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Sediment dispersal from a typical Mediterranean flood: The Têt River, Gulf of Lions

F. Bourrin [a,b,*], P.L. Friend [c,1], C.L. Amos [c], E. Manca [c], C. Ulses [d], A. Palanques [e], X. Durrieu de Madron [a], C.E.L. Thompson [c]

[a] Centre de Formation et de Recherche sur l'Environnement Marin, Université de Perpignan, 52 Avenue de Villeneuve, 66860 Perpignan Cedex, France
[b] Observatoire Océanologique de Villefranche, Laboratoire d'Océanographie de Villefranche, UMR 7093, B.P. 08, 06238 Villefranche-sur-mer, France
[c] School of Ocean and Earth Science, National Oceanography Centre Southampton, European Way, Southampton SO14 3ZH, UK
[d] Pole d'Oceanographie Côtiere de l'Observatoire Midi-Pyrenées-Laboratoire d'Aerologie, 14 Avenue Edouard Belin, 31400 Toulouse, France
[e] Institut de Ciències del Mar (CSIC), Passeig Marítim de la Barceloneta, 37–49 E-08003 Barcelona, Spain

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ABSTRACT

This paper describes an integrated study of a typical Mediterranean flood event in the Gulf of Lions. A flood with a 5-year return interval occurred in the Têt River basin and adjacent inner-shelf in the Gulf of Lions, northwest Mediterranean, during April 2004. Data were collected during this flood as part of event-response investigations of the EU-funded Eurostrataform (European Margin Strata Formation) project. Southeasterly storm winds led to a flood which directly modified the inner-shelf hydrodynamics. Sediment delivery to the coastal zone during this flood represented more than half of the mean annual discharge of the Têt River to the Gulf of Lions. This river transported a large amount of sand in suspension, representing 25% of the total suspended load, and as bedload representing 8% of the total load, during this event. Sand introduced in the nearshore was transported northwards during the peak storm and nourished a small delta. Fine sediments were separated from coarse sediments at the river mouth, and were advected southwards and seawards by the counter-clockwise general circulation. Fine-grained sediments were transported via a hypopycnal plume along the coast towards the southern tip of the Gulf of Lions and the Cap Creus canyon. The along-shore currents, which intensified from north to south of the Gulf of Lions, particularly between the Cap Creus promontory and the Cap Creus canyon, favoured the transfer of fine-grained sediments from the continental shelf of the Gulf of Lions towards the continental slope. Our results show that floods with a few-year return interval in small coastal rivers can play a significant role in the transport of sediments on microtidal continental margins and their export from the shelf through canyons.

1. Introduction

River floods are important processes in the land-to-sea transfer of sediment and associated contaminants (e.g. metals and pathogens). River floods can be classified into two different types: seasonal floods and flash-floods. Seasonal floods are generally associated with large systems such as the Amazon and the Huanghe (Yellow River) rivers, and are characterised by seasonal increase in river discharge caused by prolonged snow melting or monsoon conditions. Occurring during several weeks or months, meteorological conditions that have caused these floods are not directly linked with conditions at the coast. Seasonal floods can also affect smaller systems under prolonged storm/typhoon conditions (Liu and Lin, 2004). By contrast, flash-floods are short and intense events occurring during a few hours or days, and provoked under intense meteorological conditions. Flash-floods are common in the watersheds emptying into the Mediterranean Sea, and are associated with small mountainous catchments influenced by brief meteorological marine storm events during which depressions over the sea induce rapid and extreme rainfall over coastal relief. The result is a sudden river discharge of fresh water and sediment to the coastal zone. In this case, hydrology and water stratification in the inner-shelf are closely linked with local meteorological conditions. These floods affecting small coastal rivers under marine storm conditions are similar to the oceanic floods defined by Wheatcroft (2000).

Flash-floods occur over short time periods on small rivers, with the key aspect that the receiving basin is under the influence of

* Corresponding author at: Observatoire Océanologique de Villefranche, Laboratoire d'Océanographie de Villefranche, UMR 7093, B.P. 08, 06238 Villefranche-sur-mer, France. Tel.: +33 493763717; fax: +33 493763739.
E-mail address: fbourrin@obs-vlfr.fr (F. Bourrin).
[1] Present address: Maersk Oil, Esplanaden 50, 1263 Copenhagen K, Denmark.

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the storm that led to flooding when the flood pulse reaches the sea (Wheatcroft, 2000). Due to the event-driven nature of the discharge in small rivers, most sediment reaching the sea from them usually does so during flash-floods. As the annual load per basin area of small rivers is greater than that of moderate to large size rivers, it is particularly important for global sediment flux studies to investigate flash-floods in which steep basin topography can give rise to a high potential sediment discharge (Milliman and Syvitski, 1992). Sediment delivered to the sea during such floods may be stored, at least temporarily in prodeltas or mid-shelf mud belts, or bypass these reaching the slope/canyon region and thence the abyssal plain. Globally, small rivers are estimated to account for around half the annual suspended sediment load to the sea (Milliman and Syvitski, 1992). Flash-floods, due to their short duration and small spatial scales, require novel sampling and modelling strategies (Wheatcroft, 2000).

