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Understanding sediment dynamics of two large submarine valleys from seafloor data: Blanes and La Fonera canyons, northwestern Mediterranean Sea

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ABSTRACT

The studied area appears as a major place for dense shelf water (DSW) formation and export towards the deep basin with Blanes and La Fonera canyons as most efficient pathways. These two canyons are so deeply indented on the continental shelf and slope of the northern Catalan margin (Western Mediterranean Sea) that their heads significantly reduce the width of the shelf and interfere with coast and contour parallel sediment transport patterns. This study presents the results of the analysis of swath bathymetry data and parametric seismic reflection profiles showing the detailed morphology and uppermost sedimentary structure of Blanes and La Fonera canyons, with the focus on their heads and adjacent upper courses and shelf. The main aim is to understand their functioning and assess how they influence and respond to the hydrosedimentary processes active in the study area.

The N–S oriented Blanes canyon head, whose shortest distance to shore is only 4 km, extends along 21.7 km from 70 to 1300 m water depth with an average rim to rim width of 8 km and a canyon floor width up to 750 m. La Fonera canyon head extends along 28 km from 60 to 1700 m water depth. Rim to rim and canyon floor widths are up to 7 km and up to 700 m, respectively. The canyon head follows a general WNW–ESE trending course in its deeper part, but trends N–S in its shallower course formed by Cap Begur branch. South of it, the Illa Negra branch trends NW–SE and its tip, located at 60 m water depth and 800 m from the coastline, intersects the littoral sedimentary prism. Backscatter data show high reflectivity into both Blanes and La Fonera canyon floors as well as on tributary gullies, which at these locations is indicative of coarse sediment. The seafloor and subseafloor observations here presented are explained and best understood, from the sedimentological viewpoint, by the interplay of event-driven DSW flows, permanent mesoscale circulation and storm action. While DSW flows from the Gulf of Lion and the shelf area around the studied canyons are the most dynamic agent in terms of sediment transport and seafloor shaping, the Northern Current ensures background sedimentation of fines, and coastal storms promote episodic entries through canyon heads and upper course rims. Canyon wall morphology and sediment draping respond to the currentward or leeward position of each wall with respect to the main, southward moving water flows in the area, either episodic or permanent, that are DSW and the Northern Current. Other relevant morphosedimentary features, such as a 40 km long, southbound subdued channel on the Roses outer shelf that originates off Cap de Creus promontory to finally feed Cap Begur branch of La Fonera canyon and a contouritic ridge and moat attached to the northern wall of the canyon are interpreted in terms of DSW flows.

A comprehensive model of the sedimentary functioning of the canyoned north Catalan margin that integrates seafloor information and background data on dynamic processes is presented, which could be of application to other continental margins worldwide. Such an integrative view is eased by the enormous, unprecedented multidisciplinary research effort carried out in the study area over the last three decades.

1. Introduction

Submarine canyons are deep incisions in the continental slope that funnel large volumes of sediment and associated organic carbon from

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the shelf down to the deep sea sedimentary systems, fuelling the abyssal ecosystem (Canals et al., 2004a; Palanques et al., 2005; Paull et al., 2006; Sanchez-Vidal et al., 2008; Shepard, 1981; Shepard and Dill, 1966; Tyler et al., 2009). They mostly originated during sea-level lowstands by the erosion of the outer shelf and slope by retrograding landslides and dense sediment-laden flows (Cronin et al., 2005; Posamentier et al., 1988). During sea-level highstands, such as the present one, submarine canyons may still experience occasional activity, especially when regional and local geographic and oceanographic conditions allow either the interception of active shelf sediment-transport pathways (Canals et al., 2006; Lastras et al., 2007) or the connection between coastal sediment sources and the slope sediment dispersal systems through canyon heads (Gaudin et al., 2006a; Paull et al., 2005).

Since along canyon downslope transport enhances shelf-slope exchanges of mater and energy, they have a significant effect on the foodwebs of marine ecosystems and act as hotspots of submarine biodiversity (e.g. Gili et al., 1999; Vetter and Dayton, 1998). Along the Catalan margin, the detritivore deep-water shrimp *Aristeus antennatus* is the most important fishery target, caught almost exclusively in and around canyon heads at depths ranging between 400 and 800 m (Demestre and Martin, 1993). The life cycle of *A. antennatus* itself seems to be closely related to the morphology of the continental slope (Company et al., 2008; Sardà et al., 2009).

The concept *submarine canyon head* is often used in major submarine canyons to refer to their continental shelf-indented section, before crossing the shelf break and continuing down the continental slope to the continental rise. Canyon heads have not been the target of high-resolution mapping until recent times, mostly due to the acquisition difficulties posed by their irregular topography and to the time-consuming character of swath bathymetry surveys in relatively shallow waters. Their significance for the shelf-slope system has been demonstrated by a number of studies such as those on Gulf of Lion canyons (Baztan et al., 2005; Canals et al., 2006; Gaudin et al., 2006b; Lastras et al., 2007), Danube canyon (Popescu et al., 2004), Capbreton canyon (Gaudin et al., 2006a) and Monterrey canyon (Paull et al., 2005; Smith et al., 2005; Xu et al., 2008). Active canyon heads are heterogeneous, continuously changing environments (DeGeest et al., 2008; Paull et al., 2005; Xu et al., 2008), acting as temporary reservoirs of sediment (van Weering, et al., 2002) before eventually releasing it to the lower canyon and deep basin (Canals et al., 2006; Lastras et al., 2009; Sultan et al., 2007).

