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Dynamics of Sediment Bedforms in the Western English Channel: the Wreck of the *Victory* (Site 25C) in Context

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The First Rate English warship the *Victory* sank in the Western English Channel on 5 October 1744. Odyssey Marine Exploration discovered its wreck (site 25C) outside UK territorial waters at a depth of 75m in April 2008. The non-disturbance component of the *Victory* Shipwreck Project conducted in February 2012 incorporated environmental studies. This paper combines analyses of multibeam surveys, the tidal current regime and sediment composition to assess the nature of bedforms within the *Victory* catchment zone, notably large sandwave macroforms (megarides) and asymmetric 2D small dune mesoforms (megaripples). These migrate only in spring tidal cycles by up to 1m h^{-1}. The sedimentological and dynamic evidence suggests that the dune field located on the eastern side of the *Victory* wreck site probably previously occupied a more western position, covering the shipwreck and thus contributing to its former preservation.

1. Introduction: the Western English Channel

The English Channel is a strait that connects the Atlantic to the North Sea. It is more than 550km long and varies in width and depth (Fig. 1). The narrowest pass is the Strait of Dover (also named Pas de Calais), which develops strong tidal currents. From a geographical point of view the English Channel is divided into two sectors: the Eastern English Channel extends from the connection with the North Sea in the Strait of Dover to the strait formed by the Peninsula of Normandy, designated by a nominal line traced between Cherbourg and Weymouth. The Western English Channel is the most open and wide section and extends to the west of the Peninsula of Normandy.

From a hydrodynamic point of view tides in the Western English Channel have a semi-diurnal character and feature macrotidal conditions because the Channel acts as a funnel that amplifies the tidal range from less than 1m in the mouth of the Atlantic to more than 6m as observed in Cherbourg and Devonport. Tidal currents vary between sub-regions and important variations can occur between the neap and spring tides. A visible inequality has been demonstrated between flood and ebb tides, with the flood being the dominant tidal current (Ferret *et al.*, 2010).

The most frequent waves flow from the west to northwest, as well as from the southwest. Mean significant waves are 1-2m high with durations of between five and seven seconds. The strongest waves occur during winter storms, when amplitudes rise up to 5m with durations reaching 12 seconds (Bellessort and Mignot, 1986). Wind plays a further role, inducing currents that act in combination with tides to generate a residual component. This residual current extends from the Atlantic Ocean to the Eastern English Channel and has been deduced from numerical models (Bailly du Bois and Dumas, 2005).

In form the surface of the seabed assumes a smooth shelf that slopes very gradually down to the west. This shelf is covered by fields of plain beds with sand ribbons or sand waves and ridges tidally originated and orientated northwest to southeast (Fig. 2). The crests of the ridges have an approximate 1km wave length and heights of some 7m above the general bed level (Evans, 1990: 93).

2. The Context of Site 25C

The area under examination constitutes a surface with an orientation slightly inclined to the west-southwest, with a mean depth of 74.1m under mean sea level. On this surface three large sand waves have developed (Fig. 3). Sandwave 1 is localized immediately east of the wreck site and Sandwave 2 is positioned 200m east of the wreck and is elevated around 6m above the seabed to reach a minimum depth of 68.1m. A third sandwave is present around 650m west of site 25C.

Sandwaves are mobile transverse sandy bedforms whose heights can exceed 10m, have lengths of several kilometers, widths of hundreds of meters and depths of tens of meters (Stride, 1982: 222). They are observed on tidal-dominated continental shelves, such as the western and eastern sectors of the English Channel, most often covered with smaller dunes. In other studied areas, dune and sandwave migration rates can reach 1m per tidal cycle and 150m per year (Idier *et al.*, 2002; 2011). In the vicinity of site 25C, the

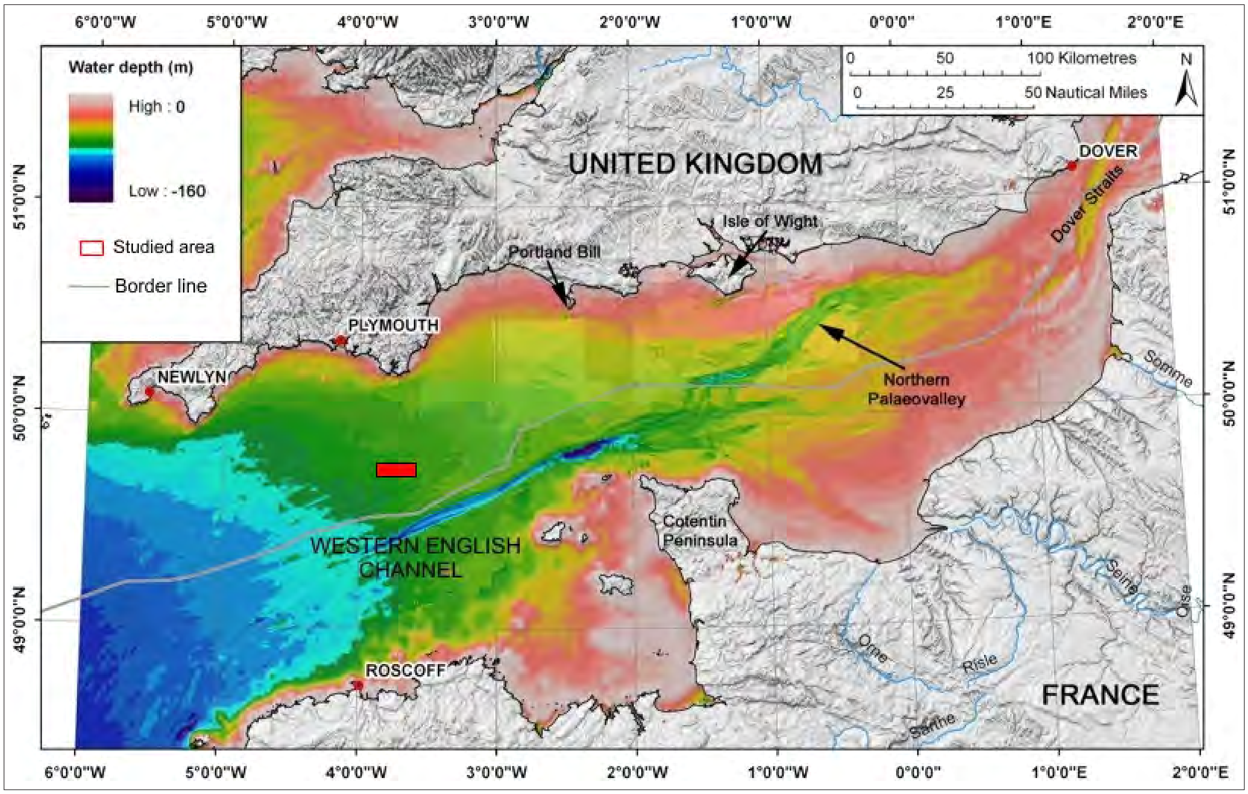

Fig. 1. Location of the study area, site 25C, in the framework of the English Channel's bathymetry. Photo: after Evans, 1990, fig. 9 and Coggan and Diesing, 2011, fig. 1.

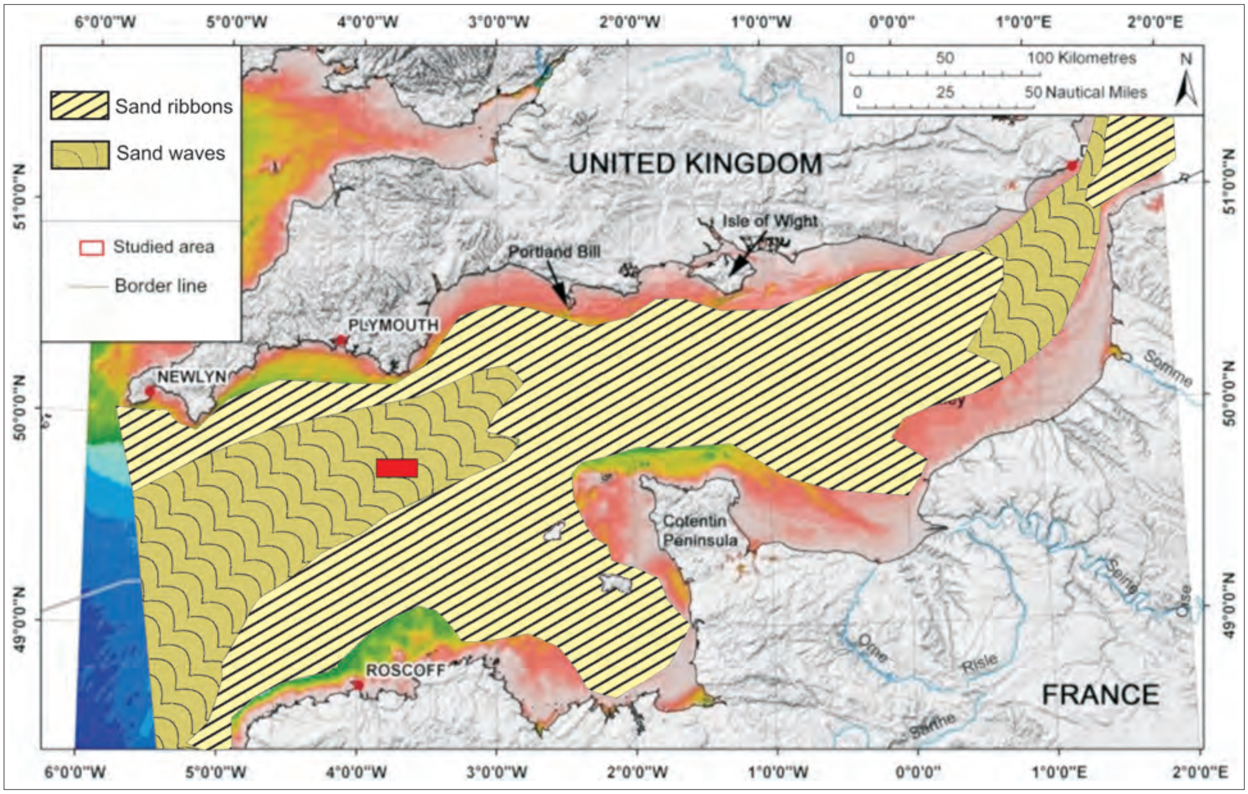

Fig. 2. Distribution of bedtypes (sandwave and sand ribbon fields) in the English Channel. Photo: after Evans, 1990, fig. 9 and Coggan and Diesing, 2011, fig. 1.

