Depositional character of submarine dunes on a Pleistocene distally steepened carbonate ramp (Favignana Island, Italy)

A. Slootman, *Department of Earth and Environmental Sciences, University of Geneva, Switzerland – arnoud.slootman@unige.ch*
M.J.B. Cartigny, *National Oceanography Centre, Southampton, UK*
P.L. de Boer, *Faculty of Geosciences, Utrecht University, The Netherlands*
A. Moscariello, *Department of Earth and Environmental Sciences, University of Geneva, Switzerland*

ABSTRACT: Distally steepened carbonate ramps are characterised by a steep proximal slope that passes basinwards into a gentle distal toe-of-slope. Such systems are controlled by clastic depositional processes and may host deposits formed by the migration and progradation of submarine dunes. This study documents the differences in depositional character and preservation potential of large-scale composite bedforms as a function of the location on the ramp slope. Such bedforms migrated as a result of the migration of small-scale parasitic dunes over their stoss-side and the subsequent deposition of compound cross-beds on their lee-side. The proximal slope zone is characterised by thick packages of compound cross-bedded sets that formed by the down-slope migration of composite dunes. The distal toe-of-slope zone is composed of form-sets that preserved the original outline of composite dunes, including the small-scale dunes on their stoss-side. Such preservation occurred by the rapid burial of large, but only marginally erosive, sediment gravity flows.

1. INTRODUCTION

Distally steepened carbonate ramps are gently inclined sea floors with a marked break in slope immediately basinwards of the carbonate factory (Fig. 1). Progradation occurs in particular through deposition on the ramp slope giving rise to the formation of seismic-scale clinoforms up to tens of metres in height.

In temperate waters such as the present-day Mediterranean Sea, non-tropical biological associations generate sand- and gravel-sized material. Such skeletal debris remains loose on the sea bed in the absence of the early cementation and coral build-ups that characterise tropical settings. Consequently, under the influence of shallow-marine unidirectional currents, subaqueous dunes ranging from small- to large-scale (*sensu* Ashley, 1990) may develop on carbonate ramps (e.g. Fornos & Ahr, 2006). Their preservation is most likely in the ramp slope zone. The sedimentary record contains numerous examples of biocalcarenite and -calcirudite bodies that formed by the lateral stacking of submarine dunes on distally steepened carbonate ramps (e.g. Pomar et al., 2002).

Here, we report on the depositional character and preservation potential of submarine dunes on the Pleistocene distally steepened carbonate ramp of Favignana Island, Italy (Fig. 2). We focus in particular on the differences between the proximal slope zone and the distal toe-of-slope zone.

2. RESULTS

2.1. Clinoform couplets: Dune deposits and event beds

The Pleistocene Favignana carbonate ramp succession is composed of clinoform couplets, which consist of repeated alternations of stacked dune deposits (ca. 50% of the succession) and up to several metres-thick gravity-flow deposits, or event beds (constituting the remaining 50%). The up to 50 metres high clinoforms dip up to 10 degrees in the proximal ramp slope zone, where event beds indicate significant basal erosion, and pass basinwards into the up-to-a-few-degrees-inclined to near-horizontal units of the distal toe-

of-slope zone, in which event beds are highly aggradational and only of limited erosional nature. Dune deposit character also markedly change from the proximal slope zone to the toe-of-slope zone.

2.2. Composite dunes generating sets of compound cross-bedding

The large-scale dunes that generated the clinoformed dune deposits of the ramp slope were composite bedforms up to 4 metres high, generated by the climbing of small-scale dunes not exceeding 40 cm in height. The stoss-side of such parent bedforms were thus covered by parasitic bedforms, both types of dunes advancing in approximately the same direction. Cross-beds were formed as small-scale dunes prograded down the lee-side of a large-scale dune. Such cross-beds are contained within compound cross-beds, the lateral stacking of which resulted in the migration of large-scale dunes and the formation of sets. (See Figs. 3, 4, 5 for visual examples of terminology.) Sediment was largely derived from the carbonate factory occupying the shallow region of the ramp. However, in situ carbonate production also occurred and is responsible for the presence of coarse lags between and within (compound) cross-beds.

