Setting of atypical marine sandwaves by rotary currents: impact of island and shoal, Ecrehou archipelago, in the local modification of tidal currents (Channel Islands, France)

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Abstract

SHOM (Service Hydrographique et Océanographique de Marine) realised many hydrographic surveys in the Deroute Channel between the Cape of La Hague and Chausey Islands since 1993, to open a new navigable way for the ferries. Three detailed surveys in the strait between Jersey and the French coast (Cotentin) have been carried out using single and multibeam bathymetry and side-scan sonar. The seafloor is characterized by large sandwaves that are good examples of mega-structures. These structures are associated with a shoal affected by strong tidal currents, this was often observed in the English Channel. Geometry of Ecrehou Archipelago and Ecrevière bank provides a complex sedimentary dynamic that generates an atypic pattern of sandwaves in this area. This large dune field, located southeast Ecrehou Archipelago, is composed of active sandwaves. The evolution of the bathymetry can be studied at different time scales: the results are supported by three surveys in 1998 and a 1939. A tidal numerical model applied in the area between Jersey and Cotentin shows anticlockwise and clockwise cells of sedimentary circulation around Ecrehou Archipelago. The existence of anticlockwise rotary current on large dune field explicates symmetrical sandwaves that are oriented north/south. The dynamic that controls construction and stability of asymmetrical sandwaves (NW/SE) is mainly governed by tidal currents.
Keywords: Channel Islands, large dunes, sedimentary dynamics, rotary current

