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First evidence of a main channel generated by the Mediterranean Outflow Water after its exit from the Gibraltar Strait

Primeras evidencias de un gran canal contornítico generado por la Masa de Agua Mediterránea tras su salida por el Estrecho de Gibraltar

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Abstract: An extensive terrace comprising sandy sheeted drifts characterises the proximal sector (close to the Straits of Gibraltar) of the Contourite Depositional System (CDS) of the Gulf of Cadiz and the western continental margin of Portugal. A novel morphosedimentary study over this terrace has been executed based on new multibeam echosounder data, seismic profiles, and surficial sediments samples collected during the CONTOURIBER-1 Cruise (2010). Based on that study, an impressive large channel laterally connected with the central part of the Strait of Gibraltar (Camarinal Sill) has been identified. It is associated southwestward with a huge contourite levee (sand bank), which has been generated by overflow processes related to the Mediterranean Outflow Water (MOW). In the middle to the distal part of the terrace, there are other minor channels, erosional scour alignments and depositional features. The mapping of all these features coupled with CTD data allows to further understand the pathway and deceleration of the MOW, in addition to aid the conceptual identification of contourite terrace.

Key words: Contourite depositional systems, contourite terraces, channels, MOW, Gulf of Cadiz.

Resumen: El sector proximal del Sistema Deposicional Contornítico (SDC) del Golfo de Cádiz y oeste de Portugal se caracteriza por una extensa terraza contornítica en la que se desarrollan *drifts* laminares arenosos. Sobre esta terraza se ha realizado un novedoso estudio morfosedimentario en base a datos batimétricos de ecosonda multihaz, registros sísmicos y muestras superficiales, adquiridos en la campaña oceanográfica CONTOURIBER-1 (2010). Se ha identificado un extenso canal sobre dicha terraza conectado lateralmente con la parte central del Estrecho de Gibraltar (Umbral de Camarinal) y bordeado por el SO por un dique (*levee*) contornítico (banco arenoso). La génesis del canal se relaciona con el desbordamiento sucesivo de la Masa de Agua Mediterránea de Salida (MOW) en el Golfo de Cádiz. En la parte media y distal de la terraza contornítica existen canales menores, surcos erosivos y rasgos deposicionales, cuya cartografía, junto al análisis de datos de CTD, permite entender mejor la circulación y deceleración de la MOW, así como la caracterización conceptual de las terrazas contorníticas.

Palabras clave: Sistemas deposicionales contorníticos, terrazas, canales, MOW, Golfo de Cádiz.

INTRODUCTION

The Strait of Gibraltar represents a key location in the Mediterranean–Atlantic water-mass exchange, and is associated with some of the observed highest bottom-current velocities. Furthermore it is also one of

the most important oceanic gateways worldwide, enabling the circulation of the Mediterranean Outflow Water (MOW) into the Atlantic Ocean (e.g.; Serra et al., 2010). After its exit through the Gibraltar gateway, the MOW represents a huge overflow (Legg et al., 2009), which evolves northwestward to a intermediate contour water mass along the middle slope, between 500 and 1400 m depth (Fig. 1). Warm and very saline, the MOW moves under the Atlantic inflow (AI) and above the North Atlantic Deep Water (NADW) generating important along-slope processes along the Atlantic margin (Hernández-Molina et al., 2011).

An extensive Contourite Depositional System (CDS) was generated during the Pliocene and Quaternary by the interaction between the MOW and the middle slope of the Gulf of Cadiz and west offshore Portugal. (e.g. Hernández-Molina et al., 2011). Five morphosedimentary sectors were defined in the CDS (cf. Hernández-Molina et al., 2003). The present work is focused on the Sector 1, the closest to the Strait of Gibraltar, and presents the preliminary results about a large channel generated by the MOW after its funneled flow-through from the Gibraltar Strait. Morphologic features are introduced and their oceanographic and geologic implications are discussed. Data to this work were acquired during the CONTOURIBER-1 Cruise (September-October, 2010) onboard the RV "Sarmiento de Gamboa" (Fig. 1) and include: a) swath bathymetry data collected with the ATLAS HYDROSWEEP DS echosounder system, b) very high

