Interaction between alongslope and downslope sedimentary processes in the Alboran Sea during the Pliocene and Quaternary

Interacción entre procesos sedimentarios longitudinales y transversales en el Mar de Alborán durante el Plioceno y Cuaternario

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Abstract: Several morphosedimentary signatures produced by the interaction between alongslope and downslope sedimentary processes have been identified in the Pliocene and Quaternary records as well as on the present-day seafloor of the Alboran Sea. The scenarios of interaction move between two-end-members: from bottom currents dominating gravity flows to gravity flows dominating contour currents. In between these extreme cases, the alternation and balancing of both processes can occur; bottom current activity influencing the gravity flows has been also detected. Although interaction occurs in the Spanish and Moroccan margins, it is especially complex and varied on the Spanish margin, with regional and local effects on the turbidite systems. In contrast, the interaction on the Moroccan margin primarily inhibits the formation of canyons and related fan lobe deposits.

Key words: *contourite, turbidite system, alongslope processes, downslope processes, Alboran Sea*

1. INTRODUCTION

Over the last decade, international collaboration between Spanish, French and Moroccan marine geologists working in the Alboran Sea has allowed a large amount of high-resolution multibeam and multi- and single channel seismic data to be collected. The integrated study of this database has increased the understanding of seafloor features and the processes that caused them, also allowing new insights into the sedimentary evolution of the Alboran Sea basin since the opening of the Strait of Gibraltar. Recent results (Ercilla *et al*., 2012; Juan *et al*., 2012, 2014) have demonstrated that the Pliocene and Quaternary stratigraphic architecture is mostly made up of the vertical stacking of contourites interrupted by turbidite systems (TSs). The contourites primarily contribute to the outbuilding of the Spanish and Moroccan distal continental margins and the infilling of the sub-basins. They have formed under the action of bottom currents of the light intermediate and dense deep Mediterranean Waters (MWs).

Contourite distribution in the Alboran Sea evidences that the action of alongslope sedimentary process is a common process on both margins. This contrasts sharply with turbidite distribution, that suggests downslope processes are common only on the Spanish margin where contourites coexisted with canyon-fed TSs during the Pliocene and Quaternary. Contrastingly, TSs are absent in the Moroccan margin, where only a few small canyons without fans deposits have been mapped. This uneven action of downslope processes is notable because the Spanish and African hinterlands have similar geographic, climatic and fluvial systems supplying sediment load. Therefore, in order to understand this unequal behaviour it is necessary to analyse the interaction between the alongslope and downslope sedimentary processes.

In this work we study the sedimentary and morphological signatures resulting from the interaction of the Atlantic Water (AW) and MWs with the gravitational processes in the Pliocene and Quaternary sedimentary record, as well as on the present-day seafloor.

2. MATERIAL AND METHODS

This contribution is based on the study of combined data obtained by means of multibeam sounders (Kongsberg-Simrad EM-12S, EM-120, EM300, EM710

and ATLAS Hydrosweep DS), ultra-high (parametric TOPAS PS 018 sounder and ATLAS Parasound P-35) and high reflection seismic systems (EG&G sparker and 3-channel Airgun) and SIGEOF databases. All the seismic profiles were integrated into IHS Kingdom Suite projects for their interpretation.

3. RESULTS AND DISCUSSION

Different levels of interaction between alongslope and downslope processes have been identified. This interaction moves between two-end-members: from bottom currents dominating gravity flows, to gravity flows dominating bottom currents. In between these extremes, both processes can alternate or stay in balance; bottom currents influencing the gravity flows have been also detected. For the definition of these levels of interaction, we have used the classification summarized by Marchès *et al*. (2010).

3.1 Alongslope dominate downslope processes

This type of interaction is evident on the present-day Moroccan margin, where the Al-Hoceima and Trois Fourches canyons do not develop turbidite fan deposits at their mouths. In the case of the Al Hoceima canyon system, the erosive surface of a contouritic channel formed by the Western Mediterranean Deep Water (WMDW) sculpts the sea bottom instead.

This point to the downslope action of the gravity flows running along the canyon is being truncated by the strong action of the WMDW that prevents any deposition. In this scenario erosion prevails and no contourites and turbidites are deposited.

