Ortegal terrace and at the heads of Ferrol and A Coruña Canyons (Fig. 11B) (Jané *et al.,* 2012; Llave *et al.,* 2013, 2018; Collart *et al.,* 2018).

Older contourite deposits may also occur along the western Iberian margin, particularly within the Iberian abyssal plain (southern *Galicia Bank CFs*). Sediment waves occur within the upper rise according to Miocene through Quaternary sediments drilled at ODP Site 1069 (Whitmarsh *et al.,* 1998) and according to middle Eocene deposits offshore of Oporto, drilled by ODP Leg 149 and in the DSDP Leg 48B area (Wilson *et al.,* 1996, 2001). Soares *et al.* (2014) have described several Cretaceous drifts consisting of elongated mounded drifts along the outer proximal margin. These workers inferred the presence of sheeted drifts along the distal margin offshore of northwest Portugal deposited after the Aptian-Albian lithospheric breakup. Near the continental margin of the Galicia Bank, deposits drilled by ODP-Leg 103 (Boillot *et al.,* 1987; Comas and Maldonado, 1988), DSDP-Leg 47B Site 398 along the southern margin of the Vigo Seamount (Maldonado, 1979), and ODP-Leg 149 Sites 897 through 901 (Alonso *et al.,* 1996; Milkert *et al.,* 1996), were also interpreted as contourites deposited in the late Miocene.

3.4. Cantabrian margin

3.4.A. Oceanographic setting

Along the Cantabrian continental margin, most of the water masses originate in the North Atlantic or result from interactions between waters originating in the Atlantic and Mediterranean. The uppermost water mass is the ENACW, which extends to depths of approximately 400 to 600 m and flows westwards along the continental margin (Fig. 1 and Table I) (González-Pola, 2006). It generally flows at a velocity of 1 cm/s, although it can occasionally reach velocities of up to 10 cm/s (Pingree and Le Cann, 1990). Between water depths of 400-500 and 1500 m, the MOW follows the continental slope as a contour current (Fig. 1). Seafloor irregularities and the Coriolis effect control the local MOW circulation. Although detailed information is lacking on MOW circulation in the Bay of Biscay, it appears to split into two branches around the Galicia Bank. One of these continues northwards while the other flows eastwards along the Cantabrian margin slope (Iorga and Lozier, 1999; González-Pola, 2006). From Ortegal Spur to Santander, the MOW propagates along the slope at reduced velocities. Its minimum velocity is around 2-3 cm/s at 8^{o} W and 6^{o} W (Pingree and Le Cann, 1990; Diaz del Rio *et al.,* 1998). The NADW occurs between water depths of 1500 and 3000 m (Fig. 1) and includes a core of LSW at a depth of approximately 1800 m (Vangriesheim and Khripounoff, 1990; McCartney, 1992). The LDW forms beneath the NADW primarily due to mixing of the deep AABW and the LSW (Botas *et al.,* 1989; Haynes and Barton, 1990; McCartney, 1992) (Fig. 1). A cyclonic recirculation cell develops over the Biscay abyssal plain. This feature exhibits a characteristic polewards velocity near the continental margin of 1.2 (±1.0) cm/s (Dickson *et al.,* 1985; Paillet and Mercier, 1997).

3.4.B. Contourite features

The Le Danois CDS has been identified along the Cantabrian margin (Fig. 12, Table II) in an area surrounded predominantly by down-slope processes (Ercilla *et al*., 2008b; Iglesias, 2009; Van Rooij *et al.,* 2010). This CDS includes both depositional and erosional features (separated drifts, plastered drifts, moats and scours) generated by the MOW circulation and controlled by seafloor irregularities including two topographic highs, the large Le Danois Bank and the smaller Vizco High (Fig. 12A) (Van Rooij *et al.,* 2010).

The Le Danois CDS includes two separated drifts: the Gijón and Le Danois drifts. The Gijon drift occurs along the upper slope at water depths of approximately 400-850 m and has a maximum thickness of 0.25 s (Fig. 12B, Table II). The Le Danois drift occurs at the foot of the southern side of the Le Danois Bank at water depths between 800 and 1500-1600 m. This feature is approximately 0.3 s thick and varies in width, reaching as much as 10 km width in its central part but only spanning 3.5 to 4 km to the west and 4.7 km to the east (Fig. 12B). Three plastered drifts of about 1 s thickness occur along the upper, southern slope of the Le Danois Bank (Van Rooij *et al.,* 2010). These appear as mounded relief along the western edge between water depths of 600 and 750 m and on the eastern edge at depths of 750-1100 m and 1100-1550 m (Fig. 12C, Table II).

Moats and scours are the main erosional features of the Le Danois CDS. The two moats identified are referred to as the Gijón and Le Danois moats. As the upslope continuation of Gijón Canyon, the Gijón moat trends NW-SE and spans approximately 45 km length and 1-4 km width. This feature begins at 1100 m water depth, incises an additional 400 m in the west and disappears to the east (Fig. 12B). The Le Danois moat trends in a WNW-ESE direction and extends from depths of 800 to 1500 m towards the east. It spans 48 km in length, varies from 0.8 to 2.8 km in width and incises 75-105 m of surface (Fig. 12B). Scour alignments trending NE and ENE occur on one of the plastered drifts. These span 5.5-28 km in length, 1250 m in width and run ~5 m deep (Van Rooij *et al.,* 2010).

3.5. Sedimentology of contourite features

Contourite deposits along the Iberian margin range in grain size from clay to sand but primarily categorize as mud-rich. Deposits include thin, interbedded layers of fine-grained sand and silt of terrigenous and biogenic origin. The fine-grained beds are predominantly poorly sorted, intensely bioturbated and typically display broad rhythmic bedding (Stow *et al.,* 2002a, b).

Gonthier *et al.* (1984) and Faugères *et al.* (1984) proposed the original contourite facies model sequence based on research across the Faro drift along the middle slope of the Gulf of Cadiz. Their model consists of two superposed units, including a basal coarsening-upward unit grading from homogeneous mud (clay, fine silt) to mottled coarser silt and finally to sandy silt/silty sand. This is followed by a fining-upward unit with an inverse facies succession. This general ‘bigradational’ model theoretically represents an increase bottom current flow followed by a decline in current strength (Stow and Holbrook, 1984; Stow *et al.,* 2002c; Huneke and Stow, 2008). Stow and Faugères (2008) extended this model to include five sedimentary divisions applied to the standard bigradational contourite sequence (C1-C5) (Fig. 13). The model can be applied to contourites of siliciclastic, volcanic, bioclastic or mixed composition. Bioturbation limits preservation of sedimentary structures but indistinct to discontinuous parallel laminations, coarser sand layers or rare cross laminations may occur. The facies model interprets the bigradational sequence as two shifts in the strength of the bottom-current flow: from weak to strong, and then back to weak. The continued presence of coarsening/fining upwards trends in grain size along with strong bioturbation and mottling indicates continuous, gradual (relative to gravity flow deposits) deposition of sediments through bottom current processes. As the velocity increases, coarser sediment predominates as removal of the fine fraction produces coarser, better sorted sedimentary packages (Nelson *et al.,* 1993). Stow and Faugères (2008) also described sandy contourites that contain an inversely graded lower sub-sequence (mud + mottled silt and mud units), a middle sandy silt and an upper, normally graded sub-sequence (mottled silt and mud + mud units). Most of these deposits were interpreted as bottom current-modified turbidites (Faugères and Stow, 1993, 2008; Stow *et al.,* 2002b, c; Stow and Faugères, 2008). Mulder *et al.* (2013) concluded that contourite sequences record changes in bottom current velocity and flow competency but may also depend on sediment supply. These workers hypothesized that increased erosion of mud along the flanks of confined contourite channels and moats or increases in sediment supply by rivers and down-slope mass transport along the continental shelf and upper slope provided the coarse, terrigenous sediment observed.

Coarse terrigenous sediment is significant in the Gulf of Cadiz. Research from IODP Expedition 339 and other cores from other cruises have detected voluminous, mature and well to moderately sorted contourite sands that form laterally extensive sheeted drifts, channel-floor cover or patch drifts in contourite channels (Buitrago *et al.,* 2001; Viana *et al.,* 2007; Hanquiez, 2006; Hanquiez *et al.,* 2007; Viana, 2008; Stow *et al.,* 2011a, 2011b, 2013a; Brackenridge *et al.,* 2013; Hernández-Molina *et al.,* 2014a, 2014b, Brackenridge et al., 2018).

The Ortegal Spur of the Ortegal contourite terrace (Llave *et al.,* 2013) also hosts compositionally mature, coarse and silty sands. Sands specifically consist of subrounded and well-sorted quartz and glauconite grains with abundant bioclastic fragments. The bioclasts include fragments of foraminifera, gastropods, bivalves and pteropods (Alejo *et al.,* 2012).

3.6. Translating seismic facies to sedimentary facies

Contourite features are described and systematised here according to their seismic characteristics. Interpretations therefore depend heavily on external drift morphology, internal stacking pattern of depositional units and other aspects apparent in seismic images. Local and regional water circulation patterns and paleoceanographic models support these interpretations.

Drift morphologies (i.e., separated, sheeted, plastered and confined drifts) are recognized at the scale of the drifts themselves (Fig. 14). Slope-plastered contourite drifts predominate upper slope settings. These often occur in the presence of elongated erosional surfaces along the uppermost slope and in downslope areas, accompanied by a mounded along-slope elongated drift, with frequent sediment waves and internal erosional surfaces (Fig. 14). In middle and lower slope areas, complex seafloor physiography caused by tectonics creates obstacles for current flow. These features induce local acceleration and create a considerable variety of drifts and erosional features such as moats, channels and furrows (Fig. 14). Middle and lower slope areas also host contourite terraces, which form from both depositional and erosional processes (Fig. 14).

Depositional units within contourites reported around Iberia are generally lenticular in shape, and have a well-layered, convex-up seismic units of good lateral continuity along both strike and dip (Figs. 2-12). Stacking patterns show downlapping (onlapping on steep slopes) and sigmoidal progradational reflector patterns where downstream and upslope migration occurred (Figs. 2-12).

Table III lists seismic facies most commonly recognized from Iberian contourite drifts. Among these are: (a) transparent layers of variable thickness intercalated with zones of high to moderate amplitude seismic reflectors, particularly in sheeted drifts (Figs. 6A, 7D, 8A-C), (b) smooth, parallel, moderate to high amplitude reflectors typically interbedded with transparent zones in plastered drifts and common throughout mounded, confined and channel-related drifts (Figs. 2B, 3A-D, 4A-B, 5B-C, 6B-D, 7C 9A, 10 B-C, 11A-B and 12B-C). Discontinuous seismic facies include short, discontinuous to chaotic reflectors (c) of moderate to high amplitude occurring in most drifts, particularly in mounded drifts and moats (Figs. 2A, 3A-and 3D, 6B-C, 7C, 9A, 10C, 11A, 12B). Sigmoid progradational reflectors (d) occur in mounded drifts where strong downstream and/or oblique migration has occurred. They are also common in separated drifts (Figs. 3B, 7C, 12B). Gently wavy reflectors (e) are common over parts of several drifts (Figs. 3C, 8D, 10D). Contourite terraces and practically all contourite depositional systems host horizontal and low-inclination (f) reflectors truncated at the seafloor or by an internal erosional surfaces (e.g. Figs. 4A-B, 5B, 9A-B, 11B-C).

