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Suspended sediment fluxes and transport processes in the Gulf of Lions submarine canyons. The role of storms and dense water cascading

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Abstract

Contemporary suspended sediment transport was studied in seven submarine canyons of the Gulf of Lions (GoL). Current meters equipped with turbidity sensors were moored 4 m above bottom at 300 m depth in the canyon axis from November 2003 to May 2004. Sediment transport events were monitored and studied in relation to forcing conditions. There was a large flood in early December, during which discharges from all of the coastal rivers increased by more than one order of magnitude. A smaller flood of the Rhone River occurred later in mid-January followed by a persistent high river discharge that lasted until mid-February. There were also several E–SE storm events during the measurement period, two of them causing large swell, one in early December (max H_s: 8.4 m), coinciding with the major river flood, and one in late February (max H_s: 7 m) during a period of lower river discharge. Most of the variability in down-canyon current speeds was linked to strong downwelling induced by E–SE storms and to cascading of dense shelf water induced by N and NW winds. The intensity and timing of these processes strongly varied spatially. Eastern storms generated higher waves and induced stronger downwelling in the western than in the eastern sector of the GoL. Shelf dense water cascading events were enhanced during eastern storms and they were also more intense in the western sector of the GoL. These events occurred frequently from January to May along the western canyons and from February to April along the eastern canyons. From February to April they occurred simultaneously in all the canyons.

Sediment transport was mainly down-canyon and mostly concentrated during storm-induced downwelling and dense water cascading events. During the high river discharge season most of the newly-supplied and resuspended sediment remained stored on the shelf. However, during the late February storm and cascading event, the stored sediment was quickly resuspended and transported, mainly through the westernmost submarine canyon (Cap de Creus), following a flushing pattern. Later, although minor storms and shelf dense water cascading hardly increased suspended sediment concentrations within the canyons, they induced strong near-bottom current velocities, increasing down-canyon sediment fluxes and generating small but significant sediment transport events. Most of the shelf-canyon transfer took place during the late February storm and cascading event through the Cap de Creus canyon where the net suspended sediment flux was between one and two orders of magnitude higher than in the other canyons.

Keywords: suspended sediment transport; submarine canyon; Gulf of Lions; storm events; cascading events

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1. Introduction

About 90% of the sediment generated by erosion on land is deposited on the continental margins. Once sediment particles are discharged by rivers into the marine system, they are dispersed under the combined action of currents and waves. Forcing conditions are governed by local hydrodynamics, meteorology, climate and bottom morphology. Subsequently particles may be affected by several transport, deposition, and resuspension cycles and are distributed over the continental shelf and slope before being more definitively deposited. Because of limitations on present observational techniques for studying the episodic and three-dimensional character of particulate transfer, the transport mechanisms, sediment fluxes and ultimate fate of this material are poorly constrained. Several projects, such as AMASEDS, SEEP, ECOMARGE, OMEX, MATER, EUROMARGE and STRATAFORM, (Nittrouer and DeMaster, 1986; Biscaye et al., 1988; Monaco et al., 1990a; Biscaye and Anderson, 1994; van Weering et al., 1998; Nittrouer, 1999; Wollast et al., 2001), have studied continent-ocean transfer during the last few decades, focusing mainly on continental margins that in some cases included submarine canyons.

One of the questions we still do not know well is how- and how much-sediment entering the ocean is transferred offshore through submarine canyons. Submarine canyons are physiographic structures that favor seaward sediment transport, funnelling sediment as preferential conduits connecting the shelf to the slope and open sea (Drake and Gorsline, 1973; Hickey et al., 1986; Gardner, 1989a; Durrieu de Madron, 1994; Puig and Palanques, 1998). A widespread concept nowadays is that particulate matter transferred from the shelf through submarine canyons comes directly from continental runoff and/or resuspension (e.g., during storms) and coastal biological productivity (Thunnell, 1998; Boyd and Newton, 1999). During the eighties, several canyon studies defined important dynamics and sedimentary patterns in them (Hickey et al., 1986; Gardner, 1989a,b), but they did not elucidate sufficiently the processes controlling shelf-canyon transfer. Sediment trap experiments conducted in NW Mediterranean canyons revealed that vertical particle fluxes reached maximum values after storms or following increases in the outflow from a nearby river, (Monaco et al., 1990b; Puig and Palanques, 1998; Monaco et al., 1999). However, the restricted resolution of sediment trap sampling, the limited information about forcing conditions and the lack of direct simultaneous measurements on the shelf and at the head of the canyons prevented such transfers from being corroborated, quantified and explained in detail.

The link between river discharge and/or windstorms and particle transfer has been identified in several other settings as is the case for canyons located in areas of low wave energy, narrow shelves and connected to rivers, such as the Guadiaro Canyon in the Alborán Sea which can be dominated by floods (Palanques et al., 2005a). Submarine canyons that are deeply incised into the continental shelf are very sensitive to storms such as the Monterrey Canyon (Xu et al., 2002), the Palamós Canyon (Palanques et al., 2005b; Martín et al., 2006), Kao-Ping Canyon (Liu et al., 2002), Hudson Valley (Harris et al., 2003) and Nazare Canyon. Other canyons connected to rivers and exposed to very energetic conditions are also dominated by storms, as is the case of the Eel Canyon, where shelf and canyon transfer processes were studied in detail (Puig et al., 2003).

Within the framework of the EUROSTRATAFORM project, one key objective was to investigate transfer fluxes and processes in submarine canyons. The Gulf of Lions (GoL) was chosen to study a river-dominated continental margin. The objectives of this paper are: 1) quantify the shelf–slope suspended sediment transport through GoL submarine canyons during winter and spring (the flood and storm season), 2) study the temporal and spatial variability of suspended sediment fluxes, 3) identify the major transfer events and 4) characterize the processes that control suspended sediment transport through submarine canyons in this area.

2. Regional setting

The Gulf of Lions is a micro-tidal continental and river-dominated margin that extends from Cap Croisette in the northeast to Cap de Creus in the southwest (Fig. 1). This margin is fed by several rivers flowing from different hydrographic basins. The most important is the Rhone River, which comes from the Alps and flows into the eastern part of the GoL. Its supplies represent about 90% of the total freshwater inputs of the GoL. The Vidourle, Herault and Orb rivers come from the Massif Central and discharge into the central part of the GoL, whereas the Agly, Tet and Tech rivers flow from the Pyrenees and discharge into the western part of the GoL (Fig. 1). The major river discharge periods are in spring and autumn.

The different wind regimes determine the circulation and the transport of suspended sediment on the shelf. Northerly (Mistral) and northwesterly (Tramontane) winds, and S– SE wind (Marin) are the predominant wind regimes in the GoL. The Mistral and Tramontane are more frequent in winter and spring and induce distinctive and opposite circulation cells on the shelf favoring the intrusion of slope waters in the eastern and