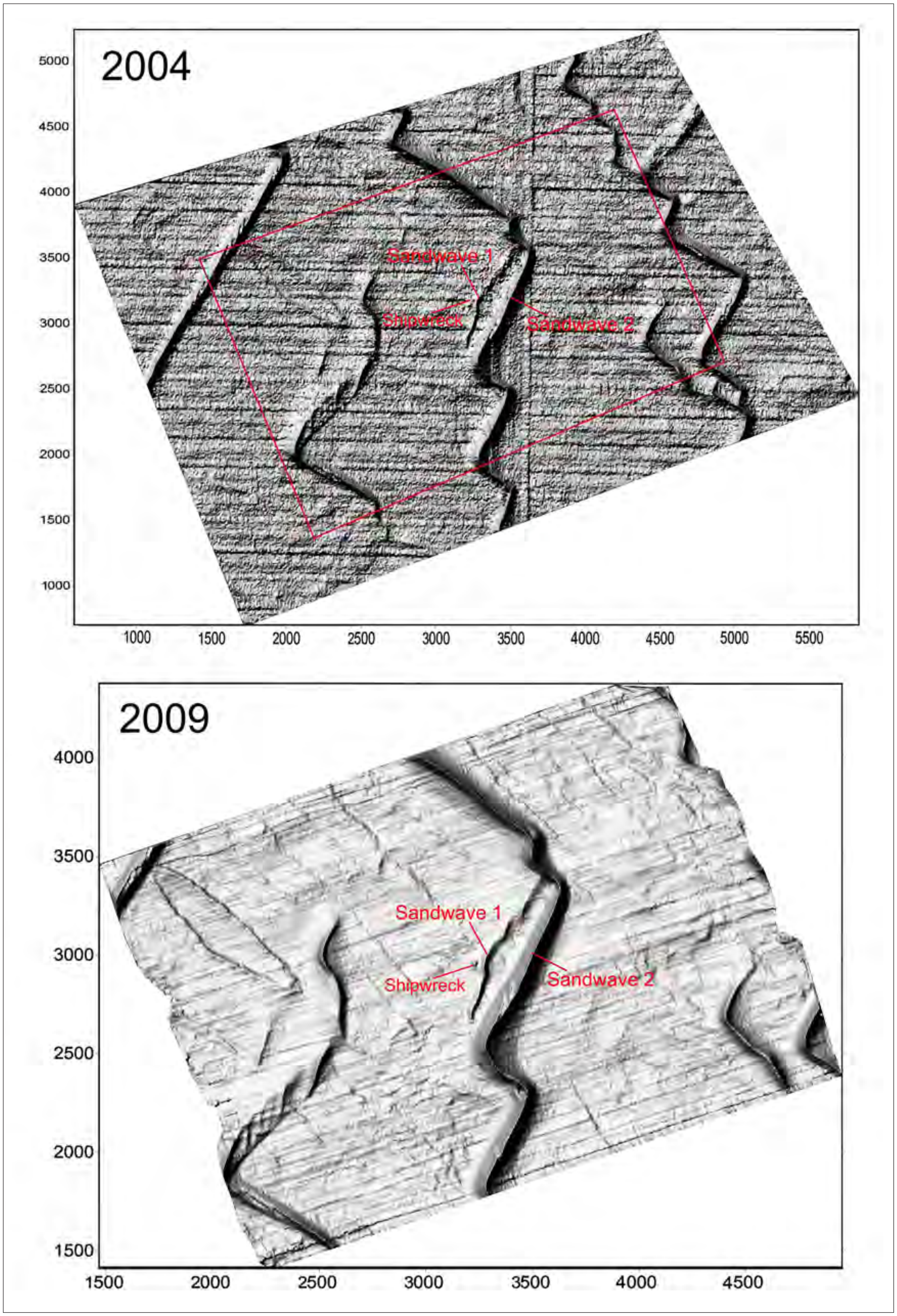

Fig. 3. Multibeam shadow map of the bathymetries obtained in studied geophysical surveys of the site 25C region. Top: data obtained by the United Kingdom Hydrographic Office in 2005 (contains UKHO date, © Crown copyright and database right). Bottom: data obtained by Wessex Archaeology in 2009. The location of Sandwaves 1 and 2 and shipwreck site 25C are also indicated.

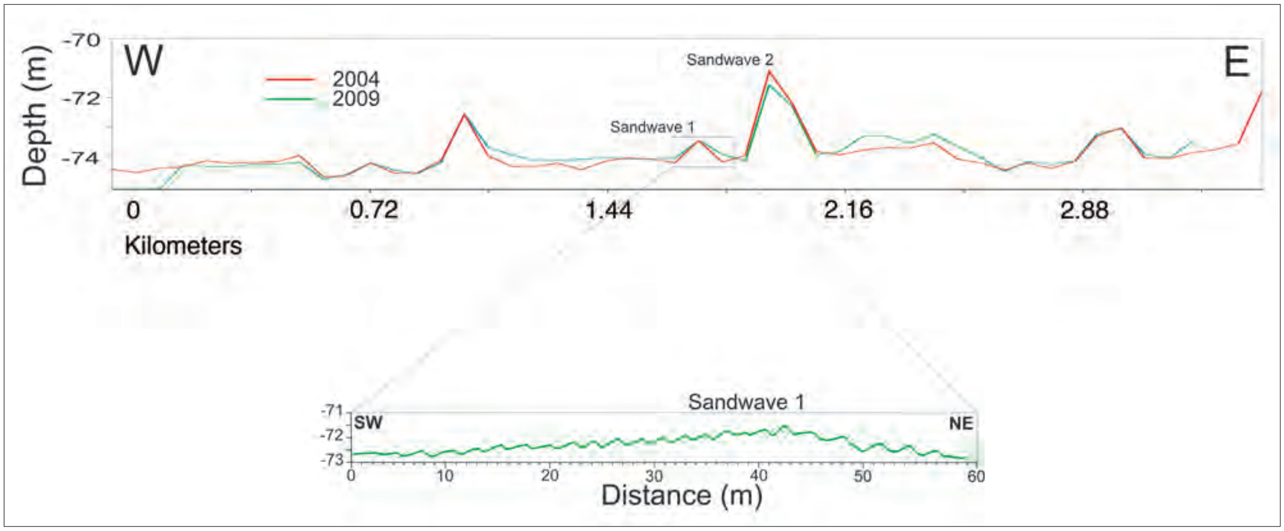

Fig. 4. Comparison of topographical profiles obtained in 2005 and 2009 at latitude 49.677° and detailed topographical profile of Sandwave 1 in 2012, where dune fields covering both of its sides can be observed. Photo: Stratigraphy Area, Faculty of Experimental Sciences, University of Huelva.

large sandwaves are sedimentary features extending at least 750m in length in a continuous northeast/southwest orientation. From a sedimentary perspective the bedforms are composed of shelly fine sand, which overlies a shelly gravel formation that is exposed on the flatter and deeper seabed to the southwest of the site.

The surfaces of the large sandwaves are completely covered by smaller dunes with wavelengths comprising between 2-3m (Figs. 4-5). These can be defined as small dunes (Ashley, 1990), and are also referred to as small sandwaves (Harms *et al.*, 1975).

The dune migration processes exhibit different timescales and involve divergent hydrodynamic forcing mechanisms. On epicontinental shelves, tides are generally the main agents responsible for sediment transport and bedform migration, and are responsible for the inversion in the migration of small forms. The variability of position and dimensions during tidal cycles has been comprehensively described by Langhorne (1982). A long-term spatial variability in the migration direction and rate of shallower dune fields has been identified (Ernstsen *et al.*, 2006; Buijsman and Ridderinkhof, 2008a; 2008b). These medium or long-term processes are generally caused by wind-driven currents, which can also play an important role in the seasonal inversion of dune polarity (Harris, 1989; 1991; Thauront *et al.*, 1996). For even longer time scales Ferret *et al.* (2010) studied a dune field in the Eastern English Channel, where they found evidence that their long-term motion can be influenced by long-term tidal oscillations and the inter-annual to decennial variability of storm activity (Gratiot *et al.*, 2008).

In the Eastern English Channel, especially in the Dover Strait, the sandwave-dune systems have been well studied, demonstrating how large dunes display changing migration rates and directions according to long-period tidal cycles (tides of equinoxes and solstices), the wind regime and the storm activity (Le Bot *et al.*, 2000; Le Bot, 2001). However, a comparative lack of knowledge exists about the dynamics of systems located in the western sector of the English Channel. The aim of this report is to describe the beds located in the environment context of shipwreck site 25C (*Victory*, 1744) in the Western English Channel (Cunningham Dobson and Kingsley, 2010) in order to interpret the dynamic nature of the sand transport and to assess how this dynamism could affect the shipwreck site form, which is located in the western border of the dune field.

3. Equipment & Methods

The current study combines environmental and sedimentological data secured in the form of 2005, 2009 and 2012 multibeam survey data complemented by a 2012 sediment analysis program (Prave *et al.*, 2012). This study represents part of the 2012 non-disturbance research into the *Victory* wreck site (*HMS Victory, 1744 (Site 25C) – Project Design*, Phase 2; *HMS Victory (1744), Key Management Principles,* Maritime Heritage Foundation, 2013, Level 2.1 research).