Relatively uniform deposits (fine or coarse sediments) tend to exhibit transparent or weak seismic facies whereas extensive sheets of interbedded coarse- and fine-grained sediments exhibit higher amplitude seismic reflectors with good lateral continuity. The aforementioned laterally extensive progradational to aggradational seismic units with sub-parallel, variable amplitude reflectors indicate muddy compositions. By contrast, moats within contourite channels and many contourite terraces exhibit High Amplitude Reflections (HARs). These high amplitude seismic reflections span a few kilometers in width and are interpreted as coarse-grained sediments (Deptuck *et al.,* 2003; Posamentier and Kolia, 2003). These facies occur in erosional features such as moats and along channels axes (Table III), which develop in channels around seafloor irregularities. Contourite terraces (e.g., Alboran, Gulf of Cadiz, WIM, Ortegal) (Fig. 14 and Table III) and overflow features can also appear as HAR seismic facies. The Gulf of Cadiz' proximal Sector 1 is an example of an overflow feature where an exceptionally thick sandy sheeted drift appears as an extensive HAR unit (Fig. 14).

Contourite features described here occur at depths corresponding to the principal interfaces between MAW-LIW-WMDW in the Western Mediterranean Sea, and between the ENACW- MOW-NADW in the Atlantic. The HARs however do not appear to correspond with enhanced bottom currents, development of terraces on top of plastered drifts or bottom current modification of sand layers exposed at the seafloor surface. Their origin and interpretation remain unresolved in spite of their economic potential as hydrocarbon reservoirs.

4. DISCUSSION

4.1. Factors influencing contourite seismic /sedimentary facies changes

Contourite drifts along the Iberian margin exhibit certain stratigraphic patterns in their reflection amplitudes (Figs. 2-12). These patterns include a more transparent facies (T) at the base, higher amplitude reflections (R) in the upper part and a subtle but continuous high-amplitude erosional surface at the top. In the case of the Faro Drift (Gulf of Cadiz) these variations have been attributed to long-term changes in bottom-current strength at different scales through the latest Pliocene and Quaternary (Llave *et al.*, 2001; Stow *et al.,* 2002a, 2002b, 2002c; Hernández-Molina *et al.,* 2016b). This mechanism creates repeated coarsening-upward sequences bounded by erosional surfaces at unit and sub-unit scales.

In the case of the Gulf of Cadiz CDS, several studies interpreted these facies as reflecting changes in MOW bottom current strength (e.g., Gonthier *et al.,* 1984; Faugères *et al.,* 1985a; Stow *et al.,* 1986, 2002c; Sierro *et al.,* 1999; Roque *et al.,* 2012) linked to eustatic/climatic drivers and MOW variability (Voelker e*t al.,* 2006; Toucanne *et al.,* 2007; García *et al.,* 2009; Rogerson *et al.,* 2012; Bahr *et al.,* 2014; Hernández-Molina *et al.,* 2014a). IODP Expedition 339 sampled some of the Gulf of Cadiz CDS seismic facies and found that transparent seismic facies corresponded to fine-grained contourites while HARs corresponded to mature, well-sorted contourite sands that reached up to 10 m in thickness (Stow *et al.,* 2013b; Hernández-Molina *et al.,* 2014b, 2016b).

Interacting factors determine the degree to which bottom currents can influence the morphology of the Iberian margin. At longer time scales, tectonic factors determine the role that downslope sediment transport plays in margin development. Tectonics also influence contourite sedimentation as the mechanism producing remnant marginal platforms, structural highs and the opening of the Gibraltar Strait itself (i.e., northwestern Iberian margins, Maestro *et al.,* 2015; Llave *et al.,* 2018). On shorter time scales, climate and sea-level changes cause deepening or shoaling of water masses. This in turn controls the vertical distribution of sand and mud deposits, associated acoustic facies, stratigraphic stacking patterns and thicknesses. Climate and sea-level changes also drive the general behavior of the water masses and influence depositional styles along the margins. In the Gulf of Cadiz and west of Iberia, Mediterranean water masses flowed more swiftly and at greater depths during glacial periods (Schönfeld and Zahn, 2000; Rogerson *et al.,* 2005; Llave *et al.,* 2006; Voelker *et al.,* 2006; Ercilla *et al.,* 2016). This would favor local development of sandy contourites at intermediate to lower water depths along the continental slope. These factors explain the Iberian margin's overall sedimentary evolution from dominantly downslope or mixed along-slope/down-slope sedimentary processes at the beginning of the Pliocene to more along-slope sedimentation with the Quaternary opening of the Strait of Gibraltar (Roque *et al.,* 2012; Brackendridge *et al.,* 2013; Hernández-Molina *et al.,* 2016b; Ercilla *et al.,* 2016).

The relationship between oceanographic processes and the depositional, erosional and mixed features observed among Pliocene and Quaternary contourites allows for interpretation of similar features in the ancient record. Ancient oceans consisted of different water masses and circulation regimes than those observed today (e.g., Hay, 2009). The most discernible patterns belong to extreme glacial maxima and greenhouse conditions (Pickering and Hiscott, 2016). Records left by ancient water masses should nevertheless resemble sandy and muddy deposits described here.

4.2. Implications for petroleum exploration

Thick and widespread progradational to aggradational depositional units characterized by sub-parallel reflectors of varying amplitude in seismic images are interpreted to represent fine-grained drifts occurring throughout the Iberian margin. Continuous high-amplitude reflections (HARs) indicative of sandier contourites occur in moats and channels, in contourite terraces and in sectors with sheeted drifts affected by overflows. IODP Expedition 339 drilled several of these drifts around the Gulf of Cadiz and western Iberian Margin. These features exhibit seismic facies similar to those observed in other sectors of the Iberian margin. Sampling of these drifts showed that sub-parallel reflectors of variable amplitude corresponded to muddy contourites that were sometimes enriched in organic carbon (up to 2 wt.%). These units could therefore serve as both seals and potential source rocks (Stow *et al.,* 2013b; Hernández-Molina *et al.,* 2013). Sampling of seismic features associated with sandy contourites also suggests extensive distribution of mature, well-sorted Pliocene to Quaternary sands (Expedition 339 Scientists, 2012; Stow *et al*., 2013b; Hernández-Molina *et al*., 2013). HARs indicate sandy contourites for example, in southeasterly areas of the Gulf of Cadiz (affected by the overflow processes), where Brackenridge *et al.* (2013, 2018) identified a tabular, aggradational sedimentary stacking pattern associated with a buried, mixed, contourite-turbidite succession. This feature includes a sand- and clay-rich interval between 925 and 1740 m reaching 815 metres thickness. With 600 m of sand alone, this contourite could serve as a potential reservoir unit (Buitrago *et al.,* 2001; García-Mojonero and Olmo, 2001). Cakebread-Brown *et al.* (2003) have also interpreted HARs and AVO anomalies from this unit as high-porosity (30%), gas-bearing contourite sands.

The Santos Drift in the northern Santos Basin includes > 600 m of fine-grained Neogene-aged sand and silt and thus acts as seal rock for Paleogene oil-bearing sandstones (Duarte and Viana 2007). Similar sandy contourites have been described along the Uruguayan margin (Hernández-Molina *et al.,* 2016c), within the Pliocene sedimentary record of the Gulf of Mexico (Shanmugam *et al.,* 1993), in Eocene deposits of the Campos Basin, Brazil (Mutti *et al.,* 1980; Viana and Rebesco, 2007) and in the northeastern Atlantic (Nelson *et al.,* 1993; Howe *et al.,* 1994; García-Mojonero and Martínez del Olmo, 2001; Habgood *et al.,* 2003; Stow *et al.,* 2002a, 2002b, 2013a, 2013b; Akhmetzhanov *et al.,* 2007; Hernández-Molina *et al.,* 2014a, 2014b). In these cases, HARs record contourite deposits mainly composed of medium- to fine-grained sand with common bedforms, such as mega-ripples and sand waves (Viana *et al.,* 1998, 2002; Stoker *et al.,* 1998; Masson *et al.,* 2004; Shanmugam, 2006, 2012a, 2013b; Mutti and Carminatti, 2012).

Similarities between these features and those described from the Gulf of Cadiz (Hernández-Molina *et al.,* 2016b) and Iberian continental margin indicate the economic potential of sandy contourites from these areas. The occurrence of coarse to fine grained sedimentary materials associated with contourites around Iberia could inform interpretation of deeper-water sedimentary facies from the ancient record. Emerging information on contourites could also facilitate innovations in deep-water petroleum exploration strategies.

5. CONCLUSIONS AND FUTURE AREAS OF STUDY

Contourite features of the Iberian continental margin include extensive depositional, erosional and mixed (depositional and erosional) features developed along the continental slope due to bottom current dynamics. Depositional features include mounded, elongated and separated, sheeted, plastered, confined and channel-related drifts. Erosional features include moats, channels and furrows while terraces are interpreted as mixed erosional/depositional features. Large mud-dominated contourite drifts with good, along-slope continuity could serve as petroleum source rocks. Moats, channels and sheeted drifts proximal to overflows and contourite terraces exhibit high amplitude reflections (HARs) in seismic images. These are interpreted as extensive sandy contourites that could also serve as potential hydrocarbon reservoirs.

The muddy/sandy contourites described here, along with the overall deep water morphology of the Iberian margin generally record intermediate to deep water masses and their interfaces from the Pliocene to Quaternary. The connection between observed features and mechanisms makes these features good analogs for interpreting recent or ancient deep water environments and useful in identifying potential seals and reservoir rocks. Similar contourite features in deeper or older sediments could represent future petroleum exploration opportunities. Advances in geophysics, offshore 3D seismic imaging and robust correlation with well-log and borehole data will help further understanding of contourites and their role in petroleum systems.

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FIGURE CAPTIONS

Figure 1. Surficial, intermediate and deep-water circulation around the Iberian continental margin (modified from Hernández-Molina *et al.,* 2011); digital bathymetric model obtained from Zitellini *et al.* (2009) and GEBCO (2003). Vertical hydrographic profiles: (A) East Iberian margin, (B) Gulf of Cadiz and (C) Galician margins (source data from the World Ocean Atlas, 2012). Locations of the study areas are also shown.

Figure 2. (A) Digital bathymetric model of the northeast Iberian margin and location of the main water masses and seismic profiles. (B) Multichannel seismic profile showing a mounded drift example as well as erosive features.

Figure 3. (A) Multichannel and (B) Sparker seismic profile (modified from Velasco *et al.,* 1996) showing mounded separated drifts and moats. (C) Multichannel seismic profile where sediment waves are developed on a plastered drift. (D) Multichannel seismic profile showing mounded and plastered drifts as well as erosional features around submarine highs. For location of the seismic profiles see Figure 2.

Figure 4. (A) Multichannel and (B) Sparker seismic profile (modified from Vandorpe *et al*., 2011) showing plastered drifts. For location of the seismic profiles see Figure 2.

Figure 5. Map of the Alboran Sea continental margin and locations of the main contourite features based (A) Digital bathymetric data and (B) Airgun and (C) Sparker seismic profiles (modified from Juan *et al.* 2012, 2013; and Ercilla *et al.* 2016) showing examples of plastered and mounded and separated drifts as well as erosive features.

Figure 6. (A) Airgun seismic profile showing an example of sheeted drift. (B) Airgun seismic profile showing an example of channel-related drift. (C) Sparker seismic profile showing a mounded separated drift and moat. (D) Airgun seismic profile showing a confined drift (modified from Juan *et al.,* 2012, 2013; and Ercilla *et al.,* 2016). For location of the seismic profiles see Figure 5.