Flash-floods have been investigated in various small mountainous systems. Some studies have focused on the dynamics and the fate of sudden river inputs to the coastal zone (Hill et al., 2000; Palinkas et al., 2005; Wheatcroft and Borgeld, 2000). Other studies have focused on the river system (runoff, fresh water and solid fluxes) during flash-floods (Gaume et al., 2004; Winston and Criss, 2002). Few studies have investigated both the processes in the river catchment and in the adjacent coastal zone. In this paper, we describe a 5-year river return interval, flood event on the Têt River and the associated fluxes of sediment and water across the continental shelf in the southwestern Gulf of Lions (northwest Mediterranean). The sediment dynamics and the main conditions leading to these fluxes are described including sediment fluxes on the shoreface/inner-shelf and across the prodelta, and the links between the shoreface/inner-shelf and canyon heads. The flood event lasted less than 1 day, from 16 to 17 of April 2004 with a peak hourly discharge of $683\,m^3\,s^{-1}$. The flood described in this paper is similar to oceanic floods described by Wheatcroft (2000), but in our case the flood was generated under storm marine conditions rather than oceanic conditions. The short-term duration of the flood event, the semi-ephemeral character of the Têt River channel in summer time and the origin of this flood allow us to name this event as a storm-generated flood or flash-flood. The aim of the study is to quantify the contribution of floods with a relatively short return interval to land–sea sediment fluxes in the southwestern Gulf of Lions. A source-to-sink approach is followed through the investigation of: (1) rainfall intensity and watershed localisation; (2) coarse and fine-grained sediment transport by the river; (3) dispersal and deposition of both coarse and fine-grained sediment in the nearshore; and (4) dispersal of fine-grained sediment towards the shelf edge and the canyon heads.

2. Regional settings

2.1. Freshwater inputs

The Têt River discharges into the southwestern part of the Gulf of Lions (Fig. 1a). The Têt catchment ($1396\,km^2$) has a mean altitude of 1023 m and a mean slope of 12.4° (Ludwig et al., 2004). Its maximum headwater elevation is at 2100 m and the river length is about 100 km (Garcia-Esteves et al., 2007). The Têt River basin can thus be considered to be a small mountainous river (Milliman and Syvitski, 1992). Precipitation for the entire basin range is $\sim 757\,mm\,yr^{-1}$ (average over the 1980–2000 period); the rainfall pattern is characterised by long dry periods interrupted by short, violent marine events that can result, within a few hours, in flood events. The average liquid discharge at the gauging station at Perpignan, 10 km upstream of the mouth, is $10.82\,m^3\,s^{-1}$. Instantaneous discharge can reach $1800\,m^3\,s^{-1}$ during major floods associated with extreme rainfall events (Serrat et al., 2001). Extreme floods (mean daily liquid discharge of up to $540\,m^3\,s^{-1}$) have a 5-year return interval, whilst relatively smaller flood events (mean daily liquid discharge of $180\,m^3\,s^{-1}$) have a return interval of 2 years. In order to reduce the intensity of peak floods, a retention dam was built in 1978 at Vinça, ~50 km upstream of the mouth, on the border between the mountainous part and the alluvial plain of the Têt River catchment.

2.2. Sediment input and prodelta deposits

Flash-floods occur mainly during the autumn, at which time most of the total annual suspended load is transported to the Gulf of Lions: 78% of the total sediment flux in the Têt River between 1980 and 1999 occurred in only 50 days (0.7% of the total time; from Serrat et al, 2001). The mean annual suspended sediment discharge from the Têt River, averaged over the 1978–2004 period, is $\sim 61\ (\pm 18) \times 10^3\,t$ (Bourrin et al., 2006). The maximum suspended sediment concentration ($47\,g\,L^{-1}$) was recorded during a catastrophic flood event in the 1940s (Serrat et al., 2001). An ephemeral fluid mud deposit, composed of silts and clays, has often been observed on the inner-shelf in front of the Têt River mouth at a depth of ~30 m after flood events (Buscail et al., 1990, 1995; Courp and Monaco, 1990; Guidi-Guilvard and Buscail, 1995). This thin deposit covers the uppermost part of the prodelta of the Têt River. The short residence time and/or the weak preservation of this deposit are mainly due to resuspension by waves and currents during high energetic events (Guillén et al., 2006).

2.3. Coastal circulation and waves

The coastal circulation in the western part of the Gulf of Lions is highly variable and dependant upon wind conditions. The main winds are the northwesterly "Tramontane" and the southeasterly "Marin". The Tramontane induces a cyclonic meso-scale circulation in the western part of the Gulf (Estournel et al., 2003). The coastal current induced by the prevailing northwesterly wind generally flows from north to south–southeast along the Roussillon coast (Millot, 1976). Circulation shifts are observed at the transition between northwesterly and southeasterly wind conditions. Southeasterly winds generate a counterclockwise circulation resulting in southward flow along the western coast of the GoL. These winds generally carry humid water masses over coastal relief, and in some cases cause extreme rainfall events. When southeasterly winds are well established, they induce alongshore currents flowing southward, intensified in the Cap Creus zone where the shelf narrows (Ulses et al., 2008a).

Waves are the main stirring mechanism causing bottom sediment resuspension in the western Mediterranean because tidal currents are negligible. In the study area, major storms are associated with waves coming from the east and southeast. Usually, large waves with significant wave height (Hs) > 6 m and period (Ts) > 12 s occur during autumn and winter. These are able to resuspend sediment on the inner and middle shelf (Ferré et al., 2005; Guillén et al., 2002; Palanques et al., 2002; Puig et al., 2001).

2.4. Shelf sedimentation and export to canyons

The Gulf of Lions margin is characterised by a sandy shoreline changing progressively to a silty inner-shelf to about 50 m water depth (Aloïsi et al., 1973). A shore-parallel mid-shelf mud-belt is located between 50 and 80 m water depths and its thickness reflects the predominance of sediment inputs from the Rhône