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Composition and temporal variability of particle fluxes in an insular canyon of the northwestern Mediterranean Sea

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A B S T R A C T

Particle fluxes have been widely studied in canyons located in continental margins; conversely, particle fluxes in canyons in sediment starved margins incising small island margins have received very little attention and remain poorly understood. The Menorca Canyon is the largest canyon system in the Balearic Archipelago. Despite the high oligotrophic conditions of the Balearic Archipelago the canyon and surrounding areas host diverse communities dominated by benthic suspension feeders. Understanding the magnitude and variability of environmental factors influencing these communities thus remain crucial. In order to characterize the temporal variability of particle fluxes, analyze its geochemical and macroscopic composition and identify the main processes that modulate particle fluxes in the Menorca Canyon, one instrumented line with a sediment trap and a current meter was deployed at 430 m water depth from September 2010 to October 2012. Particle fluxes ranged between 190 and 2300 mg m^2 d^{-1} being one of the lowest ever registered in a Mediterranean submarine canyon's head. The $CaCO_3$ fraction was the major constituent contrasting with the general trend observed in other Mediterranean canyons. Macroscopic constituents (fecal pellets, *Posidonia oceanica* detritus and pelagic and benthic foraminifera) presented a wide variability throughout the sampling period and were not significantly correlated with the total mass flux. The low magnitude of the registered fluxes and the lack of correlation with the observed environmental variables (e.g., currents, winds, wave height, chlorophyll-*a* biomass) suggest that there is no evident controlling mechanism. However, we could infer that resuspension processes and the presence of different hydrodynamic features (e.g., eddies, interchange of water masses) condition the magnitude and composition of particle fluxes.

1. Introduction

Continental and insular margins receive particulate matter derived from fluvial discharges (Syvitski and Morehead, 1999; Kineke et al., 2000) that can result in high sediment accumulation (Sanchez-Cabeza et al., 1999). Most of these margins are incised by submarine canyons (Harris and Whiteway, 2011) that act as conduits of sediments and organic matter from the continental shelf to deeper environments (Mullenbach et al., 2004; Lopez-Fernandez et al., 2013a). In this regard, particle fluxes within submarine canyons can be orders of magnitude larger than those registered over adjacent continental slopes (Martín et al., 2006; Zúñiga et al., 2009; Pasqual et al., 2013). The magnitude, composition and temporal variability of particle fluxes in submarine canyons are influenced by a wide range of environmental and biological factors (e.g. Lopez-Fernandez et al., 2013a; Puig et al., 2014). Hydrodynamic and meteorological mechanisms, such us river flooding, storms, or cascading events can punctually increase particle fluxes in submarine canyons through resuspension and gravity-driven processes over short periods of time (e.g. Puig et al., 2004, 2014; Ross et al., 2009; Heussner et al., 2006). Oceanographic processes such us eddies, tidal currents, or internal waves have also been associated with increments in downward particle fluxes as they alter bottom currents causing sediment resuspension (e.g. Quaresma et al., 2007; Ross et al., 2009; Schmidt et al., 2014).

Downward particle fluxes and the main mechanisms controlling them have been widely studied in submarine canyons associated to continental landmasses (e.g. Shepard et al., 1974; Xu et al., 2002; Khripounoff et al., 2003) and large islands with high mountain ranges (≥2000 m) and permanent rivers systems that provide large terrestrial inputs (e.g. Kineke et al., 2000; Liu et al., 2002). However, particle fluxes in canyons located in sediment starved margins incising small island margins still remain widely unknown.

In the Mediterranean, this situation is rather surprising due to the elevated number of islands found in this basin (~200), many of which incised by submarine canyons (e.g. Acosta et al., 2002; FavalliM et al., 2005; Hasiotis et al., 2007; Romagnoli et al., 2009; Sakellariou et al.,

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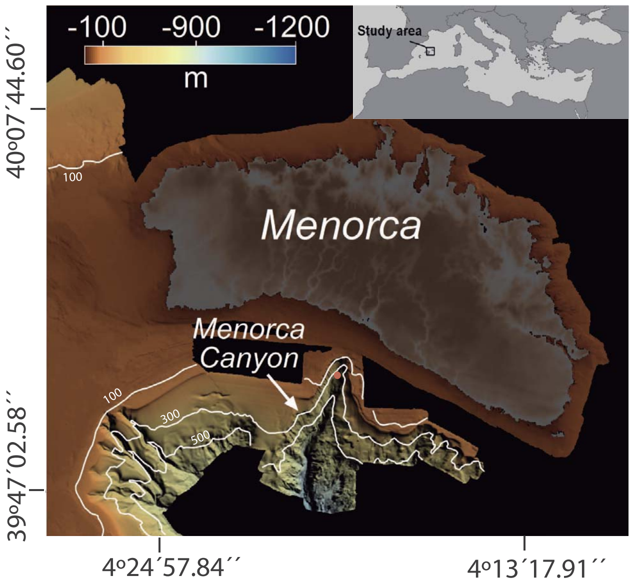

Fig. 1. Bathymetry of the southern slope of Menorca and its position in the western Mediterranean Sea, red dot indicates the location of the mooring array (Lo Iacono et al., 2014). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2015; Casalbore et al., 2016). Despite the relative abundance of Mediterranean insular canyons, most studies concerning downward particle fluxes in this basin have been conducted in less than 25 canyons located in the European margin. Moreover, most of these canyons incise river-dominated shelves (e.g. Bonnin et al., 2008) with higher productivity relative to the Mediterranean average (Bosc et al., 2004). The Baleric Archipelago is one of the most oligotrophic environments in the Western Mediterranean Sea (Bosc et al., 2004). In this archipelago the Menorca Canyon is the largest canyon and is located in the southern slope of Menorca Island (Fig. 1). Despite the high oligotrophy of the Balearic Archipelago, the Menorca Canyon and adjacent shelf edges and slopes hosts dense and highly diverse megabenthic assemblages characterized by a wide diversity of suspension feeders (Grinyó, 2016). To characterize the seasonal trends and magnitude of particle fluxes and environmental variables influencing megabenthic communities in the shelf edge and upper slope of the Menorca Canyon a mooring array was maintained for two years in the Menorca Canyon's head.

