Larger morphological sea-floor features and bedforms associated to the Mediterranean Outflow Water in the Gulf of Cadiz

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ABSTRACT: Larger morphological sea-floor elements and longitudinal and transverse bedforms associated to the overflow of the Mediterranean Outflow Water (MOW) are identified in the Gulf of Cadiz after the Strait of Gibraltar. They are located between 400 and 1000 m water depth, being the larger morphological elements indicative of the MOW deceleration, the along-slope circulation of its upper and lower cores, in addition to a secondary circulation oblique to the main flow due to the Ekman effects. In more detail, the identified bedforms are fundamental for understanding the local boundary layer and the progressive bottom friction of the proximal part of the overflow. This is the case of the large sandy 2D / 3D dunes, which are found within the main erosional channels and furrows in high-velocity bottom current settings, which constitute a very good example of dunes in deep-marine sedimentary environments.

1. INTRODUCTION

The role that bottom currents and associated processes plays in deep marine setting remains poorly understood. Overflows associated to deep Gateway constituted one of these permanent processes (Rebesco et al., 2009), and represents a dense gravity current, carrying a particular water mass, descending the regional slope to a greater depth until it reaches density equilibrium. Entrainment of surrounding water, bottom friction and inertial accelerations modify the bottom current along the slope and frictional transport is confined to a thin layer near the bottom, the *boundary layer* (Legg et al., 2009).

This is the case of the Mediterranean Outflow Water (MOW) after the exit of the Strait of Gibraltar (SG). This strait conditions the Mediterranean–Atlantic water-mass exchange, and is one of the most important oceanic gateways worldwide, enabling the addition of highly saline MOW into the Atlantic Ocean. Upon exiting, the MOW cascades downslope representing an overflow of 0.67 ± 0.28 Sv of warm saline water (Legg et al., 2009). It flows northwestwards after exiting the Strait, settling as an intermediate contour current along the middle slope, at water depths between 400 and 1400 m (mwd), with two differentiated cores: the Upper Core (MU) and the Lower Core (ML). An extensive Contourite Depositional System (CDS) was generated by the interaction of the MOW and the middle slope. The present work is focused on the proximal sector of the Gulf of Cadiz after the exit of the SG (Fig. 1), characterized regionally by an abrasion surface oriented along-slope between 500 and 800 mwd, ~100 km long and 30 km wide, and by sandy-sheeted drifts, scours, ripple marks, sand ribbons and sediment waves (Hernández-Molina et al., 2014).

Here, we described larger morphological sea-floor features and bedforms generated by the overflow of the MOW in the Gulf of Cadiz, after it is funneled through the SG (Fig. 1). Regional sedimentary processes are considered and their implications discussed. For the characterization of large morphological features, we used oceanographic data, swath bathymetry, seismic, and sedimentological characterization, However, local bedforms information derived from an ARGUS ROV (Fig. 2) used at 19 sites during the MOWER Cruise, September 2014 (Casas et al., 2015: Ercilla et al., 2015).