Figure 7. (A) Digital bathymetric model of the Gulf of Cadiz continental margin and location of the main water masses. (B) Airgun seismic profile showing contourite drifts close to the Strait of Gibraltar. (C) and (D) Sparker seismic profiles showing mounded elongated and separated drift and its basinward prolongation as sheeted drift (modified from Llave *et al.,* 2001).

Figure 8. (A), (B) and (C) Sparker seismic profiles showing deformed sheeted drifts as well as contourite channels around diapiric ridges. (D) Sparker seismic profile showing sand waves (modified from Llave *et al.,* 2001; Hernández-Molina *et al.,* 2006, 2014b; and García *et al.,* 2009). For location of the seismic profiles see Figure 7.

Figure 9. (A) Airgun seismic profile where mounded drifts and contourite channels is described. (B-E) Sparker seismic profiles showing examples of contourite erosional features such as an abraded surface, an erosive scour, a furrow and a marginal valley (modified from Llave *et al*., 2001; Hernández-Molina *et al*., 2006, 2014b; and García *et al*., 2009). For location of the seismic profiles see Figure 7.

Figure 10. (A) Digital bathymetric model of the Western Iberian continental margin and continental rise, and location of the main water masses and seismic profiles. (B-C) Airgun and Sparker seismic profiles showing examples of mounded separated drifts and moats, and (D) sediment waves (modified from Alves *et al*., 2003, 2006; Pereira and Alves, 2011, and Roque *et al.,* 2012). (E) TOPAS seismic profile where it is shown an example of plastered drift (modified from Llave *et al*., 2013). AM: Alentejo Margin; GB: Galicia Bank; GIB: Galicia Interior Basin; TZ: Transitional Zone; OMP: Ortegal Marginal Platform; PBMP: Pardo Bazán Marginal Platform; CMP: Castro Marginal Platform.

Figure 11. (A-B) TOPAS seismic profiles showing examples of mounded separated drifts and moats (modified from Ercilla *et al.,* 2011 and Llave *et al.,* 2013). (C) Airgun seismic profile showing the distribution three contourite terraces (modified from Llave *et al.*, 2013). (D) TOPAS seismic profile where an abrasion surface is shown on a plastered drift (modified from Ercilla *et al.,* 2011). For location of the seismic profiles see Figure 10.

Figure 12. (A) Digital bathymetric model of the Le Danois continental margin, and location of the main contourite features based on and location of the main water masses and seismic profiles. (B and C) Airgun seismic profiles where mounded separated drifts and moats, as well as a plastered drift are shown (modified from Van Rooij *et al.,* 2010).

Figure 13. Standard contourite sequence of facies model, linked to variation in contour-current velocity (from Stow and Faugères, 2008, based on the original figure from Gonthier *et al.,* 1984).

Figure 14. Locations and depths (in m) of the main types of drifts along the Iberian margin: C: confined; Ch: channel related; M: mound; P: plastered; S: separated; Sh: sheeted; Sw: sediment waves. Image also shows contourite features (red), erosive features (purple) and unpublished features (orange). See Table I for more detail regarding their characteristics.

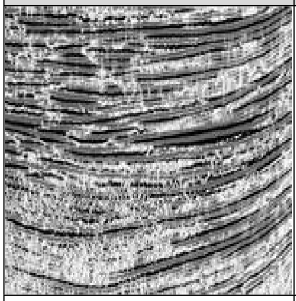
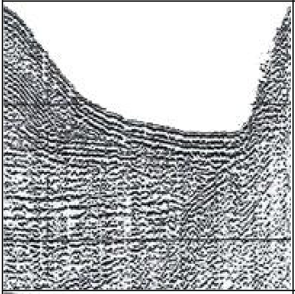
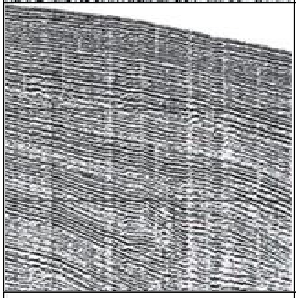
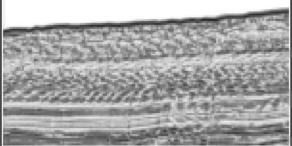
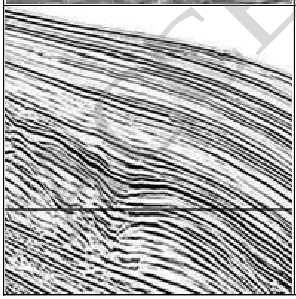
Table I. Acronyms of the main water masses present along the Iberian margin.

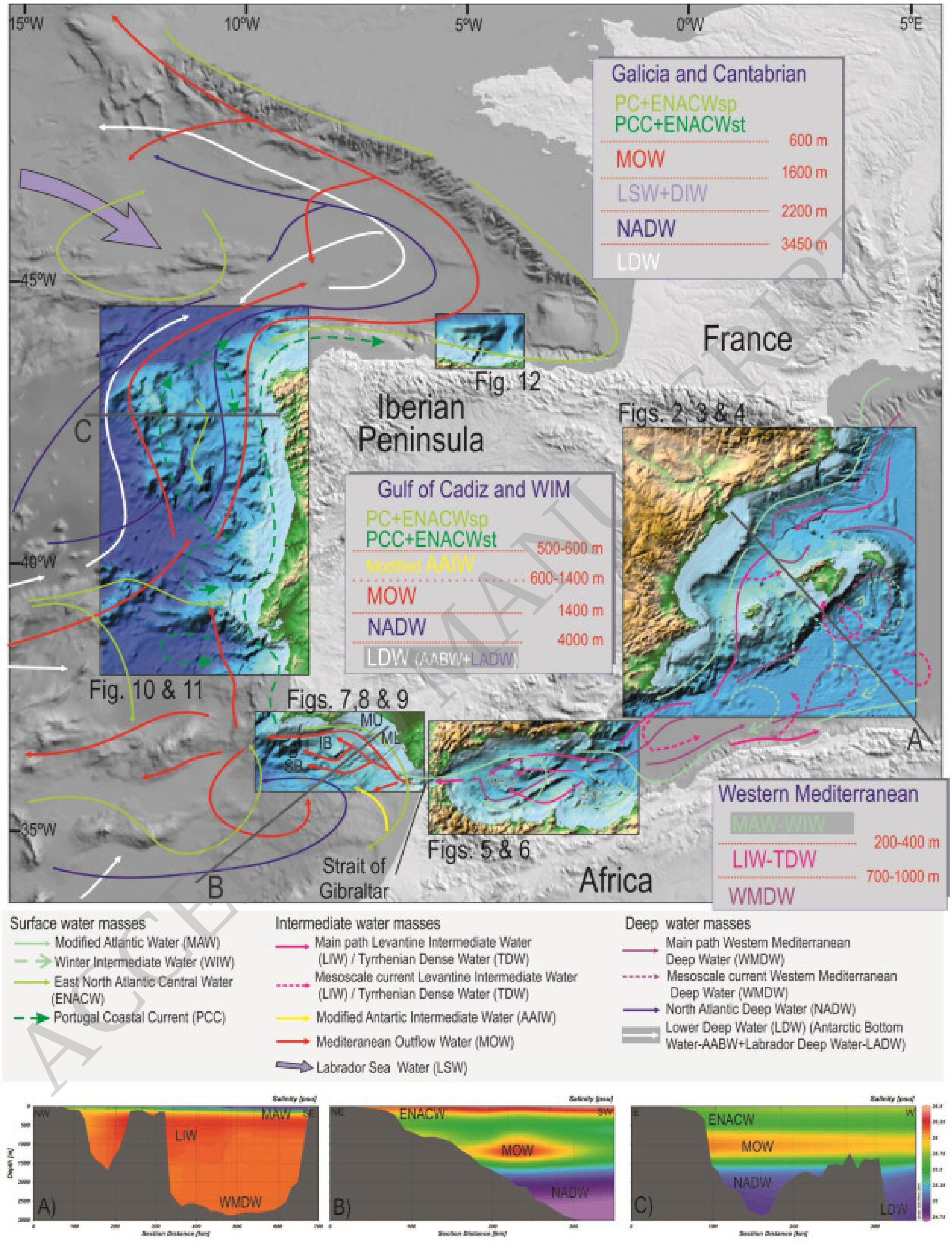
Table II. Acoustic facies, morphology and location of the main contourite features along the Iberian margin.

Table III. Main HARs for contourite features along the Iberian margins.

Mediterranean Sea	
AW	*Atlantic Water*
MAW	*Modified Atlantic Water*
EAG	*Eastern Alboran Gyres*
WAG	*Western Atlantic Gyre*
LIW	*Levantine Intermediate Water*
WMDW	*Western Mediterranean Deep Water*
WIW	*Western Intermediate Water*
TDW	*Tyrrhenian Dense Water*
LMW	*Light Mediterranean Waters*
DMW	*Dense Mediterranean Waters*
Gulf of Cadiz and West Iberia	
AIW	*Inflow of the Atlantic Water*
PC	*Portugal Current*
PCCC	*Portugal Coastal Counter Current*
ENACW	*Eastern North Atlantic Central Water*
AAIW	*Modified Antarctic Intermediate Water*
MOW	*Mediterranean Outflow Water*
MU	*Mediterranean Upper Core*
ML	*Mediterranean Lower Core*
NADW	*North Atlantic Deep Water*
LDW	*Lower Deep Water*
LADW	*Labrador Deep Water*
AABW	*Antarctic Bottom Water*
Galicia and Cantabrian	
LSW	*Labrador Sea Water*

Main depositional features	***Acoustic Facies***	***Shape/Dimensions***	***Location***
Mediterranean Sea: Barcelona CF			
Mounded drifts	Prograding upslope	High mound shape, ~5 km wide, few hundreds of m of relief	Middle-lower slope
Separated drifts	Prograding upslope	High mound shape, ~6 km wide, few tens of m of relief	Middle slope-lower slope
Plastered drifts	Prograding upslope-downslope	Low mound shape, ten km wide, few tens of m of relief	Upper-Middle slope
Mediterranean Sea: Valencia and Balearic Islands CF			
Plastered	Prograding upslope-downslope	Low mound shape, ten km wide, few tens of m of relief	Middle slope
Mediterranean Sea: Murcia CF			
Plastered	Prograding upslope-downslope	Low mound shape, ten km wide, few tens of m of relief	Middle slope
Mediterranean Sea: Alboran CDS			
Plastered drifts	Prograding upslope-downslope	Low to high mound shape, up to few hundreds of km long (< 300 km), 5.5 to 40 km wide, tens to a few hundreds of m of relief	Large drifts: Spanish and Moroccan slopes; Small drifts: seamounts flanks, Spanish base-of-slope
Sheeted drifts	Aggrading subaparallel stratified facies	Subtabular geometry; < 100 km long, 15 to 50 km wide	Large drifts: Spanish base-of-slope and subbasins; Small drifts: Alboran Ridge, seamounts tops
Channel-related drifts	Aggrading and prograding downward	Low mound shape. ~ 10 km long, <5 km wide	Alboran Trough
Mounded confined drifts	Prograding dowmward	High mound shape; Few to tens of km long and wide, 100 to 300 m of relief	Marginal shelf banks
Separated drifts	Prograding upslope	Low to high mound shape; < 40 km long, 20 km wide, few tens of m of relief	Moroccan slope and shelf-break scarp; Locally at the foot of seamounts and diapirs
Atlantic: Gulf of Cadiz CDS			
Plastered drifts	Prograding and aggrading downward	Low mound shape; ~ 10 km long, 5 km wide, few m of relief	Upper-middle slope
Separated drifts	Prograding upslope	High mound shape; 90 km long, 10-20 km wide, 150-200 m of m of relief	Middle and Lower slope
Sheeted drifts	Aggrading subaparallel stratified facies	Subtabular geometry; hundreds of km long, tens km wide	Middle slope
Atlantic: Western Iberian Margin CDS			
Mounded drift	Prograding upslope	Low mound shape; ~ 10 km long, ~ 10 km wide, few m of relief	Middle-Lower slope
Separated drifts	Prograding upslope	High mound shape; 5 km long, 5 km wide, few hundreds of m of relief	Middle-Lower slope; around structural high continental rise
Atlantic: Galicia & Ortegal CDS			
Plastered drifts	Prograding-aggrading upslope-downslope	Low mound shape, few km long, tens to few hundreds of m of relief	Middle-lower slope; at the base if structural highs slope-abyssal plain
Separated drifts	Prograding upslope	Low to high mound shape; 5 22 km long, 1-10 km wide, few tens to few hundred of m of relief	Middle-lower slope
Atlantic: Le Danois CDS			
Plastered drifts	Prograding upslope-downslope	Low mound shape, 10-20 km long, ~ 6 km wide, few m of relief	Upper southern slope of Le Danois Bank
Separated drifts	Prograding upslope	High mound shape; 10-45 km long, 3-10 km wide, few tens of m of relief	Middle slope