Three sediment samples were collected by Odyssey Marine Exploration in February 2012 using the arm of the Remotely-Operated Vehicle Zeus. The sediments were studied by the Centre for Earth Resources St. Andrews (CERSA). For analytical purposes, samples were divided

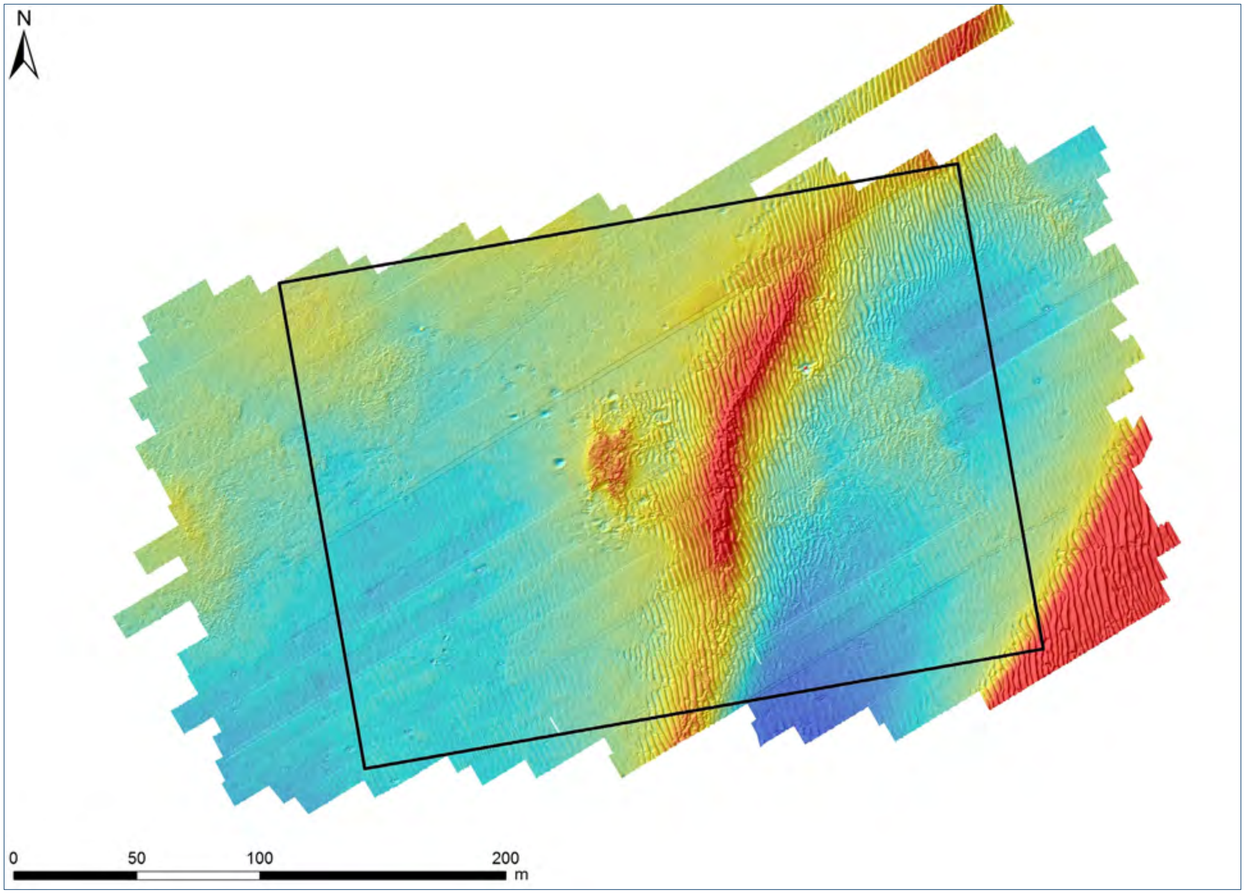

Fig. 5. Bathymetry of site 25C in 2012, showing the extension of 2D dune fields covering Sandwave 1. Photo: © Odyssey Marine Exploration.

into two fractions. The fraction greater than 1mm in size was separated by sieving and weighed. The fraction smaller than 1mm was analyzed using a Beckman-Coulter LS-230 laser difractormeter. Semi-quantitative mineralogical analysis was conducted using an X-Ray Difractometer Baker AXS.

Quantification was performed by Rietveld analysis using Siroquant software. Quantitative geochemical analysis of major oxides and trace elements was undertaken using X-Ray fluorescence Panalytical Epsilon 5 EDPXRF, which utilizes three-dimensional polarizing optical geometry, which allows sub-ppm determination of a range of elements (Prave *et al.*, 2012).

The first multibeam survey was conducted by the United Kingdom Hydrographic Office in 2005 using a dual head Kongsberg Maritime EM3000D multibeam echo sounder. Positioning was by DGPS and the survey referred to the International Terrestrial Reference Framework 2000 (ITRF2000) Datum. The resultant data were used by kind permission of the UKHO.

A further multibeam survey was conducted by Wessex Archaeology on site 25C in June 2009 over an area of 2 x 2 km. Survey lines orientated approximately ENE-WSW, parallel to the tidal currents, were run at 40m line spacing. This area was registered by multibeam geophysical analysis. The equipment used was a Simrad EM1002 system permanently hull-mounted on HMS *Roebuck* (Wessex Archaeology, 2009: 9).

Odyssey Marine Exploration conducted a survey in February 2012 across an area of 400 x 200m using a ROV-mounted Reson Seabat 7125 and related PDS 2000 data processing software. In this survey a total of 35 lines were flown during the course of eight dives. Line spacing was 50m wide, 20m altitude above the sea bottom and the resolution of grid files was 10cm, which was sufficient to identify details down to the size of individual cannon parts. Geographical positions of the records were provided using a Hemisphere R110 GPS, which received differential corrections via satellite to provide a position to a global accuracy of 0.6m.

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
	%	%	%	%	%	%	%	%	%	%	%
GO1	0.82	1.03	0.64	20.42	u.d.	<0.01	0.22	40.85	0.03	0.02	0.49
GO2	0.94	1.19	0.69	13.12	u.d.	0.04	0.21	44.41	0.04	0.01	0.42
GO3	0.89	0.92	0.72	19.29	u.d.	0.12	0.17	41.84	0.03	0.01	0.64

Table 1. Major oxides by percent from sediment samples GO1, GO2 and GO3, site 25C. After Prave et al.*, 2012: 8.*

	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br
GO1	7	7	< 5	1	47	6	< 1	< 2	< 3	< 2	4
GO2	3	12	< 5	1	33	8	< 1	< 2	< 3	< 2	6
GO3	4	7	< 5	2	57	5	1	< 2	< 3	< 2	4

	Rb	Sr	Y	Zr	Nb	I	Cs	Ba	Pb	Th	
GO1	5	1980	5	13	2	18	2	42	11	2	
GO2	1	2103	4	10	2	13	2	31	28	2	
GO3	3	1948	5	24	2	12	4	33	13	1	

	Mo	Ag	Cd	In	Sn	Sb	La	Ce	Pr	Nd	U
GO1	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.
GO2	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.
GO3	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.

* u.d. = Under Detection rate

Table 2. Trace elements from sediment samples GO1, GO2 and GO3, site 25C. After Prave et al.*, 2012: 8.*

In order to interpret the dynamism of the sandy bedforms at site 25C, theoretical tidal currents and heights were obtained from Admiralty TotalTide software, traded by the United Kingdom Hydrographic Office. This software automates the prediction process to provide accurate tidal height and tidal stream calculations. The model is able to integrate tidal height and stream outputs for more than 3,000 sea points using real tide data over a Digital Elevation Model of the near coast and seabed.

4. Results

The three sediment samples examined and classified from site 25C correspond to variable coarse sand, very coarse sand and gravel (Figs. 6-7). The mean grain sizes proved to be sample GO1: 1.07mm (very coarse sand); sample GO2: 0.85mm (coarse sand); and sample GO3: 1.27mm (very coarse sand). From a mineralogical point of view, the main component of the sediment is the bioclastic fraction, being calcite, magnesium-rich calcite and aragonite (a compound of shell fragments), which accounts for between 80% and 90% of the total sample. Quartz grains were also well represented at between 13-20%.

Chemically the major oxides are dominated by CaO (about 40%) and SiO2 (about 20%) (Table 1). The trace elements are dominated by Sr (about 2,000 ppm), which is associated with Ca in the crystalline structure of the shells (Table 2). The content of Ba, Cu, I, Pb and Zr is very significant. The first four elements are also associated with the shell structure, but Zr is normally included in the silica structure of the quartz fraction. The rest of the elements possess contents of less than 10 ppm. Mo, Ag, Cd, In, Sn, Sb, La, Ce, Pr, Nd and U co-exist below detection limits (10 ppm).

The tidal currents are asymmetric in the study area. The flood and ebb maximum velocities are 0.61 and 0.56 $m\ s^{-1}$ in mean spring conditions, and 0.36 and 0.31 $m\ s^{-1}$ under mean neap conditions. These tidal currents are oriented northwards in a direction of 79° during flood tides and northwards at 258° during the ebb (Fig. 8).

