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Article

Relict geomorphological and structural control on the coastal sediment partitioning, North of Bay of Biscay

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With 3 figures and 1 table

Abstract: From the Glénan Island to Guérande plateau in south Brittany (France, Bay of Biscay), based on 10000 km of seismic lines, submerged rocky barriers/inherited structural elements were interpreted as the primary controls on variance of coastal topography and incision of palaeovalleys. Sediment infilling is regulated by valley morphology and fluctuation of energy conditions since the last marine transgression associated with the opening of the sea which in turn is a function of climate warming and sea level rising. Dynamics of sedimentation and their subsequent preservation are governed by the shape of the valley and exposure to coastal weather action. Given these structural, geomorphic and climatic constraints, the shoreward transport of sandy sediments is impeded. Thus, coastal topography and structural inheritance are critical factors determining volume of sediments transferred between seaward and landward regions.

Keywords: Coastal sediment partitioning, Coastal topography, Structural inheritance, Climate, Bay of Biscay

1. Introduction

Globally, geomorphologic inheritance and Quaternary variations of sea level strongly influenced evolution and distribution of ancient and present-day coastal systems. Marine transgression often encroach palaeovalleys incised during previous sea level falls. Over the last twenty years, several studies (Dalrymple et al. 1992, Zaitlin et al. 1994, Tesson et al. 2011, Green et al. 2013) have documented the stratigraphy and infilling of incised valleys in different parts of the world. More recent works on the Atlantic Seaboard have helped to envisage a model for the filling of the "fossil" valleys extending onto the continental shelf (Proust et al. 2001). A network of palaeovalleys located along the continental shelf of south Brittany were highlighted by examining approximately 18000 km of seismic profiles and 158 cores (Menier et al. 2014). Appearing at ca. –70 m bathymetric depth and at a distance of ca. 70 km from the present day coast, these palaeovalleys were established by incision of the upper substratum deposited during the Hercynian and Tertiary (Fig. 1 and 2).

Morphology of the incised valleys and stratigraphy of their sedimentary filling have been described previously (Proust et al. 2001, Paquet et al. 2010, Menier et al. 2010, Chaumillon et al. 2010, Estournes et al. 2012, Traini et al. 2013). The valleys are oriented at right angles or appear parallel to the south Brittany coast, and range in width from 200 m to 4000 m (Fig. 2; Table 1). They display diverse architectures including V-shaped valleys with curved bases, flat-bases and steep sided valleys, and valleys with stepped terraces. Construction of longitudinal profiles revealed the presence of topographic highs and major discontinuities. Most of these relic geomorphic features are associated either with reactivation of major Cadomian and Hercynian faults in the locality, or with lithological contrasts, and/or a combination of both factors (Menier et al. 2010). According to Proust et al.

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(2001), the infilling of incised valleys in southern Brittany comprises of two sedimentary sequences. A basal sequence corresponding to braided-river sediments deposited during Saalian and/or Elsterian or even older sea level lowstands (Estournes et al. 2012, Traini et al. 2013); capped by a second depositional sequence related to meandering estuarine environments of unknown age, evolving later into Holocene open marine facies in the offshore.

This work focuses on the dispersion of post-glacial sediments from the offshore zone to present-day coast of south Brittany. It is based on an approach combining seismic and morpho-bathymetric surveys conducted between the Pointe de Penmarc'h and Loire's Estuary.