Seismic section	Seismic facies characteristics	Depositional setting	Location
	Transparent layers intercalated with high/moderate amplitude reflectors	Sheeted drifts	Proximal sector Gulf of Cádiz CDS
	Smooth, parallel moderate to high amplitude reflectors typically interbedded with transparent zones	Plastered drifts and throughout mounded, confined and channel-related drifts	Around Iberia middle continental slopes
	Short, discontinuous to chaotic reflectors of moderate/high amplitude reflectors	Moats, Channels, Furrows	Around Iberian continental slope bathymetric irregularities
	Sigmoid and/or oblique progradational reflectors with strong downstream migration	Mounded drifts	Around Iberia middle continental slopes
	Gently wavy reflectors	Over parts of several drifts	Around Iberia middle continental slopes and rise
	Horizontal or low-inclination high/moderate amplitude reflectors truncated by HARs erosional surfaces	Contourite terraces	Alboran Sea, Gulf of Cadiz, Galician margin (marginal platforms)



15ºW
10ºW
5ºW
0ºW
5ºE
45ºW
40ºW
35ºW
Galicia and Cantabrian
PC+ENACWsp
PCC+ENACWst
600 m
MOW
1600 m
LSW+DIW
2200 m
NADW
3450 m
LDW
France
Fig. 12
Iberian Peninsula
Figs. 2, 3 & 4
C
Gulf of Cadiz and WIM
PC+ENACWsp
PCC+ENACWst
500-600 m
Modified AAIW
600-1400 m
MOW
1400 m
NADW
4000 m
LDW (AABW+LADW)
Fig. 10 & 11
Figs. 7,8 & 9
MU
ML
IB
SB
A
Western Mediterranean
MAW-WIW
200-400 m
LIW-TDW
700-1000 m
WMDW
Figs. 5 & 6
Strait of Gibraltar
Africa
B
Surface water masses
Modified Atlantic Water (MAW)
Winter Intermediate Water (WIW)
East North Atlantic Central Water (ENACW)
Portugal Coastal Current (PCC)
Intermediate water masses
Main path Levantine Intermediate Water (LIW) / Tyrrhenian Dense Water (TDW)
Mesoscale current Levantine Intermediate Water (LIW) / Tyrrhenian Dense Water (TDW)
Modified Antartic Intermediate Water (AAIW)
Mediteranean Outflow Water (MOW)
Labrador Sea Water (LSW)
Deep water masses
Main path Western Mediterranean Deep Water (WMDW)
Mesoscale current Western Mediterranean Deep Water (WMDW)
North Atlantic Deep Water (NADW)
Lower Deep Water (LDW) (Antarctic Bottom Water-AABW+Labrador Deep Water-LADW)
NW
SE
MAW
LIW
WMDW
A)
NE
SW
ENACW
MOW
NADW
B)
E
W
ENACW
MOW
NADW
LDW
C)
Salinity (psu)
Depth (m)
Section Distance (km)

Figure 1

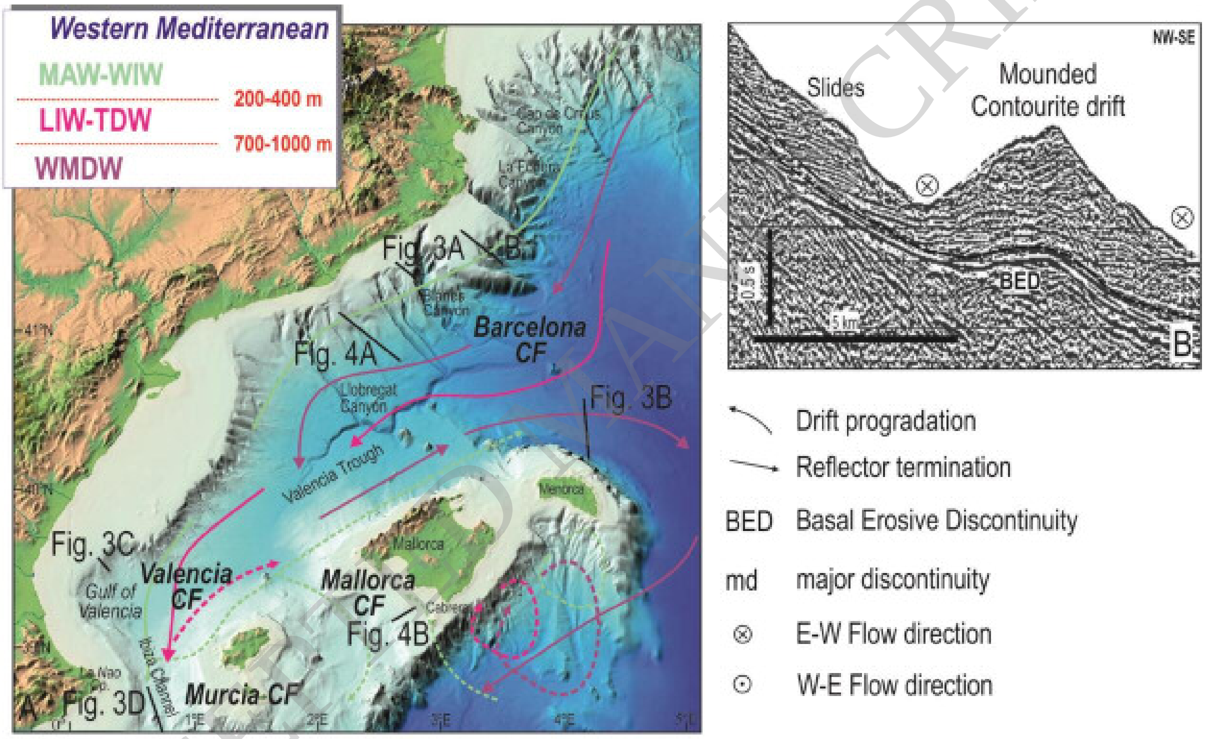

Western Mediterranean
MAW-WIW
200-400 m
LIW-TDW
700-1000 m
WMDW
Cap de Creus Canyon
La Fonera Canyon
Fig. 3A
B
Blanes Canyon
Fig. 4A
Barcelona CF
Llobregat Canyon
Fig. 3B
Valencia Trough
Menorca
Mallorca
Fig. 3C
Gulf of Valencia
Valencia CF
Mallorca CF
Cabrera
Fig. 4B
La Nao Cp.
Ibiza Channel
A
Fig. 3D
Murcia CF
41°N
40°N
39°N
0°
1°E
2°E
3°E
4°E
5°E
NW-SE
Slides
Mounded Contourite drift
BED
0.5 s
5 km
B
Drift progradation
Reflector termination
BED Basal Erosive Discontinuity
md major discontinuity
⊗ E-W Flow direction
⊙ W-E Flow direction

Figure 2

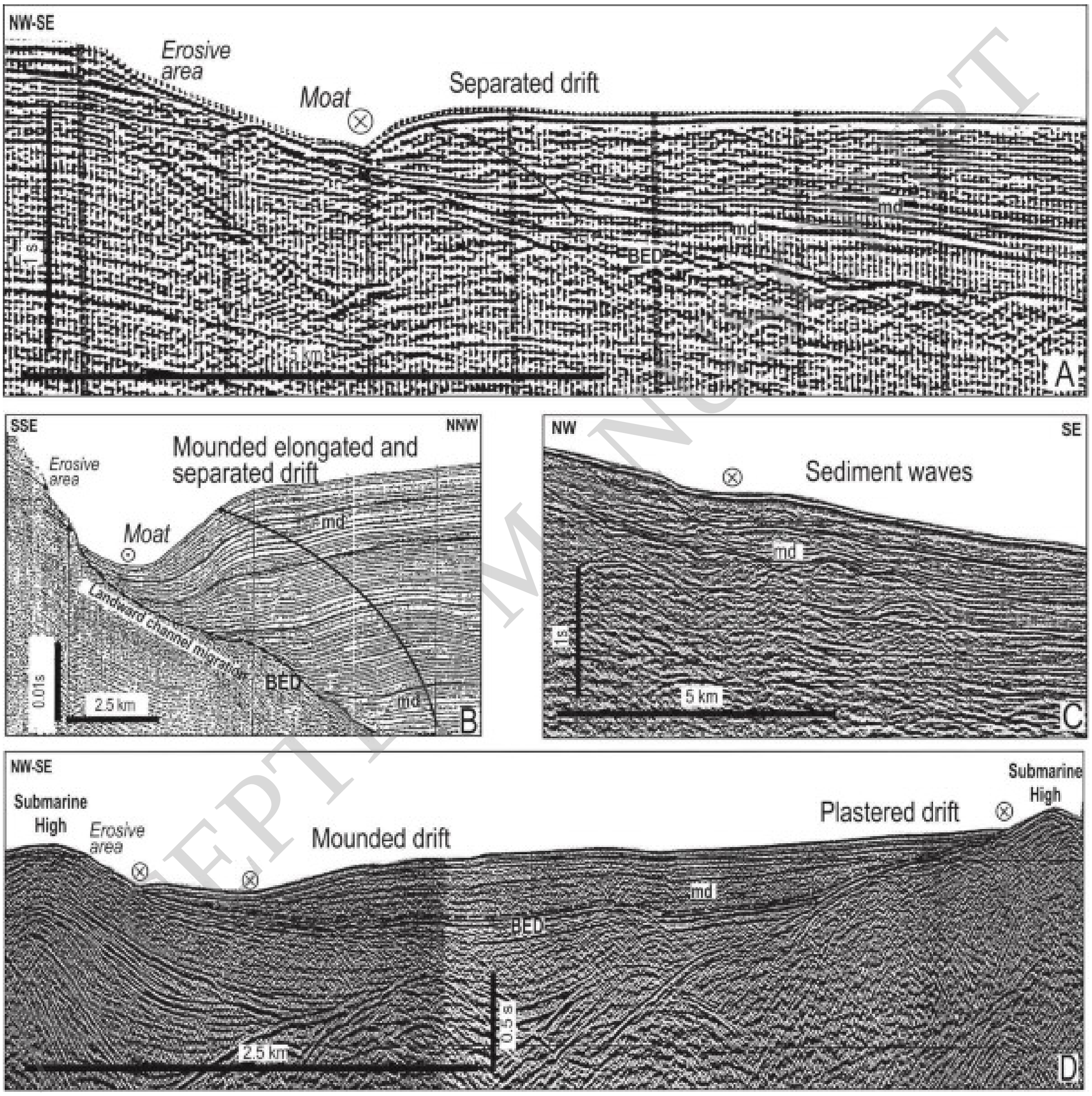

NW-SE
Erosive area
Moat
Separated drift
md
md
BED
1 s
5 km
A
SSE
NNW
Erosive area
Mounded elongated and separated drift
Moat
md
Landward channel migration
BED
md
0.01s
2.5 km
B
NW
SE
Sediment waves
md
1s
5 km
C
NW-SE
Submarine High
Erosive area
Mounded drift
Plastered drift
Submarine High
md
BED
0.5 s
2.5 km
D

