Morphological and internal variability of sand banks on a macro tidal dispersive shelf

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ABSTRACT: We investigated the morphological and architectural variability of four sandbanks, from the same area, at intermediate depths (from 50 to 120m) along the continental shelf of Western Brittany (France) in the Iroise Sea, a dispersive shelf exposed to large storms. In order to identify the parameters controlling the variability of sandbanks morphologies and architectures, we analyzed geophysical data (seismic, reflectivity and bathymetry) from several oceanographic cruises. Preliminary results reveal internal architectures composed of 4 to 5 seismic units for each bank. They are interpreted as controlled by the stepwise flooding of the Armorican basement shelf during the last transgression. This igneous basement that outcrops on the seafloor up to 100m deep has constrained local tidal circulation and swell exposure during the progressive flooding of the shelf, which explains the very contrasting morphologies and internal architectures of these coeval banks on the Iroise Sea shelf.

INTRODUCTION

Sandbanks are the main sedimentary bedforms on the median continental platforms. Understanding their formation, their evolution and their role as shelf sedimentary pathway is crucial for many applications such as the control and the exploitation of marine resources or the protection of marine species (Trentesaux 1993; Bajjouk et al. 2015). Numerous studies performed on these structures have brought a solid knowledge base on the sedimentary processes at play in their genesis and morphodynamics (Berné et al. 1989; Berne 1999; Trentesaux 1993; Mhammdi 1994; Lericolais 1997; Marsset et al. 1999; Le Bot 2001; Bastos, Collins, and Kenyon 2003; Ferret 2011; Vecchi et al. 2013; Franzetti 2014; Traoré et al. 2021). But most of these studies were conducted in areas either deeper or shallower than the intermediate depth area due to the difficulty to collect accurate morphodynamic data at this 50 to 120m depth range. The objective here is to highlight the parameters controlling the morphological and internal variations between four banks located on a dispersive shelf with a low sediment rate subject to large storms. To this end, we analysed geophysical data (seismic, reflectivity and bathymetry) from several oceanographic cruises (Geobrest, Sisplateau, SpeedDunes, Bankable and Sabaseti). This study also presents the first detailed description of the Pierres Noires Bank since it was identified (Hinschberger and Pauvret 1968).

1 STUDY ZONE

The Iroise Sea shelf (fFig. 1) is located in the Western Brittany (France). This highly dispersive platform is delimited by the Pointe du Raz and the Raz de Sein at the South, the Molene archipelago at the North and the Rade de Brest at the East. The tide is semi-diurnal with tidal range variation from 3 to 6 meters (macrotidal) between flood and ebb (Mariette et al. 1982). The hydrodynamic conditions are directly impacted by the English Channel's discharge (Kenyon and Stride 1970) due to the position of the shelf at the confluence of the Atlantic Ocean and English Channel. The Iroise Sea is also particularly exposed to large storms. The shelf presents a very limited sediment cover mainly composed of biogenic sediments. Between -50 and -120m, the shelf hosts 4 large sandbanks considered as banner banks (10 to 50 sq. km, *Four* Bank, *Armen* Bank, *Pierres Noires* Bank, *Haut Fond de Ouessant* Bank), all having their base at the same depth around 90 meters, and showing very contrasted morphologies.

The *Four* Bank is located between the coast and the Ouessant Island, in the north part of the shelf, with a size of 12 by 10 km for 45 meters high. This is the most studied of the four banks, with more than 10 years of bathymetric monitoring. The *Haut Fond de Ouessant* Bank is located at the south of the Ouessant Island and at the south-western end of the Fromveur channel. This bank has a size of 5 by 2 km and is more than 45 meters high.

The *Pierres Noires* Bank, located at the south of the *Haut Fond de Ouessant* Bank