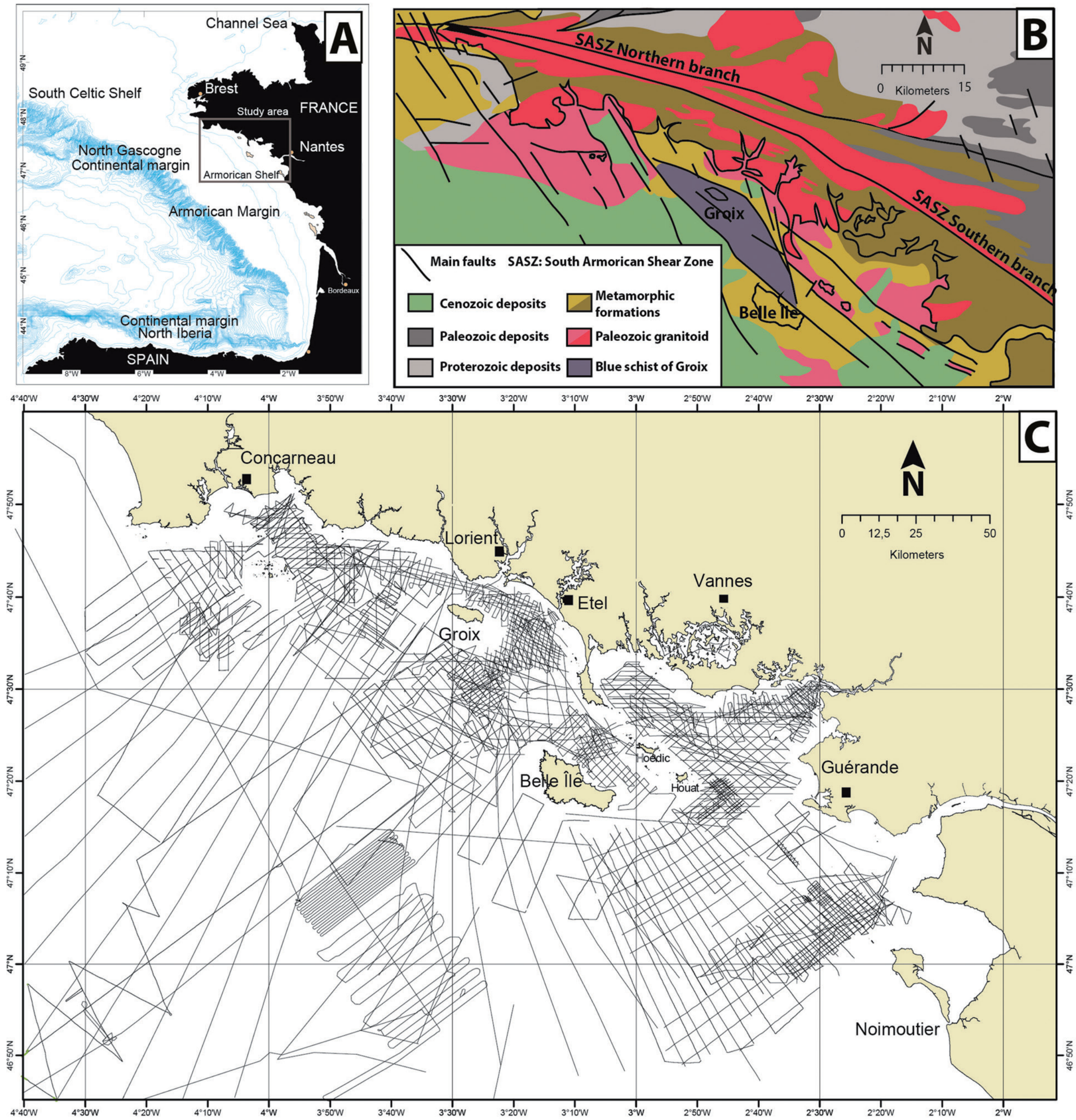


Fig. 1. A) Location map, B) Geological map (modified from Menier et al. 2006) and C) synthesis of seismic profiles acquired during last 40 years; About 18000 km of seismic lines were acquired by the French Marine Research Institute (Ifremer), the French Geological Survey (BRGM) and French Universities since 1967 (modified from Menier et al. 2014).

Specifically, the objective of this research is to elucidate the intrinsic influence of basement morphology on successive infilling stages and sediment redistribution under effects of hydrodynamics and changes in relative sea level. Given cognizance are also modern climate warming and resultant attenuated sea level rise in the context of coastal zone management.