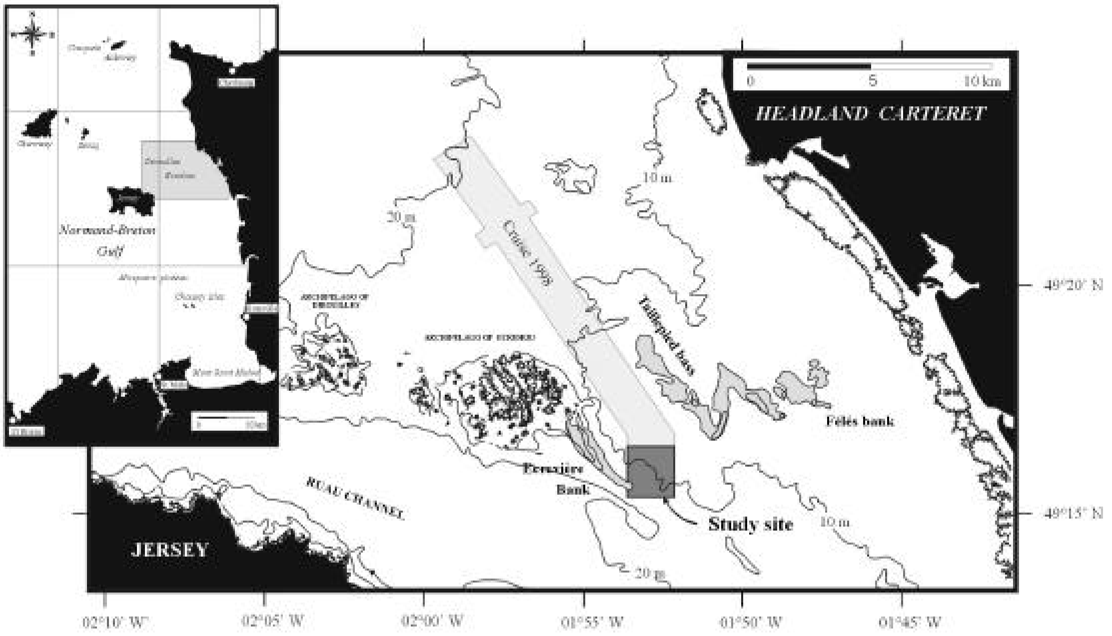
1. Introduction

Observations and numerical models show the existence of residual eddies. They are formed by the vorticity generated by frictional effects on headlands, islands and shoals (Pingree and Maddock, 1979; Zimmerman, 1981; Pingree and Maddock, 1985; Pattiaratchi and Collins, 1987; Pingree and Mardell, 1987; Mc Ninch and Wells, 1999). Around the Channel Islands, the tidal current circulation is modified by the presence of many islands (Jersey, Guernesey, Aurigny, etc...) and the proximity of shoals (Casquets, Dirouilles and Ecrehou Archipelagoes) that endanger the navigation (Fig.1). A tidal circulation pattern for the Channel Islands area was presented based on anticlockwise gyres around all major topographic feature in this region (Pingree and Mardell, 1987). The headland of Carteret provides rotary current (70 cm/s) that can explain the presence of subaqueous giant dune field (Berné *et al.*, 1989).

Results of a study concerning the movement of sandwaves, in relation with the local and regional hydrodynamic conditions, are presented here. The latter are associated with strong tidal currents and residual currents that are generated by the presence of a shoal. Two points have been developed: (1) examination of the sedimentary processes on a sandwave field associated with banner bank and archipelago; this is to find out if the sandwaves are relict or active structures; (2) identification and evolution of the mechanisms explaining the sand bodies over both short and long periods. This is in relation with current circulation (measurements and modelling) across the sandwave field associated with shoal and islands.

2. Field setting and methodology

The study area lies between Jersey North-East coast and French Coast (Fig.1). This area is characterized by huge tidal amplitude associated with a macrotidal regime (tidal range: 3 to 10 metres), particularly in Deroute and Ruau's Channels where tidal currents are canalized and accelerated (Hommeril, 1971; SHOM, 1968).



Garnaud *and al.*, 2000

Fig. 1. Location map of Ecrehou archipelago and bathymetrical track coverage of the cruise.

The studied zone is 1 km northeast of Ecrehou and Ecrevière Bank; it is partially protected from the prevailing westerly winds. The survey area covers more than 15 km^2, including the extremity of Ecrevière Bank. The area was surveyed during May, June and July 1998 by the "Mission Hydrographique de l'Atlantique" (MHA). During these three oceanographic cruises, 150 short bathymetric and side-scan sonar profiles, totalling 120 km in length, were recorded on board research vessels Lapérouse and Borda.

The area located SE of Ecrehou Archipelago (NE of Jersey) is characterized by water depths comprised between 6 and 20 m. Echosounder and side-scan sonar profiles show that the seafloor is composed of symmetrical or asymmetrical sandwaves with heights to up 2 m and wavelengths of about 100 m (Fig.2). Side-scan sonar images show a cover of various and sedimentologic limits as well as sedimentary structures like megaripple fields or erosive figures. Maps of crest position of sandwaves allow to quantify sand movements between the two surveys (Garnaud, 1999). Current measurements (SHOM, 1998) and a mathematical model of tidal and residual currents (Pineau, 1997) prove the role of the tidal current in the control of the sedimentary dynamics. The use of new hydrodynamic numerical models with a better resolution is needed to dispose of an evolutive model. This will take into account the variability of the environment and the complexity of the coastal line. In case of a shoaling environment, the local impact of these structures can be evaluated. Numerical models in the Normand-Breton gulf have been improved due to a better spatial resolution (Orbi and Salomon, 1988) and to a better use of bathymetric data linked to increases accuracy (Pineau, 1998).