To calculate the sediment mobility induced by these tidal currents the critical velocity of movement was used. The critical velocity was determined using a Hjulström's curve, with the mean grain size calculated for the studied samples. The value of critical velocity required to start the movement of sand particles in the study region is 0.36 $m\ s^{-1}$. This first movement will manifest in the form of creeping or rolling and configures the bottom as a low flow regime plane bed. The critical thresholds needed to transform the bed and develop dunes with straight crests (2D)

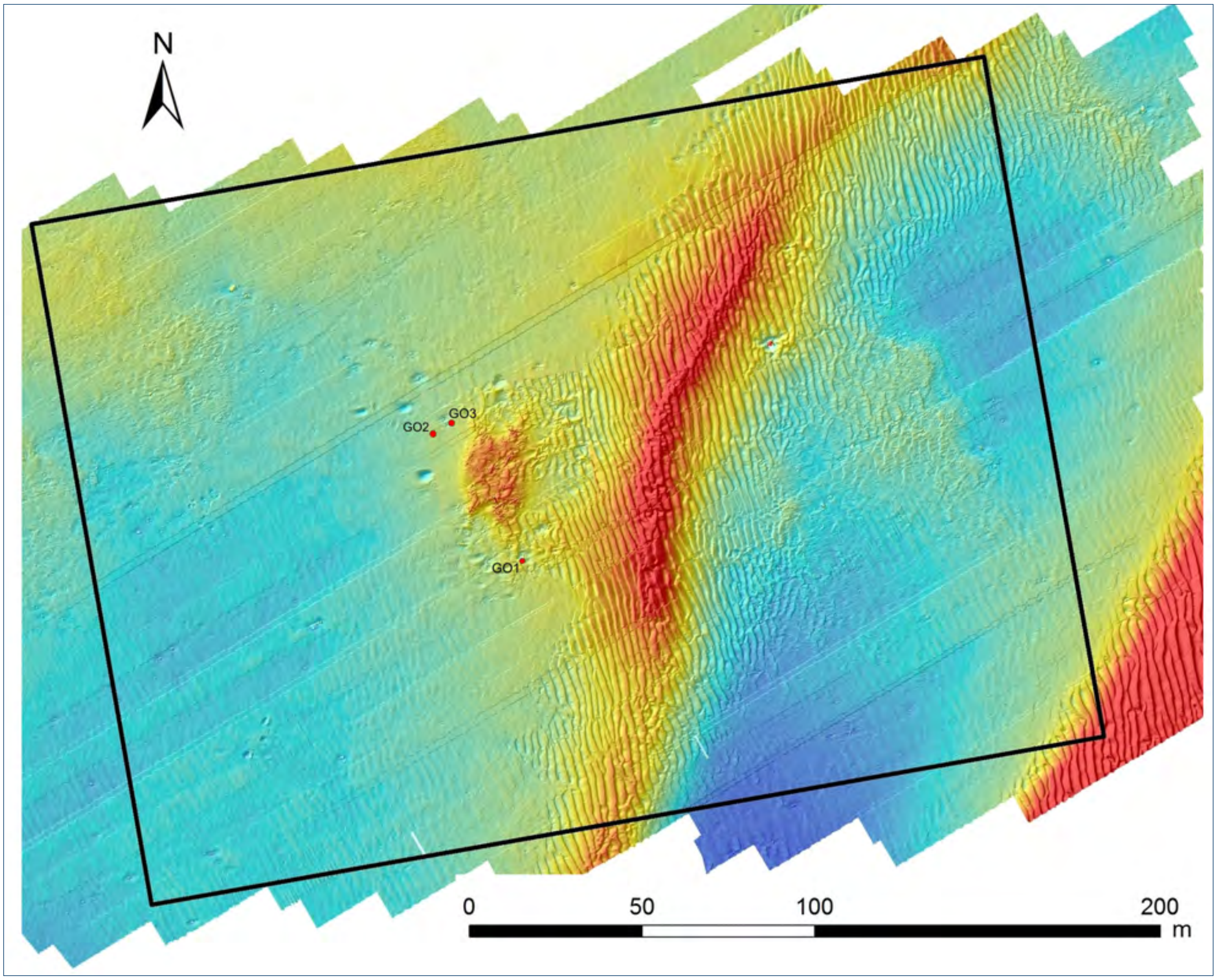

Fig. 6. Location of studied sediment samples on the edges of site 25C, as collected in February 2012. Photo: © Odyssey Marine Exploration.

were also calculated using an experimental diagram based on Southard and Boguchwal's (1990: 668) development curve. Accordingly, based on calculated values the beds in the vicinity of site 25C will develop 2D dunes at 0.49 m s^{-1} (Fig. 9).

The calculated thresholds were represented over the tidal current curve velocity to determine the time at which sand starts to be transported and when the bed acquires the corresponding morphologies (Fig. 8). This graph shows how during neap tides the sediment is not mobilized, because even the maximum registered current (middle flood) did not reach the critical velocity for movement. In spring conditions the sediment is mobilized by flood and ebb currents, but some differences can be observed when both phases are compared.

A first observation can be made in respect of the time of motion. Sediment is mobilized for similar durations during flood and ebb (2.25 hours and 2.37 hours respectively). Nevertheless, the higher velocities developed during the flood phase are responsible for the development of more energetic bedforms (3D dunes) that cannot be developed by the ebb. This situation is responsible for a higher transport volume and a faster migration rate of the bedform in relation to the flood. In consequence, these results demonstrate a flood-dominated sediment dynamic.

Macroforms and mesoforms are present in the study area. Macroforms are large sandwaves and mesoforms are small dunes (megaripples). The large sandwaves possess sinuous crests with orientations that oscillate between 60° and 140° northwards, with two preferential orientations at

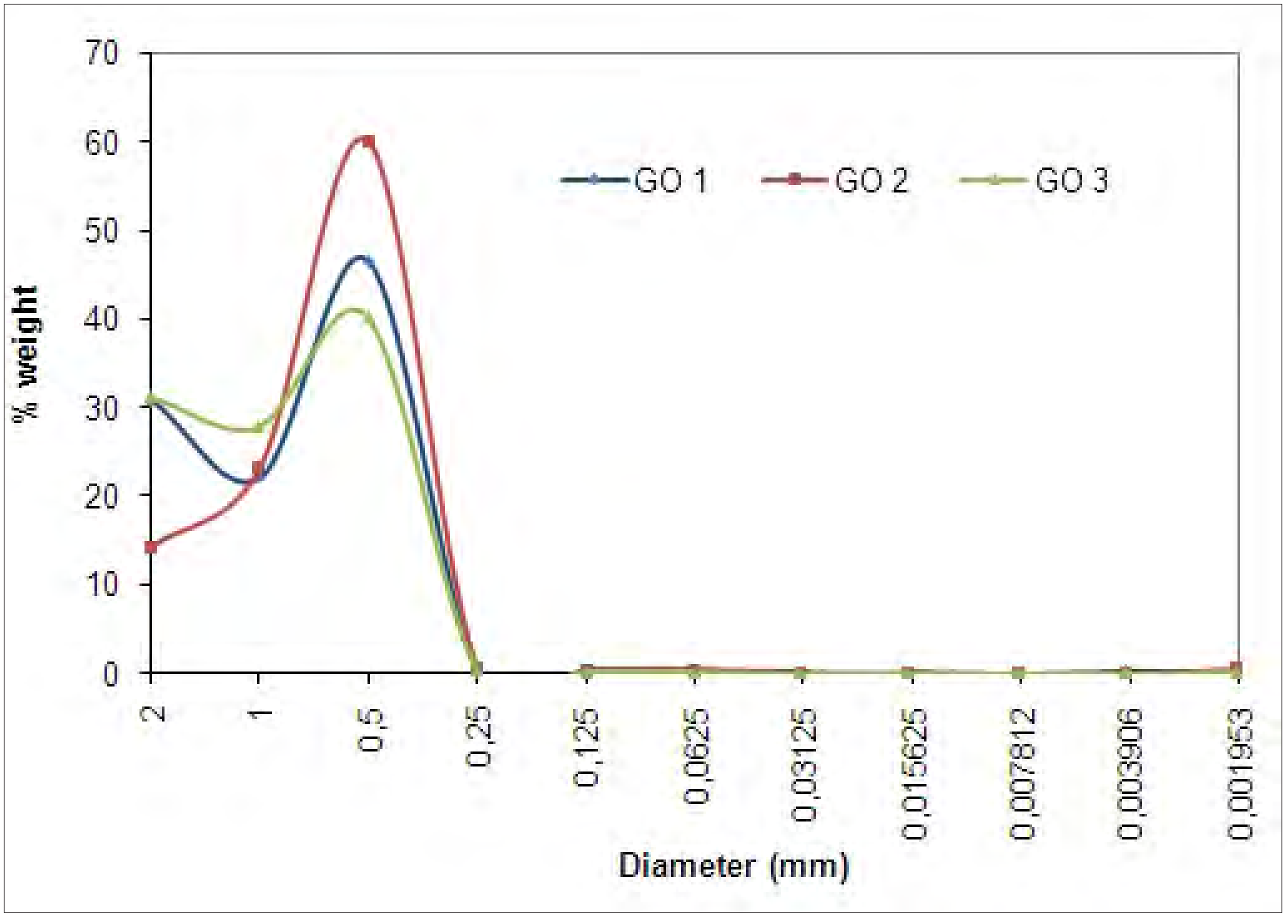

Fig. 7. Grain size distribution of sediment samples studied from site 25C. Photo: Stratigraphy Area, Faculty of Experimental Sciences, University of Huelva, after data in Prave et al.*, 2012.*

18° and 130° to the north (Fig. 10). Their heights reach up to 3m, crest lengths range from 600m to more than 2.5km, and their widths vary from 50-130m. Distances between the two dunes (Sandwave 1 and Sandwave 2) range from 100-700m. The sandwaves have a symmetry index oscillating between 0.95 and 1.20, being near symmetric forms. The mean bed slope of the stoss side of the sandwave was estimated to be 2.1° (3.7%), whereas the mean slope of the lee side is 2.0° (3.4%).

The site 25C region's sandwaves are covered by 2D dunes (megaripples) (Fig. 11). Their heights oscillate between 0.3-0.4m and their wavelengths comprise between 2.0-2.8m. The crests are straight or slightly sinuous and are oriented 172°, perpendicular to the mean tidal direction (Fig. 12), 26° anti-clockwise from Sandwave 1's preferential orientation. The slope of the stoss side of the dunes is about 11.5° (16.5% over the 2.1% of the sandwave) and the slope of their lee side is at about 39°. These forms have a symmetry index of 0.21 (very asymmetric), with the asymmetry oriented in the direction of the tidal current that last caused the sediment migration.

During the February 2012 survey of the *Victory* wreck site the 2D dunes' asymmetry was oriented in accordance with the dominant tidal current present. Thus, in the northern part of the study area all the dunes were flood-oriented because the bathymetric data measures were obtained during the flood phase (Fig. 13). In the same survey, the southern lines of the bathymetry were conducted under ebb conditions, revealing a bed covered by ebb-oriented dunes (Fig. 14). Nevertheless, the orientation of the crest remained constant despite the reversal of bedforms.