Figure 3

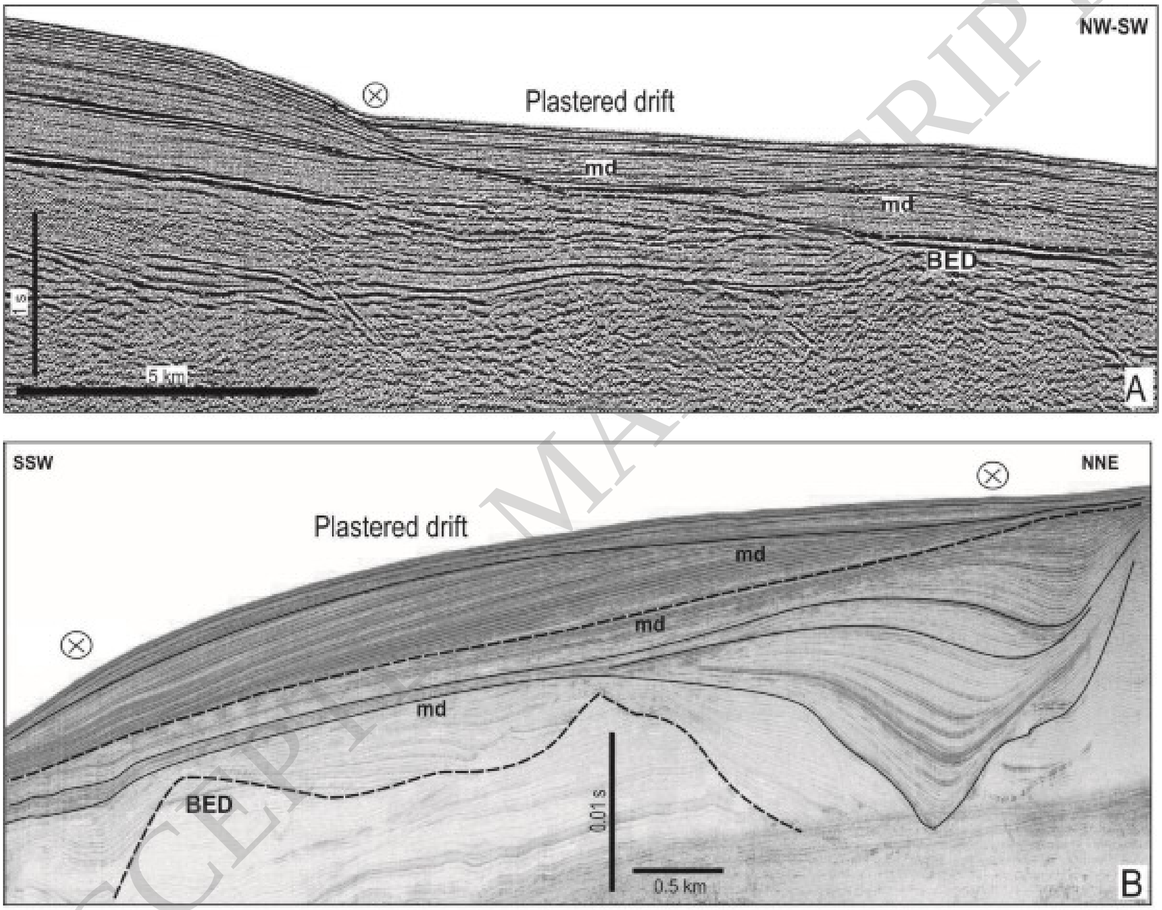

NW-SW
Plastered drift
md
md
BED
1 s
5 km
A
SSW
NNE
Plastered drift
md
md
md
BED
0.01 s
0.5 km
B

Figure 4

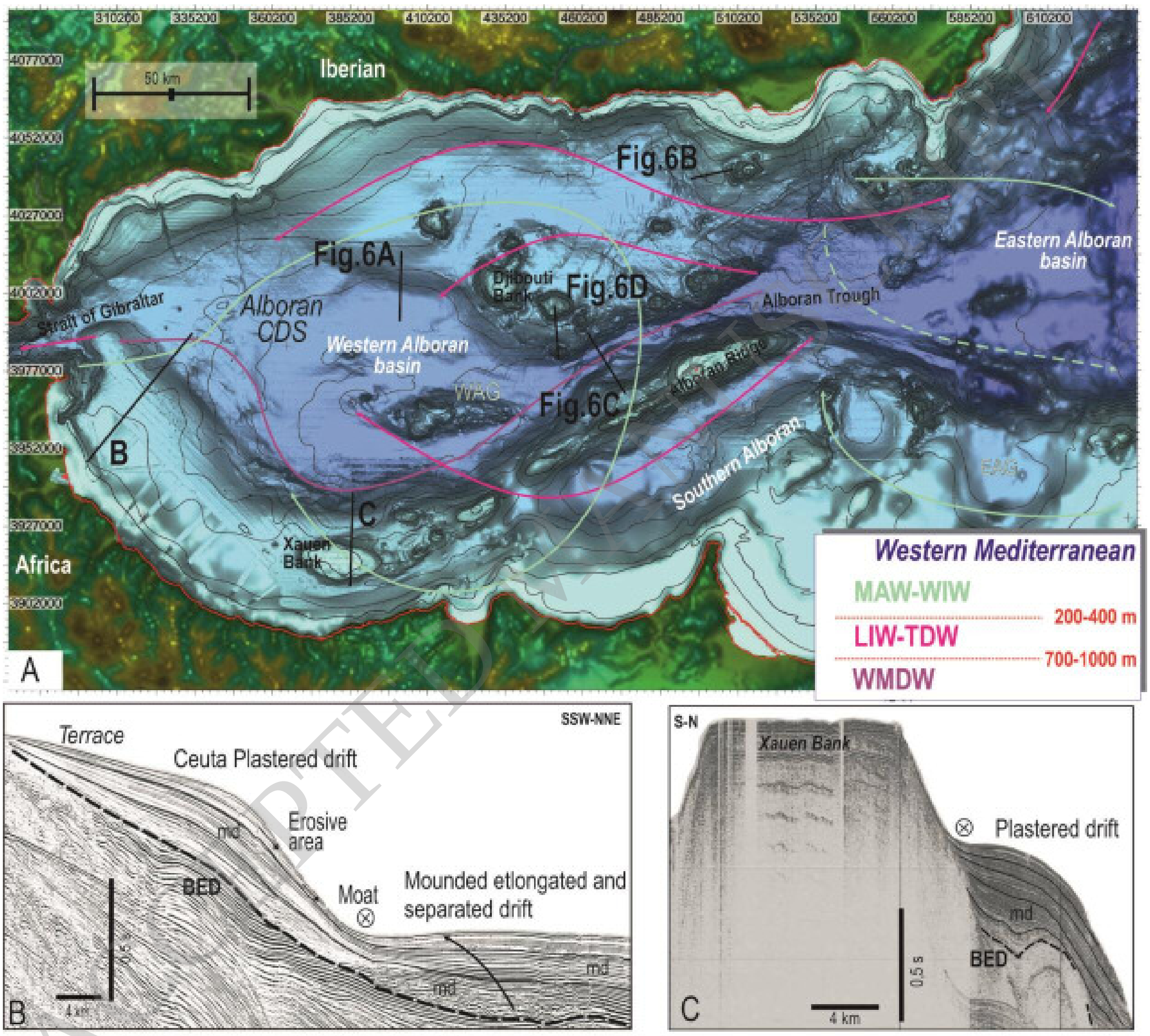

310200
335200
360200
385200
410200
435200
460200
485200
510200
535200
560200
585200
610200
4077000
4052000
4027000
4002000
3977000
3952000
3927000
3902000
50 km
Iberian
Fig.6B
Fig.6A
Djibouti Bank
Fig.6D
Eastern Alboran basin
Strait of Gibraltar
Alboran CDS
Western Alboran basin
Alboran Trough
WAG
Fig.6C
Alboran Ridge
Southern Alboran
EAG
B
C
Xauen Bank
Africa
A
Western Mediterranean
MAW-WIW
200-400 m
LIW-TDW
700-1000 m
WMDW
SSW-NNE
Terrace
Ceuta Plastered drift
md
Erosive area
BED
Moat
Mounded etlongated and separated drift
md
md
0.5 s
4 km
B
S-N
Xauen Bank
Plastered drift
md
BED
0.5 s
4 km
C

Figure 5

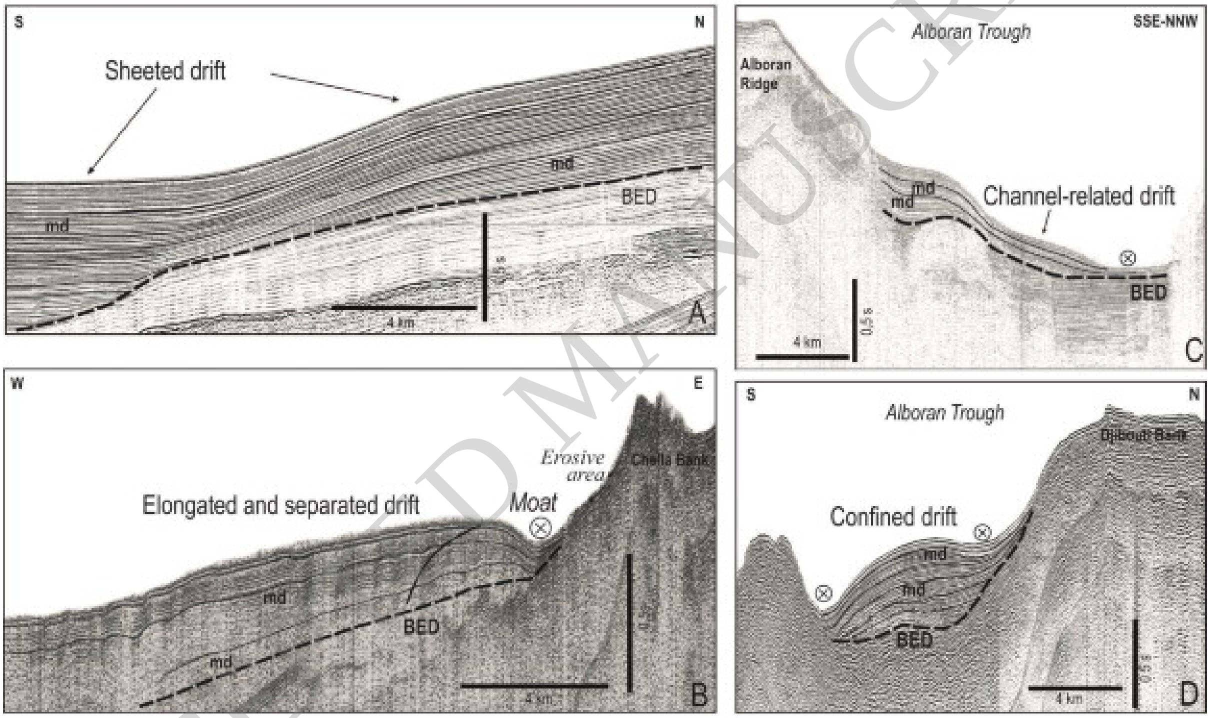

S
N
Sheeted drift
md
md
BED
0.5 s
4 km
A
Alboran Trough
SSE-NNW
Alboran Ridge
md
md
Channel-related drift
BED
4 km
0.5 s
C
W
E
Erosive area
Chella Bank
Elongated and separated drift
Moat
md
BED
md
0.5 s
4 km
B
S
N
Alboran Trough
Djibouti Bank
Confined drift
md
md
BED
4 km
0.5 s
D