2.3. Proximal ramp slope zone

In the proximal ramp slope zone, preservation occurred through the lateral stacking of compound cross-bedded sets as large-scale composite dunes, which were generated on the vast area of the carbonate factory (Fig. 1), migrated down the ramp slope. This process mimics the down-slope migration of parasitic small-scale dunes over the lee-side of larger parent bedforms. Extensive skeletal production in the carbonate factory resulted in high rates of net sediment supply that allowed for slope progradation over a few kilometres length for the entire Pleistocene carbonate ramp succession. Event beds demonstrate significant truncation of dune deposits, locally reaching to the base of containing clinoforms. Nevertheless, in most places in the proximal slope zone several metres-thick (rarely exceeding 15 metres) stacked sets of compound cross-bedding are preserved. Sets have a variable thickness, are composed of variably dipping tabular to trough cross-beds and compound cross-beds, and contain numerous reactivation surfaces and different degrees of bioturbation (Fig. 3).

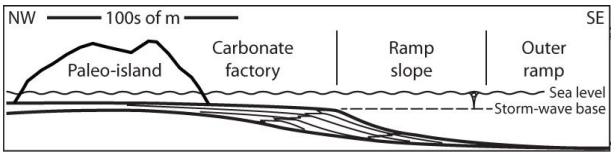

Figure 1. Conceptual cross-section through the Pleistocene distally steepened carbonate ramp of Favignana Island. The carbonate ramp consisted of a near-horizontal carbonate factory, where most of the skeletal material was produced, that connected distally to a ramp slope. The latter is subdivided into a relatively steep (up to 10°) proximal zone and a gently inclined toe-of-slope zone. The outer ramp comprises the area basinwards of the ramp slope. See Fig. 2 for location.

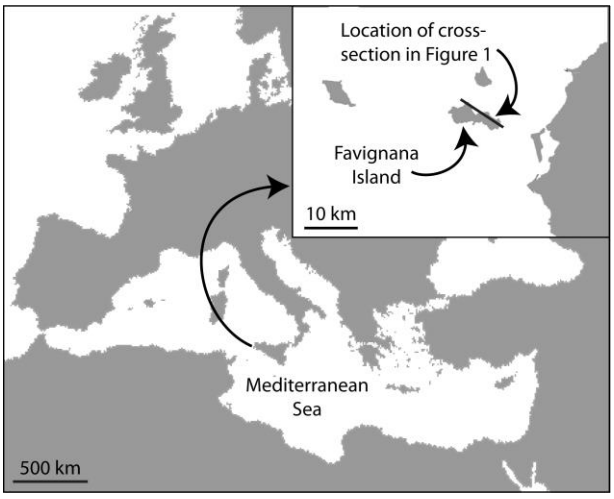

Figure 2. Favignana Island, located on the westward continuation of the Sicilian shelf in the Central Mediterranean Sea.

2.4. Distal toe-of-slope zone

The toe-of-slope zone, located basinwards of the proximal ramp slope and farther away from the carbonate factory, received significantly less sediment than the proximal ramp slope zone. As a result, large-scale composite dunes in the toe-of-slope zone were migrating with stoss-side erosion being equal to lee-side deposition, instead of becoming laterally and vertically stacked due to the climbing of such bedforms. Dip direction of cross-beds in the toe-of-slope zone is more variable, although compound cross-beds generally dip conform the direction of the containing set, which itself follows the dip of the clinoform. The preservation of (fields of) such migrating large-

scale composite dunes is rare in the sedimentary record due to a common lack of aggradation. In the Pleistocene carbonate ramp succession of Favignana Island, however, the frequent occurrence of very large sediment gravity-flow events repeatedly blanketed the entire toe-of-slope zone with no or limited erosion taking place. This resulted in the 'freezing' of large-scale composite dunes and the parasitic bedforms on their stoss-side, which have been preserved as large-scale form-sets that are covered with fields of small-scale subordinate form-sets (Fig. 4, 5).