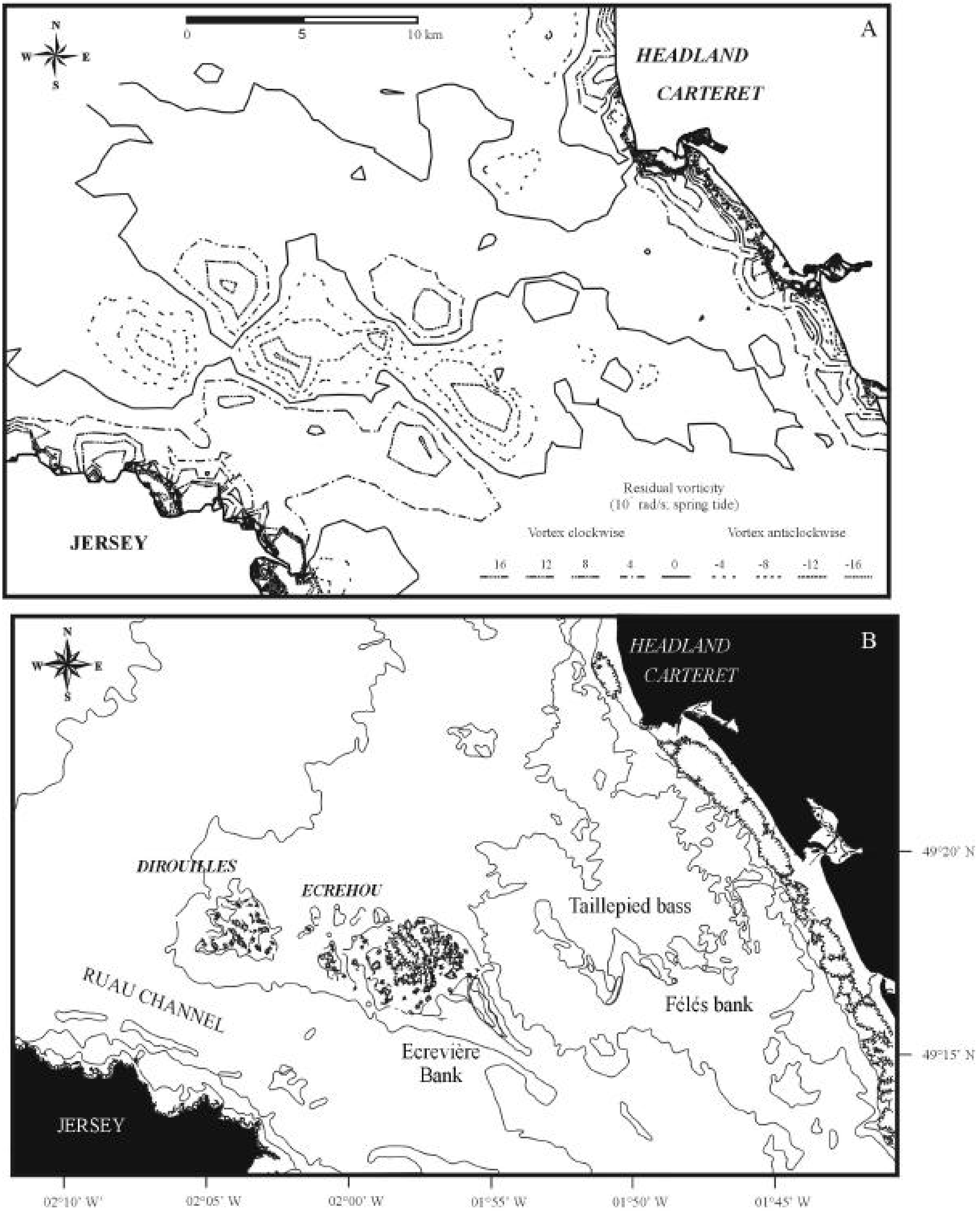


Fig. 2. Residual vorticity over tidal period during spring tide conditions around archipelagos between Jersey and headland Carteret [A] and location map of the study for comparison with bathymetyric map [B].

3. Results

Two dune families are formed by different and complementary hydrodynamic mechanisms in the same study area. The sandwaves evolution can be characterized by the strong tidal currents in the channel and the presence of the archipelago.

3.1. Short term evolution (monthly): instantaneous current velocity

In the study area, the first family of sandwaves is mostly asymmetric NW/SE; it is oriented obliquely of the flood current at angles of about 0°- 15° (Fig.2). Megaripples are superimposed on the two flanks of most asymmetric sandwaves.

