Holocene evolution of sand ridges in a tideless continental shelf (Western Mediterranean)

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ABSTRACT: The evolution of sand ridges was investigated in a tideless continental shelf, the Murcia continental shelf in the Western Mediterranean, using high-resolution multibeam bathymetry and seismic data. Sand ridges are 1.5-3 m high and show a predominant E-W orientation, oblique to the shoreline. They are composed of sandy sediments and display asymmetric transverse profile, with the lee side towards the southwest. Internally, sand ridges display southwest dipping oblique reflections indicating episodic ridge migration in that direction. High-resolution seismic data show a stacked sand ridge system formed during the Holocene transgression. Smaller scale subaqueous dunes (0.3-1.3 m high) appear overimposed on the sand ridges showing a predominant NW-SE orientation, oblique to the ridge crestline, and suggesting present-day sedimentary dynamics.

1. INTRODUCTION

Large and very large subaqueous dunes (as defined by Ashley, 1990) or sand ridges (Dyer and Huntley, 1999) are pervasive bedforms on many continental shelves worldwide. In tidal-dominated settings, sand ridges show elevations up to 40 m with orientations that are primarily determined by the peak tidal direction (Dyer and Huntley, 1999; Liu et al., 2007). Sand ridges in non-tidal continental shelves, however, are smaller (up to 12 m high) and show an orientation oblique to the shoreline (Snedden et al., 2011). They show a linear, elongated shaped and a predominant asymmetric transverse profile, with steeper down-current flanks (Bassetti et al., 2006; Li and King, 2007). Internally, sand ridges display high-angle dipping reflectors that have been associated with mud beds, suggesting episodic processes related to storm events (Snedden et al., 2011; Durán et al., 2015).

Most of sand ridges located in the middle and outer shelf were formed in shallow environments as shoreface-connected sand ridges, which develop during storms and with a strong steady flow component (Calvete et al., 2001). When these ridges detached from the shoreface during sea level rise, their growth gradually slows down and their migration rate decreases until they eventually drowned when the near-bed orbital velocity dropped below the critical velocity for sediment erosion (Nnafie et al., 2014).

Previous studies in non-tidal shelves noted that sand ridges commonly rest on a major erosional surface composed of coarse sand and gravel corresponding to the Holocene ravinement, as observed in the continental shelf off Florida (Snedden et al., 2011), New Jersey (Goff and Duncan, 2012), Valencia (Durán et al., 2015), and the Gulf of Lion (Bassetti et al., 2006). In fact, Goff (2014) argued that sand ridge migration along the basal surface provides a mechanism for formation of the shoreface ravinement in the Florida inner shelf.

In this work, we present the morphology and evolution of sand ridges identified in a tideless continental shelf, the Murcia shelf (Western Mediterranean), based on the analysis of swath bathymetry and high-resolution seismic data.

2. STUDY AREA

The Murcia continental shelf is a micro-tidal shelf with maximum tidal amplitude of 0.2 m. Wave climate follows a marked seasonal pattern with the most intense events usually occurring from September to May, and the highest waves (maximum significant height of 5.5 m) coming from NE and SW directions. The circulation on the shelf is dominated by the wind stress and the general circulation of the Northern Current, carrying old Atlantic Waters towards the southeast along the shelf break (Millot et al., 1999).
The continental shelf is 8 km wide but it narrows off Cape Cope, where it is less than 3 km wide (Fig. 1). It comprises a seaward dipping planform that is cut by shelf-indenting submarine canyons with their heads located at short distances of the coastline (Acosta et al., 2013).

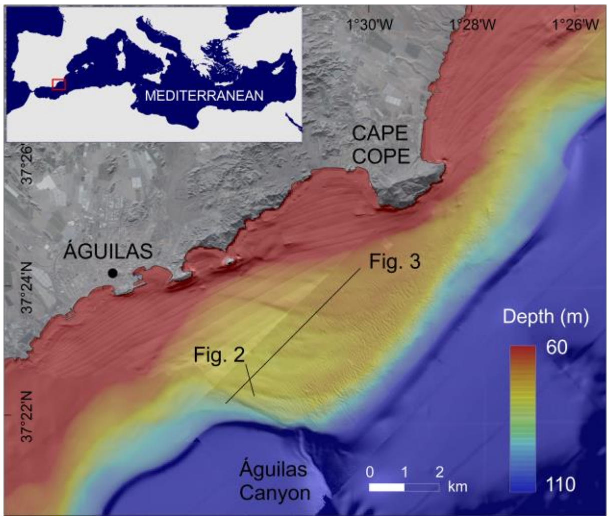

Figure 1. Location map and bathymetry of the Murcia continental shelf. Location of figures 2 and 3 is included.