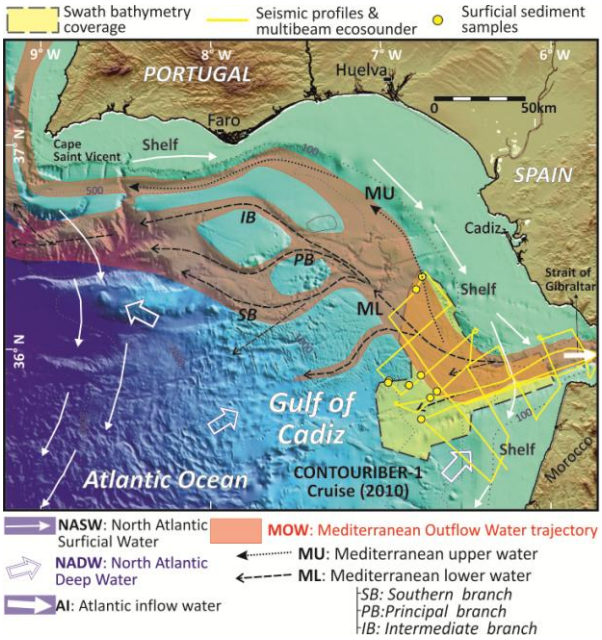

FIGURE 1. *Study area location, regional water masses circulation and data set acquired during CONTOURIBER-1 Cruise.*

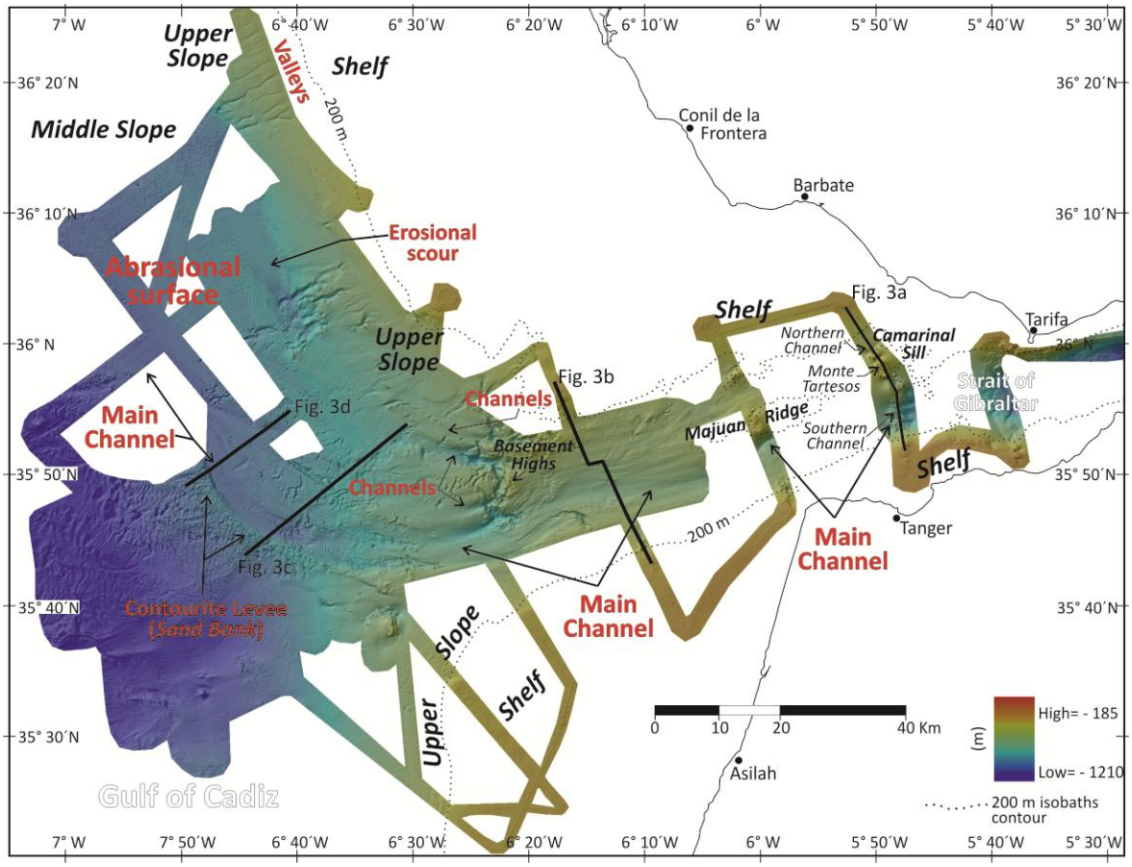

FIGURE 2. *Swath bathymetry showing the main channel location as well as the major morphologic features at the exit of the Strait of Gibraltar westward from the Camarinal Sill. Seismic profiles location from Fig 3 are indicated.*