Short term sandwave movements have been assessed from repeated surveys (3 months). Many bedforms are observed, particularly longitudinal current ones. They result from the intense tidal currents that control the distribution of superficial coarse-grained sediment. Morphologic changes between the surveys (May, June and July 1998) are clearly restricted to the northwestern end of the sandwave field. There are active structures whose movements present variations in intensity and direction. The maximum mobility of a sandwave crest is 50 m southwestward between June and July 1998. In the other sandwaves, no significant displacements have been observed (i.e. < 5 m). The accuracy of the bathymetric data is of a few metres and the observed variations cannot be explained by line-positioning error. The sandwave crest orientation indicates the direction of bottom current. Moreover, the bedform asymmetry in the study area can be used as a good indicator of the net sand transport on sand ridges southeastward. These sandwaves are also influenced by exceptional storms (Le Bot *et al*., 1999).

The dominant flow direction of tidal currents is southwest during the flood and northeast during the ebb. During each tidal cycle, current velocities of more than 240 cm/s are maintained during several hours. The maximum current velocity occurs generally about 4 hours after high and low waters. In this area, previous measurements of tidal currents show an asymmetry between flood and ebb currents; this asymmetry is responsible of southeastward sediment transport (SHOM, 1998).
Over a short term period, the sedimentary dynamics fit with the regional scheme of the tidal currents that induce a transport towards the SE.

3.2. Long term evolution (decennial): residual rotary current

The second family of sandwaves is composed of symmetric bedforms elongated regarding the N-S great axis. These sand bodies cut the asymmetric sandwave system (Fig.2).
Analysis of 1939 charts shows that the sandwave field was permanent, within the error limits of position. Data from 1939 show that is not possible to extrapolate the rate of movement of sandwave over long period. Significant changes can be observed in Ecrevière Bank that suggest an elongation and development of "son-bank" southeastward (Garnaud, 1999). In the sandwave field, no movement is really observed, but the height of the sandwaves is principally due to vertical evolution, i.e. sometimes 3 or 4 metres. The long term evolution of sandwave field emphasized residual movements, in relation with the archipelagoes and shoals.

