

(Paleo)circulation models in the Alboran seas during the Pliocene and Quaternary

Carmen Juan¹, Gemma Ercilla¹, F. Javier Hernández-Molina², Ferran Estrada¹, Belén Alonso¹, David Casas^{1,3}, Marga García^{1,4}, Marcel·lí Farran¹, Estefanía Llave³, Desirée Palomino⁵, Juan Tomás Vázquez⁵, Teresa Medialdea³, Christian Gorini⁶, Elia D'Acremont⁶, Bouchta El Moumni⁷, Abdellah Ammar⁸ and CONTOURIBER, MONTERA and MOWER Teams

- 1 ICM-CSIC. 08003, Barcelona, Spain (cjuan@icm.csic.es; gemma@icm.csic.es; festrada@icm.csic.es; belen@icm.csic.es; mfarran@icm.csic.es)
 2 Royal Holloway U. 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; t.medialdea@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 U. Pierre et Marie Curie. 75252, Paris, France (christian.gorini@upmc.fr; elia.dacremont@upmc.fr)
 7 U. Abdelmalek ESSAADI. Larache, Morocco (elmoumni@fpl.ma)
 8 U. Mohammed V-Agdal. Rabat, Morocco (siadamammar@yahoo.fr)

Abstract: A multiple Contourite Depositional System has been defined in the Plio-Quaternary sedimentary register in the Alboran Sea. This multiple system formed by the Atlantic and the low density and high density Mediterranean Waters, which shaped the margins and basins since the opening of the Gibraltar Strait. Three different (paleo)circulation scenarios are proposed since then: the Atlantic water Flooding; the Pliocene circulation, characterized by immature low and high density Mediterranean waters and a strong countercurrent in the Western Basin; and the Quaternary circulation, characterized by tabular Mediterranean water masses with multiple current dynamics, an increasing influence of density contrasts, and climate shifts causing major vertical and horizontal displacements of their interfaces.

Key words: contourites, Alboran Sea, Plio-Quaternary, stratigraphy, paleoceanography.

INTRODUCTION

The Alboran Sea, located at the westernmost Mediterranean, is characterized by its complex physiography, with two main basins (Eastern, Western), two main intra-slope basins (Southern, Motril) and several morphologic traits (structural and volcanic highs, ridges and plateaus) acting as obstacles to the intermediate and deep flows. Also, its closeness to a main oceanographic gateway (Strait of Gibraltar) conditions its dynamics.

DATA

We have reviewed and analyzed about 2000 seismic profiles, available at the ICM-CSIC (<http://www.icm.csic.es/geo/gma/SurveyMaps/>) and SIGEOF (http://www.igme.es/internet/sistemas_infor/BASESINTE_RNET/sigeof.htm) databases, comprising single and multi-channel seismic records with different resolutions. All seismic profiles were integrated in a Kingdom Suite project.

In addition, more than 3000 CTD profiles (conductivity, temperature, depth), available in open-access on Sea Data Net (<http://www.seadatanet.org/Data-Access>) and other platforms (as the Medatlas II database, <http://odv.awi.de/en/data/ocean/medatlasii/>), were analyzed using the Ocean Data View software.

RESULTS

The detailed stratigraphy study allowed us to attain a new stratigraphic architecture, in agreement with the

conclusions reached by Ercilla et al. (1994), who suggested the Plio-Quaternary sedimentary evolution was controlled mainly by the interplay of tectonics, sea-level changes, and a complex ocean circulation, the latter being governed by climate shifts (Fig. 1).

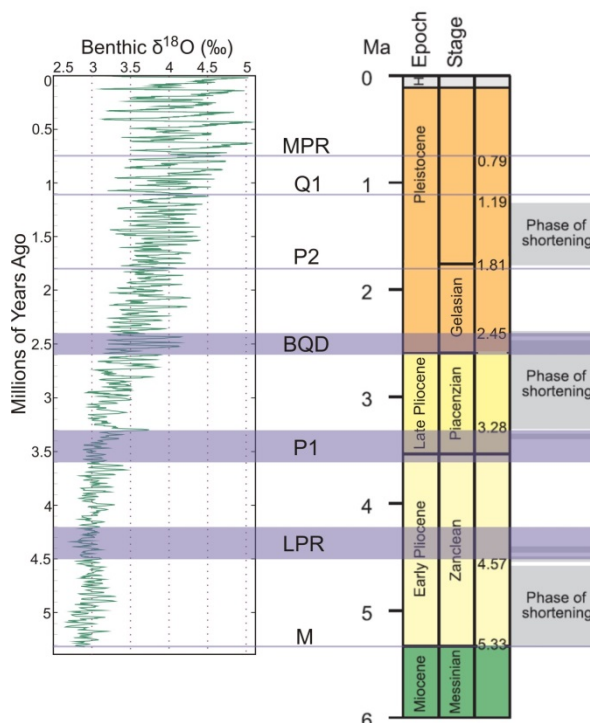


FIGURE 1. Modified from Lisiecki and Raymo, 2005 (left) and from Martínez-García et al., 2013 (right). Influence of tectonic pulses and climate shifts in the newly defined boundaries.

