Deep-water sand dunes – case study from Upper Miocene outcrops in the southern Riffian Corridor, Morocco.

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ABSTRACT: Bottom current controlled deposits have been recognized in both modern and ancient sedimentary records along continental margins and in abyssal plains. Despite the scientific and economic importance, bottom current deposits and their diagnostic criteria are still not properly understood. This study aims to improve our knowledge by investigating four Upper Miocene sandy contourite outcrops pertaining to the Southern Riffian Corridor (Morocco). Most common characteristics are the laterally migrating channelized sandbodies encased within hemipelagic background sedimentation. Bottom current controlled sedimentation, recognized by the stacking of sandy 2D and 3D "unidirectional" dunes, shows a direct relation with gravitational processes.

1 INTRODUCTION

In this sedimentological study, we investigate four upper Miocene sandy contourite outcrops from the Southern Riffian Corridor (SRC) (Morocco). Our aim is to increase understanding of the processes, products and characteristics of sandy contourite depositional features.

1.1 Geological setting

The Riffian Corridor (RC) (Fig. 1) was a marine gateway, connecting the Atlantic and Mediterranean, where water flowed over a submerged orogenic foreland. The corridor evolved during the latest collisional stage of the Betic-Rif Arc, up to around 8 Ma ago (Feinberg 1986; Wernli, 1988; Mutti et al. 2003). The gateway was limited northwards by the Rif orogenic wedge and southwards by the Atlas Mountains (Iribarren et al., 2009; Barbero et al., 2011).

1.2 Importance of the Riffian Corridor

The present-day Strait of Gibraltar allows the overflow of dense Mediterranean water (MOW) to feed the contourite channels along the Iberian and Portuguese margins. A similar process is thought to have existed in the RC during Late Miocene.

This study focusses on the sandy, mixed carbonate-siliciclastic structures observed in deep marine settings of the SRC. These structures are interpreted as being the product of bottom currents, initiated by the overflow of dense MOW during the Late Tortonian.

Gradual closure of both the RC and the Betic corridors (in southern Spain) during the Late Tortonian to Early Miocene led to the onset of the Mediterranean Salinity Crisis (MSC) (e.g. Krijgsman et al., 1999; Garcia-Castellanos, 2011; Achalhi et al., 2016; Flecker et al., 2015; Capella et al., 2017b).

4. 2 FIELDWORK / METHODS

The fieldwork area (Fig.1) is located in the Saiss Basin (Northern Morocco). Two field-campaigns have been undertaken, focussing on 4 outcrops that are aligned along the northern margin of the former RC.

Detailed sedimentological logs and basin-scale sediment distribution studies have been undertaken to enable palaeogeographic, tectonic, palaeoceanographic, and, sedimentological reconstructions.

Palaeodepth reconstructions for the RC are critical for establishing the depositional depth of sedimentation. In this study, values proposed by Capella et al., (2017a) and Capella (2017) based on microfossil assemblages; (1) P/B ratios, (2) depth-indicative benthic foraminifera, and (3) transfer functions are used.

3 RESULTS

The main data presented in this study are related to field observations and measurements regarding bedform distribution, size, geometries and composition.

All studied outcrops show different depositional features and styles and are characterized by a similar mixed bioclastic-siliciclastic composition in the sand-dominated units.

(a) The easternmost outcrop, El Adergha, consists of extensive Blue Marl deposits which show a sudden increase in siliciclastic arenitic content towards the top. The arenitic interval, can be divided from the base to the top, into three main intervals consisting of a 3 m thick thin-bedded sandy marl dominated interval, a 14 m marl interval with sandy bi-gradational sequences and at the top, 17 m of medium to coarse-grained sandstone, with westward migrating cross-stratified bed-sets (Fig. 2a).