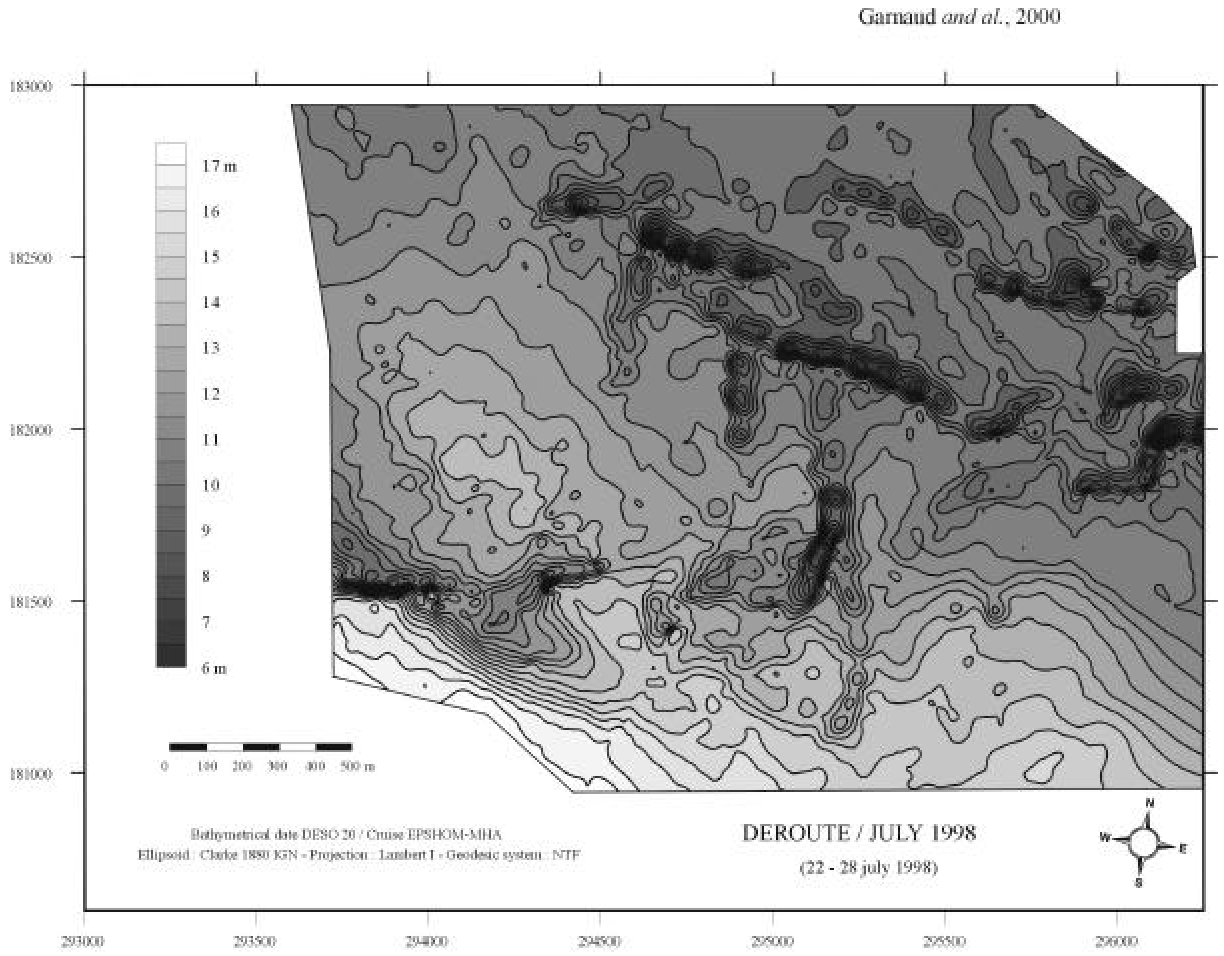


Fig. 2. Bathymetrical map of study area (contours are in 0.25 meters).

The tidal streams around Jersey are rotary anticlockwise and the residual Lagrangian displacements around the islands during spring tides are directed anticlockwise with a velocity typically of 20 cm/s (Pingree and Mardell, 1987; Le Hir *et al*., 1986; Orbi 1986; Pineau, 1998). The mechanisms accountable for rotary movement around islands and shoal have been studied by many authors (Zimmerman, 1981; Pingree and Maddock, 1985; Orbi, 1986; Orbi and Salomon, 1989). Headlands locally create an acceleration of the tidal current (Cape of La Hague, Grouin and Cancale) with the formation of two vortexes. In the study area, the shoal induces the formation of four vortex systems, alternatively positive and negative (ex: Ecrehou and Dirouilles archipelagoes). The cells are separated by calm zones where residual currents are very small and therefore form an area of potential accumulation of sediment. The Ecrevière bank is located at the boundary of this low rotary system (Fig.3). The existence of residual eddies in the study area can be explained by the vorticity dynamics tied with the islands and banner banks geometry that provides tidal vorticity gradients. The residual vortexes are at the origin of the shape and the NS orientation of the sandwaves.

Over a long term period, residual rotary current show that the presence of Ecrehou shoal and archipelago create a residual vorticity that alters the characteristics of the residual sand transport and fashions sandwaves of NS orientation.