3. DATA COLLECTION

High-resolution swath-bathymetry and seismic data were gathered during the COPESANDS cruise conducted on board R/V Ángeles Alvariño in February 2013. Swath bathymetry data were collected using a Kongsberg EM 710 system (70-100 kHz). Information on the shallow structure of the seabed was obtained using a Kongsberg TOPAS PS18 parametric sub-bottom profiler. In addition, twenty sediment samples of the sand ridge field were collected using a box corer grab.

4. RESULTS

Sand ridges were observed in the outer shelf between 65 and 76 m water depth, showing a predominant E-W orientation that gradually changes to NE-SW with increasing water depth, and displaying a curved morphology (Fig. 1). The height of these bedforms ranges from 1.5 to 3 m, the spacing between 300 and 600 m and the length from 1500 to 3500 m. Sediment samples collected in the sand ridge field are consist on fine to coarse sand. Very-high resolution seismic profiles display a backstepping stacking pattern of prograding seismic units with high-angle reflectors dipping seaward and toward the southwest (Fig. 2). These units display variable thickness from 1.5 to 5 m, a limited areal distribution and an asymmetric transverse profile with the steepest slope facing southwards. They overlay a strong, continuous reflector that can be traced across the study area and displays major channel incisions, particularly near the Águilas submarine canyon (Fig. 3). The thickness of the sedimentary infill overlaying this reflector increases significantly towards the south, where it is ~12 m (considering a sound velocity in sediments of 1650 $m \cdot s^{-1}$).

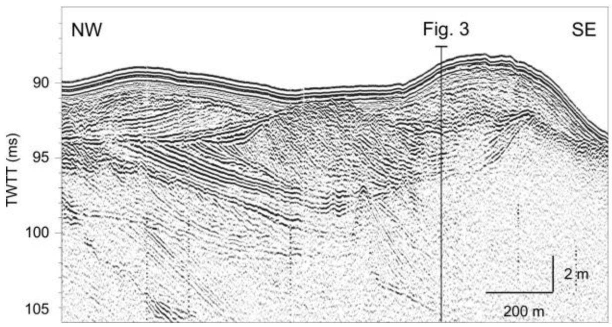

Figure 2. Very-high resolution seismic profile showing stacked sand ridges. Vertical scale in milliseconds two-way travel time (TWTT). Thickness in meters is calculated considering a sound velocity in sediments of 1650 $m \cdot s^{-1}$. Profile location plotted in Figure 2 is shown. See figure 1 for location.

Smaller-scale dunes appear superimposed to the sand ridges, showing a predominant NW-SE orientation, oblique to the sand ridges. They are 0.3-1.3 m high and show and asymmetric profile with the steep slope towards the SW (Fig. 3).

5. DISCUSSION

The sand ridges identified in the Murcia outer shelf show similar morphology and internal structure to other storm-dominated sand ridges described on the NW Atlantic (e.g. Li and King, 2007, Snedden et al., 2011; Goff and Duncan, 2012) and Mediterranean shelves (Bassetti et al., 2006; Lo Iacono et al., 2010; Durán et al., 2015). They are asymmetrical and oblique to the shoreline, with the steep face towards the SW.

