

Short-Timescale Strata Formation on a Canyon-Dominated Margin: Assessing the Link Between Shelf and Slope Systems

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LONG-TERM GOALS

It is commonly thought that significant amounts of sediment do not escape to areas seaward of the shelf break during the present highstand of sea level because of sediment trapping in estuaries and on broad continental shelves. Modern sediment accumulation past the shelf break (i.e. the slope and deep-sea) is observed in many locations, but rates are typically low and the mechanism of escape is nepheloid layer advection off the shelf break. Contrary to this premise, recent studies have shown that significant amounts of sediment can escape the shelf break during sea-level highstands, particularly on tectonically-active margins (e.g., Kineke et al., 2000). These studies reveal the importance of off-shelf sediment exchange during present conditions in certain environments; however, the specific characteristics (e.g., shelf morphology, regional circulation) that permit significant sediment export from the continental shelf are not well understood, particularly near canyon heads. The long-term goal of this research is to assess how a bathymetrically complex shelf break (i.e., with many canyons) affects the link between shelf and slope sedimentary systems on broad continental margins.

OBJECTIVES

This research (as part of the EuroSTRATAFORM Program) focuses on understanding the link between the shelf and slope sediment dispersal systems in the Gulf of Lions (GOL), a margin with variable shelf widths and many submarine canyons. The seabed study aims to achieve the following objectives: determine the primary pathways of seaward sediment dispersal over the shelf and slope, estimate the timing of sediment delivery to the canyon, delineate the deposition/accumulation patterns on the shelf and slope, and estimate the amount of sediment sequestered by the upper slope.

APPROACH

Previous research has suggested that the western GOL (Fig. 1) may be the primary outlet for sediment due to narrowing of the shelf and the general east-to-west circulation pattern. This project has focused on the western GOL, including the western shelf and Cap de Creus Canyon (the western most canyon), where seaward escape is expected to be most intense. Information on the spatial and temporal changes in seabed characteristics was collected (using shipboard coring techniques). Grain sizes, sedimentary structures, radioisotopic signatures and accumulation rates were monitored during different seasons to capture the timing of sediment delivery to the shelf and canyon heads. In addition, cores were collected across the western shelf and canyons to define the spatial patterns of sediment accumulation.

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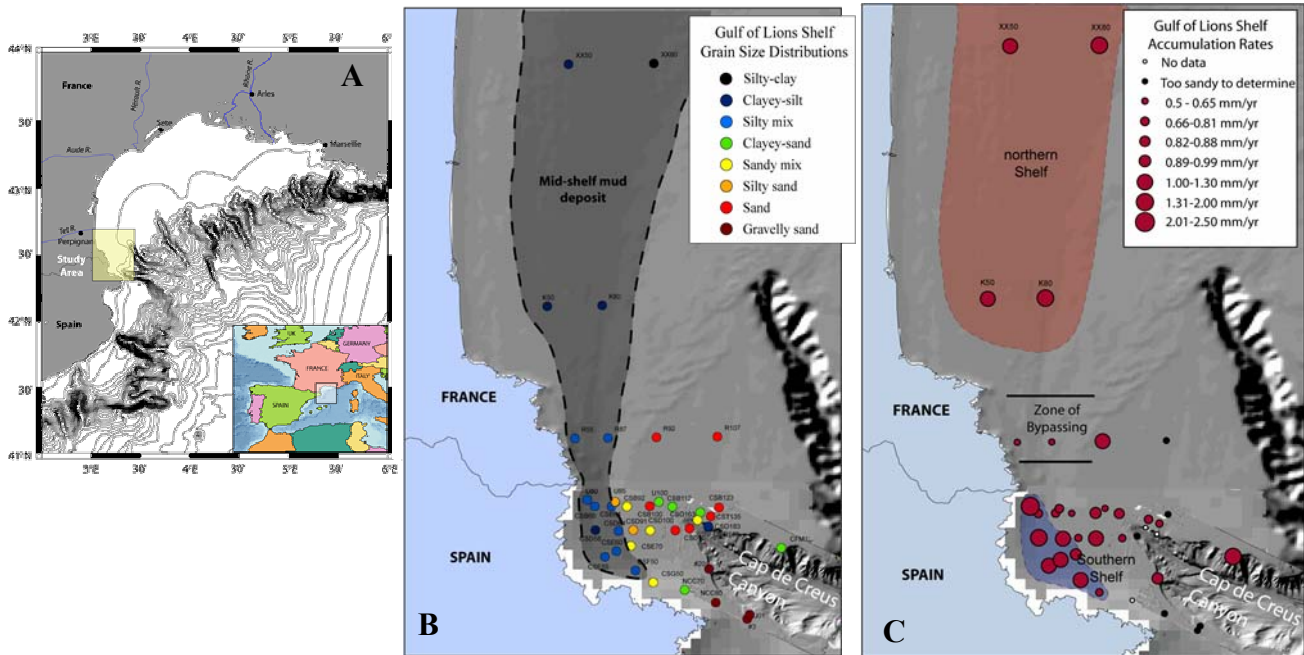


