Water mass footprints in uneven turbidite system development in the Alboran Sea

Gemma Ercilla[1], Carmen Juan[1], Belén Alonso[1], Ferran Estrada[1], David Casas[1,3], Marga García[1,4], Francisco Javier Hernández-Molina[2], Juan-Tomás Vázquez[5], Estefanía Llave[3], Desirée Palomino[5], Marcel·lí Farran[1], Christian Gorini[6], Elia d'Acremont[6], Bouchta El Moumni[7], Abdellah Ammar[8]and CONTOURIBER and MONTERA Teams

1 ICM-CSIC, 08003, Barcelona, Spain (gemma@icm.csic.es; cjuan@icm.csic.es; belen@icm.csic.es; festrada@icm.csic.es; mfarran@icm.csic.es)
2 Royal Holloway, University of London, Egham, TW20 0EX, UK (Javier.Hernandez-Molina@rhul.ac.uk)
3 IGME, 28003, Madrid, Spain (d.casas@igme.es; e.llave@igme.es)
4 IACT-CSIC, 18002 Granada, Spain (marguita.garcia@gmail.com)
5 IEO, 29640, Fuengirola, Spain (desiree.palomino@ma.ieo.es; juantomas.vazquez@ma.ieo.es)
6 Sorbonne Universités, UPMC Univ. Paris 06, ISTEP and CNRS UMR 7193, Paris, France (christian.gorini@upmc.fr; elia.dacremont@upmc.fr)
7 Abdelmalek ESSAADI University, Larache, Morocco (elmoumni@fpl.ma)
8 Mohammed V-Agdal University, Rabat, Morocco (siadamammar@yahoo.fr)

Abstract: *Multidisciplinary work between oceanography, geomorphology and sedimentology has uncovered evidence explaining the uneven development of the turbidite systems (TSs) in the Alboran Sea. Nine TSs have been mapped in the Spanish margin, ranging from sandy to mixed sand-mud fans, and which become sandier towards the Strait of Gibraltar; in contrast TSs do not develop in the Moroccan margin, where three canyons incise the continental slope but there is no TS formation. We interpret that the uneven development of TSs in the two margins and their variable architectures are conditioned by the interaction of alongslope with downslope processes. Two different interaction scenarios with varying intensities are proposed.*

Key words: *Alboran Sea, turbidite system, contourite, oceanography.*

INTRODUCTION

The Alboran Sea (SW Mediterranean) is a semi-enclosed basin bordered by the Spanish and Moroccan margins where Atlantic and Mediterranean water masses meet and interact. Ever since marine geology research began in this area, about 25 years ago, a question has remained unanswered: why does only the Spanish margin develop turbidite systems (TSs) even though the hinterlands of both countries have similar geographic and climatic characteristics and their continental shelves also have similar deposits. In this work, we tentatively propose an answer, which has been made possible thanks to the multidisciplinary studies of oceanography, geomorphology and sedimentology.

DATA

We have analysed approximately 2000 single and multi-channel seismic records at different resolutions, from the ICM-CSIC (*http: //www.icm.csic.es/geo/gma/ SurveyMaps/*) and SIGEOF (*http://www.igme.es/ internet/sistemas_infor/BASESINTERNET/sigeof.htm*) databases. All the seismic profiles were integrated into a Kingdom Suite project.

Additionally, more than 3000 CTD (conductivity, temperature, depth) profiles, available on Sea Data Net (*http://www.seadatanet.org/Data-Access*) and other platforms (such as the Medatlas II database, *http://odv.awi.de/en/data/ocean/medatlasii/*), have been analysed using the Ocean Data View software.

RESULTS AND DISCUSSION

Detailed mapping of the sedimentary systems characterizing the Alboran Sea (Fig. 1) has revealed that continental slopes are made up of contourites. However, they show an important difference from a morpho-sedimentary point of view: the uneven development of TSs. Nine TSs (15 to 99km long) have been mapped in the Spanish margin (Fig. 1). In contrast, TSs do not develop in the Moroccan margin, where the Ceuta canyon and the two relatively shorter Al Hoceima and Trois Fourches canyons are the only submarine valleys incising the slope. We began from the premise that the uneven development of TSs on the two margins and the variable architecture of the fans are a result of the unequal interaction between alongslope and downslope processes. Several indicators were analysed so that the different dynamics governing both margins could be understood, in order to reinforce or allow us to reject this interpretation:

Oceanographic context: The present-day circulation is defined by three major water masses: 1) the surficial Atlantic Water (AW), (down to 150–200m water depth) that describes two anticyclonic gyres, Western and Eastern; 2) low density (LD) Mediterranean water, formed by the Western Intermediate Water (WIW) and Levantine Intermediate Water (LIW), which on the Spanish continental slope only extends down to 600m water depth; and 3) the underlying high density (HD) Mediterranean water, formed by the Western Mediterranean Deep Water (WMDW) and which is largely restricted to the Moroccan margin (below 180m

water depth), deep basins and the Spanish base-of-slope (below 600m water depth) (Millot 2009 and references therein).