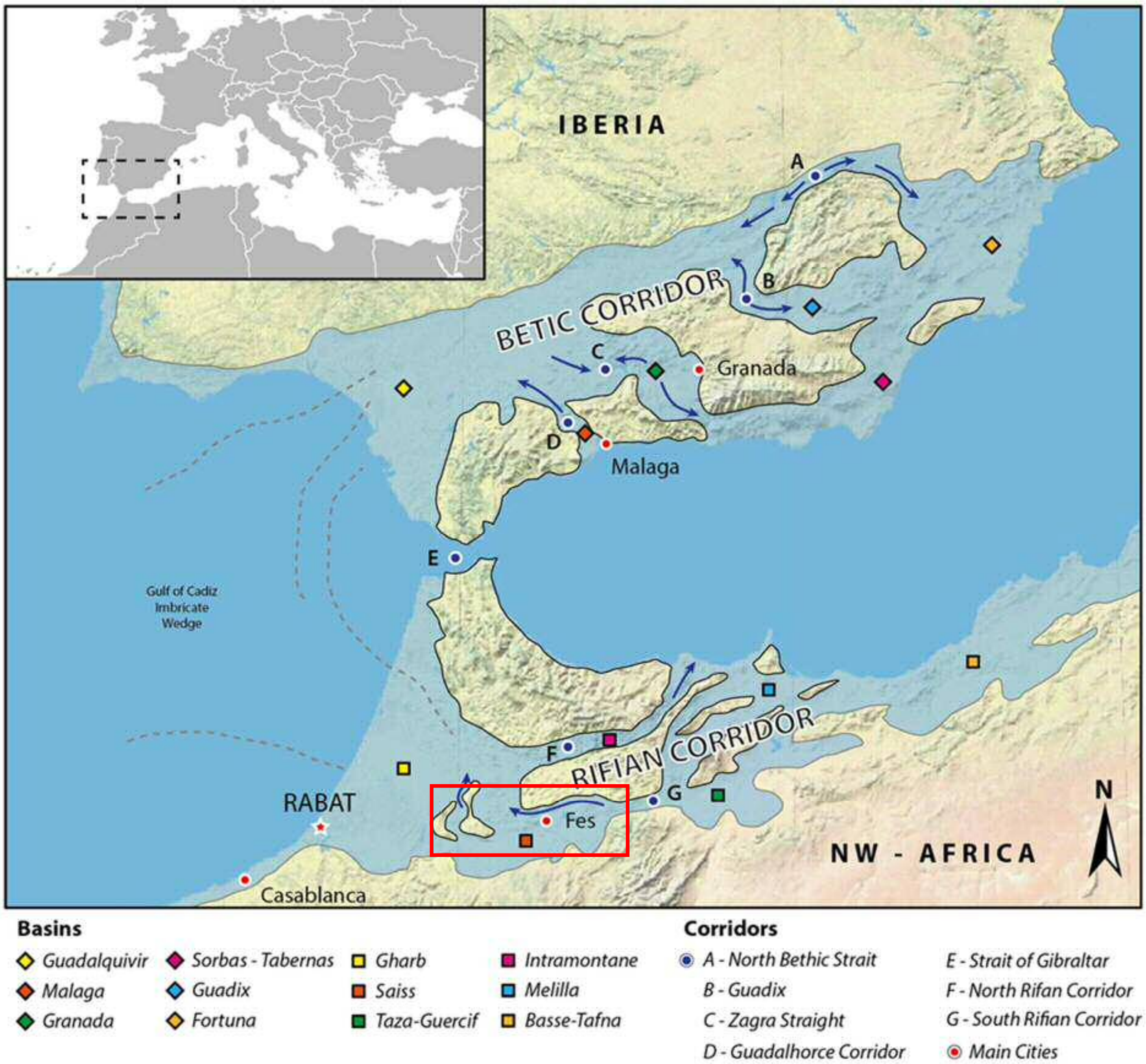

Figure 4. Palaeogeographic reconstruction of the Late Miocene Betic- and Riffian-Corridors in Southern Spain and Northern Morocco respectively. Bleu arrows indicate main palaeocurrent directions. The red box shows the main study area.

(b) The outcrop north of the city of Fes (Fes-north) shows both SSW- and W- directed palaeocurrent features (Fig. 2b). These commonly comprise cross-stratified bed-sets with mud caps and internal drapes. The SSW-directed component consists of breccia and slumped deposits.