On the other hand, our CTD analysis allowed to discern the Atlantic Waters –AW– and the Mediterranean low density –LD– (Western Intermediate Water –WIW–, Levantine Intermediate Water –LIW–) and high density –HD– (Western Mediterranean Deep Water –WMDW–) waters (Millot, 2009), to deduce their pathway, to observe the superimposed hydrological and geological structures (Fig. 2), and to highlight the importance of interfaces.

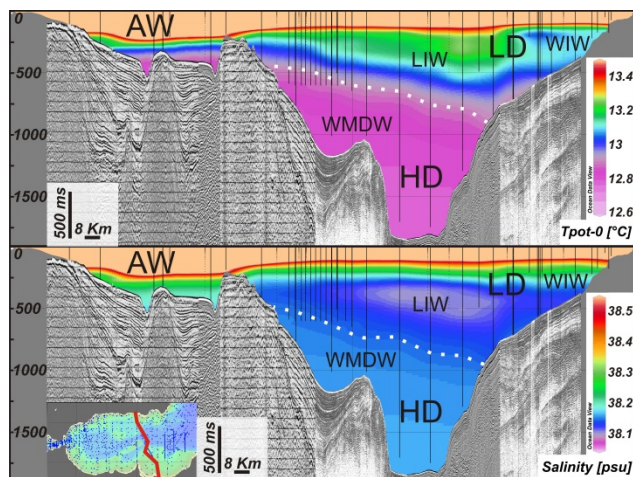


FIGURE 2. Main water masses superimposed to the geological features observed in a mosaic of seismic profiles cutting S-N the Eastern Basin

DISCUSSION

The cross-disciplinary studies carried out between geomorphology, stratigraphy and physical oceanography conducted in the Alboran Sea have changed the interpretation of sedimentary processes governing the long-trend morphosedimentary records of the margins and deep-sea areas of the study area. In contrast with previous interpretations, this study highlights the governance of the water masses and their interfaces on the sedimentation of the margins and basins of the Alboran Sea during the Pliocene and Quaternary, previously considered as a local influence (Ercilla et al., 2002).

The results obtained from analyzing the intricate relationship between the sedimentary processes and the action of the LD and HD waters were transferred to the paleosurfaces of the main stratigraphic divisions, allowing to define a multiple Contourite Depositional System (CDS) formed by the LD and HD waters and their interfaces with the AW, and dominated by a great variety of depositional and erosive features.

The seismic facies characterizing the CDSs, as well as their temporal and spatial variability suggest the action of LD and HD Mediterranean waters since the beginning of the Pliocene. The results allow decoding of the paleocirculation and indicate that significant relocation of main flow pathways, both longitudinal and transversal, occurred.

CONCLUSIONS

We have inferred three circulation models: 1) during the infilling of the Mediterranean basin by the Atlantic

flooding, highly erosive (Estrada et al., 2011); 2) during the Pliocene, when a strong countercurrent occurred in the Western Alboran Basin, eroding the Spanish base of slope; it comprises two stages: 2a) Lower Pliocene, the Western and Southern basins were connected allowing the circulation of tabular HD waters; 2b) Upper Pliocene, the uplift of the SW Alboran Ridge interrupted the connection, favoring the splitting of HD waters into accelerated branches; and 3) the Quaternary model is similar to the present day, characterized by an enhanced density contrast between the LD and HD Mediterranean waters that show multiple current dynamics including a less energetic recirculation of the HD in the Western Alboran Basin and larger vertical and horizontal displacements of the water mass interfaces directly related to 4th-order glacioeustatic changes. All these mentioned stages reflect variability in the bottom current regimes and related along slope efficiency in transport, deposition and erosion mainly governed by large and small scale margin and basin geometries, and climatic changes.

ACKNOWLEDGEMENTS

CTM 2008-06399-C04; CTM2009-14157-C02-02; CTM 2012-39599-C03-02; IGCP 619; INQUA 1204; Actions Marges; EUROFLEETS FP7/07-13, n228344.

REFERENCES

- Ercilla, G., Alonso, B., Baraza, J., 1994. Post-Calabrian sequence stratigraphy of the northwestern Alboran Sea (southwestern Mediterranean). *Marine Geology* 120, 249-265.
- Ercilla, G., Baraza, J., Alonso, B., Estrada, F., Casas, D., & Farran, M., 2002. The Ceuta Drift, Alboran Sea, southwestern Mediterranean. From: *Deep-Water Contourite Systems: Modern Drifts and Ancient Series, Seismic and Sedimentary Characteristics* (Stow, D.A.V., Pudsey, C.J., Howe, J.A., Faugères, J.-C. & Viana, A.R., eds.). Geological Society, London, Memoirs 22, 155-170.
- Estrada, F., Ercilla, G., Gorini, Ch., Alonso, B., Vázquez, J.T., García-Castellanos, D., Juan, C., Maldonado, A., Ammar, A. & Elabbassi, M., 2011. Impact of pulsed Atlantic water inflow into the Alboran Basin at the time of the Zanclean flooding. *Geo-Marine Letters* 31, 361-376.
- Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic D18O records. *Paleoceanography* 20, PA1003.
- Martínez-García, P., Comas, M., Soto, J.I., Lonergan, L., Watts, A.B., 2013. Strike-slip tectonics and basin inversion in the Western Mediterranean: the Post-Messinian evolution of the Alboran Sea. *Basin Research* 25, 1-27.
- Millot, C., 2009. Another description of the Mediterranean Sea outflow. *Progress in Oceanography* 82, 101-124.