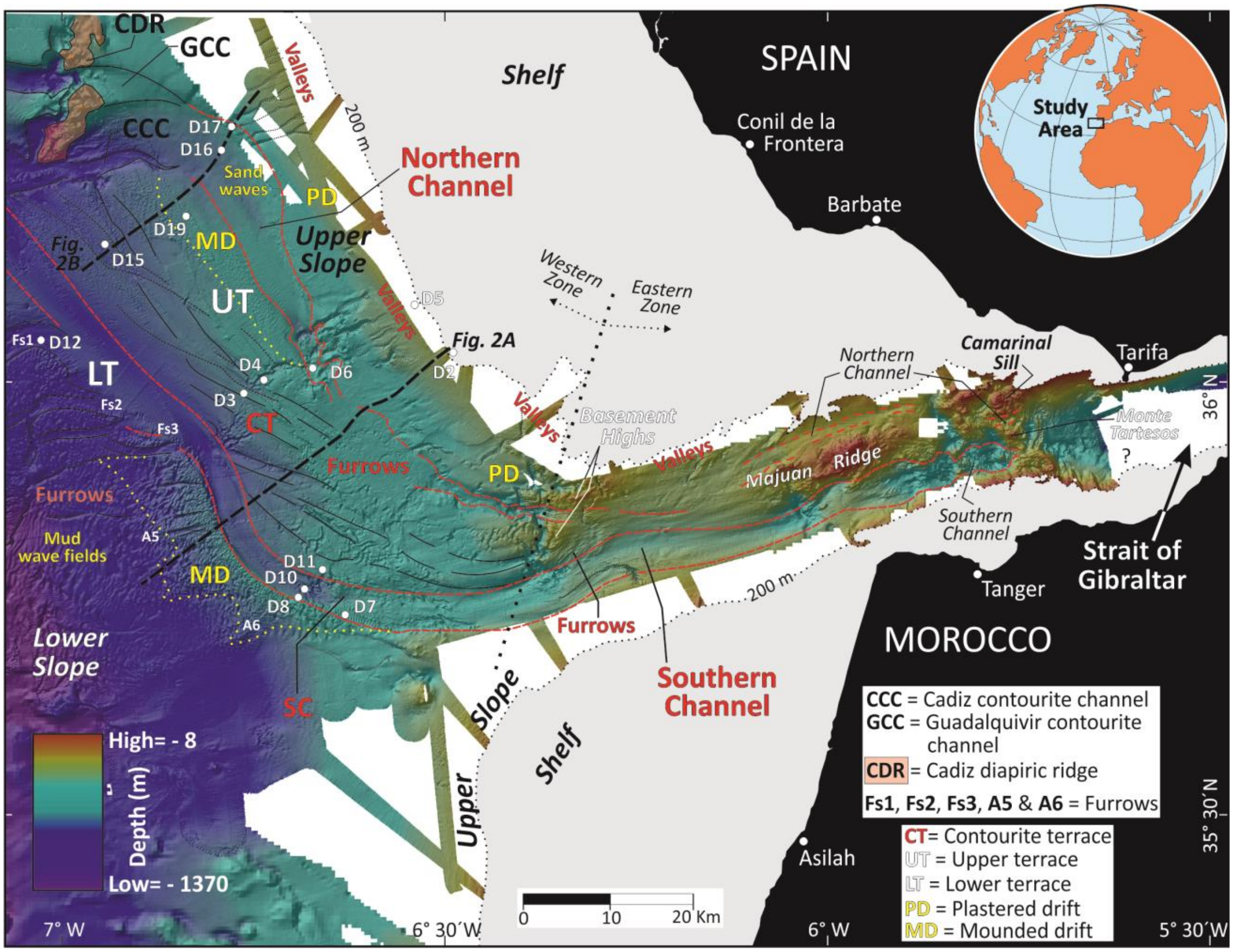

Figure 1. Study area location with swath bathymetry indicating the morphological features (Hernández-Molina et al., 2014) and the dive ROVs´ position (D2 to D 19, but positions of dives 13, 14 and 18 are out of this figure).

2. RESULTS

Two terraces (upper & lower) have been identified along the middle slope. They comprise several associated morphologic depositional and erosional elements, including furrows and two large erosive channels (southern and northern, Fig. 1 and 3). When these erosional features were visualized with the ROV, exposed bedrock surfaces are commonly composed by (blue?) marls, and rarely by other rocks types (as calcarenites).

Dive ROVs´ results allow to identify smaller scale erosional and depositional features within the aforementioned major morphological elements. Longitudinal and transverse bedforms are abundant (Fig. 4), with a variable sediment composition of bioclastic, terrigenous and mixed. Sandy and bioclastic gravel deposits are dominant, including locally rip-up clasts from the marly susbtrate. *Linear longitudinal bedforms* are: *scours*, *grooves* and *ridges*, (bioclastic/gravel) *ribbons*, *crag* and *tails*, *ribbon marks*, and *lineations*. *Comet scours* are common around obstacles. *Transverse bedforms* are sandy *ripples*, *small dunes*, *large 2D / 3D dunes* and giant *mudwaves*. Gravel dunes are also occasionally reported. Ripples have few cm in height (H) and ~10 to 20 cm in wavelength (λ). They present straight, sinuous, catenary, linguoid, cuspate, or lunate shapes. Small 2D dunes have ~0.5-1 m in H and several m in λ, being straight and sinuous the usual shapes. Large 2D and 3D dunes have several m in H and a λ of ~10 to 20 m. Superposition of longitudinal and transverse bedforms is frequent as well as the progressive lateral change of the ripples types. For example, ripples changes from straight to lingouid over the *stoss* of dunes, being straight on their *lee* side. Interference of ripples and small dunes is typical.