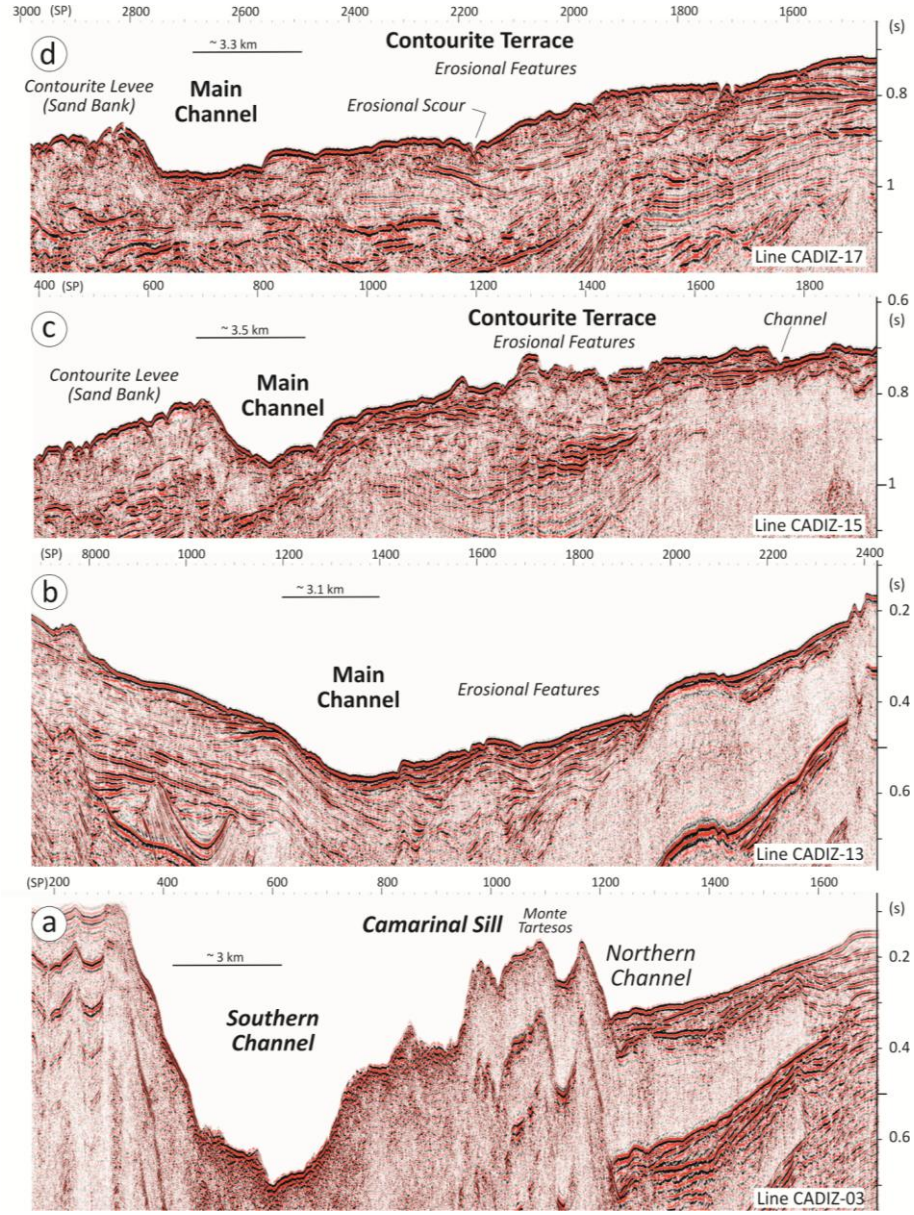

FIGURE 3. *Seismic profile examples showing the main characteristics of the Main Channel, from the Camarinal Sill toward the contourite terrace within the proximal sector at the CDS of the Gulf of Cadiz. See the seismic profiles location at Fig 2.*

resolution seismic data acquired with the ATLAS PARASOUND P35; c) mid-resolution reflection seismic data obtained using an air-gun source system; d) sediment samples taken by piston cores, multicores and box-cores; e) integrated acoustic approach to image and analyse nepheloid layers and comparable particle clouds; and f) CTD data compiled by both the universities of Cádiz and Hamburg.