Figure 1. (A) Map of Gulf of Lions.(B) Surficial grain size on the western shelf. (C) Accumulation rates on the western shelf. Regional bathymetry courtesy of S. Berne. High-resolution bathymetry of Cap de Creus canyon courtesy of Fugro Surveys Ltd. and AOA Geophysics Inc. Data acquired with Fugro's M/V "Geo Prospector", Simrad EM300 and GeoAcoustics 534A. [(A) Regional map of Gulf of Lions indicating study area in the western area. (B) Surficial grain size shows a mid shelf mud deposit, with a sharp transition to coarser grained material at the outer shelf. (C) Accumulation rates show two distinct depocenters separated by an area of bypassing.]

WORK COMPLETED

A coarse survey of seabed characteristics across the entire western GOL study area was completed in FY04 to aid in focused coring efforts of the shelf and the upper-mid Cap de Creus Canyon in FY05. Cores were collected along multiple across canyon transects, down the main thalweg, and along seismic lines on the shelf (collected by Field et al.) during cruises in Oct04, Feb05 and Apr05 on R/V Oceanus and Endeavor. Analyses of sedimentary structures, grain sizes, radioisotopic signatures (^7Be , ^{210}Pb , ^{234}Th) and accumulation rates (^{210}Pb) have been completed for most cores. Within the canyon, the spatial distribution of seabed characteristics have been compared to morphology (e.g., water depth, slopes, aspect) using a high resolution bathymetric map (courtesy of D. Orange). Shelf seabed data indicating regions of modern sediment accumulation were compared to seismic data (courtesy of M. Field) to determine the relationship between modern processes and longer term margin development. The spatial distribution of accumulation rates and grain size distributions also were related to hydrographic data collected in the canyon (P. Puig, X. de Madron) to help infer transport pathways in the western margin.

RESULTS

Accumulation rates and grain-size patterns in the western GOL reveal distinct depocenters on the shelf and in the canyon. Surficial grain sizes show a sharp transition from mud-dominated at mid-water depths (30-90 m) to sand-dominated near the slope and canyon head (Fig. 1). Fine sediment is accumulating at two distinct depocenters: a northern section, and a localized “bulge” in the southern section (which matches the location of a sediment wedge identified in seismic records from M Field). The two primary depocenters on the shelf are separated by a zone of bypassing, apparently due to acceleration around the northern-most part of the headland (Fig. 1). Within the canyon, distinct grain size and accumulation patterns clearly show localized zones in the canyon that experience different transport processes and strata formation. Accumulation rates are asymmetric across the canyon, showing higher accumulation rates on the northern flank compared to little or no accumulation on the southern flank (Fig. 2).