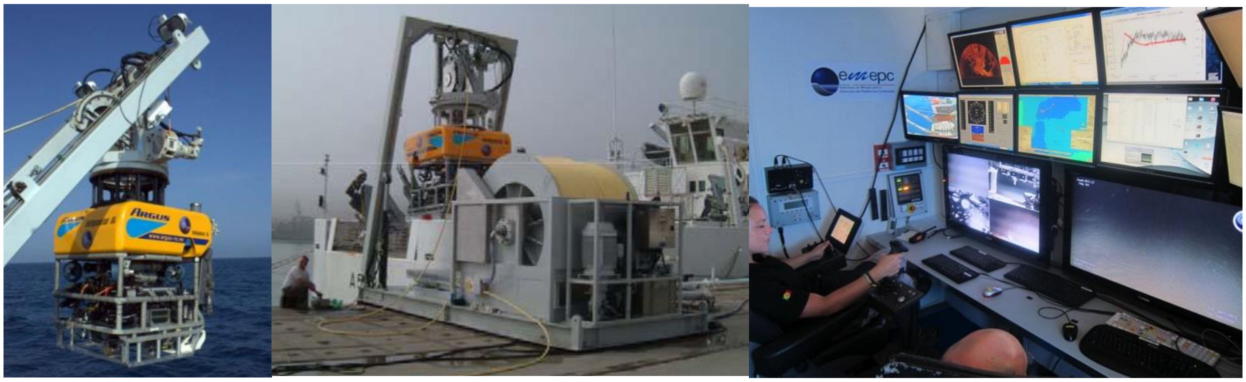

Figure 2. Image of the ARGUS ROV system (left), ROV with its umbilical cable (middle), and control cabin (right).

3. DISCUSSION

Large identified morphological elements indicated on the Fig. 1 result from the MOW undergoing a marked reduction in density, increase in volume, and deceleration within the first ~100 km after its exit from the SG. They evidence for along-slope circulation of the MOW´s upper and lower cores (Fig. 3), in addition to a secondary circulation oblique to the main flow due to the bottom Ekman effects (Hernández-Molina et al., 2014).

Limited data existed in the study area from scattered bottom photographs (e.g.; Melières et al., 1970; Stow et al., 2013). Therefore, images of the ARGUS ROV system have been essential for determining the nature of the seafloor and bedforms distribution due to the interaction between the MOW and the seafloor within each major morphological element. However, even more significantly, they are fundamental for the understanding of the boundary layer and the progressive bottom friction of the proximal and laminar part of the overflow. Longitudinal and transverse bedforms are indicative of the behavior of processes in that boundary layer and how it is affected by both sea-floor irregularities and regional MOW dynamic. That is the case of the sandy large 2D / 3D dunes, which are located within the main channels and furrows. Therefore, their formation corresponds to the particularities of the bottom flow in these deep-marine settings. Based on Stow et al (2009) bottom current higher than 0.5-1 m/s are required for developing those dunes, but > 1 for generating the gravel dunes, gravel ribbons and scours.