In this sense, the aims of this study were to characterize (1) the temporal (interannual) variability of downward particle fluxes analysing its geochemical and (2) macroscopic composition, (3) identify the main processes that modulate particle fluxes in the Menorca Canyon, and (4) set the present results within a Mediterranean context.

2. Regional setting

The Menorca Canyon is well incised in the continental shelf and slope in the southwestern margin of Menorca Island (Fig. 1) and is the largest submarine canyon system in the Balearic Archipelago.

The canyon's head is at approximately 80 m water depth and is less than 5 km off Menorca's coastline (Acosta et al., 1991). The flanks at the canyon's head are characterized by vertical walls and steep escarpments up to 20 m height (Lo Iacono et al., 2014). The continental shelf surrounding the canyon is relatively narrow and it only extends few kilometers (3–6 km) (Alonso et al., 1988). In the Menorca Canyon's head sediment creeping and cone-shaped "sediment collectors" with feeder channels have been observed with side scan sonar, demonstrating that sediment transfer from the inner shelf to the deep basins is an active process (Acosta et al., 2002). In this regard the Menorca canyon is the only canyon system in the archipelago that transports sediment to the deep basin in a confined manner (Acosta et al., 2002).

The canyon's axis presents several changes in direction. Between 80 and 1000 m depth the canyon axis presents a NNE–SSW orientation; between 1000 and 1200 m depth it presents a N-S orientation; from 1200 to 1400 m it is orientated NW–SE (Acosta et al., 2002). Finally, the canyon axis turns N-S at about 2400 m depth, where it turns into a channel with a U section (Acosta et al., 2002), which ends at the Menorca Fan a deep-sea depocenter derived from the canyon's sediment draining (Acosta et al., 2001).

The southern flank of Menorca Island is characterized by Neogene sedimentary rocks with high carbonate contents (Obrador et al., 1992). Sediment composition in the canyon and the adjacent shelves is characterized by biogenic sands with carbonate contents higher than 65% (Alonso et al., 1988). The lack of permanent river systems in the southern flank of Menorca, that deliver sediments in the adjacent coast and shelf, allow characterizing the southern margin of Menorca as a sediment starved margin (Lo Iacono et al., 2014).

The Balearic archipelago separates the Balearic-subbasin in the north from the Algerian-subbasin in the south (Amores and Monserrat, 2014) in such a way that different hydrodynamic processes and water masses influence the northern and southern slopes of the archipelago (Balbín et al., 2014). The northern slope is influenced by the Balearic current (Balbín et al., 2012; Amores et al., 2014) and is mostly characterized by the presence of resident Atlantic water (AW) (Salinity > 37.5) (Balbín et al., 2014). Conversely, the southern slope is influenced by the sporadic arrivals of mesoscale structures detached from the Algerian current and from the instability of the Almería-Oran front (Millot, 1987), which is characterized by the presence of recent AW (Salinity < 37.5) (Balbín et al., 2014). During spring and summer, when western intermediate water (WIW) is present in the Ibiza and Mallorca channel, a density front that separates the resident AW from the recent AW develops south of the archipelago (Balbín et al., 2014). Under these conditions anticyclonic gyres have been detected in the southern slope of the Menorca Island (García et al., 2005; Balbín et al., 2014). Waters surrounding the archipelago are considered oligotrophic (Fernández de Puelles et al., 2007) as they receive little quantities of nutrients from land runoff due to low precipitation and the absence of rivers (Estrada, 1996). In some areas of the archipelago these conditions are enhanced by the intrusion of nutrient-poor recent AW including the southern slope of Menorca Island (García et al., 2005).

3. Material and methods

3.1. Field work and instrumentation

One mooring array was maintained for two consecutive years in the Menorca canyon's head (39°50.6601′N, 004°01.2600′E) at approximately 430 m water depth. The mooring array was equipped with one cylindrical sediment trap Technicap PPS3 and a Aanderaa current meter RCM9, tethered 30 m above the seabed and 25 m above the seabed, respectively. The sediment trap was set with 24 sequential collecting cups filled with a buffered 5% formaldehyde solution. The first sampling period (T1) continuously operated for 412 days (09/15/2010–10/11/2011). Sediment trap cups sampled during sequential intervals of 17 days except the last cup that sampled for 21 days. The second sampling period (T2) continuously operated for 365 days (11/03/2011–11/02/2012) and the sediment trap cups sampled for 15 days intervals except for the last five cups that sampled for 16 days intervals. Forty-seven samples were obtained from mid-September 2010 (9/15/2010) to mid October 2012 (10/17/12). The 24th sampling cup of T1 (October 2011) was lost during the recovery process. The current meter was equipped with oxygen, turbidity and temperature sensors and it acquired measurements every 10 min.

3.2. Processing of sediment trap samples

Refrigerated (4 °C) sediment trap samples were processed in the