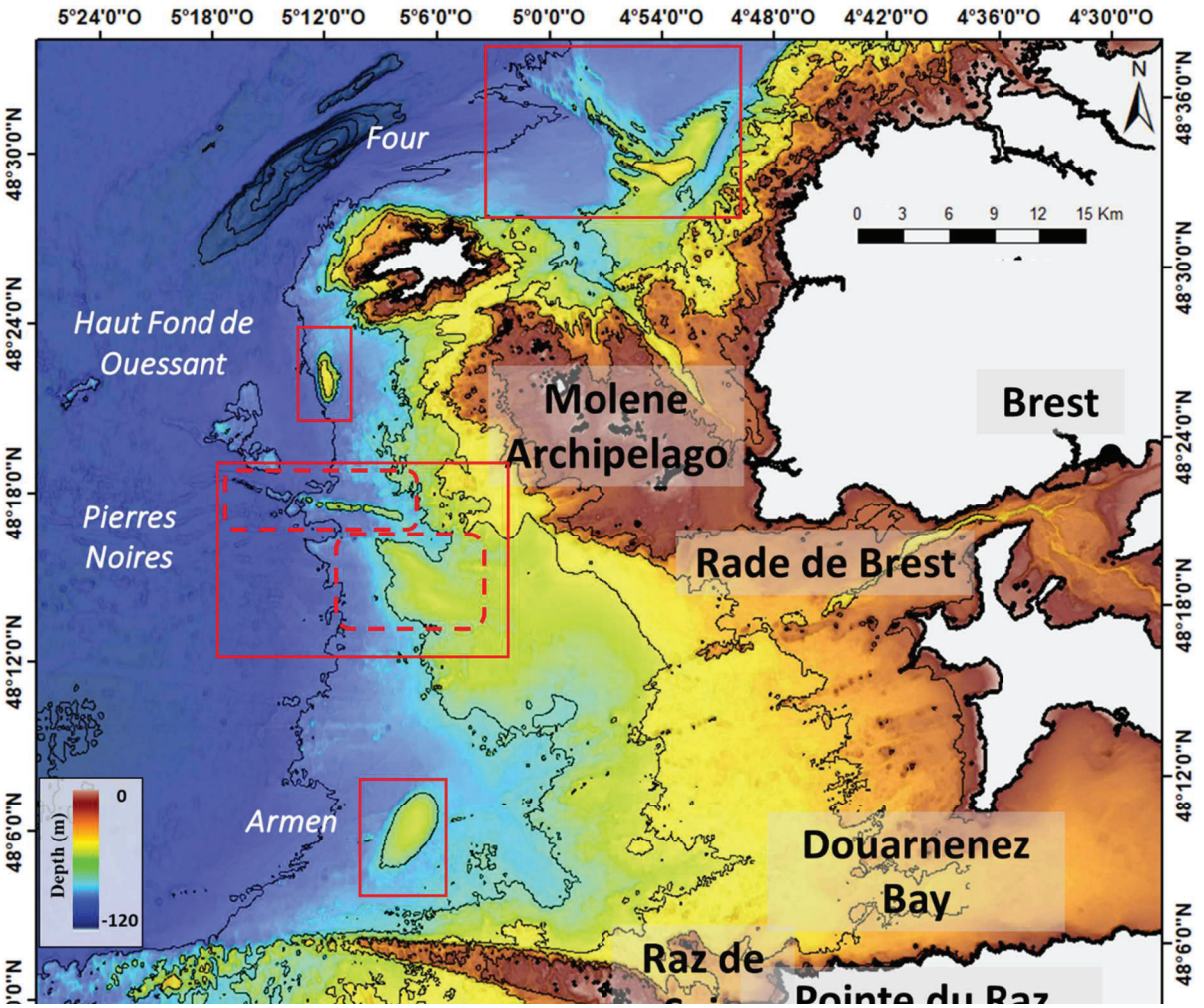

Figure 1: Localisation of the Banks (red squares) on the Iroise Sea shelf, showing the bathymetry, (insert: localisation of the Iroise Sea).

and at the South west of the Molene archipelago is a composite system comprising two contrasted parts. The first one to the north exhibits a quite spectacular elongated shape (13 by less than 1 kilometer). The second component was discovered recently and is reported for the first time in this study. It is larger than the first one and reveals a diffuse, non-ellipsoidal morphology (6 by 6 km, elevation 30m), with edges that are not so well-marked, especially on the eastern side that lies over a slightly steeper seafloor area.

Table 1: Marine seismic acquisitions

Missions	Years	Materials
GEOBREST	2011	Sparker monotrace
GEOBREST	2012	Sparker monotrace
GEOBREST	2013	Sparker monotrace
GEOBREST	2014	Sparker monotrace
GEOBREST	2019	Sparker monotrace
SISPLATEAU	2015	Sparker monotrace
SPEEDUNE	2015	Sparker multitrace HR
BANKABLE	2019	Sparker monotrace / multitrace HR
SABASETI	2023	Sparker monotrace

Armen Bank, located at the north of the Raz de Sein and the south of the Banc des *Pierres Noires* measures 8 km long for 5 km large and 20 m high.