(c) The Sidi Chahed outcrop is located west of the Moulay Yacoub city. The basal contact of the sand-dominated units in this section consists of the distinct sudden deposition of a medium-grained, scoured, monomictic, laterally extensive para-conglomerate, followed by a deeply incised channel that is filled with ortho-conglomerates. These deposits are topped by SW-directed slumps. On top of this interval, the outcrop (Fig. 3) shows three sand intervals encased in blue marls with turbidite deposits. The sand intervals are upward fining and thinning sequences and consist of channel-shaped geometries filled by dominantly SW- to NW-directed, compound sandy 3D and 2D dunes (Fig. 2c).

d) The Kirmta outcrop is located 10 km NE of the Sidi Chahed village. Similar to the other sections, the outcrop consists of three main sand units encased within the Blue Marl Formation. The sand units form extended, symmetric, shallow incised, channel shaped geometries. Between the sand units we find turbidite deposits, and there is no evidence of slumps, as encountered in the Sidi Chahed section. Sedimentary structures are scarcely preserved due to intense bioturbation. Locally, ripples and dunes indicate a dominant NNW flow direction (Fig. 2d).

3.1 Biostratigraphy

(a) The planktonic foraminiferal assemblage of the El Adergha section, characterized by the presence of *G. menardii 5* with specimen of the *G. miotumida* group, implies an age between 7.35 and 7.25 Ma, which indicates a late Tortonian to early Messinian age. Benthic assemblages commonly reflect upper bathyal environments with species commonly found in upper slope / outer shelf environments. Estimated depositional depths range from 150 – 300 m water depth.

(b) The foraminiferal assemblages of the Fes-north outcrop indicate a latest Tortonian age between 7.51 and 7.28 Ma. Between the LcO of *G. menardii 4* and the coiling change of the *G. scitula* group.

(c) The planktonic foraminiferal assemblage suggests a late Tortonian age between 8.35 and 7.51 Ma for the Sidi Chahed outcrop. The benthic foraminiferal assemblages suggest that the outcrop was deposited in upper bathyal environments, roughly equivalent to 250 – 400 m water depth. The upper part of the section contains less slope taxa, indicating a slightly shallower depth range (150 – 300 m water depth).

(d) Biostratigraphic work of the Kirmta outcrop is still in progress. First results, however, indicate an age between 8.37 and 7.31 Ma, i.e. between the first occurrence of *G. suterea* and the first common occurrence of *G. menardii 5*.

3.2 Palaeocurrents

Over 600 palaeocurrent data points have been

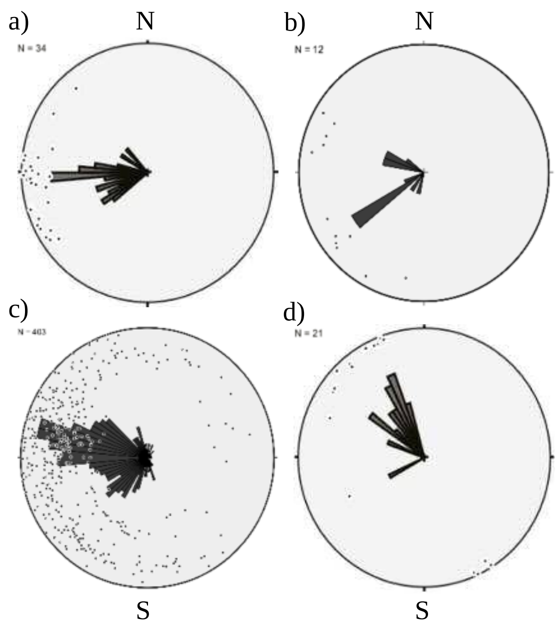

Figure 2. Palaeocurrent data for a) El Adergha, b) Fes-north, c) Sidi Chahed & d) Kirmta. These circular diagrams display palaeoflow directional data. In b and c we can easily differentiate between SW-directed gravitational and W-directed bottom cur-

measured over the four studied sections during the field campaigns. Measurements are primarily made on dunes and ripples and are plotted in rose diagrams (Fig. 2).