2. Geological setting

The south Armorican shelf (NW–SE) is a morphological segment of the northern Bay of Biscay. This is located along the margin of the Armorican Massif, an old block of the Variscan Orogen, composed mainly of crystalline rocks (granites, gneisses, and mica schists). Cadomian/Hercynian faults of this domain were reactivated several times since the rifting during the Cretaceous, in response to the Pyrenean and Alpine collision (Bourillet et al. 2006). In the studied area (Fig. 1, 2), preexistent Mesozoic sequences were eroded duting the uplift of the rift shoulder, and the deposits resting on the crystalline basement are mostly Paleogene clastic limestones deposited in areas seaward of the present-day coast. The morphology of the coast is complex, marked principally by a number of rivers flowing parallel to each other (Fig. 1, 2; Table 1). The prominent offshore morphological feature is a series of islands and basement shoals oriented parallel to the regional faults trending N120° inherited from the VariscanOrogeny. In addition, there is a series of horsts amidst 40–50 m deep waters. This morphology has resulted in the formation of five bays, each about 20 meters deep (Fig. 2), that lie between the coast and the horst.

The faults were reactivated episodically during the Cenozoic, in response to the NW–SE-oriented Alpine compression (Hibsch et al. 1993).These faults were probably active during the former stages of valley evolution, bringing about a general uplift of the area during the Pliocene that favoured valley incision in the hinterland (Bonnet et al. 2000) and sediment delivery to the deep shelf. In this paper, however, the faults are considered only as the cause of the major morphological differences between the valleys, not as active controls on sedimentation in particular during the Pleistocene and Holocene epochs.

The submarine valleys are mostly incised in the bays located between the coast and the basement shoal complex that occur 70 m below sea level (Fig. 2B). The amount of sediment delivery to the bays by modern rivers is small, and is mostly trapped in estuarine and lagoonal basins such as the Morbihan Gulf (Menier et al. 2011). The present day coast is wave-dominated, and locally tide-influenced. To the south of Belle Île, wave heights range from 4 to 6 m (Hs), with a mean period of 6 to 8 s, and emanate from W-NW (Tessier 2006). Tides are semi-diurnal with a mean range of 4–5 meters. Storm waves show a mean height ranging between 1 and 3 meters and approach the coast from the NW during the winter and SW during the summer. As a result of the intense wave action, the Holocene mainland coast northwest of Quiberon consists of wave-dominated beaches that are subjected to strong littoral drift. Thus, the coastal deposits are composed of high-energy lithic sands and gravels, while the muddy facies occurs only in the sheltered bays, estuary and tidal flats (Traini et al. 2013, Menier et al. 2014).

3. Methodology

The seismic dataset presented in this article (Fig. 1) was gathered during numerous missions since the 1990s by the French Marine Research Institute (Ifremer), the French Geological Survey (BRGM) and French Universities since 1967. Data acquisition was conducted using several monotrace high-resolution seismic reflection devices with various seismic sources (sparker array with a power of 750 J, IKB Seistec Boomer and Air Gun) that were positioned by GPS with metre-scale resolution (Menier et al. 2014). Swell amplitude has been filtered from seismic signal on Kogeo Seismic toolkit. Seismic profiles were manually adjusted to the available bathymetric data for Southern Brittany (Dem Shom-Ifremer) to minimize the vertical uncertainty of seismic signal positioning.

Reflectors with a regional extent (Proust et al. 2001, Paquet et al. 2010, Menier et al. 2010, Chaumillon et al. 2010, Estournes et al. 2012, Traini et al. 2013) were georeferenced on each profile by digital seismic picking on Kogeo Seismic Toolkit before time-to-depth conversion. Each picking on every profile was then spatially localized in x, y (geographic coordinates) and in z (in two way travel time in ms) allowing to produce the regional topographic reconstitution of each picked reflector by interpolation, with a resolution of 500 m in latitude and 300 m in longitude. Isopach map of Quaternary unconsolidated sedimentary cover was obtained by subtracting the depth of top (sea floor) and basal surface (Fig. 2). For time-to-depth inversion, seismic wave velocities of 1500 m.s-1 in salted water and of 1800 m.s-1 in water-saturated sediments were utilized following NAFE and Drake (1961). The derivative maps were then interpreted together with regional geology, morphology, oceanographic and sedimentological processes and features.