Sand ridges developed over a major erosional surface that shows major channel incision and can be traced along the whole shelf. This surface is related to the sea-level fall associated to the Last Glacial Maximum (LGM), based on seismic data and recent studies in the adjacent continental shelves (Lobo et al., 2015). According to this, sand ridges are interpreted as developed during the Holocene transgression, which is in agreement with previous observations that proposed sand ridge formation during the deceleration of sea-level rise around the Younger Dryas (Bassetti et al., 2006; Durán et al., 2015).The backstepping stacking pattern of sand ridges is suggestive of relative sea-level rise conditions, thus reinforcing this interpretation. As the sand ridges migrated towards the southwest, new sand ridges are continually replacing the old ones, resulting in a stacking pattern of sand ridges where some sand ridges of earlier phases might be preserved in the lower part of the stacked section. This configuration differs from previous observations in other non-tidal shelves where sand ridges commonly overlays a basal erosional surface interpreted as the ravinement (Bassetti et al., 2006; Snedden et al., 2011; Goff and Duncan, 2012; Goff, 2014; Durán et al., 2015).

Internally, sand ridges display SW dipping oblique reflections indicating episodic ridge migration in that direction, which is consistent with the configuration of the dune-field superimposed to the sand ridges. The presence of dipping reflections within the ridges was also described in other storm-dominated shelves associated with mud beds, indicating cessation of migration followed by reactivation of the sand ridge movement during major storms (Snedden et al., 2011; Durán et al., 2015). This is supported by recent observations in the near Valencia outer shelf reported active sediment resuspension and transport episodes during storms that were able to mobilize the first centimeters of the surface sediment (mud and sand) producing a net transport transverse to the sand ridges (Simarro et al., 2015). These authors also proposed that similar events occurring during the late Holocene highstand could have contributed to the migration, maintenance or progressive degradation of these morphologies. In fact, the presence of subaqueous dunes overimposed to the sand ridges also suggests present-day sedimentary dynamics.

6. CONCLUSIONS

Sand ridges were examined in a tideless continental shelf, the Murcia shelf (Western Mediterranean). Sand ridges are 1.5-3 m high and are located between 65 and 76 m water depth, showing a predominant E-W orientation, oblique to the shoreline. Their asymmetry and internal structure indicate episodic ridge migration towards the southwest.

The continental shelf stratigraphic record reveals a backstepping stacking pattern of sand ridges formed during the last Holocene transgression. Their formation should be favoured by the deceleration of sea-level rise around the Younger Dryas, followed by a rapid sea level rise that promoted their preservation.

Smaller scale subaqueous dunes superimposed on the sand ridges suggest present-day sedimentary dynamics.

7. ACKNOWLEDGMENTS

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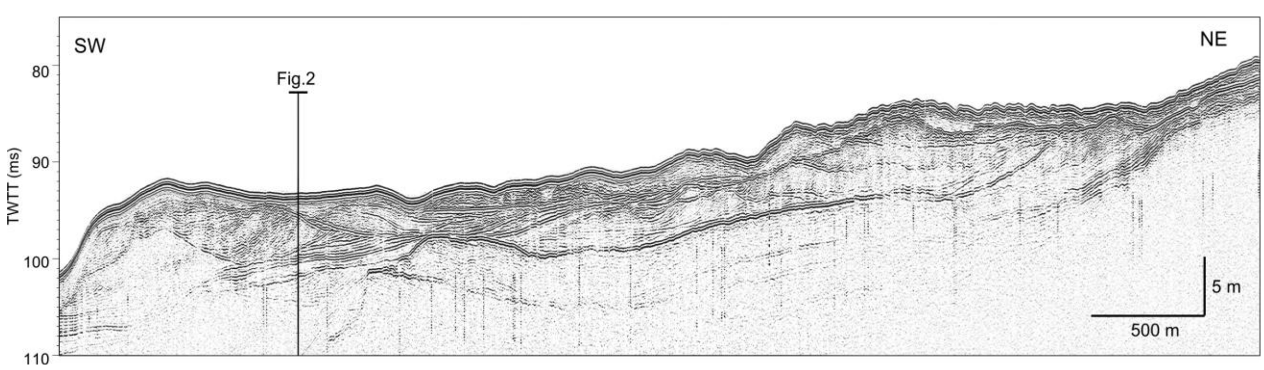

Figure 3. Very-high resolution seismic profile across the sand ridge field. Vertical scale in milliseconds two-way travel time (TWTT). Thickness in meters is calculated considering a sound velocity in sediments of 1650 m·s^{-1}. Profile location plotted in Figure 2 is shown. See figure 1 for location.