

Onset of Mediterranean Outflow into the North Atlantic

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Abstract: Sediments cored along the southwestern Iberian margin during Integrated Ocean Drilling Program Expedition 339 provide constraints on Mediterranean Outflow Water (MOW) circulation patterns from the Pliocene epoch to present day. After the Strait of Gibraltar opened (5.33 Ma), a weak and limited volume MOW entered the Atlantic. Depositional hiatuses indicate erosion by bottom-currents related to higher volumes of MOW circulating into the North Atlantic beginning in the late Pliocene. The hiatuses coincide with regional tectonic events and changes in global thermohaline circulation (THC). This suggests that MOW influenced Atlantic Meridional Overturning Circulation (AMOC), THC, and climatic shifts through the supply by contributing a component of warm, saline water to northern latitudes, while in turn being influenced by plate tectonics.

Key words: Contourites, Gulf of Cadiz, IODP Expedition 339, Mediterranean Outflow Water, global thermohaline circulation, Atlantic Meridional Overturning Circulation.

INTRODUCTION

Changes in the Mediterranean Outflow Water (MOW) co-occurred with some shifts in global ocean circulation and climate, but the exact timing of MOW evolution vis-à-vis major climate events remains unclear. This paper interprets the sequence of events very recently identified by Hernández-Molina et al (2014) that established a significant MOW contribution to North Atlantic thermohaline dynamics, and how these

dynamics relate to Neogene and Quaternary climatic and tectonic events. This study combines geophysical and drill-core data acquired along the southwestern Iberian margin during Integrated Ocean Drilling Program (IODP) Expedition 339 aboard the RV *JOIDES Resolution*.

DEPOSITS FROM LATE MIOCENE TO PRESENT: SEISMIC RECORDS AND DRILL CORE INTERPRETATION

Major regional discontinuities appear as high-amplitude seismic reflections within late Miocene to present-day sediments around the Gulf of Cadiz (Fig. 1). These discontinuities provide a record of MOW circulation relative to coeval tectonic and environmental events. In seismic records, Pliocene deposits appear as sheeted drifts, overlying a weakly reflecting Miocene unit that progrades downslope (Fig. 1). The late Pliocene to early Quaternary section records significant synsedimentary deformation associated with two discontinuities that define erosional surfaces (Fig. 1). Quaternary deposits are distinguished by high amplitude seismic reflections and show clear upslope progradation.

The predominant sedimentary facies in the late Miocene to present-day sedimentary record include pelagites, hemipelagites, contourites, turbidites, debrites and slump deposits. Contourites constitute up to 95% of Quaternary deposits, and about 50% of the recovered Pliocene succession. This facies includes sand-rich, silt-rich and mud-rich contourites, deposited at moderate (20-30 cm/ky) to very high (> 100 cm/ky) sediment accumulation rates. Dolomitic mudstone and dolostones are rare, but also occur in drill core material. The chronostratigraphy and absolute ages of key horizons, namely several depositional hiatuses and stratigraphic boundaries derive from shipboard bio- and magnetostratigraphic analyses of core samples collected at IODP Expedition 339 sites. Two depositional hiatuses (Fig. 1), evident at 3.2 - 3.0 Ma and 2.4 - 2.1 Ma, indicate that MOW did not significantly circulate into the North Atlantic until the late Pliocene and early Pleistocene. A latter event, occurring at 0.9 - 0.7 Ma, suggests the existence of an additional Pleistocene phase of MOW intensification.

CONCLUSIONS

The results presented here show that initial MOW circulation, into the Atlantic following the opening of the Strait of Gibraltar, was relatively weak. Significant interaction between MOW and the North Atlantic did not begin until the late Pliocene. The establishment of MOW added relatively salty water at intermediate

depths and contributed to enhanced THC and AMOC. The addition of the warm, salty MOW component reduced pole-to-equator temperature gradients during the mid-Pliocene warm period (3.2 - 3.0 Ma), during the early Pleistocene (2.4 - 2.0 Ma), and at 0.9 - 0.7 Ma. These climatic events coincide with widespread depositional hiatuses, pronounced changes in the sedimentary stacking pattern and establishment of the present-day sea-floor morphology (Fig. 1). Hiatuses and shifts in depositional processes are related to regional tectonic events and margin instability. Similar changes in deep water sedimentation and tectonics have been described in association with other margins and basins around the same time in both the Northern and Southern hemispheres, demonstrating that the relationship between climatic shifts and plate tectonic events operates over a wide range of timescales.

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REFERENCES

Hernández-Molina, F.J., Stow, D.A.V., Alvarez-Zarikian, C.A., Acton, G., Bahr, A., Balestra, B., Ducassou, E., Flood, R., Flores, J.A., Furota, S., Grunert, P., Hodell, D., Jimenez-Espejo, F., Kim, J.K., Krissek, L., Kuroda, J., Li, B., Llave, E., Lofi, J., Lourens, L., Miller, M., Nanayama, F., Nishida, N., Richter, C., Roque, C., Pereira, H., Sanchez Goñi, M.F., Sierro, F.J., Singh, A.D., Sloss, C., Takashimizu, Y., Tzanova, A., Voelker, A., Williams, T., Xuan, C., 2014. Onset of Mediterranean Outflow into the North Atlantic. *Science*, 344 (6189): 1244-1250.

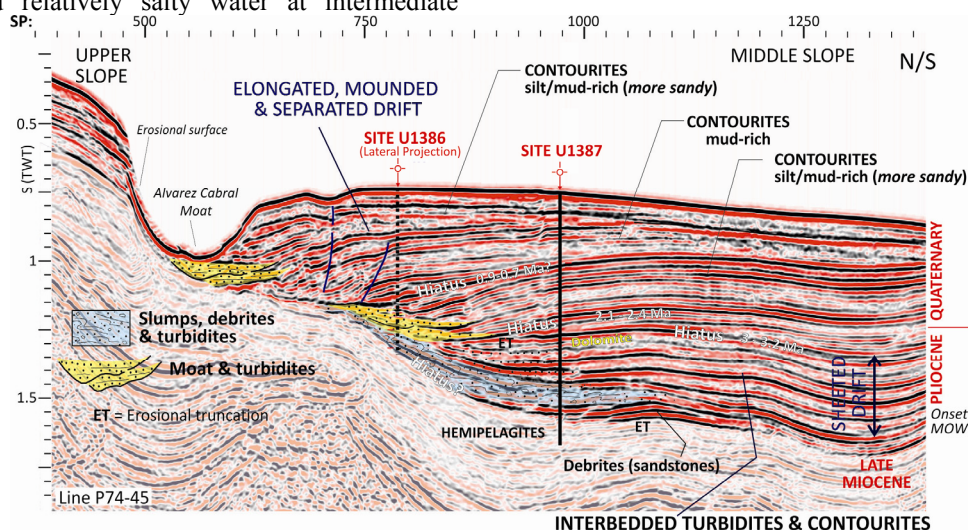


FIGURE 1. Seismic profile showing the major sedimentary stacking pattern, from the Pliocene sheeted drift to the Quaternary elongate and mounded drift, based on the correlation between Sites U1386 and U1387 and the multichannel seismic reflection line P74-45. The hiatuses and main type of contourite drifts are indicated (data courtesy of REPSOL).