3 MATERIALS AND METHODS

The dataset used for this study consists of a large panel of seismic lines acquired during research cruises (Table 1).

The dataset was corrected manually for tide, wave, and offset depending of the parameters of acquisition. The lines were interpreted on IHS Kingdom Suite software.

4 RESULTS AND DISCUSSIONS

4.1 Bathymetric observations

The bathymetric dataset analysis shows significative variations of basement morphologies over the intermediate depth range (50 to 120 m) where the banks are located. Four domains are distinguished. For water depths larger than 110m, the shelf is relatively flat with a slope gradient below 0.1%. From 90 to 110m depth, the slope gradient rises up to 2% and delineates a morphological step corresponding to the edge of the Cenozoic and Mesozoic basement cover. The four Banks are located on the inflexion point at the top of this domain. The step, from 60 or 70 to 90 meters is a domain with rough seafloor where no sediment seems to be accumulated. It is bounded to the top by another flat domain at about 60m (slope gradient << 1%) where large bedforms are absent. The four banks are surrounded by rocky reefs, and have been anchored essentially along this internal shelf break.

The morphology of the platform suggests the existence of a paleo embayment at about -90 m below present sea-level. It could have featured an initial stage where the four banks (*Armen, Ouessant and Pierres Noires*) may have been connected into a large coastal sand system. A residual continuous sandy belt is still identified at this depth range. Fluvial incisions connected to the inner shelf and terminating at the base of the banks are also identified, and could have contributed to sediment preservation during the nucleation phase of the banks.

4.2 Seismic observations

Seismic lines recorded along the banks reveal an internal architecture composed of 5 seismic units identified for each bank. The first unit is described with a strong amplitude seismic response, a thickness around 8m and a polarity toward the coast. The tops of these basal units of the four banks are at the same depths, about 85 meters.

The second units also have a comparable size between the banks, with the same erosive top discontinuity at a depth around 75 meters.

The top of units 3 and 4 are less visible than for units 1 and 2. Unit 5 highlights a currently active dune system on the banks.

4.3 First interpretations

The evolution of the bank is analyzed using the changes in polarity of the seismic units over time. The aggradation of Armen bank is associated with progradation from SouthWest to NorthEast. The basal unit of Haut Fond de Ouessant unit is located at the South West of the Bank, and the overall polarity of the Bank is in West SouthWest direction. The elongated shape of Pierres Noires Bank is first oriented in eastern direction for the basal unit, then in South western direction for unit 2, whereas the other units are oriented in South direction.

The basal units 1 and 2 are interpreted as residual estuarine or fluviatile deposits, maybe paleoshoals, and we suggest a non-bioclastic sediments composition, as the bank du Four (Franzetti 2014).

All these morphological variations seem to be controlled by two major factors: the shelf morphology and the flooding of the continental shelf, which are closely linked and are thought to have led to major local hydrodynamic variations on the Iroise shelf. Today, the tidal gyres that are present over the Haut Fond de Ouessant and Armen Banks explain the current morphodynamics on these banks. Pierres Noires Bank, at the confluence of the two gyres, also seems to be also controlled by these tidal gyres. They provide both sediment supply and oblique directions of the hydrodynamic currents, the later favoring the steep and elongated morphology of the bank, comparable to morphology of a linear dune.

5 CONCLUSIONS

Two main factors affect the formation of the banks and explain the visible and synchronous morphological and internal variations in the banks: the basement morphology and the flooding of the platform. These factors are linked and have given rise to changes from a local to a regional scale the shelf hydrodynamics.

-Sand Banks are localised at the same depth around 95 meters. This depth corresponds to a morphological step in the basement, which is thought to have stopped the progradation of the banks toward the coast in their early stages. The analysis of the bathymetry suggests the existence of a paleo embayment where the banks South of Ouessant were connected. Fluvial incisions on the inner shelf could be also a control factor.

-The flooding of the shelf affected the banks directly through the modification of regional hydrodynamic conditions, both in tidal currents and in the impact of storms. Local changes in hydrodynamic conditions most likely also occurred as indirect effects of the flooding of the shelf, in relation to the flooding of rocky reefs and inner shelf incisions.

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