5. Conclusion

The study of the sedimentological and geomorphological characteristics of the seabed and its evolution can serve as a significant tool to understand the preservation-destruction trends of underwater heritage, since clear relationships exist between the sea features, sediments and the processes that affect the environment where wrecks are located.

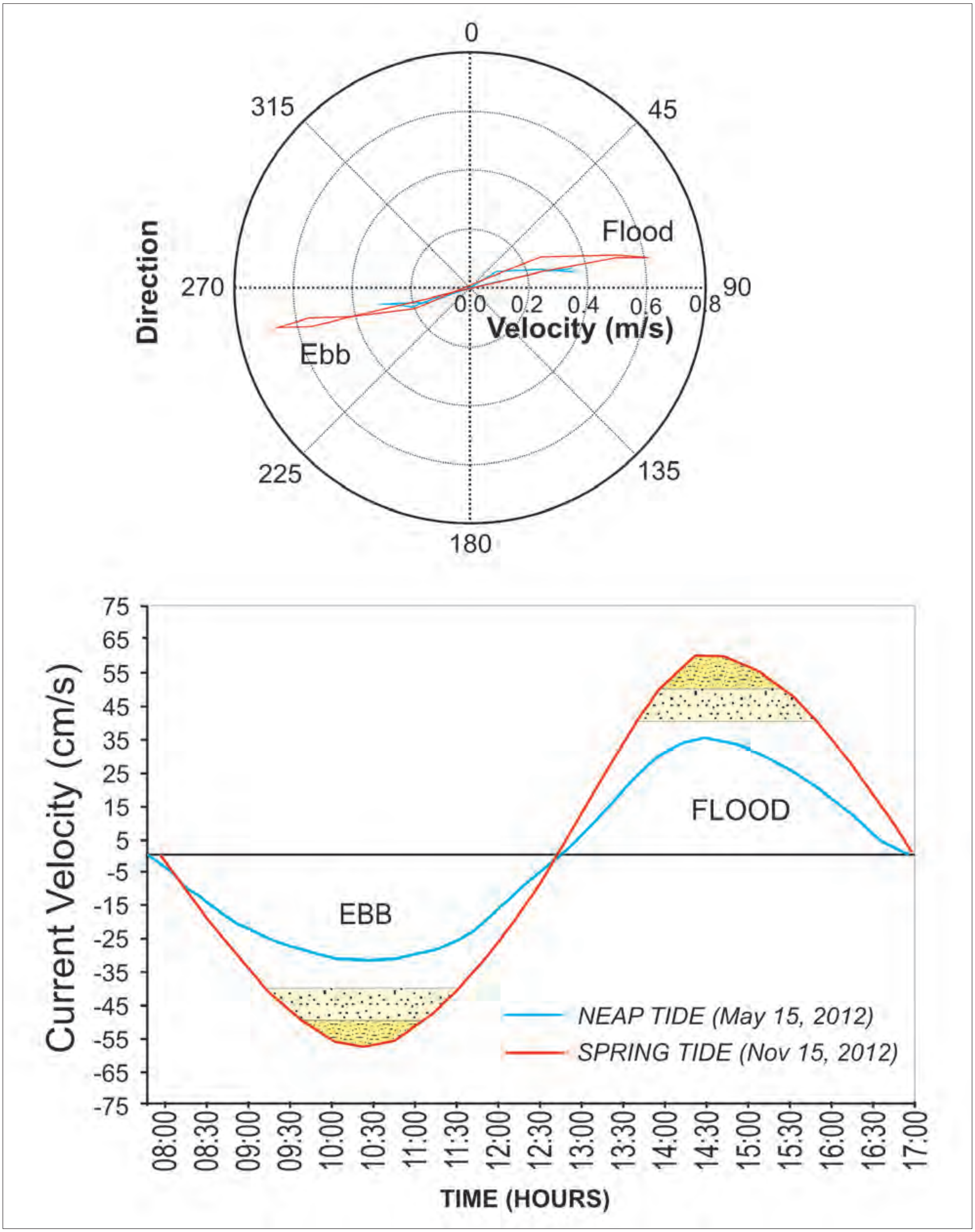

Fig. 8. Tidal currents of the site 25C study area during mean and spring tides. Top: rose diagrams of tidal currents measured during neap and spring tides. Bottom: curve time-current velocity indicating the stability fields for lower plane beds (pale yellow clear spots) and 2D dunes (dark yellow waves). Calculated after Southard and Boguchwal (1990: 668) for a mean sediment grain size of 1.07mm (see Fig. 9). Photo: Stratigraphy Area, Faculty of Experimental Sciences, University of Huelva.

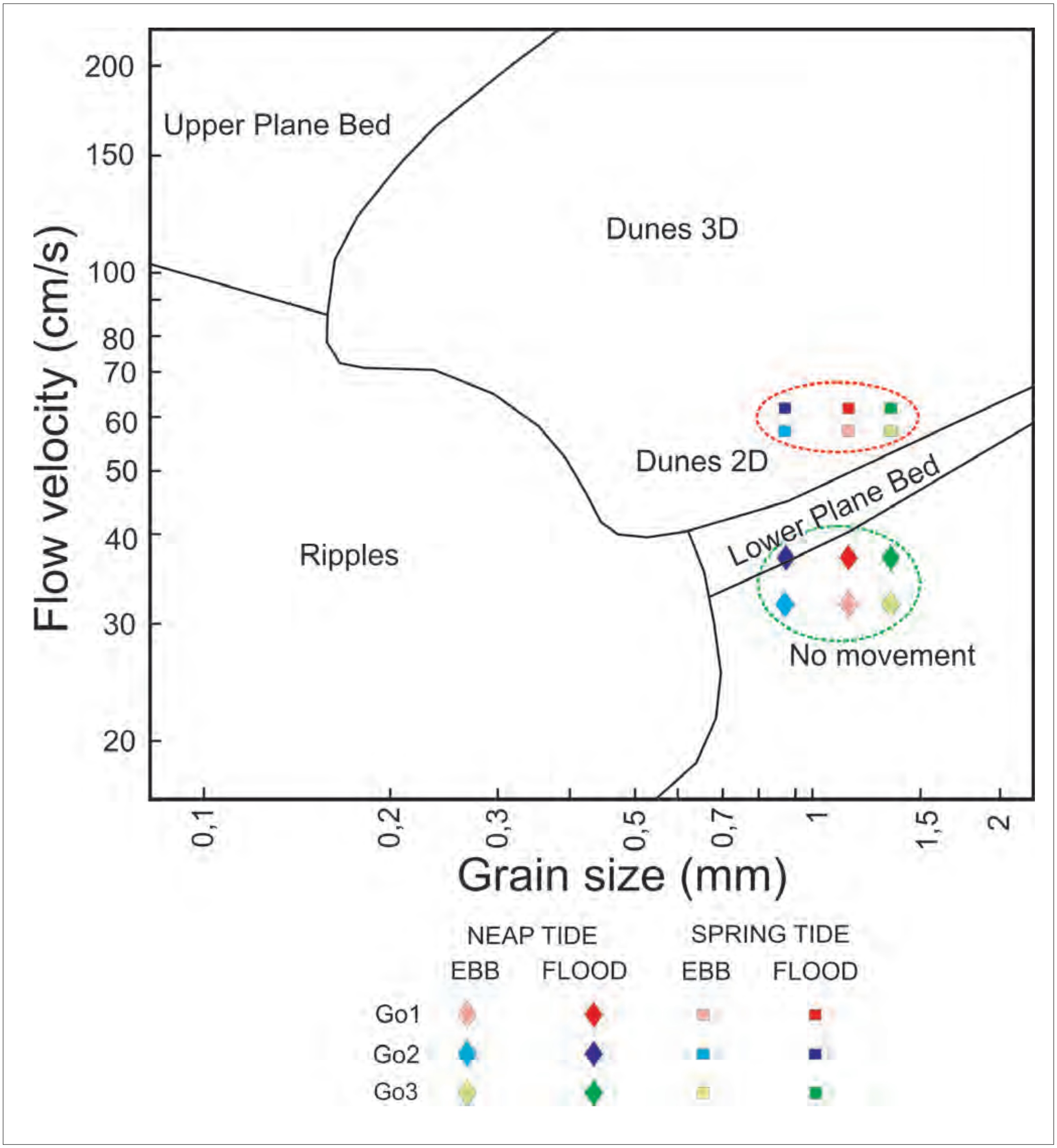

Fig. 9. Diagram of bedform stability fields based on the sediment existing in the bed and the dominant current (after Southard and Boguchwal, 1990: 668). The values of the studied sediment samples are represented in relation to the maximum measured currents in neap and spring tides. Photo: StratigraphyArea, Faculty of Experimental Sciences, University of Huelva.