4 DISCUSSION

The SRC formed a gateway during the late Tortonian to early Messinian. This gateway allowed Atlantic – Mediterranean water exchange. The depositional features along the northern margin of this gateway indicate an interaction between dominantly southward-directed gravitational, and westward dominated contour parallel sedimentation in the slope of the submerged imbricated foreland. Tectonically induced gravitational processes dominantly precede the deposition of unidirectional compound 3D and 2D dunes migrating in channelized geometries at deep-water depths in slope environments.

Based on the bedform velocity diagrams for deep-water sedimentation proposed by Stow et al. (2009), along-slope bottom current velocities, induced by the overflow of dense Mediterranean water, might have well exceeded 1 ms^{-1}.

5. 5 CONCLUSION

The bottom current controlled deposits exposed in the remainder of the SRC form a unique example of sandy dunes in deep-water environments. These outcrops represent a good analogue for understanding both conceptual and economic implications of

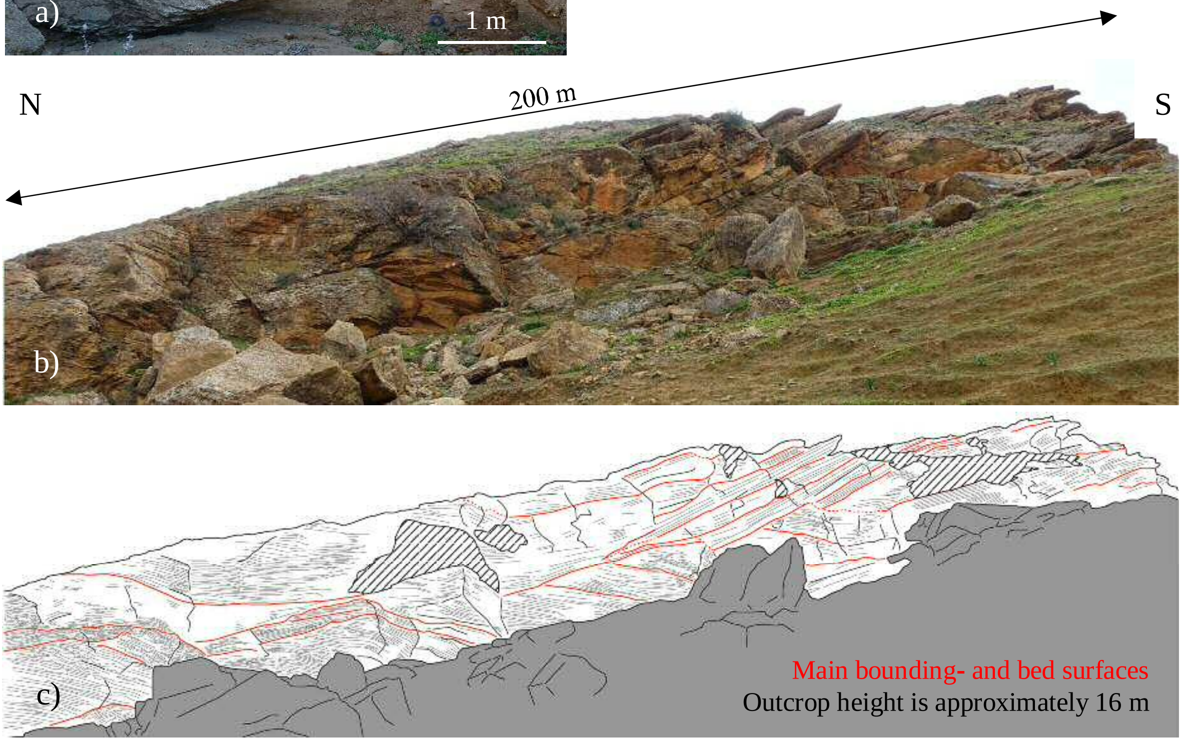

Figure 3. Sidi Chahed – a) Mixed bioclastic-siliciclastic, compound dunes. Upward we see the dominant facies, consisting of approximately 1 m thick tabular cross-stratification. b, c) lateral view of compound dunes. c) line drawing of insert b. Main bounding surfaces and bed boundaries in red. The upper part of the figure shows an extensive, incised dune.

sandy dunes in modern and ancient deep-water systems.

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