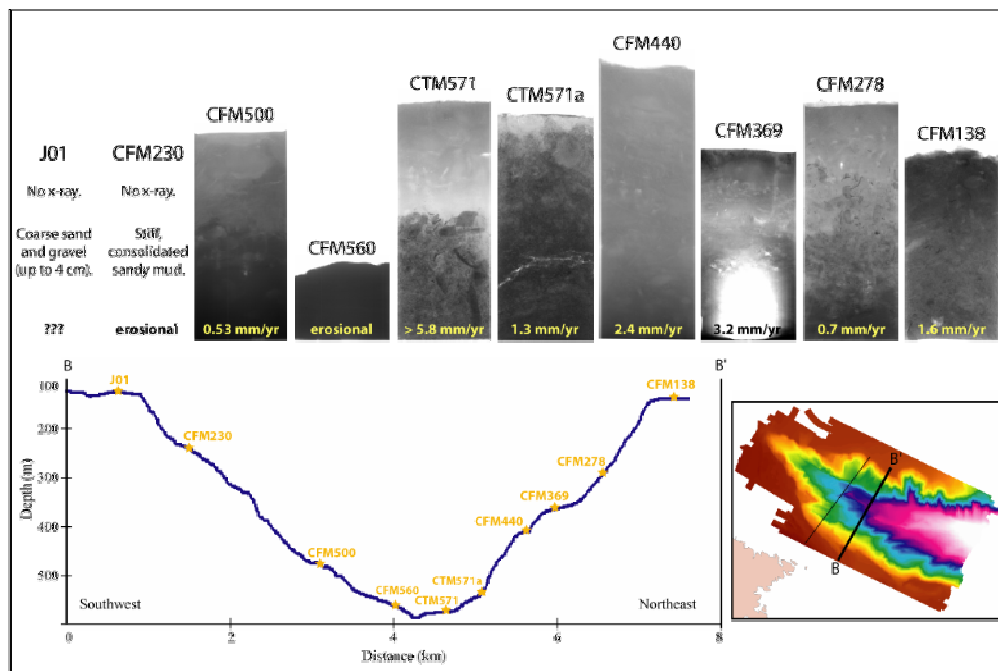


Figure 2. Across canyon transect of core x-radiographs and accumulation rates. Note the asymmetry in accumulation rates. [Across canyon cores shows the asymmetry in accumulation rates when comparing the northern and southern flanks. Northern flanks have moderate accumulation rates (1.3-3.2 mm/yr), whereas southern flanks have little or no accumulation.]

Grain-size distributions show even more dramatic asymmetry, with finer grain sizes observed on northern flanks and adjacent shelf compared to gravel and sand observed to the south (Fig.3). A sharp transition in surficial grain size also is observed in the main thalweg, with sandy deposits (~4 cm thick) unconformably overlying consolidated mud in the upper canyon (<300 m), and unconsolidated muddy layers (4-22 cm thick) unconformably overlying sand in the mid canyon (300-700 m) (Fig.4). The mud layer at mid depths shows no decrease in ^{210}Pb activity with depth, which indicates rapid deposition (likely < 10 years); the underlying sand has above-supported levels of ^{210}Pb activity which indicates this deposit is < 100 years old. The thalweg data indicate non-steady state accumulation over decadal timescales, which suggests rapid deposition and periodic flushing of this mud layer.

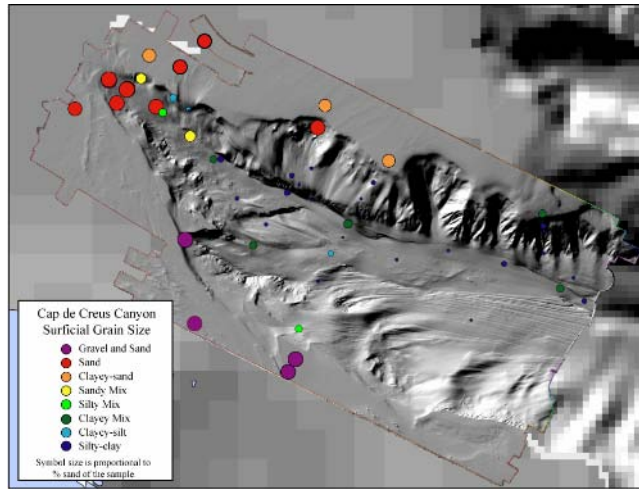


Figure 3. Surficial grain size in Cap de Creus canyon. Note the much coarser grained sediment on the southern flank compared to the northern. [Surficial grain size indicates that gravels and sands dominate sediment on the southern flanks, whereas fine sands and muds dominate to the north.]