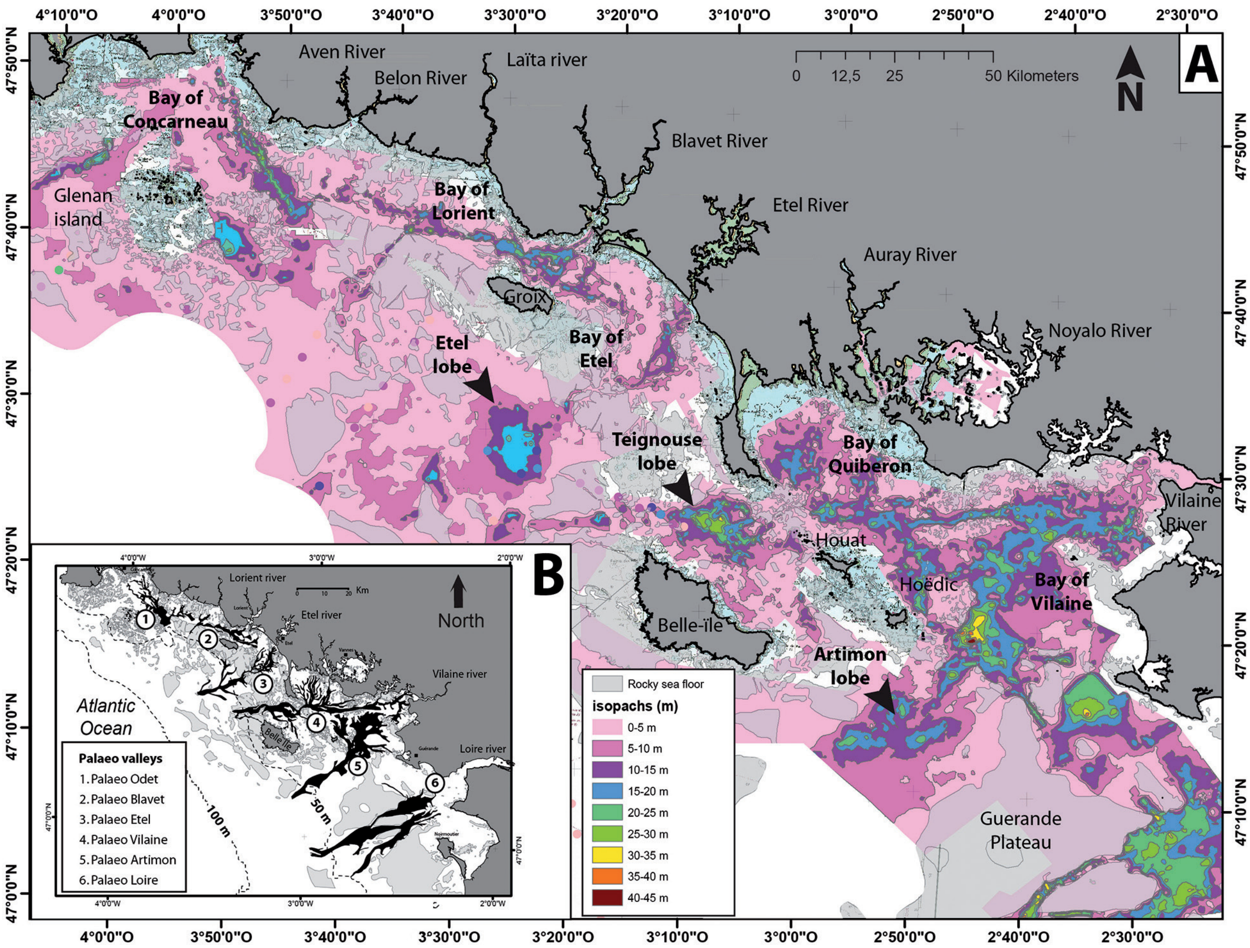


Fig. 2. A) Isopach map based on seismic data using a sediment velocity of 1800 m/ms; and B) Location of incised valleys on the Armorican shelf margin (modified from Menier et al. 2014).