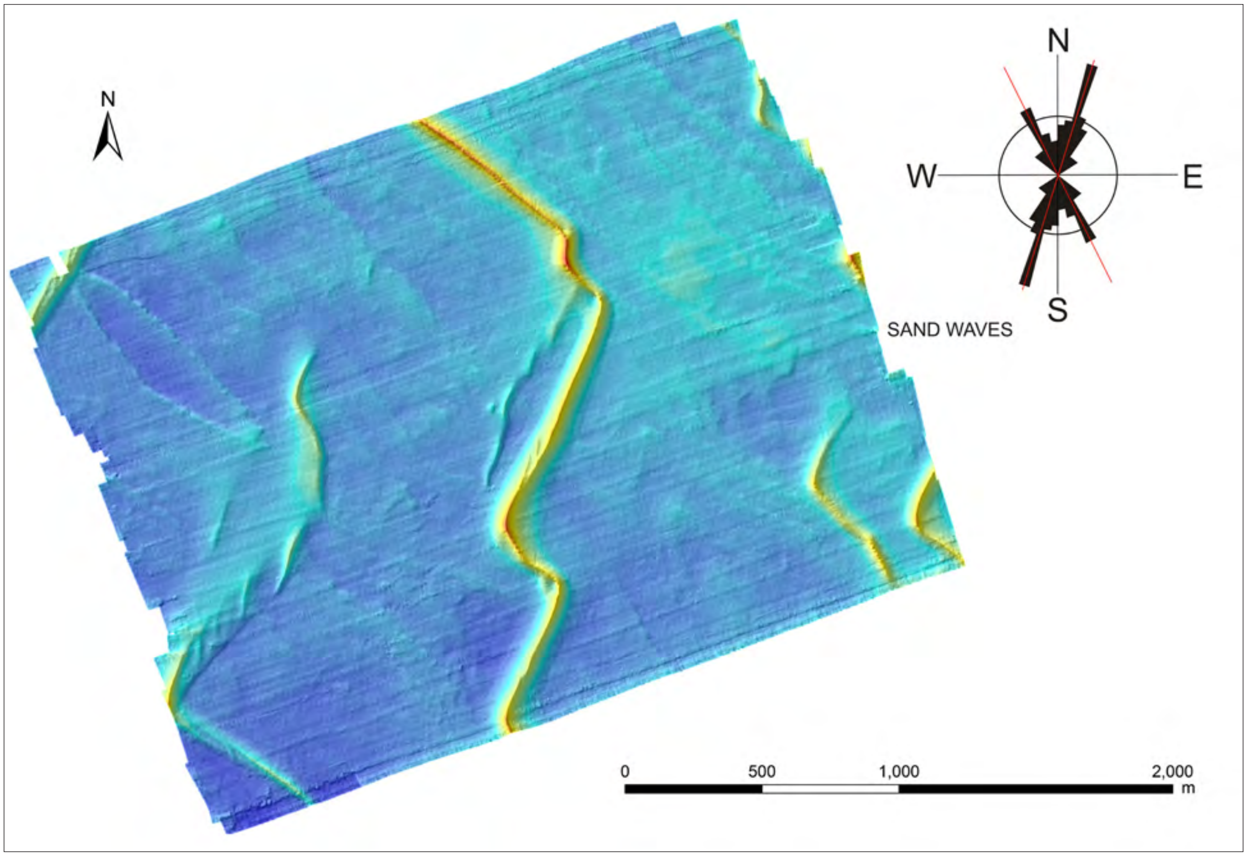

Fig. 10. Sandwaves in relation to an indicative rose diagram with main crest orientations. Photo: Stratigraphy Area, Faculty of Experimental Sciences, University of Huelva, based on Wessex Archaeology data, 2009.

The nature and size of the sediment that constitutes the seabed at site 25C enabled the tidal currents to configure wide mesoforms fields. These mesoforms are asymmetric 2D dunes (straight crested) that are in equilibrium with the flow regime imposed by tides and their crest orientation. Their asymmetry is in harmony with the current regime. These characteristics can be defined as active forms, but the movement predictions based on the currents on Southard and Boguchwal's graph (1990: 668) indicate that the dunes can only migrate during spring tidal conditions. The migration rate of these forms could not be determined, but similar forms studied in other parts of the English Channel provide values of migration rate up to 1m h^{-1} during spring tidal cycles (Idier *et al.*, 2002; 2011).

Not just dunes but also bigger megaforms, such as large sandwaves, were also identified in the site 25C region. These sandwaves display crests that form an oblique angle with preferential dune orientations. The dynamic mechanism of genesis and migration of these sandwaves could not be examined, but a GIS comparison between the topographies obtained during the 2005 and 2009 surveys demonstrates that the position of the crests developed only submetric changes. This last observation means that in these six years the migration of the sandwaves was not significant. Nevertheless, changes in the height of these forms were observed, which can be attributed to constant reworking caused by the minor dunes.

The lack of migration under normal tides, united to the existence of an oblique angle in respect to the main tidal currents, suggests another agent is responsible for the sandwave genesis. In inner areas of the English Channel high energy events like big storms have been suggested to be the main cause of the medium-term dynamism of sandwaves. In our case there is a clearly influential relationship between the smaller bedforms in regard to the dynamism of the larger ones. The 2D dunes migrate over both sides of Sandwave 1, which exhibits a slight angle and a marked symmetry. This migration of minor forms over the large sandwaves is continuously retouching the crest and reworking their sediments. Consequently, through

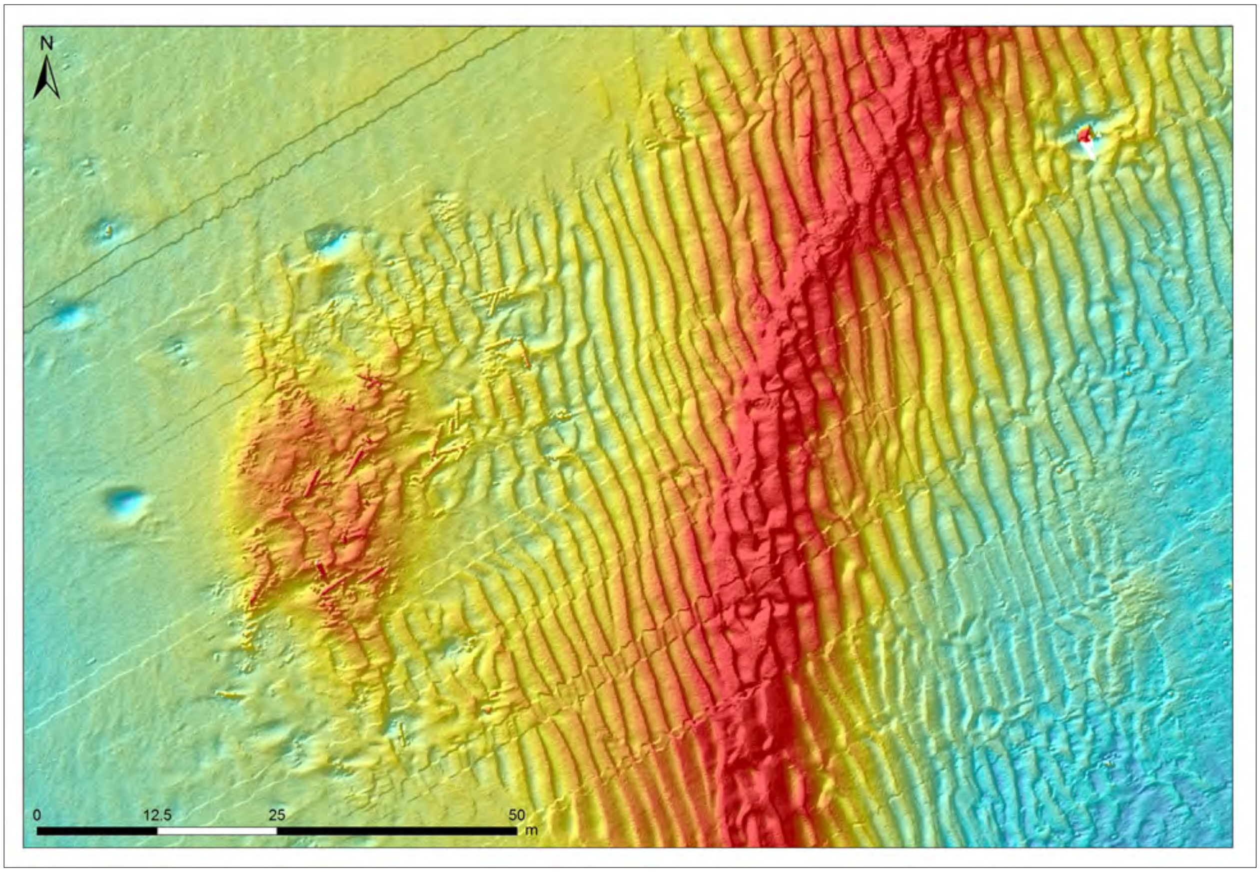

Fig. 11. Sandwave 1 covered with 2D dunes. An oblique orientation between the crest of the sandwave and the trains of 2D dunes can be observed. Photo: © Odyssey Marine Exploration.

tide-controlled reworking the sandwave loses height and smooths its profile, as was observed by comparing the 2005 and 2009 bathymetric data.

The process presented shows clear differences to the dynamics described in other areas. In shallower zones of the Eastern English Channel, 2D dunes migrate from the foot of the gentle slope of the stoss side toward the crest of the sandwave and then induce avalanches on the lee side of the same. This process is demonstrated by a clear asymmetry of the tidal currents and the different slopes of the sandwave, which shows a high-diped lee side (Idier *et al.* 2002; Le Bot and Trantesaux, 2004), but is clearly controlled by the high speed of tidal currents that surpass 1m s^{-1}.

According to this data, large sandwaves are not active forms and can only be activated and migrate during high-energy events. By contrast, the minor 2D dunes present a high degree of dynamism. Their sand content can be only transported during spring tides by reversing currents. The presence of dominant flood-oriented dunes and the measurement of tidal currents suggest that the transport character is slightly unbalanced in relation to the flood. This indicates that the dune field located presently on the western side of Sandwave 1 probably occupied a more western position in the past, covering the rest of the shipwreck and contributing to its preservation.

The theory that site 25C may be a relatively recent cultural exposure is supported by its absence in UKHO records of wreck snags. Other wrecks are documented in the general catchment area in UKHO records, with two sites located 2,379m and 4,060m from *Victory*. Its former location is evidenced by the shells observed to the southwest of the wreck that appear to be a lag deposit formed by the exposure of coarser shells that could not be transported by the tidal current, which otherwise stripped away the light sands. In the future, this dune field will continue to be displaced to the east and eventually the rest of the wreck will be totally revealed, but it is foreseeable that this will be a slow process.

