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20th century sediment budget trends on the Western Gulf of Lions shoreface (France): An application of an integrated method for the study of sediment coastal reservoirs

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ABSTRACT

This paper presents a shoreface sediment budget established for the 20th century (1895–1984–2009) along the microtidal wave-dominated coast of the western Gulf of Lions (Languedoc-Roussillon, Mediterranean Sea, SE France). The implementation of a diachronic bathymetric approach, coupled with the definition of sand reservoirs (upper sand unit — USU) by very high-resolution seismic surveys and the results of LiDAR investigations, offers a new means of defining precisely the magnitude and change trends of the sediment budget. The aim of this study is to link the Large Scale Coastal Behaviour (LSCB) of the littoral prism (expressed in terms of shoreface sediment budget, shoreface sediment volume and spatial distribution pattern of cells) to climatic change, river sediment input to the coast, longshore sediment transport distribution, impact of hard coastal defence structures and artificial beach nourishment. The results show a significant reduction of the volume of the western Gulf of Lions littoral prism over 114 years ($-26.1 \pm 4.6 \times 10^6$ m^3). From 1895 to 1984, the overall budget is slightly positive, with a volume estimated at $4.1 \pm 3.5 \times 10^6$ m^3. For 1984–2009, however, the estimated sediment budgets clearly indicate that erosion is dominant over the last 25 years, with a volume loss of $-30.2 \pm 4.2 \times 10^6$ m^3. In relation to the long-term sediment budget and longshore drift pattern, the long-term trend of the USU volume distribution displays strong spatio-temporal contrasts linked to longshore sediment drift, spatial distribution of fluvial sediment inputs and hard engineering structures. Locally, the sedimentary reservoir is significantly eroded within a century (−80% of USU), since the initial amount present was low and not sustainable. The emphasis is on the importance of considering the volume changes of available sediment reservoirs rather than their losses and gains. Erosion of the Languedoc-Roussillon shoreface is likely to continue in the future due to the "natural" decrease of river sediment input and the sand removal for human purposes. Consequently the littoral sand prism results in sedimentary reservoirs that are gradually being used up.

1. Introduction

The coastal system is highly dynamic at different scales in time and space, which can have potentially significant impacts upon both ecological and human environments (Pilkey and Hume, 2001). Indeed, the morphological unit located between the beach and the shelf, most commonly referred to as the shoreface (Wright and Short, 1984; van Rijn, 1998), represents a "buffer zone" between the land and the sea, where waves have a significant impact on sediment transport and distribution. Consequently, the shoreface contributes in a major way to the coastal sediment budget by acting as either a sink or a source of sediment and represents an important control on shoreline movement (McNinch and Wells, 1999; Aagaard et al., 2004; Héquette and Aernouts, 2010; Aagaard, 2011). Unfortunately, it is extremely difficult to establish shoreface sediment budgets accurately (Pilkey et al., 1993; Kana, 1995). The shoreface behaviour remains poorly understood (Cowell and Thom, 1994; Masselink and Hughes, 2003; Hinton and Nicholls, 2007), especially at the longest (secular) timescales because: (1) the lack of a good-quality long-term data means that it is necessary to observe coastal behaviour on a sufficiently large spatial scale (100 km) (Stive et al., 1990, 2002), (2) there is limited understanding of interactions between numerous forcings in time and space, and (3) the difficulties of upscaling knowledge of short-term processes on a longer timescale (de Vriend, 1991). As a result, many approaches for studying coastal systems often focus on detailed processes or small spatio-temporal scales rather than considering Large Scale Coastal Behaviour (LSCB) that describes coastal evolution taking place over decades or centuries.

Hence, due to the increasing natural and anthropic pressures on the coastal environment (Hinton and Nicholls, 2007), many examples worldwide show the importance of grasping the long-term response of the coastal zone to different forcings. Indeed, the spatial and temporal behaviour of the shoreface has direct applications in coastal engineering projects involving beach nourishment (van Duin et al., 2004), the siting of coastal structures (Larson and Kraus, 1994), or more generally, the preservation of towns and touristic complexes on the sandy shoreface

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over the next decades (Sabatier et al., 2006). Furthermore, according to Stern (2007), it is cheaper to prevent erosional problems than to be faced with their consequences.

In this paper we propose an integrated approach to provide a meaningful assessment of the availability of sediment in the littoral zone at a regional scale and its evolution throughout the last century.

This study, based on bathymetry and high-resolution seismic data for determining the volumes of the nearshore sediment prism (McNinch, 2004; Miselis and McNinch, 2006; McNinch and Miselis, 2012), concerns the Languedoc-Roussillon shoreface (western Gulf of Lions, Mediterranean Sea, SE France). Many coastal studies have been conducted in this region, including several quantitative approaches (Barusseau and Saint-Guily, 1981; Barusseau et al., 1994, 1996; Durand, 1999; Certain et al., 2004, 2005). However, most of these studies have concentrated on shoreline evolution on meso- to macro-scales (month to year or decametre to kilometre), with the result that issues such as overall sediment budget and shoreface evolution at hyper-scales (>100 km and decade to century scale) remain poorly understood.

The overall aim of the present study is to illustrate how an integrated method putting together extensive bathymetric datasets, seismic and LiDAR investigations, and a sound knowledge of the morphodynamic context allows quantifying the evolution of a shoreface sediment budget over a period of more than a century (1895–2009) at the regional scale (>100 km).

