

Short-term sediment dynamics on a contourite body (off NW Iberia), Part II: The impact of hydrographic fronts as deduced from numerical modelling

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Abstract: A 3-Dimensional process-based morphodynamic model is applied to simulate deep-sea current – topography interaction and sediment dynamics on a contourite body located between 1,700 and 2,200m modern water depth at the NW Iberian continental slope. Different oceanographic scenarios were designed to investigate the impact of mixing between the Mediterranean Outflow Water (MOW) and its underlying water mass (Labrador Sea Water) on the morphogenesis of the contourite body. The simulated short-term sediment dynamics and bed-level elevation changes induced by density-anomaly induced oceanographic fronts provide a reasonable explanation on the grain-size distribution pattern derived from a sediment-core transect across this body. Based on this good agreement, we hypothesized that local-scale strong gravity-driven oceanographic fronts, generated by density disturbances in the mixing zone between two water masses, might play a significant role in the long-term morphogenesis of a contourite system.

Key words: process-based modelling, mixing, density front, moat erosion, eddy.

INTRODUCTION

Contourite drifts are medium- to large-scale sedimentary units generated by contour-parallel sediment transport and deposition (Heezen et al., 1966). Rapidly growing knowledge during the past two decades has strengthened our knowledge on possible driving mechanisms for morphogenesis of these sedimentary systems. However, comprehensive studies combining seismic and sediment-core data sets across an entire contourite body with a process-based simulating approach are still extremely sparse. This triggered our motivation for the study presented here.

METHOD AND RESULTS

Short-term sediment dynamics and current-topography interaction on a contourite body located between 1,700 and 2,200m water depth off the NW Iberian continental slope (Fig. 1) are simulated by a 3-Dimensional hybrid morphodynamic model (Zhang et al., 2014). The model applied to the research area consists of 5 major modules which calculate the processes of interest at different temporal and spatial scales (Hanebuth et al., subm.). Two types of fine sediments (i.e. cohesive, non-cohesive) are distinguished in the calculation according to the fraction of clay component by a threshold value of 10%. Simulations are carried out in a nested grid system. A rectilinear regional grid (Fig. 1, left panel) with a spatial resolution of 4×4 km is used to provide open boundary conditions (tidal constituents and flow flux) for a local grid (Fig. 1, bottom right panel) covering the contourite drift with a maximum spatial resolution of $\sim 150 \times 150$ m. After a removal of a surface sediment layer (15cm) on the contourite body which is recognized from the sediment cores as late Holocene hemipelagic deposit, a map of the underlying sediments' grain-size is used as model input to calculate sediment transport.

Two scenarios are designed in the local model to investigate the impacts of mixing between the Mediterranean Outflow Water (MOW) and its underlying water mass (Labrador Sea Water) on the morphogenesis of the sedimentary system.

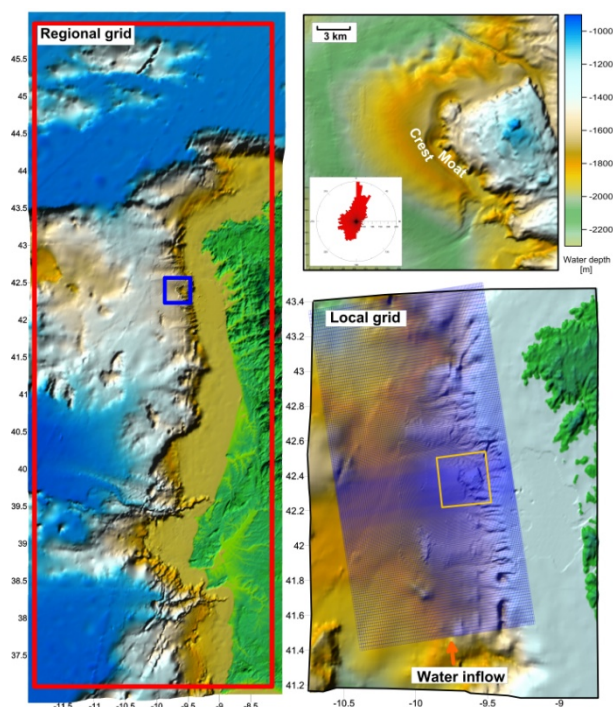


FIGURE 1. Location of the contourite body and computational grids used in the numerical model. A current rose (upper right panel) derived from the MORENA mooring program (1993-1994) indicates a predominant northward flow component at 2,000m in the study area.