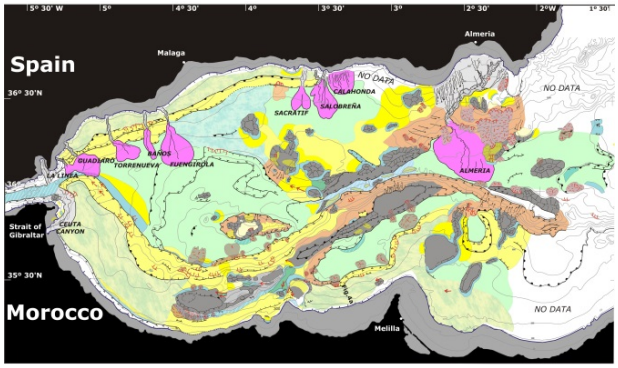

FIGURE 1. Geomorphologic map of the Alboran Sea. The purple colour indicates turbidite systems (TSs). Note the lack of TSs in the Moroccan margin.

Sedimentary context: The continental slopes mostly comprise alongslope plastered drifts with striking terraces formed under the action of the LD (Spanish margin) and HD water masses (Moroccan margin). The plastered drifts connect to a deeper plastered drift on the Western Spanish base of slope, and to sheeted drifts in the basins, all formed under the action of the HD waters. In this scenario, the TS feeder canyons cross the continental slope eroding the terraces and the alongslope plastered drifts. Canyons mouth directly into fan lobes on the base of slope and in adjacent basins, with aggrading and migrating leveed channels interrupting the lateral continuity of the plastered and sheeted drifts. The abrupt transition is always coincident with features sculpted by contour currents.

Comparative morphoarchitecture of TSs in gross plan view: The comparative patterns of the TSs distributed along the Spanish margin highlight their similarities and longitudinal differences. The similar features are the canyons, mostly characterised by non-leveed margins. The differences are mostly related to the shift in fan lobe architecture, from a single linear to lower sinuous leveed channel in those fans close to the Strait of Gibraltar, to a single main leveed channel linked downslope to distributary channels in the others. The channel pathways are mostly rectilinear, although sinuous channels are more frequent in the fans located in the east. The architecture, dimensions, and plan-view morphology of the TSs elements based on Reading and Richard's classification (1994) suggest that the sedimentary composition of the fans ranges from sandy to mixed sand-mud, becoming sandier towards the Strait of Gibraltar.

CONCLUSIONS

Based on the oceanographic and sedimentary contexts, as well as the overall architecture and geometry of the TSs, we can distinguish two scenarios where there is interaction between alongslope and downslope processes, occurring at different intensities. These scenarios help us understand the potential mechanisms that may have been conditioning the uneven development of TSs.

1) *The Spanish margin scenario, where the interaction has conditioned the fan architecture and its variability.* In this scenario when sediment arrives to the sea, the finest fraction is pirated by the AW. The dynamic of the two anticyclone gyres and the well-developed isopycnal and related processes (e.g., internal waves) between the Atlantic and Mediterranean waters represent potential mechanisms for maintaining the fine sediment in suspension and dispersing it in the nepheloid layer throughout the Alboran Sea. Piracy would result in fine sediment deprivation in the downslope flows feeding the fans, explaining the lack of defined levees in the canyon margins and the sandier fans towards the Strait of Gibraltar, where the currents are faster. The importance of piracy depends on the intensity of the currents. Thus, the interplay between the unequal activity of the AW (its eastwards velocity decrease) and its two anticyclonic gyres (Eastern-permanent versus Western-semi-permanent), as well as the LD and HD accelerating toward the Strait of Gibraltar, would favour significant piracy from the gravity flows outbuilding the fan lobes in the west. This would explain the trend of the western fans from mixed sand-mud-rich to sand-rich.

2) *The Moroccan margin scenario, where the interaction is stronger and has conditioned the lack of TSs.* In this scenario, the interplay between the piracy by the Atlantic anticyclonic gyres, more sediment in suspension, and dispersion due to the enhanced density contrast between the AW and HD Mediterranean waters, together with the waters of the HD core impinging and accelerating along the Moroccan margin due to being forced to flow upslope, all favours intense alongslope sediment transport. This intense transport prevents the convergence of sediment along the Moroccan margin, inhibiting the local occurrence of potential erosive gravity flows and leading to the formation of canyons and/or their related fan lobes.

ACKNOWLEDGEMENTS

This work is in the framework of the MOWER (CTM2012-39599-C03-02), MONTERA (CTM2009-14157-C02-02), projects and Action Marges Program.

REFERENCES

Millot, C., 2009. Another description of the Mediterranean Sea outflow. Progress in Oceanography 82,101–124.

Reading, H.G. and Richards, M. (1994). Turbidite systems in deep water basin margins classified by grain size and feeder system. AAPG Bulletin 78, 792-822.