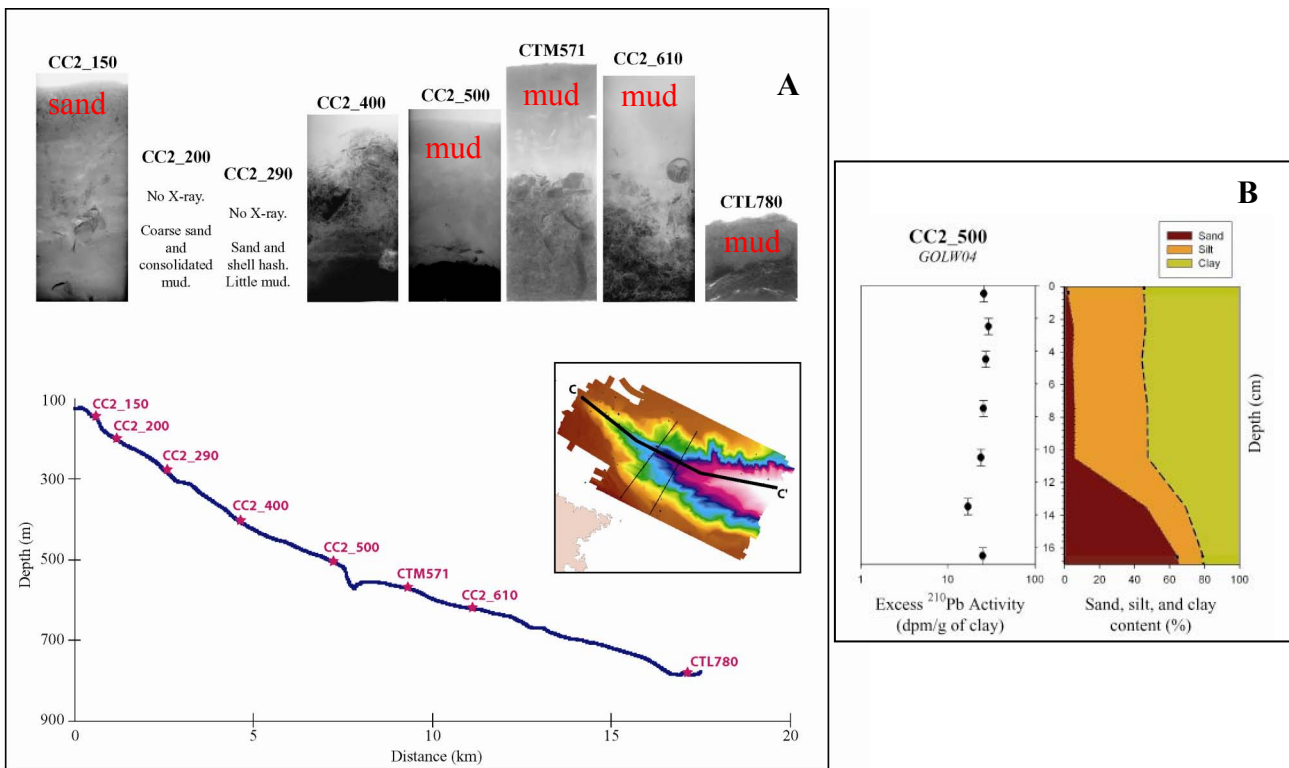


Figure 4.(A) Down thalweg transect of core x-radiographs. Note the transition from a sandy surficial layer to mud layer, moving down canyon. **(B)** $^{210}\text{Pb}_{\text{xs}}$ activity and grain size profile for core CC2_500 showing the characteristics of the mud layer. Note that there is no down-core decrease in ^{210}Pb activity in the layer and the underlying sand has excess activity.

Seabed data from the western GOL show that some of the muddy regions are acting as long-term depocenters (such as the northern flank and mid-shelf deposits), while others appear to be more ephemeral (primarily the thalweg muds within the canyon). Seabed data also indicate zones of sediment bypassing associated with the coastal promontory: the southern canyon flank and adjacent shelf is non-depositional and possibly erosional, and the mid-shelf has a zone of decreased accumulation. These data can be used to infer the following off-shelf transport mechanisms (Fig. 5):

- (1) sediment is preferentially supplied to the canyon from the shelf/slope adjacent to northern flanks via nepheloid transport from the regional current, and/or
- (2) strong currents are scouring fines from the southern canyon flanks due to enhanced currents veering around the headland.