3. DISCUSSION AND CONCLUSIONS

Progradation of the distally steepened carbonate ramp occurred in two ways: (1) lateral stacking of composite dune deposits, and (2) event bed deposition. The near vicinity of the proximal ramp slope to the carbonate factory resulted in higher rates of sediment supply relative to the amount of sediment delivered to the toe-of-slope zone. Consequently, thick packages of compound cross-bedded sets, generated by the lateral stacking of large-scale composite dunes, characterise the proximal ramp slope, which locally display major truncation by event beds. In contrast, the distal toe-of-slope zone was formed under limited aggradation. Under conditions of no net sediment supply, stoss-side erosion equalled lee-side deposition and composite dunes merely migrated. Such dunes were preserved by the rapid burial under a thick gravity-flow deposit, which was accompanied by marginal basal erosion.

The presence of lags of large skeletal remains, indicative of in situ produced carbonate material, suggests that long periods of tranquillity separated times of active dune migration and progradation. This inference is in line with the occurrence of numerous reactivation surfaces and different degrees of bioturbation that characterise (compound) cross-beds. We propose that submarine dunes on the studied carbonate ramp migrated solely during storm-induced bottom currents. Consequently, the sediment gravity flows correspond to events of extreme energy that were capable of delivering vast amounts of material to the ramp slope where excess-density generated short-lived underflows.

4. REFERENCES

Ashley, G.M. 1990. Classification of large-scale subaqueous bedforms: A new look at an old problem. Journal of Sedimentary Petrology, 60(1): 160-172.

Fornos, J.J. & Ahr, W.M. 2006. Present-day temperate carbonate sedimentation on the Balearic Platform, western Mediterranean: compositional and textural variation along a low-energy isolated ramp. In H.M. Pedley & G. Carannante (eds), Cool-Water Carbonates: Depositional Systems and Palaeoenvironmental Controls. Geological Society, London, Special Publications, 255: 71-84.

Pomar, L., Obrador, A. & Westphal, H. 2002. Sub-wavebase cross-bedded grainstones on a distally steepened carbonate ramp, Upper Miocene, Menorca, Spain. Sedimentology, 49: 139-169.