The first scenario is based on the modern oceanographic setting in which the mixing zone is located far above the contourite body. Simulation results indicate that the seabed surface flow is relatively calm and stable, with only minor changes during the pass of a

regional surface storm. Current speeds are persistently below $20\text{cm}\cdot\text{s}^{-1}$ on top of the contourite body which is too weak to induce detectable sediment re-suspension. This simulation result matches the oceanographic MORENA mooring data (Fiuza et al., 1998) covering the period 1993-1994 as well as the uni-modal grain-size composition of the Late Holocene-to-modern surface sediments on the contourite system.

The second scenario assumes a 300-m deeper relocation of MOW which places the most dynamic parts of the contourite system (i.e. moat and crest) into the range of the mixing zone. As the mixing between two water masses leads to highly dynamic and unstable conditions, any disturbance on the physical properties (salinity, temperature) may result in a strong response of flow pattern which might affect the sediment dynamics.

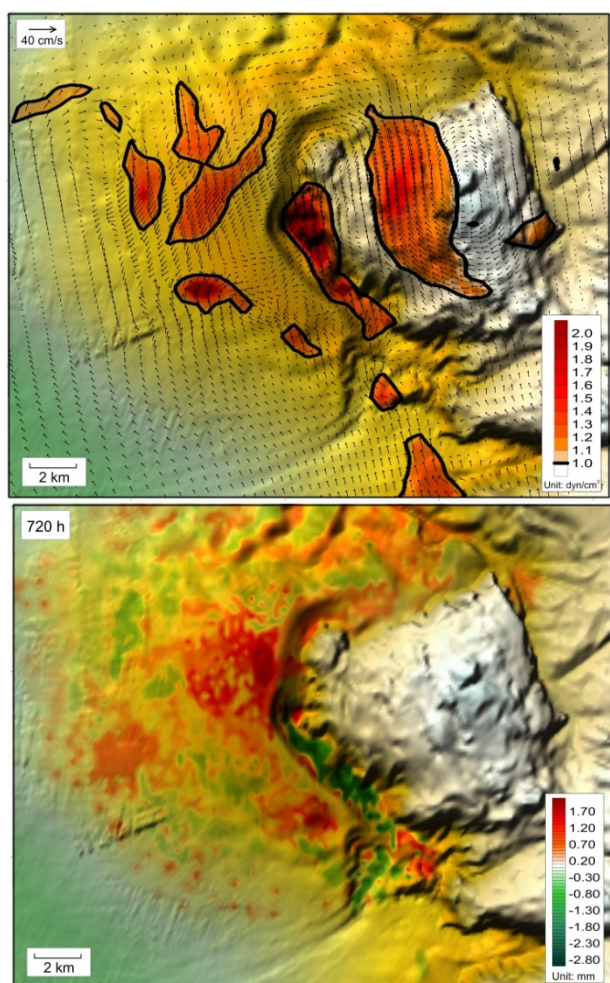


FIGURE 2. Top: Simulated horizontal bottom-current velocity field (plotted every three grid cells in both x and y directions) and corresponding bed shear stress during a northward march of the density front. The critical shear stress ($1\text{dyn}\cdot\text{cm}^{-2}$) for re-suspension of surface sediment is marked by black line. Bottom: Simulated bed-level change (positive value for deposition and negative for erosion) induced by such an event.

Our simulation results indicate that, rather than a continuous mode imposed by quasi-stable water-column stratification, episodic strong fronts induced by density anomalies in the mixing zone are the major driving

force for sediment remobilization inside the moat. Density anomalies in the mixing zone can be generated by internal-wave trains and benthic storms which result in denser-water intrusion into the moat through the channel in its southern entrance. Due to a topographic constraint by the moat, this density front flow is further strengthened and remains active for a considerably long period (e.g. several days) inside the moat to erode and transport sediment towards the north, until those are being lifted up along the moat's outer flank. Strong mixing and interaction between the density front and the surrounding water at the contourite crest cause high turbulence energy dissipation and result in a weakened flow, which is no longer able to entrain the full load of suspended sediment originated from the moat. Parts of the suspended sediment settle down on the crest as a result. The interaction between the density front and the background water is a dynamic process as the front continuously migrates northward. Further redistribution of sediments on the contourite body itself is driven by medium-scale eddies with extent from 1 to 5km which are produced by the passing front.

CONCLUSION

The simulated sediment dynamics and bed-level elevation changes induced by density-anomaly induced fronts provide a reasonable explanation on the grain-size distribution pattern derived from a sediment core transect. Based on this good agreement, we hypothesized that local-scale strong gravity-driven oceanographic fronts, generated by density disturbances in the mixing zone between two water masses, play a significant role in the morphogenesis of a sedimentary contourite system. The vertical migration of a mixing zone, controlled by long-term climate changes, induces an alternation of the system between two modes, one of calm and one of high-energy oceanographic conditions, which are well reflected in the sediment cores.

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