Figure 6

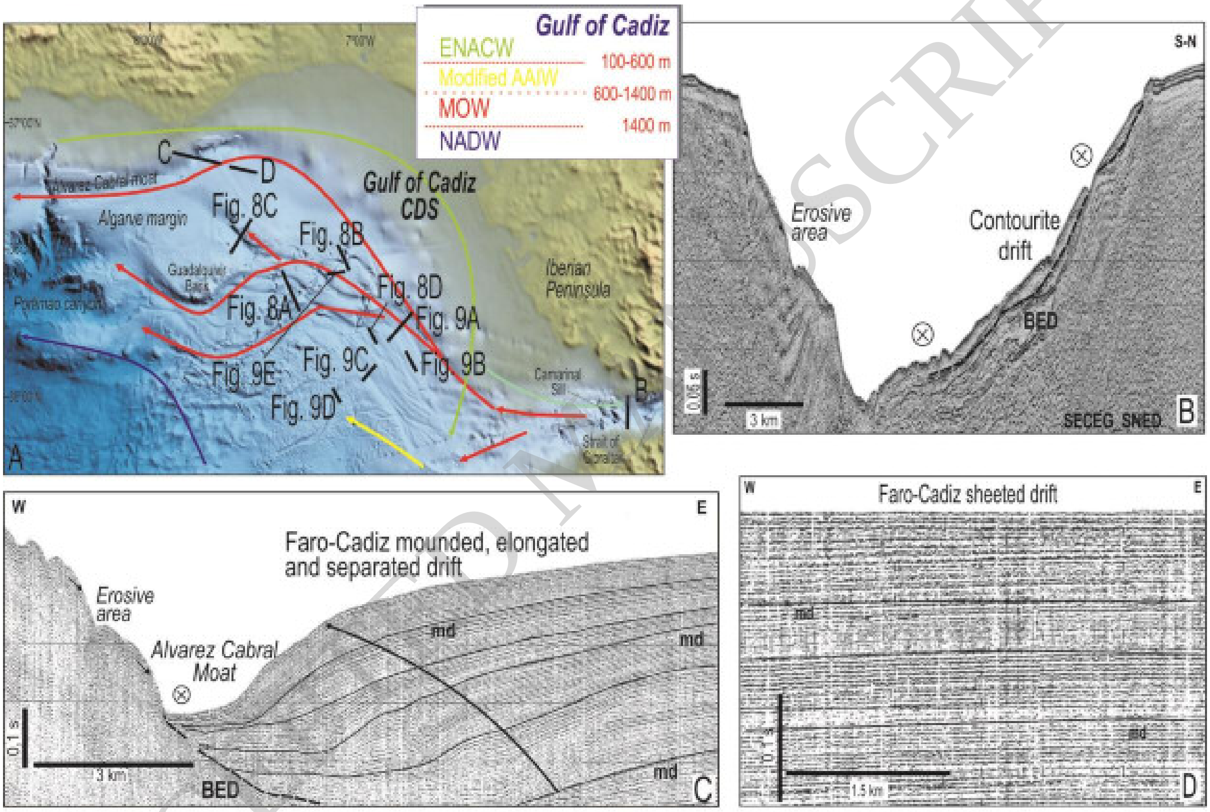

Gulf of Cadiz
ENACW
Modified AAIW
MOW
NADW
100-600 m
600-1400 m
1400 m
C
D
Alvarez Cabral moat
Algarve margin
Fig. 8C
Fig. 8B
Gulf of Cadiz CDS
Iberian Peninsula
Guadalquivir Bank
Portimao canyon
Fig. 8A
Fig. 8D
Fig. 9A
Fig. 9E
Fig. 9C
Fig. 9B
Fig. 9D
Camarinal Sill
B
Strait of Gibraltar
A
S-N
Erosive area
Contourite drift
BED
0.05 s
3 km
SECEG_SNED
B
W
E
Faro-Cadiz mounded, elongated and separated drift
Erosive area
Alvarez Cabral Moat
md
md
md
0.1 s
3 km
BED
C
W
Faro-Cadiz sheeted drift
E
md
md
0.1 s
1.5 km
D

Figure 7

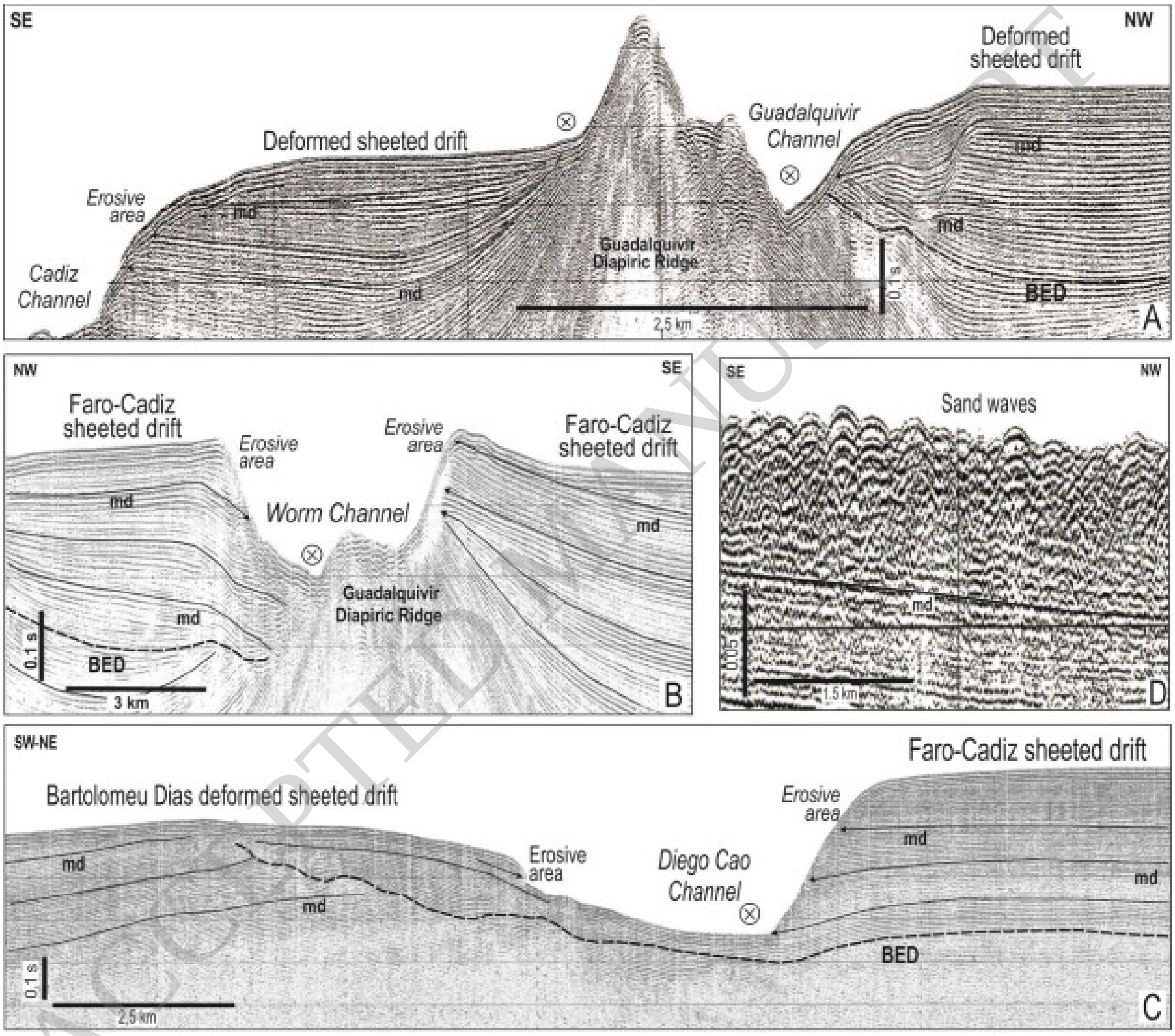

SE
NW
Deformed sheeted drift
Deformed sheeted drift
Guadalquivir Channel
Erosive area
md
Cadiz Channel
md
Guadalquivir Diapiric Ridge
md
md
BED
0,1 s
2,5 km
A
NW
SE
Faro-Cadiz sheeted drift
Erosive area
Erosive area
Faro-Cadiz sheeted drift
Worm Channel
md
md
Guadalquivir Diapiric Ridge
md
0,1 s
BED
3 km
B
SE
NW
Sand waves
md
0,05 s
1,5 km
D
SW-NE
Faro-Cadiz sheeted drift
Bartolomeu Dias deformed sheeted drift
Erosive area
md
md
Erosive area
Diego Cao Channel
md
md
md
BED
0,1 s
2,5 km
C