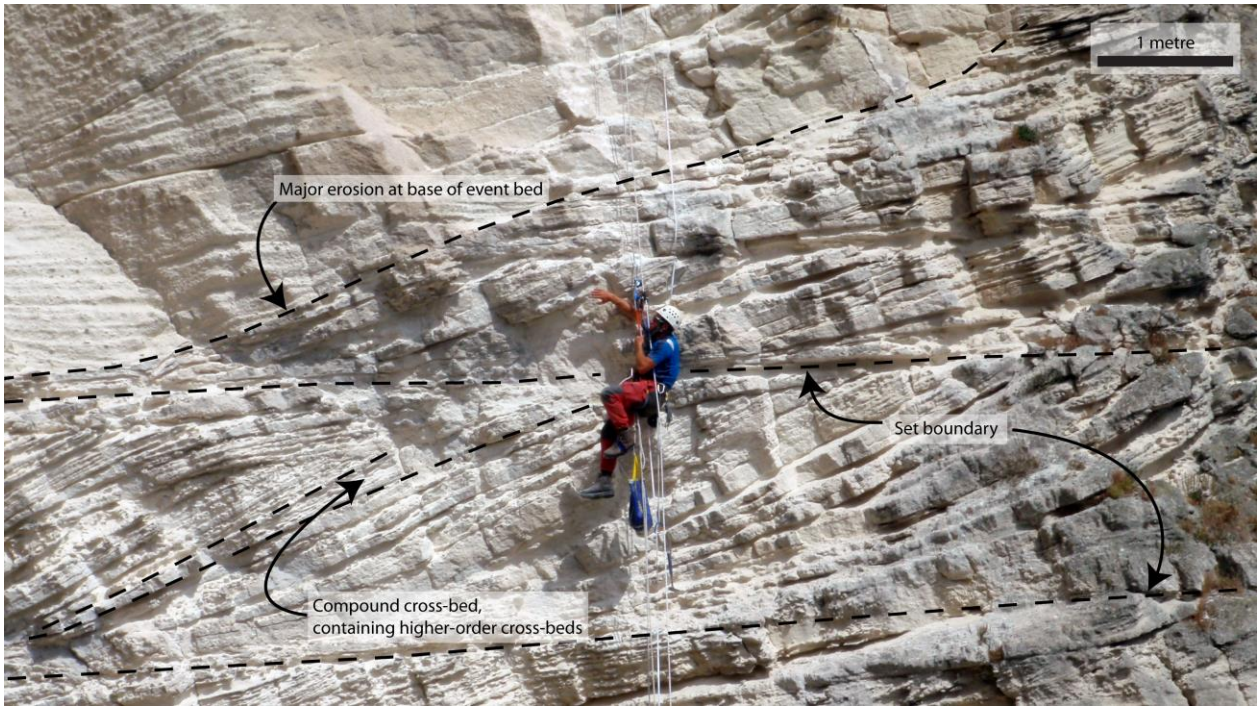

Figure 3. Stacked compound cross-bedded sets, which formed by the down-slope superposition of large-scale composite dunes in the proximal ramp slope zone. Set boundaries truncate the top of compound cross-beds, suggesting that the formative large-scale dunes were slightly higher than the preserved sets. Preservation occurred by the continual burial of large-scale dune sets by younger ones as they migrated down the slope and the carbonate ramp prograded. Note the major erosion at the base of the event bed, truncating deeply into the stacked large-scale dune sets.

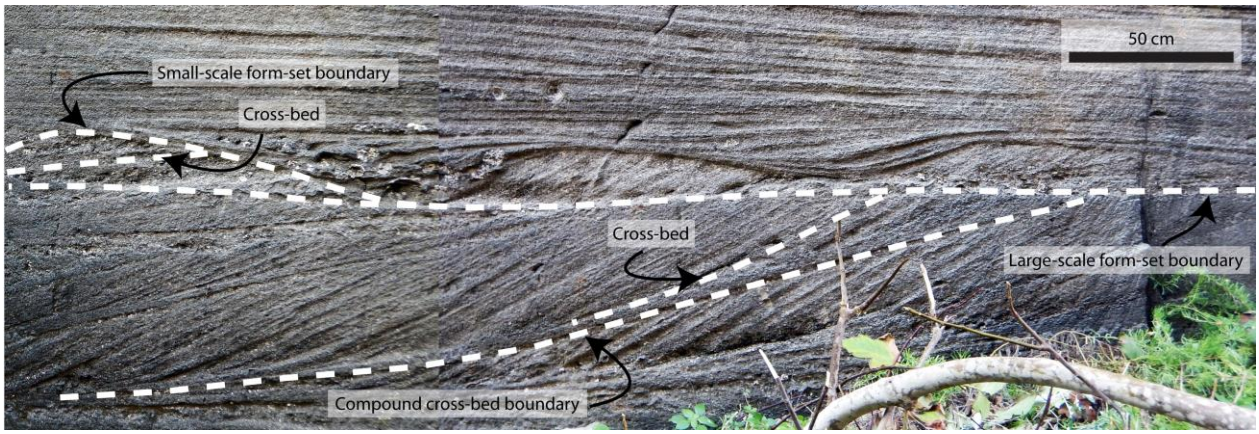

Figure 4. Detail of erosion-based small-scale form-sets on top of a large-scale compound cross-bedded form-set in the toe-of-slope zone, representing a geological snapshot of a train of small-scale parasitic dunes that migrated over the gentle stoss-side of a large-scale composite dune. The large-scale parent dune and small-scale parasitic dunes were preserved by the rapid burial by an event bed (gravity-flow deposit).