To calculate the migration rate of Sandwave 1 objectively would necessitate the measurement of the velocity of tidal currents in the vicinity of site 25C at several points and at different times using equipment such as an ADCP

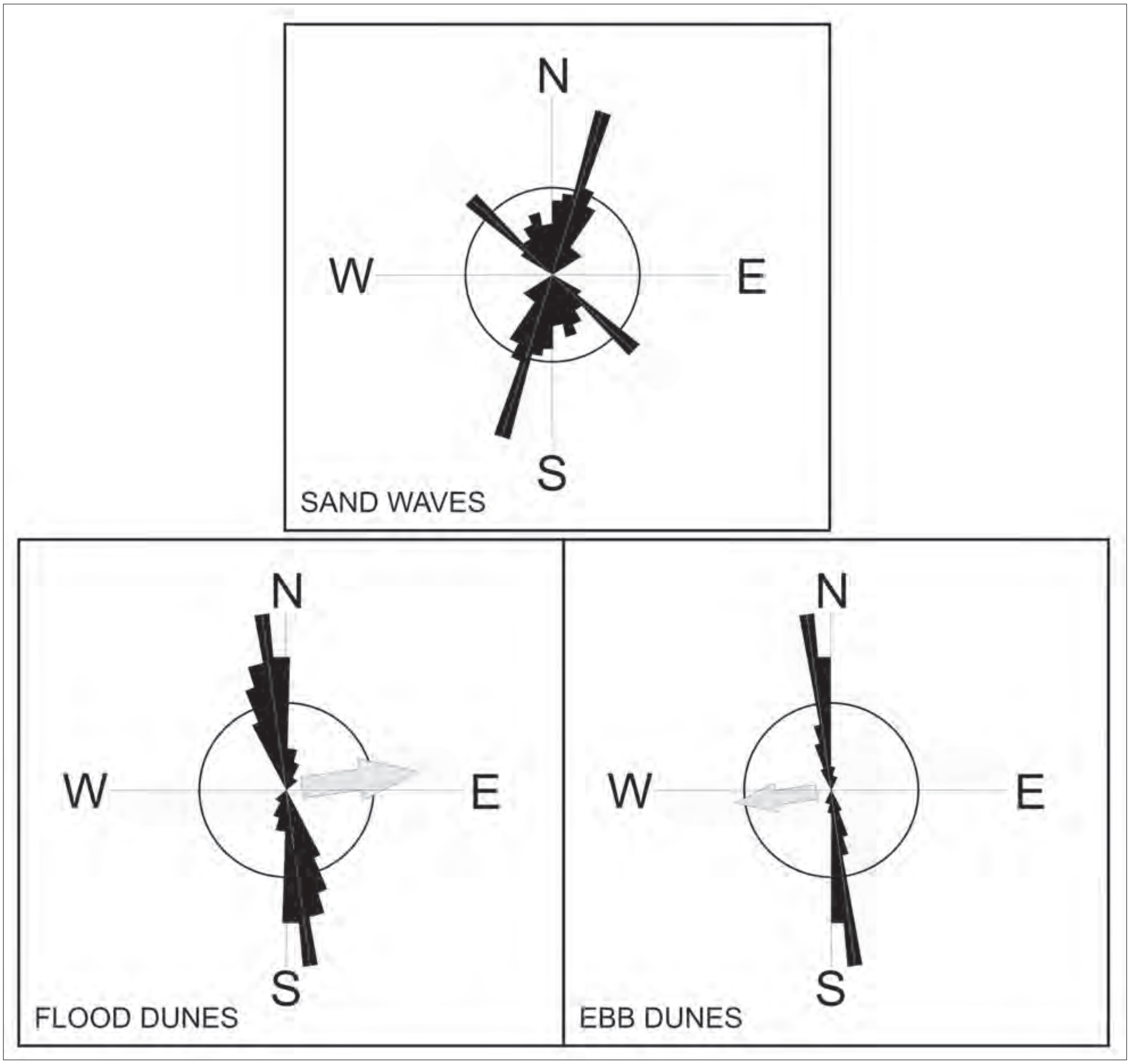

Fig. 12. Rose Diagrams of the crest orientations of sandwaves and dunes (flood and ebb-oriented) within the site 25C region. Photo: Stratigraphy Area, Faculty of Experimental Sciences, University of Huelva.

(Acoustic Doppler Current Profiler). Simultaneously, corings would need to be drilled through Sandwave 1 and the shell deposit over which this bedform is interpreted as having formerly lain and passed. This research would enable a mathematical model to profile the rate of Sandwave 1's migration.

This dynamic natural configuration is probably responsible for having naturally preserved some archaeological stratigraphy on site 25C. In comparison to other deep-sea shipwrecks examined by Odyssey Marine Exploration in the Western English Channel, the mid-18th century armed French privateer *La Marquise de Tourny* (site 33C) is an important cultural counterpoint (Cunningham Dobson, 2011). This shipwreck lies about 100km southeast of Plymouth at a depth of 80m.

The main difference to the *Victory* wreck is that at site 33C the seabed is composed of a matrix of very shallow gravel flints and small stones intermixed with far more limited areas of coarse sands. No sandwaves exist to feed a system of smaller sand dunes as at site 25C. The sediment matrix achieves an average depth of about 15cm, with apparent maximum deposits in some points of no more

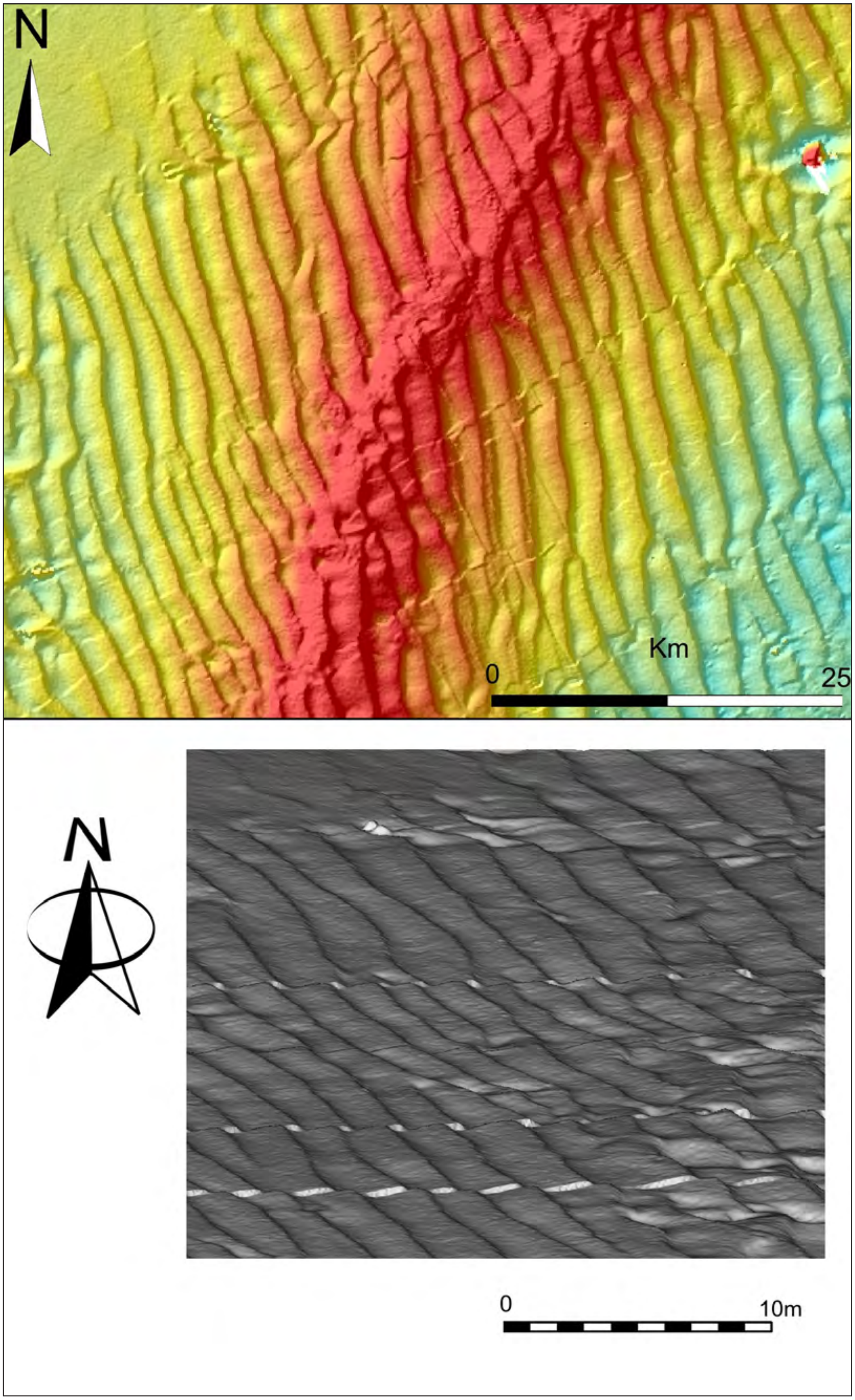

Fig. 13. Flood-oriented bedforms in proximity to Sandwave 1. Photo: © Odyssey Marine Exploration.