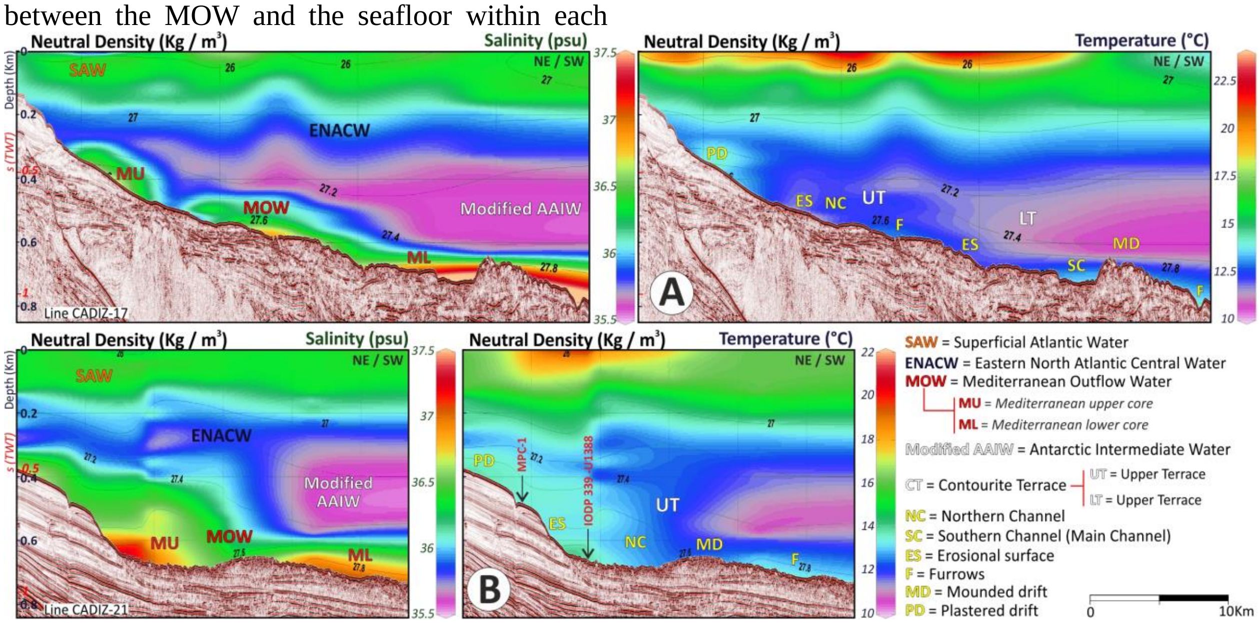

Figure 3. Seismic and hydrographic vertical sections from the exit of the Strait (from Hernández-Molina et al., 2014). The water column colors indicate salinity (left) and temperature (right). Water-mass interpretations are shown on the left sections and major contourite features, on the right sections. Profile locations in Fig 1.

4. CONCLUSIONS

Larger morphological sea-floor elements and bedforms are identified associated to the overflow of the Mediterranean Outflow Water (MOW) and the local behavior of its boundary layer. In this setting, excellent example of large sandy 2D / 3D dunes in deep-marine sedimentary environments are located within main erosional channels and furrows in high-velocity bottom current settings.

5. ACKNOWLEDGMENT

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6. REFERENCES

Casas, D., Ercilla, G., Hernández-Molina and MOWER cruise team, 2015. Bottom current-generated bedforms: the action of the MOW (Mediterranean outflow). 31st IAS Meeting of Sedimentology, 22-25 June, 2015, Krakow, Poland. Abstract Book p. 111.

Ercilla, G., Casas, D., Hernández-Molina, F. J., Roque, C. and MOWER cruise team, 2015. Bottom current-generated bedforms: the action of the MOW (Mediterranean outflow) at the exit of the Strait of Gibraltar. In: *J. Acosta, S. Berné, F. Chiocci, A. Palanques, J. Guillen (eds) Atlas of Bedforms in the Western Mediterranean ELSEVIER, In press.*

Hernández-Molina, F.J., Llave, E., Preu, B., et al, 2014a. Contourite processes associated to the Mediterranean Outflow Water after its exit from the Gibraltar Strait: global and conceptual implications. *Geology, 42*: 227-230.

Legg, S., Briegleb, B., Chang, Y., Chassignet, E.P., et al., 2009. Improving Oceanic overflow representation in climate models. The Gravity Current Entrainment Climate Process Team. *Bulletin of the American Meteorological Society*, 657-670.