3.2 Downslope and alongslope processes alternate

The main morphosedimentary signature of this alternation is found in the Western Alboran Basin (WAB), in the most recent lobe deposits of the Guadiaro TS. The recent sedimentary record of the western side of the lobe deposits is characterised by wedge chaotic facies, thinning toward the lobe border that alternate with stratified mound facies, pinching out toward the Guadiaro channel (Fig. 1).

This pattern is interpreted as the vertical stacking of alternating mass-flow deposits and contourite drift deposits. Mass-flows coming from the Guadiaro channel alternate with contourites deposition formed by the recirculation of WMDW in the deep western basin, suggested by Ercilla *et al*. (2012) and Juan *et al*. (2014).

The deposition of the mass-flow deposits occurs mainly during sea level lowstands (Ercilla *et al*., 1994). When these flows do not occur, the permanent steady bottom flows of the WMDW favour drift formation until this is interrupted by new mass flow avenues. In this scenario, contourite drift and mass-flow deposits alternate locally in the sedimentary record of the Guadiaro lobe (Fig. 1).

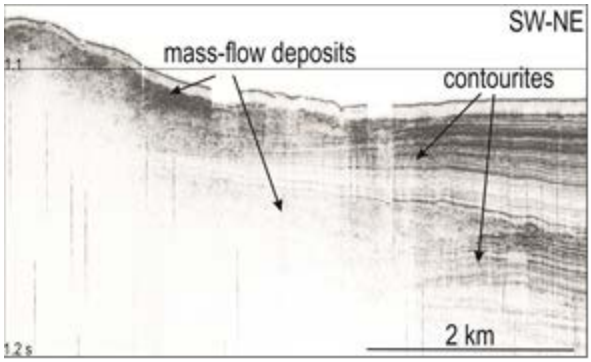

Fig. 1. Topas seismic record showing the alternation of mass-flow deposits and contourites, in the right margin of the lobe deposits of the Guadiaro TS.

3.3 Downslope and alongslope processes are balanced

This balanced action has been detected in the northeastern sector of the WAB, where the building of the whole Fuengirola lobe system coexists with the building of the sheeted drift deposits of the Motril Basin. The wedge shaped bodies of the channelized lobes are laterally confined by the vertical stacking of the stratified facies making up the sheeted drift in the Motril Basin. We interpret that the route of the gravity flows sourced by the Fuengirola channel is deflected by the adjacent sedimentary pile formed by the sheeted drift (Fig. 2). In this scenario, drift and lobe systems grow simultaneously.

3.4 Alongslope processes influence the downslope processes

There are three main morphological and sedimentary signatures identified from this type of interaction:

First, the eastward migration displayed by the lobe deposits of the TSs in the WAB, during the uppermost Pliocene. At that time the WAB was about to attain its quasi-confined present-day configuration after the uplifting of the SW Alboran Ridge (Martínez-García *et al.*, 2013) and the Al Hoceimas and Tofiño Banks (Ammar *et al*., 2007). We tentatively suggest that this quasi-confined geometry favoured the acceleration of the previous mentioned WMDW filament that probably recirculates in its deep domain.