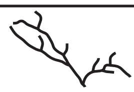
4. Discussion

4.1 Hydrodynamic and geomorphological factors controlling Quaternary deposition

Sea level variations during the last two million years have substantially shaped the valleys and impact processes of erosion, transportation and sedimentation. With the onset of sea level regression, erosion of older sedimentary units by incised valleys and subsequent transportation of material towards offshore regions are prevalent. These effects create equilibrium with the newly introduced base level. In order to accomplish this equilibrium, most of the continental sediments move seaward, toward the new shoreline, permitting the augmented supply of detrital sediments to build coastal depositional systems (sandy barrier islands, lagoons or estuaries). Simultaneously, marine factors such as tidal currents, waves and associated longshore drifts rework one part of marine sedimentary volume approximately between the shoreline and depths up to 30 meters. At the geological scale, this sedimentary equilibrium along the coast is temporally interrupted by sea level change. During the transgressive phase, hydrodynamic agents redistribute coastal sediments, forcing their transfer landward. Consequently, downstream parts of incised valleys record the first stage of marine flooding; superimposed on the pre-existing fluvial sediments.

Isopach map of south Brittany indicate ongoing accumulation of marine deposits within the incised valleys from the foot of the basement shoal until the present day coastline. From the Bay of Concarneau until the Bay of Vilaine, , numerous sandy lobes namely, Etel, Teignouse and Artimon lobes, have been identified; preserved in regions of ca. 30–60 m bathymetric depth (Fig. 2). These lobes occur on a surface area of approximately 525 km^2. The maximum thickness of the Etel lobe is around 15–20 m, and the Teignouse and Artimon lobes are each more than 25 meters in thickness.

Table 1. Synthesis of geomorphic and facies information for the southern Brittany incised valleys (modified from Menier et al. 2014).

	Concarneau Valley	Lorient Valley	Etel Valley	Vilaine Valley	Artimon Valley	Loire Valley
Drainage pattern	 parallel	 parallel	 denditric	 parallel	 denditric	 parallel
Setting	sheltered by basement high	sheltered by basement high	Open shelf	sheltered by basement high	Open shelf	sheltered by basement high
Valley width (min, max, m)	200 to 4000	200 to 2500	300 to 2500	300 to 3000	300 to 7500	1500 to 6000
Valley length (from the present-day coast) (km)	25	27	22	50	30	70
Max entrenchement (m)*	40	35	25	20	20 (supposed)	60
Max. thickness units (m)	32	32	20	30	45	70
Bathymetric limits of palaeovalley (m)	10-55	5-70	5-75	5-25	15-60	5-60

4.2 Coastal topography and rocky barrier

The architecture and sediment-distribution patterns within any incised-valley fills are influenced by external boundary conditions, such as changes in eustatic sea level, climate, sediment supply and their process-form interplays (Woodroffe et al. 1989, Chaumillon et al. 2010, Zhang et al. 2014). In this context, the last marine transgressive phase occurred with a variety of incised valleys, cutting the basement shoal. Following the last marine inundation, this basement shoal or submerged rocky barrier plays a crucial role in controlling ongoing distribution and preservation of sedimentary deposits (Fig. 2; Table 1).

In this geological setting, the transport of sediments landward from offshore is strongly affected by the submerged rocky barrier and the presence of several islands (Fig. 1). These are surrounded by 40–50 m deep waters that act as a bathymetric threshold, and shelter the bays and adjoining coastal regions from marine agents. The last marine inundation occurred through a narrow incision (200 m wide, 30 m deep) within the Etel, Vilaine and Artimon valleys, cutting the basement shoal (Fig. 2; Table 1). As a result, a part of the sediment volume was carried toward the narrow corridor, but significant volume of sediments appeared to have been blocked at the downstream regions. Occurrence of this rocky barrier–island complex and relatively deeper waters surrounding the complex collectively impedes sediment transport between offshore and onshore zones despite favorable energy conditions. It also leads to an imbalance in terms of volume for the building of a successive littoral system.

Coastal topography is a critical factor determining the character of deposits in the present day coastal embayments (Zhang et al., 2014, Gomes et al. 2014). It holds true in the case of south Brittany, as the present day sheltered bays, estuary and tidal flats located behind the basement shoal comprises of muddy facies (Traini et al. 2013). Predominance of muddy facies amidst an otherwise wave and tide influenced high energy region also affirms the prominent role played by relict geomorphic features.