Melières, F., Nesteroff, W.D., Lancelot, Y., 1970. Etude photographique des fonds du Golfe de Cádiz. Cah. Océanogr. 22, 63–72.

Rebesco, M.; Hernández-Molina, F.J.; Van Rooij, D., Wåhlin, A., 2014. Contourites and associated sediments controlled by deep-water circulation processes: state of the art and future considerations, *Marine Geology, 352: 111-154.*

Stow, D.A.V., Hernández-Molina, F.J., Llave, E., Bruno, M., García, M., Díaz del Río, V., Somoza, L. and Brackenridge, R.E. 2013. The Cadiz Contourite Channel: Sandy contourites, bedforms and dynamic current interaction. *Marine Geology*, 343, 99-114.

Stow, D.A.V., Hernández-Molina, F.J., Llave, E., Sayago-Gil, M., Díaz-del Río, V., Branson, A. 2009. Bedform-velocity matrix: The estimation of bottom current velocity from bedform observations. Geology 37, 327-330.

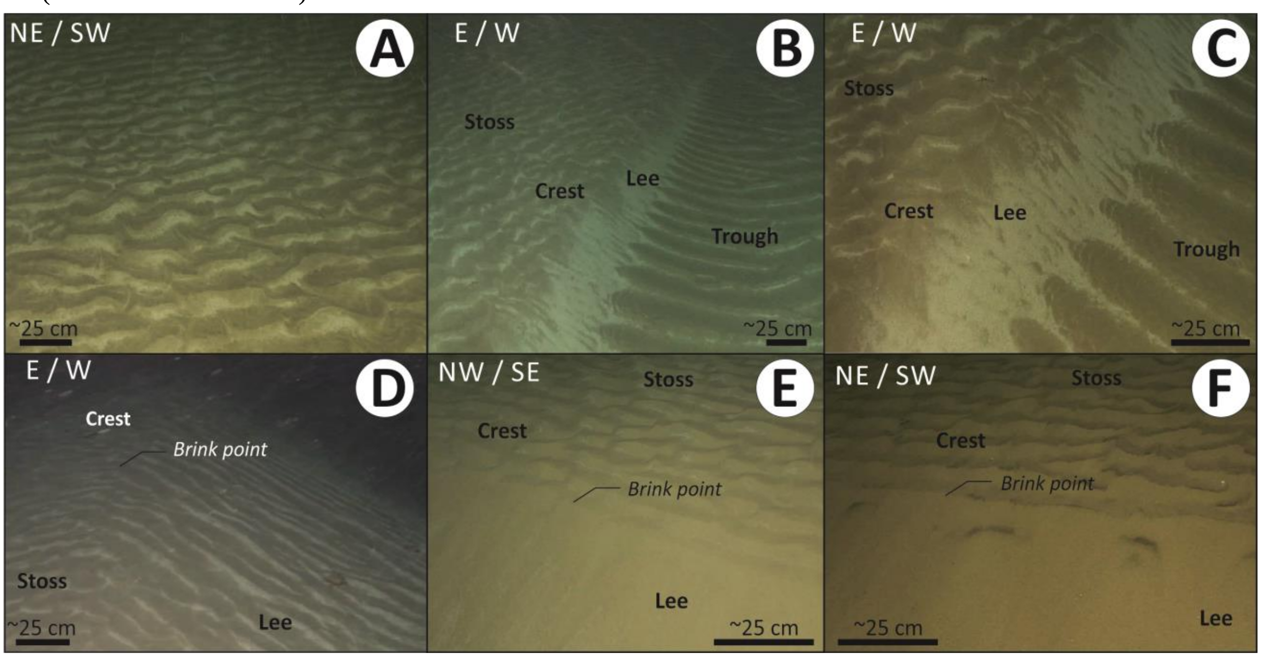

Figure 4. Examples of transverse bedforms related to the MOW. A) Ripples (D13); B and C) Small dunes (D12); D, E and F) Large Dunes (D07 for D and D15 for E and F). See position of ROV sites in Fig. 1.