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Marine Geology 234 (2006) 63–92

MARINE GEOLOGY
INTERNATIONAL JOURNAL OF MARINE GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS

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Spatial and temporal variability of downward particle fluxes on a continental slope: Lessons from an 8-yr experiment in the Gulf of Lions (NW Mediterranean)

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Accepted 5 September 2006

Abstract

A long-term experiment of downward particle fluxes and currents has been initiated in 1993 on the continental slope of the Gulf f Lions (NW Mediterranean) and pursued within the frame of several French and European projects (PNEC, Euromarge-NB, MTP I-MATER, EUROSTRATAFORM). Sediment traps and current meters were deployed at several locations on this slope deeply ncised by numerous canyons, with an extensive spatial coverage for the first 2 years (canyons at the entrance, middle and exit of he gulf with respect to the general along-slope circulation, head and mid-canyon depths, adjacent open slope). From late 1995 nwards, this design was reduced to the two mid-canyon moorings at the entrance and exit of the gulf. Monthly fluxes and hourly emperatures and currents were recorded at 500 m (30 m above bottom, mab) in the canyon heads, at 500 and 1000 m (respectively 30 and 30 mab) nominal depths at the mid-canyon sites, and at 750 m (30 mab) open slope.

This study aims at describing the spatial, seasonal and interannual variability of flux intensity and composition of settling articles, and at analyzing the role of diverse forcings in the control of particle exchange across the margin. Results from the first years (1993–2001) show that total mass fluxes – in the 10^1–10^4 mg m^{-2} d^{-1} range – increase along slope, particularly for the ear-bottom traps, between the NE (Planier Canyon) and the SW (Lacaze-Duthiers Canyon) limits of the Gulf of Lions, indicating n increased shelf export of particulate matter in the western part of the system. Bulk chemical composition (organic matter, arbonate, opal and lithogenic fraction) remained rather stable during the course of the experiment, tending towards values typical f superficial shelf sediments at higher mass fluxes. First-order calculations using a simple two-component mixing model suggest a ecreasing contribution of primary particles settling out of the overlying waters to the total flux from the entrance towards the exit f the system. Particulate material transferred to the deeper slope in the southwestern part of the Gulf of Lions appears therefore to redominantly originate in resuspended shelf and/or upper slope sediment. Downward particle fluxes and potential forcing arameters exhibit a high seasonal variability, with higher values from late autumn to early spring. Furthermore, unprecedented inter flux peaks observed in 1999 dominated the interannual differences, which otherwise were quite limited. Correlations etween sources of particulate material on the shelf (i.e., river and atmospheric inputs, phytoplankton biomass and sediment

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025-3227/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
oi:10.1016/j.margeo.2006.09.003

resuspension), cross-slope exchange mechanisms (derived from in situ temperature and current records) and flux data indicate a predominant effect of dense cold water cascading on the exchange of particulate matter between the shelf and the slope.
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Keywords: particle flux; continental margin; organic carbon; interannual variability; resuspension; NW Mediterranean

1. Introduction

Continental margins represent buffer zones between the continent, the open ocean and the atmosphere. They act both as a sink for particulate matter supplied by continental inputs (riverine and atmospheric) and biological production, and a source for the adjacent open ocean. From a biogeochemical viewpoint, assessing how shelves concentrate and export organic particulate matter to the open ocean is a necessary step to estimate their influence in the global carbon cycle (Liu et al., 2000). From a geological viewpoint, knowledge on the fate of particles is needed to investigate the present impact of coastal sediment dispersal in the formation of strata in deeper slope and basin environments (Nittrouer and Wright, 1994). It also helps to better understand how environmental conditions can be archived in the sediment record, an aspect of major importance in disentangling recent climatic and oceanographic evolution of the Earth.

Over the last two decades, knowledge on the present export of shelf particulate matter to the slope essentially derived from measurements of downward particle fluxes by sediment traps (e.g., Biscaye et al., 1988; Monaco et al., 1990; Biscaye and Anderson, 1994; Puig and Palanques, 1998; Antia et al., 1999; Heussner et al., 1999; McCave et al., 2001; Fabres et al., 2002; Iseki et al., 2003). All these experiments used basically the same strategy: weekly to monthly fluxes were measured at single locations or along transects and from short-term process studies to longer times scales, generally an annual cycle. Such observations allowed building a picture of horizontal and vertical gradients and seasonal variability of flux characteristics (intensity, composition). Monitoring of particle fluxes over several years has been largely restricted to the open ocean and was or is largely intended to evaluate variations in the export of carbon to the deep realm, a mechanism that contributes to the regulation of CO_2 exchange between the atmosphere and the sea (e.g., Deuser et al., 1995; Karl et al., 1996; Wong et al., 1999; Conte et al., 2001; Unger et al., 2003; Waniek et al., 2005). On continental margins however studies covering more than one annual cycle are more than scarce (e.g., Thunell, 1998), despite their fundamental importance in the characterization of shelf–slope exchange variability and the understanding of the factors controlling these fluctuations.

In the Gulf of Lions, a temperate continental margin of the northwestern Mediterranean Sea (Fig. 1a), several multidisciplinary studies such as the French ECOMARGE programme and its European extensions EUROMARGE-NB and MTP II-MATER unveiled a variety of factors that could potentially influence the pathways and observed spatial and temporal variabilities of particle export to the open ocean (Monaco et al., 1990, 1999; Durrieu de Madron et al., 1999; Flexas et al., 2002; Van Wambeke et al., 2002). These studies suggested that flux variations on the slope respond to the major particulate sources feeding the shelf and particularly to physical transport mechanisms. In order to improve the quantification of the particle flux towards the intermediate and deep layers of the adjacent basin, and also to validate and better understand the effective role and the recurrence of the exchange processes, two consecutive experiments have been carried out since 1993. A network of 3 sites distributed over the whole slope was first instrumented with an extended array of 7 moorings (Fig. 1b). This 2-year experiment was designed to describe horizontal and vertical variations of flux and particle composition at the local scale, within and outside canyons, and at a larger scale, by comparison of fluxes at several locations along the slope. The deeper moorings at both ends of the gulf were maintained to provide a long-term monitoring of downward fluxes (current duration: 13 years). This unique time series, part of three consecutive European projects (Euromarge-NB, MTP II-MATER and EUROSTRATAFORM) and the French PNEC (Programme National Environnement Côtier), was completed with contemporaneous information on the variability of major sources of particulate matter on the shelf, and physical exchange processes. The aim of the latter study was to describe the interannual variability of downward particle fluxes on the slope and that of potential forcing parameters (sources, physical exchange processes), and to possibly discriminate the forcings responsible for the major flux events