2. Environmental setting

2.1. The geological context and morphology of beaches

The investigated area corresponds to the "Languedoc-Roussillon" coast, located in the western part of the Gulf of Lions, forming about 200 km of coastline between Argelès in the south, close to the border between France and Spain, and Le Grau du Roi in the north (Fig. 1), close to the Western limit of the Rhône delta.

The coast is mainly made up of sand beach barriers interrupted by rocky capes (Cap Leucate, Cap d'Agde, Sète) delimiting four main sedimentary compartments (Fig. 1) (Barusseau and Saint-Guily, 1981; Barusseau et al., 1994, 1996).

Beach states are mainly intermediate to dissipative and rarely reflective according to Wright and Short's classification (1984). The upper shoreface is generally characterized by a succession of 1–3 bars and troughs and a mean slope of 1 to 3% (Aleman et al., 2011). The lower shoreface, located offshore from the outer bar, is characterized by a very gentle and uniform slope (<1%). In the case of the Languedoc-Roussillon coast, the mean closure depth (Hallermeier, 1981) is around −6 and −8 m (Sabatier et al., 2004).

The superficial sediments of the shoreface are represented on average by generally well sorted fine to medium sands (125–320 μm). However, significant cross-shore variations are observed with a general seaward decrease of grain size (Jago and Barusseau, 1981). Longshore variations are also seen in the grain size distribution. The coarsest sediments are generally found in the vicinity of river mouths and a downdrift decrease in grain-size is observed along the coast. The littoral sands generally overlie a rocky substratum or older sedimentary formations ranging from the Quaternary to the Pliocene in age (Martin et al., 1981; Barusseau et al., 1996; Raynal et al., 2009).

2.2. Marine dynamics

The Gulf of Lions is a typical wave-dominated microtidal environment according to the classification of Hayes (1979). Two wind orientations prevail in the study area: NW offshore winds (60% of the time) and

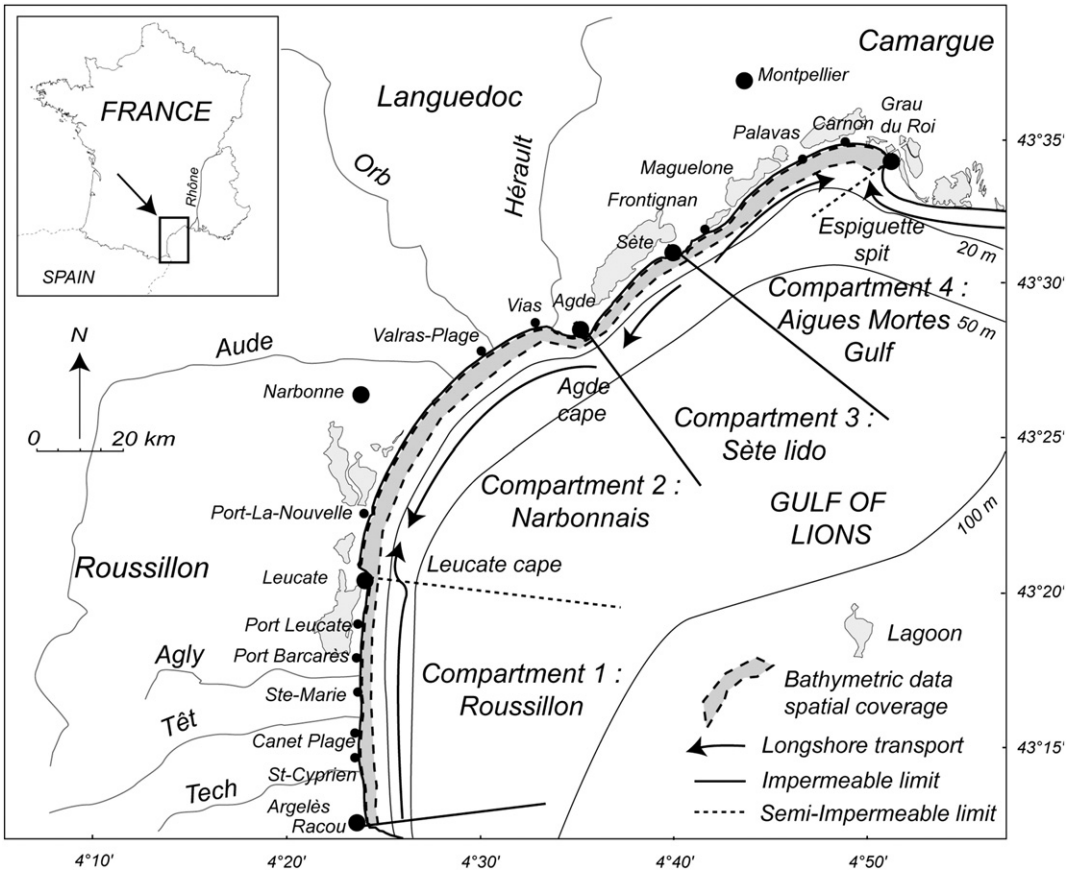

Fig 1. Coastline of the western Gulf of Lions divided into four main compartments. Arrows indicate the longshore drift direction (Barusseau and Saint-Guily, 1981). The nature of the limits between compartments is explained in the text.