Northwestern Mediterranean shelves and slopes are carved by a variety of submarine canyons of contrasting morphologies, from short, linear canyons with no or few tributaries disconnected from direct fluvial sources in the Ebro margin (Amblas et al., 2006; Canals et al., 2000), to branching canyon networks converging towards the base of slope such as those in the Gulf of Lion (Alonso et al., 1991; Berné et al., 1999), to shelf-incised, long canyons running from the coastline to depths in excess of 2400 m in the Catalan margin (Canals et al., 2004a).

In this paper, we present the results of the study of the heads of Blanes and La Fonera (also known as Palamós) canyons and adjacent upper courses and neighbouring shelf using swath bathymetry data and parametric seismic reflection profiles. The data is used to interpret the associated sedimentation and erosion processes and subsequent products and morphologies occurring in canyon heads, which represent the most dynamic component of the transition zone between the continental shelf and the deep sedimentary system. Accurate seafloor and sub-seafloor imaging and subsequent interpretation of the functioning of these two submarine canyons is a keystone for research undergoing in the two areas, which include systematic ROV exploration, sediment trap and currentmeter measurements, and sediment coring.

2. Geographic and geologic setting

The northeastern Iberian margin is formed by the northern Catalan margin, the southern Catalan margin and the Ebro margin (Amblas et al., 2006). It represents the northwestern shoulder of the Valencia Trough, an aborted rift related to the opening of the oceanic Provençal Basin. The asynchronous opening of the Valencia Trough, which started at the Gulf of Lion to the north of the region and propagated southwards, occurred during the Late Oligocene–Early Miocene period due to the extensional stress regime that occurred within the general framework of convergence between the African and European plates (Roca et al., 1999). It produced a series of NE–SW oriented horsts and grabens forming the northwestern Neogene Mediterranean rift system (Maillard and Mauffret, 1999). Crustal thinning, which did not reach oceanisation, was accompanied by NW–SE transfer zones guiding the opening of the basin and producing the rotation of the Corsican and Balearic blocks (Gueguen et al., 1998).

Post-rift thermal subsidence and sedimentary and hydrostatic load allowed the accumulation of thick Early Miocene to Recent sedimentary sequences on the northeastern Iberian margin. During the Late Miocene (Messinian), a dramatic sea-level fall produced by the isolation of the Mediterranean Sea from the Atlantic Ocean after the closure of the Gibraltar strait (Hsü, 1977) lead to the deposition of thick evaporitic sequences in the deep basin and the formation of major unconformities over the margins (Maillard et al., 2006). The submarine canyons of the northern Catalan margin (from north to south, Cap de Creus, L'Escala — now buried, La Fonera, and Blanes canyons) originated during this period, deeply incising the subaerially exposed continental shelves and slopes (Maillard et al., 2006; Tassone et al., 1994). More than 2 km thick Plio-Quaternary sequences (Maillard et al., 1992) were deposited during marine transgressive–regressive pulsations overlying the Messinian evaporites and unconformities, partly filling the canyons. During the Late Pliocene, a sea-level stand below the shelf break produced the re-excavation of the canyons on the outer shelf (Tassone et al., 1994).

The present northern Catalan margin as defined by Amblas et al. (2006) is more than 100 km long and is delimited by Cap de Creus canyon to the north and Blanes canyon to the south. La Fonera canyon divides the northern Catalan margin into two sectors: Roses margin to the north, and La Planassa margin to the south (Fig. 1).

The north–south oriented Roses continental shelf is located in front of the Gulf of Roses coast, where it reaches up to 30 km in width, with a minimum width of 4 km off Cap de Creus (we use “Cap de Creus” instead of “Creus Cape” as the former name is widely implanted in the international scientific literature, especially when referring to “Cap de Creus canyon”) (Fig. 1). The emerged Gulf of Roses is mainly made of Quaternary sediments (Ercilla et al., 1994; Got, 1973) supplied by Muga, Fluvià and Ter rivers, the later with a mean annual water discharge (averaged over the period 1985–2002) of 12.1 m^3 s^{-1} (Liquete et al., 2009). Cap de Creus, which is the eastern termination of the Pyrenean mountain range, is made of Palaeozoic sediments and metasediments with gneisses. Offshore, the main sediment body on the inner shelf is the Muga-Fluvià prodelta, developed during the Holocene sea-level highstand (Díaz and Ercilla, 1993).

La Planassa shelf, up to 20 km wide, is located, together with La Fonera canyon, in front of the Costa Brava, a rugged and predominantly steep section of the coastline made of Palaeozoic rocks and Hercynian granite outcrops where only torrential rivulets discharge. Blanes canyon head is 5 km east of the prodelta of Tordera river and relict deltas (Serra et al., 2007) (Fig. 1). The main characteristics of the regional current pattern in the northern Catalan margin are a mesoscale current, referred to as the Northern Current, which flows SW over the outer shelf and slope from the Gulf of Lion (Millot, 1999) forming a shelf-slope density front (Font et al., 1988).

Cap de Creus canyon is 96 km long and bisects the continental shelf, slope and rise in a general west–east direction until it joins the Sète canyon at 2140 m water depth (Lastras et al., 2007). Its head is located north of Cap de Creus, and its southern wall is just 4 km from the coastline. Cold-water coral colonies have been reported predominantly in areas with hard substrate (boulders or hardrock