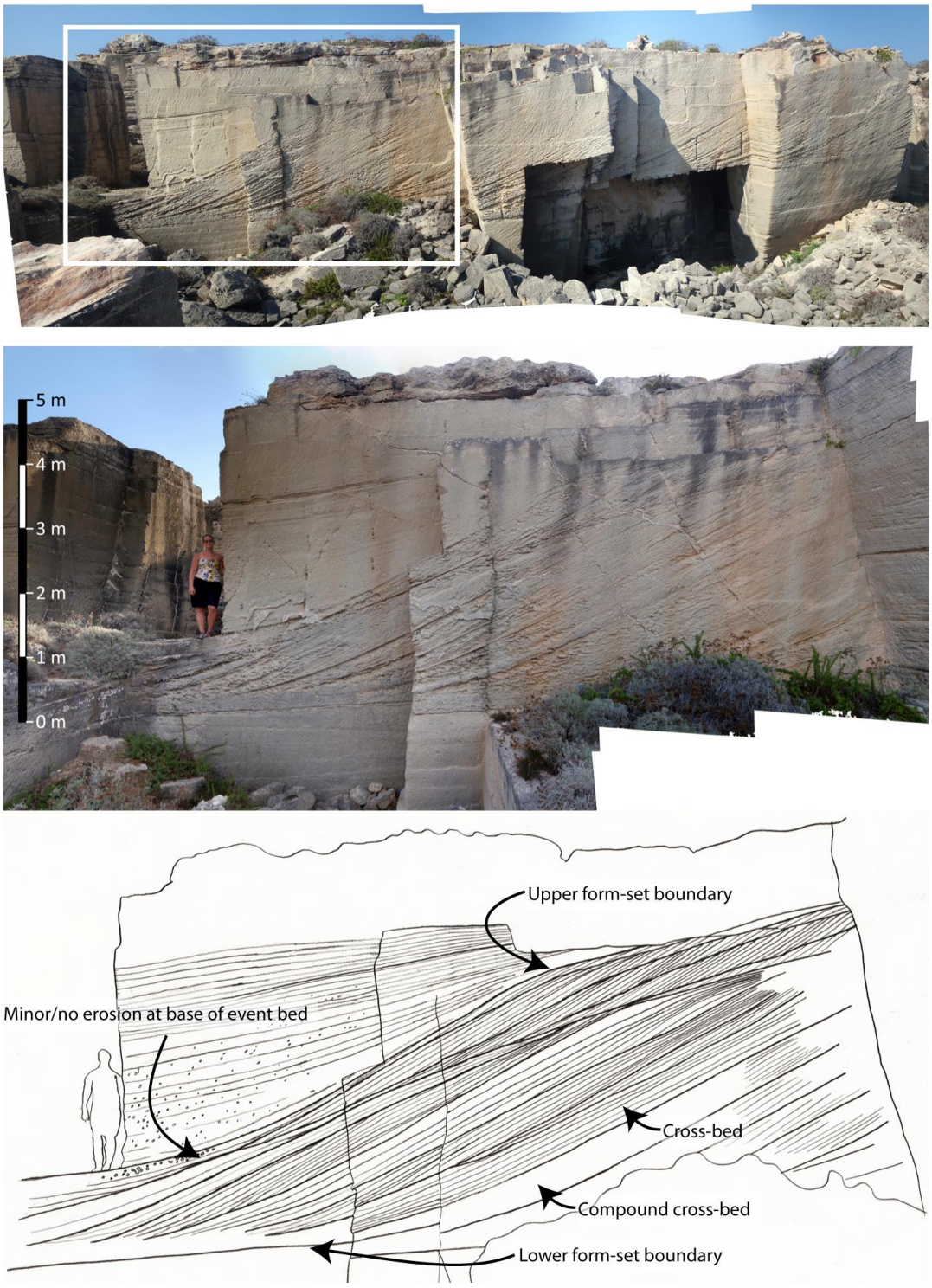

Figure 5. Large-scale compound cross-bedded form-set in the toe-of-slope zone. Cross-beds were formed by small-scale parasitic dunes that migrated over the stoss-side and were ultimately deposited in a compound cross-bed on the lee-side of a large-scale parent dune. The large-scale dune migrated over an event bed (gravity-flow deposit) and became preserved when it was rapidly blanketed during deposition of the subsequent event bed. Note the limited erosion at the top of the large-scale form-set.