Times-series data on sediment transport rates within the canyon (5 mab) suggest both processes are operating (from P. Puig); these data also indicate that scouring of the southern flank may be due primarily to swift dense-water cascading from the southern canyon head, that carries its sediment load to deeper parts of the canyon. The furrowed seabed on the southern flank is another indication that strong near-bottom flows may be preferentially sweeping this area. Processes operating within the thalwegs are less obvious from the seabed data. Unconformable sand and mud layers and non-steady state ^{210}Pb profiles suggest that the upper and mid canyon is periodically flushed of sediment, which is then transported to deeper parts of the canyon. Gravity-driven sediment flows may have produced the observed deposits; however, the seabed data of the upper-mid canyon does not offer sufficient evidence for identification of the transport method. Regardless of the details, all seabed data point to the upper-mid Cap de Creus Canyon as a zone of bypassing and a preferential conduit for off-shelf sediment export in the western GOL. The estimated sediment budget (100-year timescale) of the upper-mid canyon supports this conclusion, indicating that only 1.4 – 3.6% of the total sediment discharge to the GOL is sequestered by the canyon.

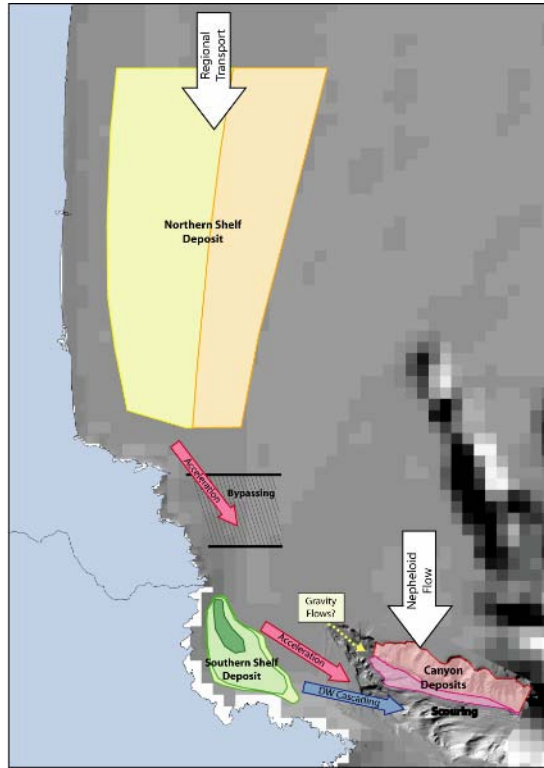


Figure 5. Cartoon of proposed transport mechanisms on the western GOL based on this study’s core data and collaborator’s time-series data (P. Puig, X. de Madron). Acceleration of regional currents around headlands may cause bypassing. Dense water cascading also contributes to scouring of the southern flank. Fine-grained sediment is supplied via nepheloid layers transported by the regional circulation. Gravity flows may be responsible for the ephemeral nature of the thalweg mud deposit.

IMPACT/APPLICATIONS

Recent studies have shown that voluminous amounts of sediment can be transported from the shelf through present-day canyons in areas where the sediment source is near the canyon head (i.e., a river discharging onto a narrow shelf) (e.g., Kineke et al., 2000). The GOL data support these results showing active sediment escape through a submarine canyon that is adjacent to a narrow shelf. However, results from the GOL indicate that active sediment escape can occur via a canyon that is distal to a major fluvial sediment sources. Both coarse and fine grained material appear to be entering the canyon system. These data suggest that the combination of coastal physiography (i.e., shoreline morphology, shelf width) and regional circulation can exert strong controls on the link between shelf and slope systems.

RELATED PROJECTS

Interdisciplinary collaborations have been a necessary component of the EuroSTRATAFORM program, including the free exchange of resources and data. The seabed-sampling plan in western GOL was extensive, so resources were pooled with C. Nittrouer for analysis of radioisotopic and grain size data (e.g., upper-mid canyon samples– Mullenbach; lower canyon samples– Nittrouer). Collaboration with EU scientists that have collected time-series data on water properties and sediment transport

mechanisms in the western GOL (X. Durrieu de Madron, P. Puig) has greatly aided in the interpretation of transport pathways inferred from the seabed data. The collaboration with D. Orange has afforded us access to high-resolution bathymetry data of the upper canyon, which was needed to analyze the relationship between seabed data and complex morphological features. M. Field has offered access to seismic data collected in western GOL, which was used to compare short- and long-term sediment accumulation patterns. It is anticipated that plans for joint publications with all of these collaborators will be established at the annual EuroSTRATAFORM meeting, and papers will be submitted shortly thereafter.

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PUBLICATIONS

DeGeest, A.L., 2005. Cap de Creus Canyon: A link between shelf and slope sediment dispersal systems in the western Gulf of Lions, France. Master's thesis, Texas A&M University, Department of Oceanography.