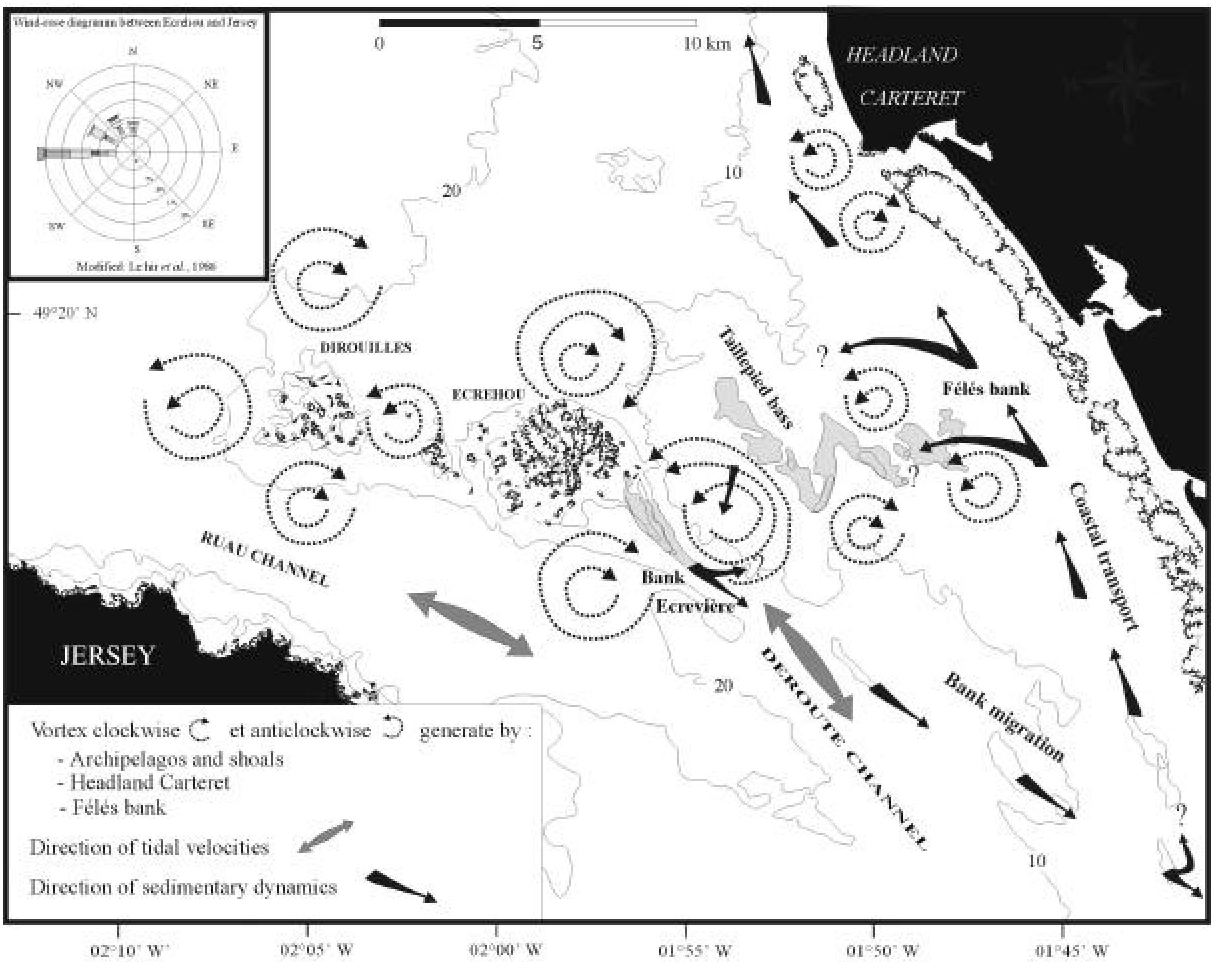


Fig. 4. Synthesis of instantaneous and rotary residual current, direction of tidal velocities and sedimentary dynamics identified from field observation between Jersey and Cotentin.

4. Conclusion

The sandwave forms and positions are in equilibrium with the overall short and long term hydrodynamic conditions. Instantaneous and a residual current pattern, identified from field observations carried out during the investigation, are summarised on Figure 4. The changes in the sandwaves morphology, in response to cyclic tidal conditions at short and long terms, can be summarized as follow:

1) the asymmetric pattern of these bedforms, with a steep-side facing toward the ridge crest, shows that on the sandwaves, the sediment transport is oriented NW/SE and is controlled by the dominant flood tidal currents in this area.

2) comparison of the 1949 and recent bathymetric maps displays changes in the sandwaves location and their shape, during the last 50 years. Long term evolution of the sedimentary dynamics is controlled by residual tidal current vorticity that build and fashion NS oriented sandwaves,

3) a model of numerical tidal vorticity shows that bathymetric effects plays a key role in the dynamics of subtidal sandwaves evolution.

Thus, the comprehension of hydrodynamic mechanisms around shoals and islands requires a fine-scale modelling of the bathymetry.

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