Figure 8

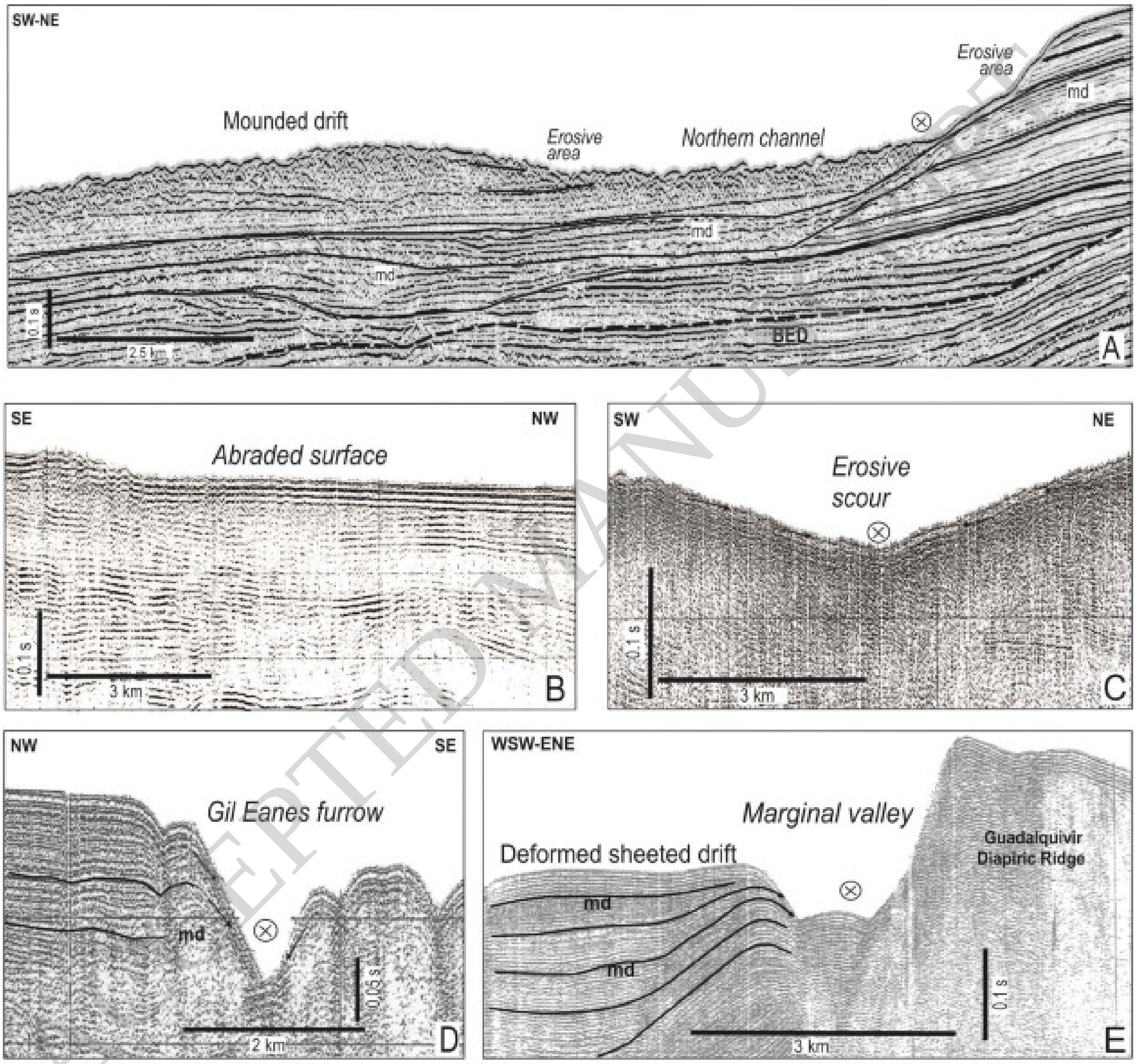

SW-NE
Mounded drift
Erosive area
Northern channel
Erosive area
md
md
md
BED
0.1 s
2.5 km
A
SE
NW
Abraded surface
0.1 s
3 km
B
SW
NE
Erosive scour
0.1 s
3 km
C
NW
SE
Gil Eanes furrow
md
0.05 s
2 km
D
WSW-ENE
Marginal valley
Deformed sheeted drift
Guadalquivir Diapiric Ridge
md
md
0.1 s
3 km
E

Figure 9

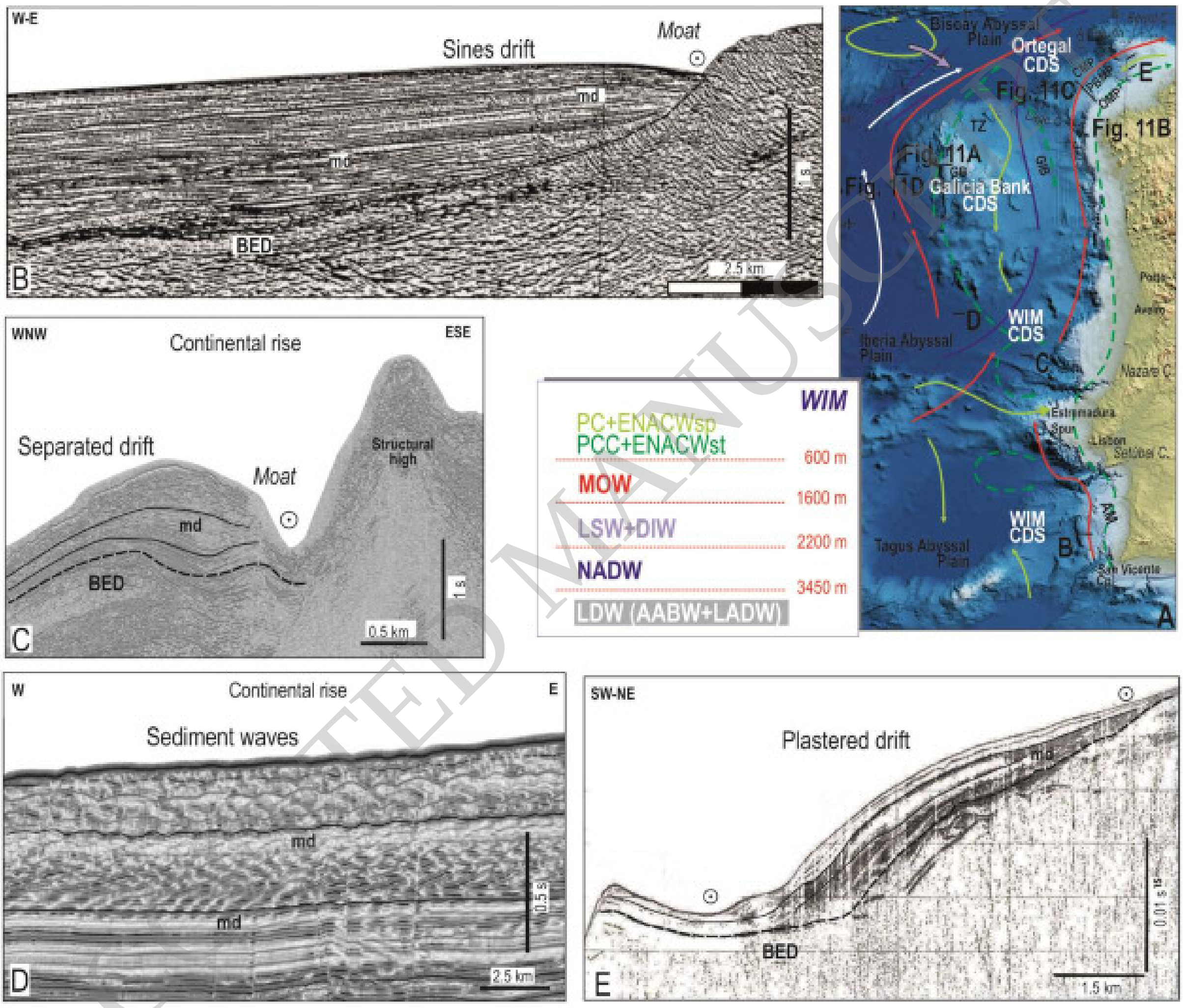

W-E
Sines drift
Moat
md
md
BED
1 s
2.5 km
B
WNW
Continental rise
ESE
Separated drift
Moat
Structural high
md
BED
1 s
0.5 km
C
WIM
PC+ENACWsp
PCC+ENACWst
600 m
MOW
1600 m
LSW+DIW
2200 m
NADW
3450 m
LDW (AABW+LADW)
Biscay Abyssal Plain
Ortegal CDS
Fig. 11C
E
Fig. 11B
TZ
Fig. 11A
Fig. 11D
Galicia Bank CDS
D
WIM CDS
Iberia Abyssal Plain
C
Nazare C.
Porto
Aveiro
Estremadura Spur
Lisbon
Setúbal C.
AM
Tagus Abyssal Plain
WIM CDS
B
San Vicente C.
A
W
Continental rise
E
Sediment waves
md
md
0.5 s
2.5 km
D
SW-NE
Plastered drift
md
BED
0.01 s
1.5 km
E

Figure 10

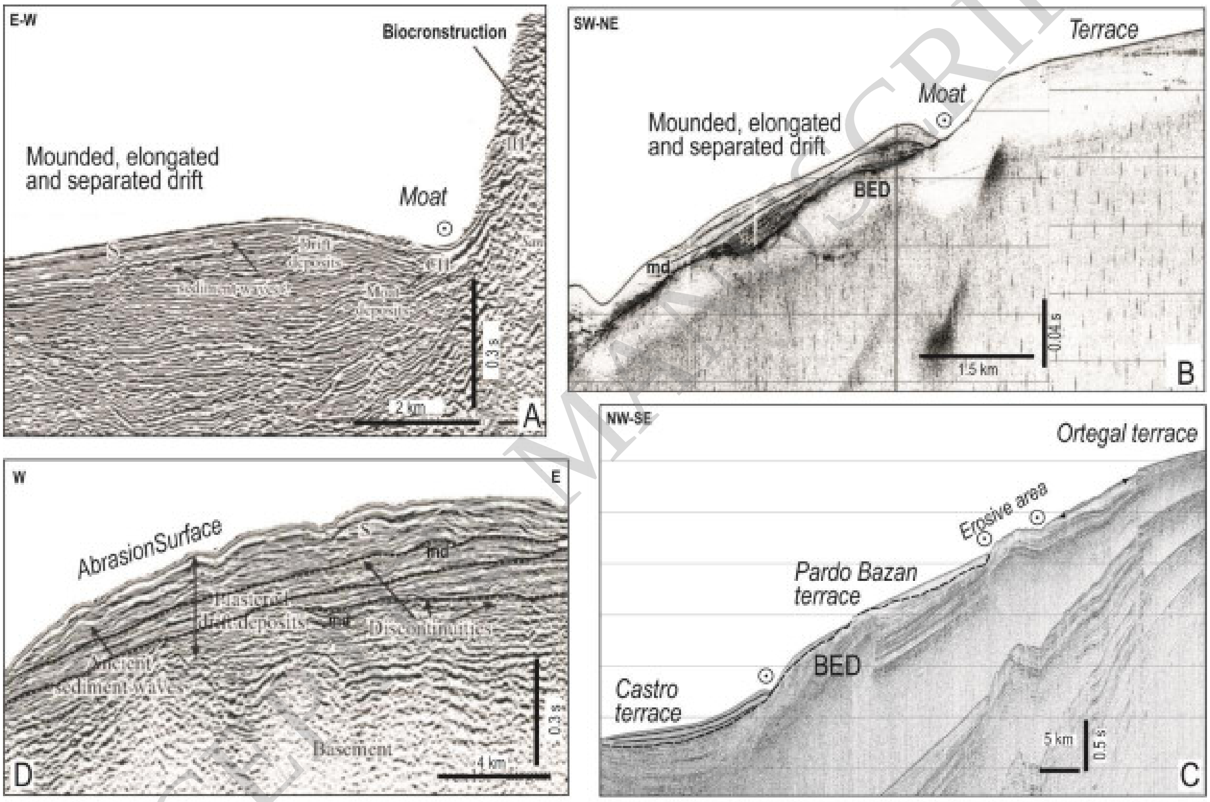

E-W
Biocronstruction
Mounded, elongated and separated drift
Moat
Drift deposits
Sediment waves
Moat deposits
0.3 s
2 km
A
SW-NE
Terrace
Moat
Mounded, elongated and separated drift
BED
md
0.04 s
1.5 km
B
W
E
Abrasion Surface
md
Plastered drift deposits
Discontinuities
Ancient sediment waves
Basement
0.3 s
4 km
D
NW-SE
Ortegal terrace
Erosive area
Pardo Bazan terrace
BED
Castro terrace
5 km
0.5 s
C