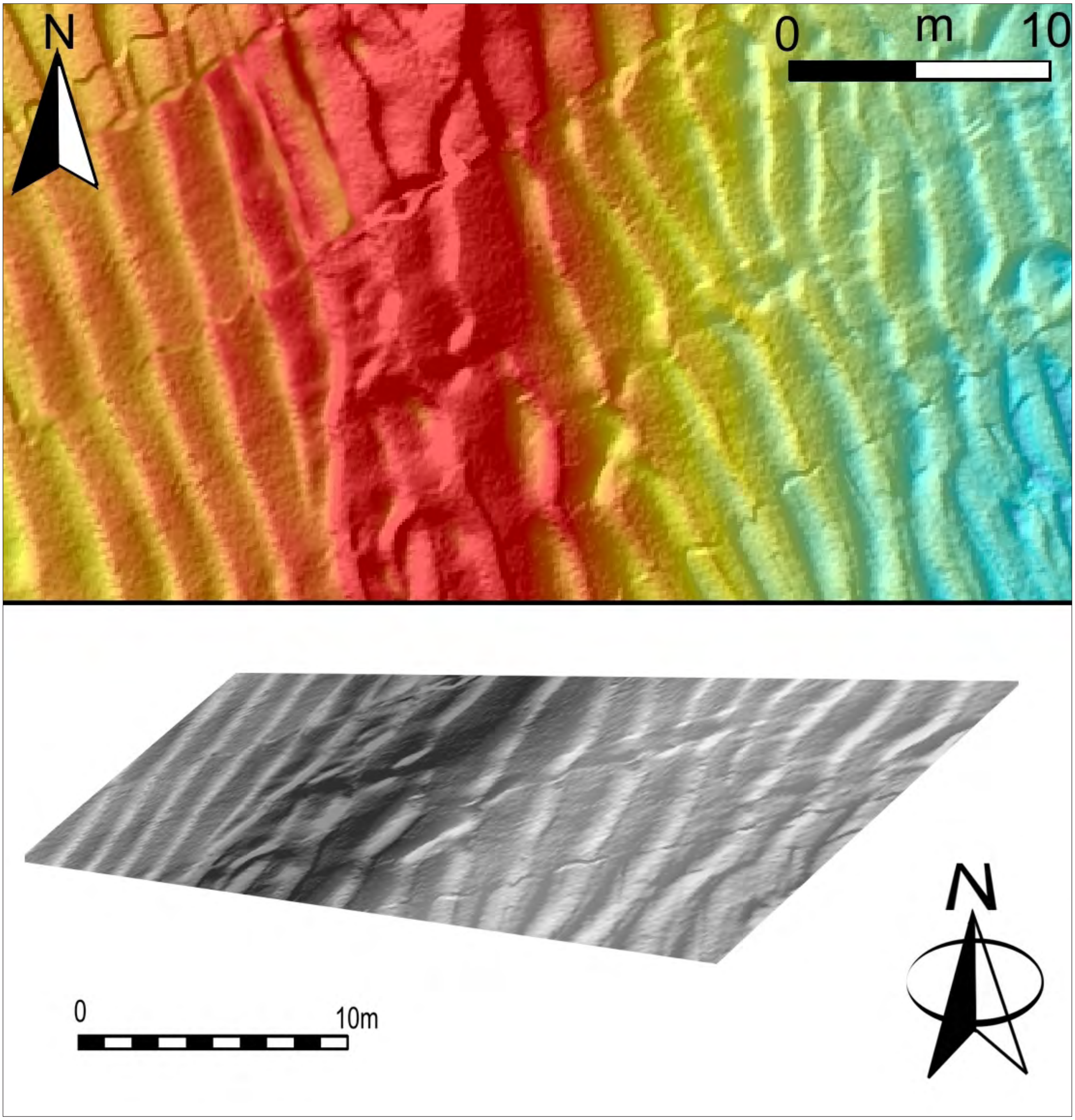

Fig. 14. Ebb-oriented bedforms in proximity to Sandwave 1. Photo: © Odyssey Marine Exploration.

than 40cm. The site has been heavily abraded, reducing the wreck to a concentration of durable concreted iron cannon and iron ballast blocks. Other than the ship's bell, no other artifacts were present on the surface. Select soundings identified very minor sections of badly preserved timbers pinned down by ballast.

Thus, the potential for stratigraphic preservation on sand-starved site 33C is low in comparison to the sand-inundated case of site 25C. The random geographical position of the loss of the *Victory*, combined with the fortunate presence of sandwaves and sand dunes at this location, seems to have resulted in comparatively significantly superior archaeological stratigraphy and preservation. Should Balchin's *Victory* have sunk away from such a specific sedimentological feature, its archaeological preservation is likely to have resembled that of the heavily ground down *La Marquise de Tourny*. By extension, if site 25C remains exposed to the elements following its exposure, and following the continual migration of Sandwaves 1 and 2 eastwards, erosion may be comparatively swift and destructive.

Acknowledgements

The authors wish to extend their sincere gratitude to the entire survey and management team at Odyssey Marine Exploration. Particular gratitude to Project Managers, Data Managers, Data Loggers, ROV Operators and ROV Technicians and the entire team of the RV *Odyssey Explorer*. Thanks to Miguel Ángel González Sánchez from Navíos de Aviso S.L who helped develop the images in the University of Huelva. Paul Baggaley at Wessex Archaeology kindly facilitated use of their multibeam data obtained in 2009. Thanks are also extended to the UKHO for providing similar access to Crown multibeam data for the site 25C region produced in 2005.

Bibliography

Ashley, G.M., 'Classification of Large-scale Subaqueous Bedforms: a New Look at an Old Problem', *Journal of Sedimentary Petrology* 60.1 (1990), 160-72.

Bailly du Bois, P. and Dumas, F., 'Fast Hydrodynamic Model for Medium- and Long-term Dispersion in Seawater in the English Channel and Southern North Sea, Qualitative and Quantitative Validation by Radionuclide Tracers', *Ocean Modelling* 9 (2005), 169-210.

Bellessort B. and Migniot, C., *Catalogue sédimentologique des côtes françaises. Côtes de la Mer du Nord et de la Manche: de la baie de Somme à la baie de Seine* (Laboratoire Central d'Hydraulique de France, Paris, 1986).

Buijsman, M.C. and Ridderinkhof, H., 'Long-term Evolution of Sandwaves in the Marsdiep Inlet. I: High-resolution Observations', *Continental Shelf Research* 28 (2008a): 1190-1201.

Buijsman, M.C. and Ridderinkhof, H., 'Long-term Evolution of Sandwaves in the Marsdiep Inlet. II: Relation to Hydrodynamics', *Continental Shelf Research* 28 (2008b) 1202-15.

Coggan, R. and Diesing, M., 'The Seabed Habitats of the Central English Channel: A generation on from Holme and Cabioch, How do their Interpretations Match-up to Modern Mapping Techniques?', *Continental Shelf Research* 31.2 (2011), 132-50.

Cunningham Dobson, N., '*La Marquise de Tourny* (Site 33c): A Mid-18th Century Armed Privateer of Bordeaux'. In G. Stemm and S. Kingsley (eds.), *Oceans Odyssey 2. Underwater Heritage Management & Deep-sea Shipwrecks in the English Channel & Atlantic Ocean* (Oxford, 2011), 69-108.

Cunningham Dobson, N. and Kingsley, S., 'HMS *Victory*, a First-Rate Royal Navy Warship Lost in the English Channel, 1744. Preliminary Survey and Identification'. In G. Stemm and S. Kingsley (eds.), *Oceans Odyssey. Deep-Sea Shipwrecks in the English Channel, Straits of Gibraltar & Atlantic Ocean* (Oxbow Books, Oxford, 2010), 235-81.

Ernstsen, V.B., Noormets, R., Winter, C., Hebbeln, D., Bartholomä, A., Flemming, B.W. and Bartholdy, J., 'Quantification of Dune Dynamics during a Tidal Cycle in an Inlet Channel of the Danish Wadden Sea', *Geo-Marine Letters* 26 (2006), 151-63.

Evans, C.D.R., *Geology of the Western English Channel and its Western Approaches* (HMSO, London, 1990).

Ferret, Y., LeBot, S., Tessier, B., Garlan, T. and Lafite, R., 'Migration and Internal Architecture of Marine Dunes in the Eastern English Channel over a 14 and 56 Year Interval: the Influence of Tides and Decennial Storms', *Earth Surface Processes and Landforms* 35 (2010), 1480-93.

Gratiot, N, Anthony, E.J., Gardel, A., Gaucherel, C., Proisy, C. and Wells, J.T., 'Significant Contribution of the 18.6 Year Tidal Cycle to Regional Coastal Changes', *Nature Geoscience* 1 (2008), 169-72.

Harms, J.C., Southard, J.B., Spearing, D.R., and Walker, R.G., 'Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences: SEPM', *Short Course Notes* 2 (1975), 161.

Harris, P.T., 'Sandwave Movement Under Tidal and Wind-driven Currents in a Shallow Marine Environment: Adolphus Channel, Northeastern Australia', *Continental Shelf Research* 9.11 (1989), 981-1002.

Harris, P.T., 'Reversal of Subtidal Dune Asymmetries Caused by Seasonally Reversing Wind-driven in

Torres-Strait, Northeastern Australia', *Continental Shelf Research* 11.7 (1991), 655-62.

Idier, D., Ehrhold, A. and Garlan, T., 'Morphodynamique d'une dune sous-marine du détroit du Pasde Calais', *Comptes Rendus de l'Academie des Sciences* 334 (2002), 1079-85.

Idier, D., Astruc, D. and Garlan, T., 'Spatio-temporal Variability of Currents over a Mobile Dune Field in the Dover Strait', *Continental Shelf Research* 31 (2011), 1955-66.

Langhorne, D.N., 'A Study of the Dynamics of Marine Sandwaves', *Sedimentology* 29.4 (1982), 571-94.

Le Bot, S., *Morphodynamique de dunes sous-marines sous influence des marées et des tempêtes. Processus hydro-sédimentaires et enregistrement. Exemple du pas de Calais* (Thèse, Université Lille-1, France 2001).

Le Bot, S., Herman, J.P., Trentesaux, A., Garlan, T. and Berné, S., 'Influence des tempêtes sur la mobilité des dunes tidales dans le détroit du Pas-de-Calais', *Oceanologica Acta* 23.2 (2000), 129-41

Le Bot, S and Trentesaux, A., 'Types of Internal Structure and External Morphology of Submarine Dunes under the Influence of Tide and Wind-driven Processes (Dover Strait, Northern France)', *Marine Geology* 211 (2004), 143-68.

Southard, J.B. and Boguchwal, L.A., 'Bed Configurations in Steady Unidirectional Water Flows. Part 2. Synthesis of Flume Data', *Journal of Sedimentary Research* 60.5 (1990), 658-79.

Prave, A.R., Herd, D.A., Calder, A.C., and Allison, S.G., *Sediment Analysis Report for HMS Victory Site 25C* (Centre for Earth Resources St. Andrews, University of St. Andrews, 2012).

Stride, A.H., *Offshore Tidal Sands* (New York, 1982).

Thauront, F., Berné, S. and Cirac, P., 'Evolution saisonnière des dunes tidales dans le bassin d'Arcachon, France', *Comptes Rendus de l'Academie des Science* 323.IIa (1996), 411-18.

Wessex Archaeology, *OME Site 25C Western English Channel. Archaeological Desk-based Assessment* (London, 2009).