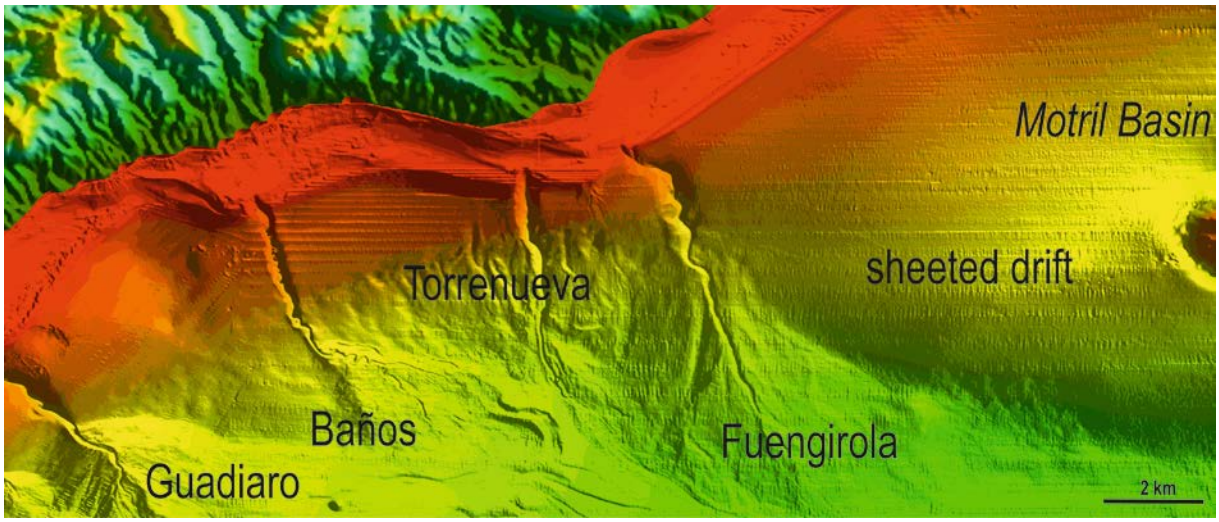

Fig. 2.Multibeam bathymetry map displaying most of the TSs in the Western Alboran Basin and the sheeted drift in the Motril Basin. Note the confinement of the lobe deposits of the Fuengirola TS by the drift in the Motril Basin.

Second, the architecture of the TSs in the WAB (Ercilla *et al*., 2014). Specifically, canyons mostly characterised by non-leveed margins and differences in the architecture the fanlobes, are favoured. The architecture shows a lateral change from a single linear to lower sinuous leveed channel in those TSs close to the Strait of Gibraltar, to a single main leveed channel linked downslope to distributary channels in the others. Sinuous channels are also frequent in the fanlobes located in the east.

Last, this type of interaction also conditions the sedimentary composition (grain size) of the TSs that ranges from sandy to mixed sand-mud, becoming sandier towards the Strait of Gibraltar (Ercilla *et al*., 2014).

We interpret these architectural and textural characteristics of the TSs as a consequence of the interplay between the activity of the western anticyclone gyre of the AW (whose influence reaches ~700 m deep, and decreases in velocity eastwards; Naranjo *et al*., 2012), and the activity of the light intermediate and dense deep MWs. The MWs accelerate toward the Strait of Gibraltar, favouring the piracy of the sediment supplied by the gravity flows. Piracy results in fine sediment deprivation in the downslope flows feeding the TSs, explaining the lack of defined levees in the canyon margins and the sandier fans towards the Strait of Gibraltar, where the currents are faster.

In this scenario water masses favour the piracy of the sediment supplied by the gravity flows, conditioning the geometry and grain size of sediment of the TSs. In addition, TSs migrate in the direction of the bottom currents.

3.5 Downslope processes dominate alongslope processes

The main morphosedimentary evidence of this dominance is found mainly on the eastern Spanish margin, where the Almeria turbidite system develops. Its Pliocene and Quaternary depositional architecture reveals that the trajectories and morphoseismic characteristics of the Almeria canyon, its complex tributary systems, as well as that of the main leveed channel and lobe deposits, have all been primarily conditioned by the characteristics of the gravity flows. The occurrence of these flows has mainly been controlled by glacioeustasy, and the spatial relocation of the turbidites during the Pliocene and Quaternary by tectonics (Estrada *et al*., 1997; Alonso and Ercilla, 2003). In this scenario, only turbidites deposit.

4. CONCLUSIONS

In the Alboran Sea, the interaction between the alongslope and downslope sedimentary processes occurs on both margins. But this interaction is especially complex and varied on the Spanish margin, where various levels of action are interpreted, with regional and local effects on the TSs. Here, the alongslope action is related to the AW, the light intermediate and the dense deep MWs.

Contrastingly, on the Moroccan margin, the alongslope processes dominate over the downslope ones. Here, the alongslope action is mainly governed by the energy of the AW and also of the WMDW, whose core impinges on and accelerates along the Moroccan margin. This favours intense alongslope sediment transport that prevents deposition and avoids the convergence of sediment along the

Moroccan margin, inhibiting the local occurrence of potential erosive gravity flows and thus, the formation of canyons and/or their related fan lobes.

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