Figure 11

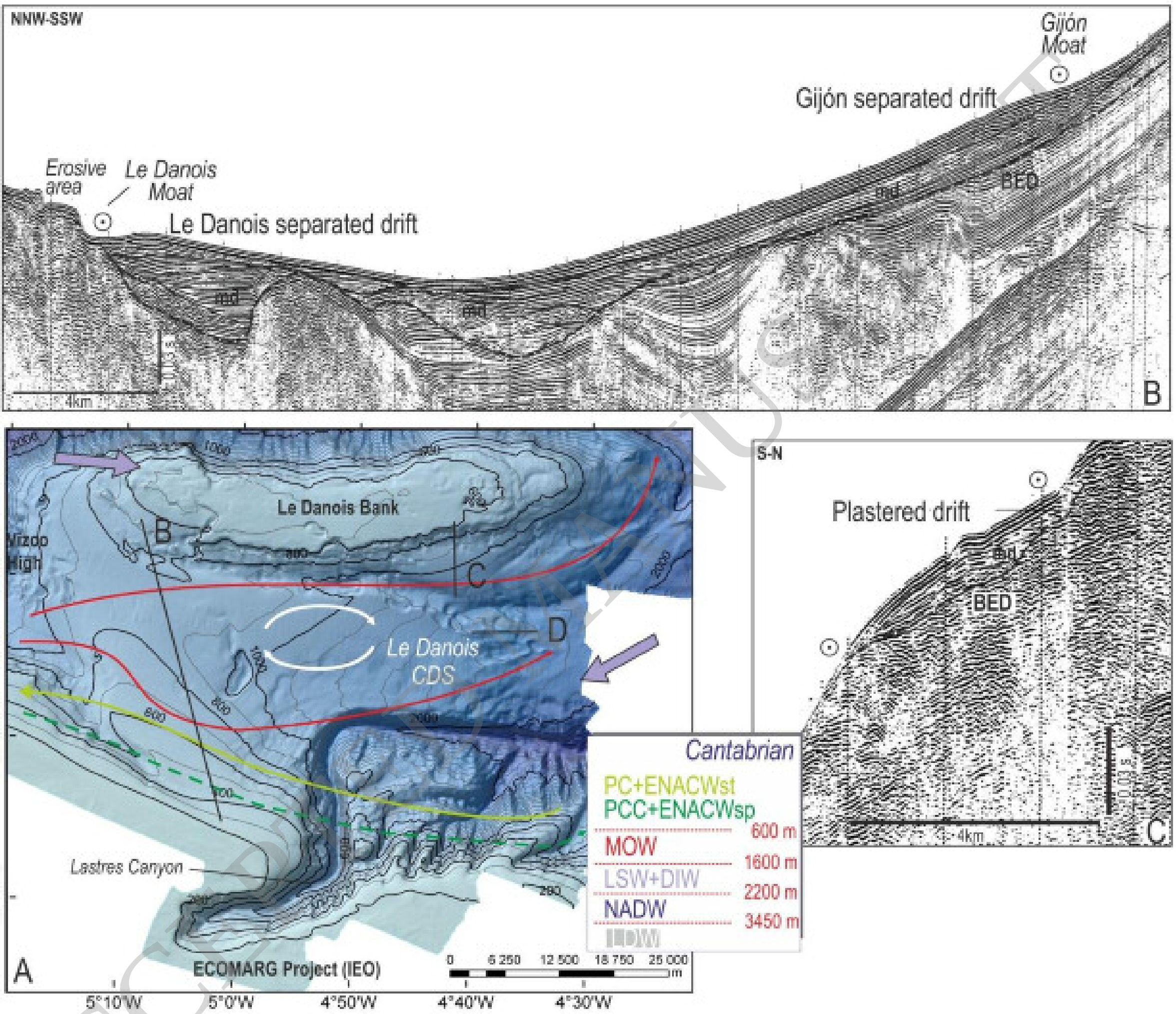

NNW-SSW
Gijón Moat
Gijón separated drift
Erosive area
Le Danois Moat
Le Danois separated drift
md
BED
4km
B
Le Danois Bank
Vizco High
Le Danois CDS
B
C
D
Lastres Canyon
ECOMARG Project (IEO)
0 6 250 12 500 18 750 25 000 m
44°0'N
43°50'N
43°40'N
5°10'W
5°0'W
4°50'W
4°40'W
4°30'W
A
Cantabrian
PC+ENACWst
PCC+ENACWsp
600 m
MOW
1600 m
LSW+DIW
2200 m
NADW
3450 m
LDW
S-N
Plastered drift
md
BED
4km
C

Figure 12

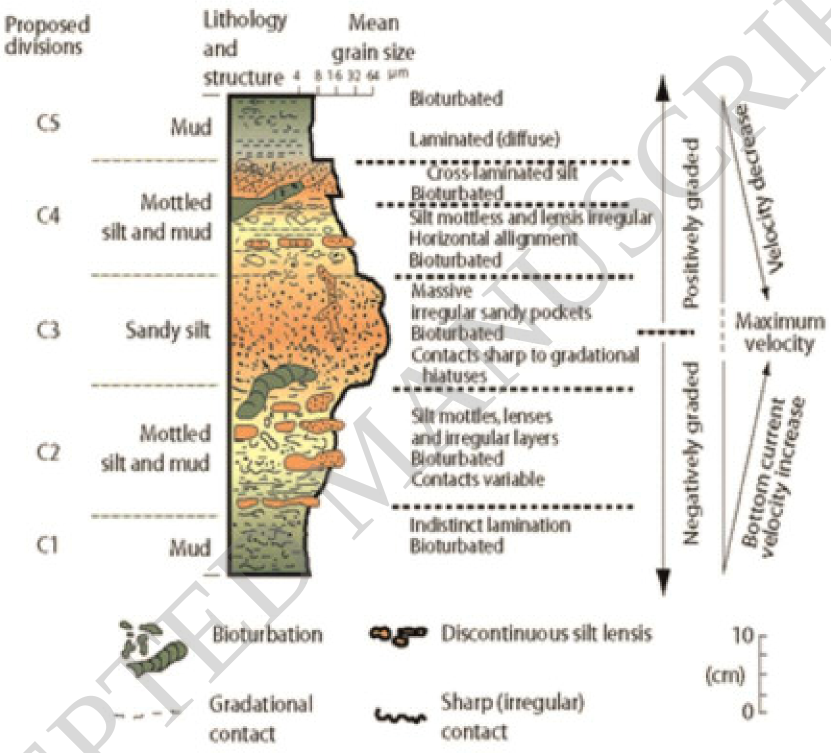

Proposed divisions
Lithology and structure
Mean grain size
4 8 16 32 64 μm
C5
Mud
C4
Mottled silt and mud
C3
Sandy silt
C2
Mottled silt and mud
C1
Mud
Bioturbated
Laminated (diffuse)
Cross-laminated silt
Bioturbated
Silt mottless and lensis irregular
Horizontal allignment
Bioturbated
Massive
irregular sandy pockets
Bioturbated
Contacts sharp to gradational
hiatuses
Silt mottles, lenses
and irregular layers
Bioturbated
Contacts variable
Indistinct lamination
Bioturbated
Positively graded
Negatively graded
Velocity decrease
Maximum velocity
Bottom current velocity increase
Bioturbation
Discontinuous silt lensis
Gradational contact
Sharp (irregular) contact
10
(cm)
0

Figure 13

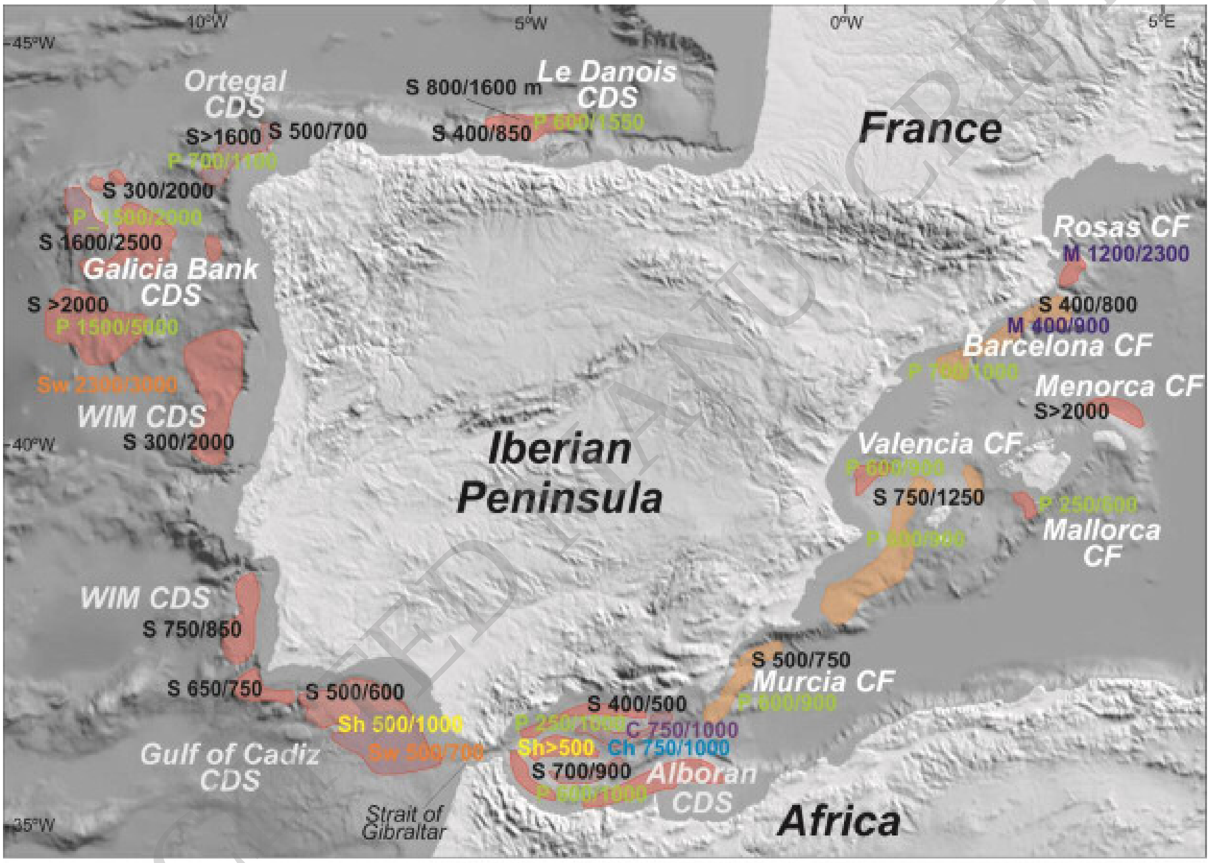

10ºW
5ºW
0ºW
5ºE
45ºW
40ºW
35ºW
Ortegal CDS
S>1600
S 500/700
P 700/1100
S 800/1600 m
Le Danois CDS
S 400/850
P 600/1550
France
S 300/2000
P_1500/2000
S 1600/2500
Galicia Bank CDS
S >2000
P 1500/5000
Sw 2300/3000
WIM CDS
S 300/2000
Rosas CF
M 1200/2300
S 400/800
M 400/900
Barcelona CF
P 700/1000
Menorca CF
S>2000
Iberian Peninsula
Valencia CF
P 600/900
S 750/1250
P 250/600
Mallorca CF
P 600/900
WIM CDS
S 750/850
S 650/750
S 500/600
Sh 500/1000
Sw 500/700
Gulf of Cadiz CDS
Strait of Gibraltar
S 500/750
Murcia CF
P 600/900
S 400/500
P 250/1000
C 750/1000
Sh>500
Ch 750/1000
S 700/900
P 600/1000
Alboran CDS
Africa

Figure 14