THE PROXIMAL SECTOR OF THE CDS

The proximal sector of the CDS of the Gulf of Cádiz (*proximal scour and ribbons sector* of Hernández-Molina et al., 2003) is located in the SE area between Cádiz and the Strait of Gibraltar (Fig.1) and is characterized by a smooth contourite terrace oriented along-slope between 500 and 800 m water depth. It was first described by Kenyon and Belderson (1973). It is an extensive area (~100 km long and 30 km wide), dominated by an abrasion surface and characterized by sandy-sheeted drifts. There are several erosive scour alignments with a NW–SE orientation, and with smooth ‘‘V’’-shape expression and truncated reflectors in seismic profiles. In the NW part of this sector some depositional features occur at the surface, including a sequence of longitudinal bedforms, ripple marks, sand ribbons, and sediment waves (Hernández-Molina et al., 2003; Llave et al., 2007). In addition, a sand bank is identified at the SE end of this sector.

THE MAIN CHANNEL AT THE EXIT OF THE STRAIT

Westward from the Camarinal Sill there is a large

(~130 km in length) erosive channel (hereafter Main Channel) along the exit of the Strait of Gibraltar. It can be divided into two major parts (Fig. 2). The first part has a relatively linear WSW trend, approximately 3-4 km wide, until reaching basement highs located at 35º54´8.98´´N/05º48´2.65´´W. The second part of this Channel has a sinusoidal shape and is approximately 6 km wide with a SW trend until 35º46´12.78´´ N/ 06º43´W. Here, it changes its trend towards the NW and narrows to approximately 4 km. At around 35º59´33.52´´N / 06º53´16.34´´W the Main Channel starts losing its previous morphology, changing to a small depression toward the NW. In this second part, the Main Channel is bounded by a contourite terrace to the NE and an associated huge contourite levee (sand bank) to the SW. In the middle to distal part of the terrace there are other minor channels, erosional scour alignments (with two main trends: NW and WNW), valleys and depositional features (Fig. 2).

DISCUSSION AND CONCLUSIONS

The proximal sector within the CDS of the Gulf of Cadiz results from the strong and turbulent overflow of the MOW, which contours the slope between 300 and 1000 m water depth after entering the Gulf of Cádiz (Legg et al., 2009). Its velocity decreases from a maximum of 240 cm/s, immediately W of the Gibraltar gateway, to approximately 60-100 cm/s further NW (see details in Serra et al., 2010 and Hernández-Molina et al., 2011)

The Main Channel identified over the sandy contourite terrace in the proximal sector of the Gulf of Cadiz allows to trace the MOW westward of the central part of the Strait (Camarinal Sill). This channel is laterally connected with the southern channel defined by Esteras et al. (2000). Its occurrence clearly shows that the MOW is mainly flowing along the southern sector of the exit of the Strait for about 55 km from the Camarinal Sill until the basement highs located at approximately 35º54´8.98´´N/05º48´2.65´´W. Beyond these highs, the Main Channel abruptly changes its trend toward the NW, and the sandy contourite levee starts being developed at its SW flank. In addition, other minor channels, erosional scour alignments and valleys are identified over the terrace toward the NW, which indicate a complex interference of along- and down-slope sedimentary processes.

Recent tectonic activity has conditioned the present sea-floor morphology and its Quaternary evolution, especially where basement highs are present within the exit of the Strait of Gibraltar. This in turn has controlled the evolution of the Main Channel and therefore the overflow of the MOW.

The mapping of all these features coupled with the new CTD dataset, allows further understanding of the pathway and of the deceleration of the MOW, as well as aiding the conceptual identification of sandy contourite terraces. In addition, an improved knowledge of these sand-rich contourite deposits will have significant implications, both in establishing a facies model for sandy contourites, as well as in assessing their potential as a future deep-water hydrocarbon exploration targets.

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