4.3. Hydrodynamics and Sediment Supply

Tidal currents, waves and related longshore drifts are overwhelmed by coastal topography which consequently affects the volume of sedimentation and shoreward–seaward transport of sediments. Tidal and wave influences are considerably impacted by geomorphologic situations where morphology varies rapidly as a result of

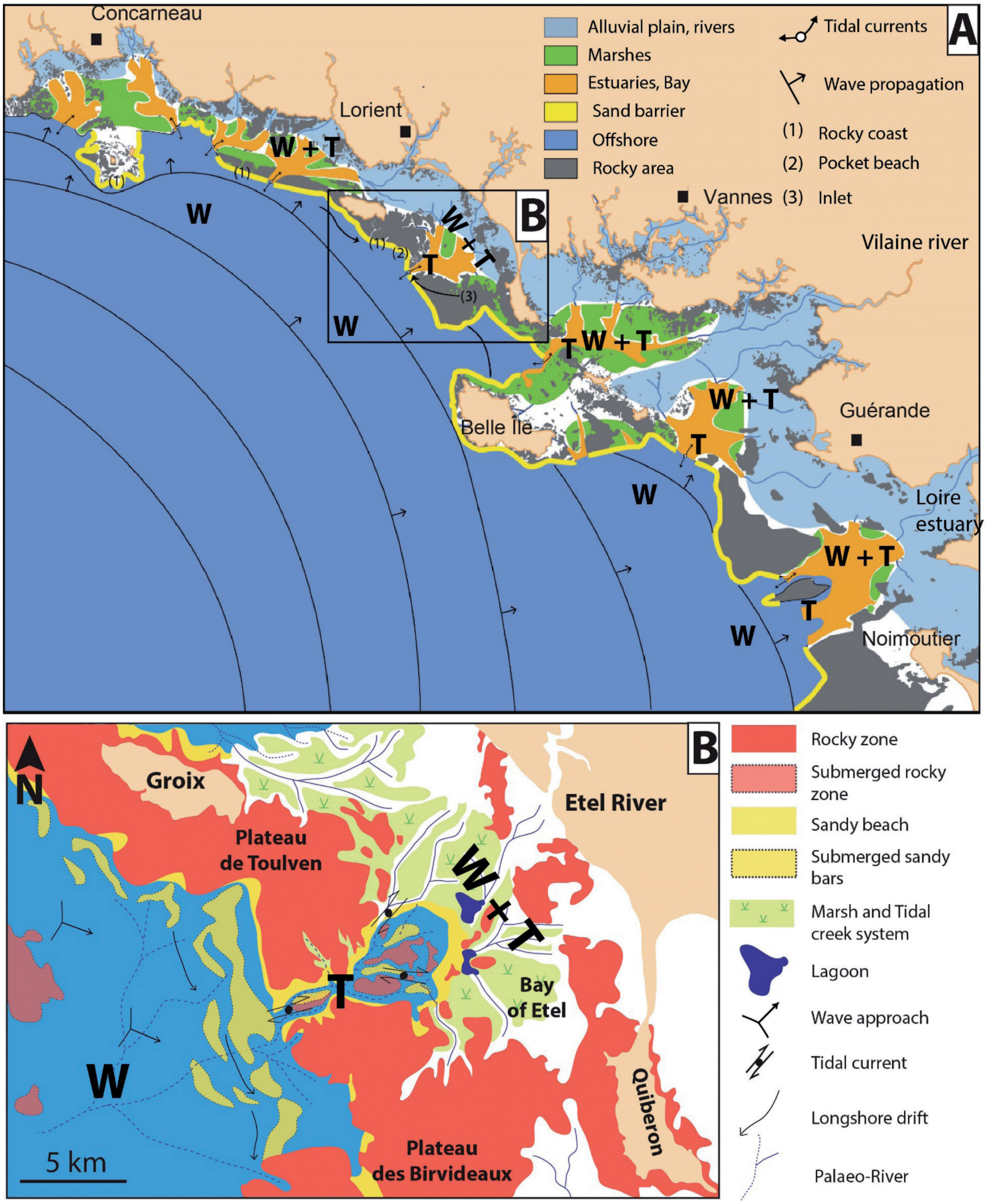


Fig. 3. Schematic diagram illustrating the various subenvironments during the last stage of Holocene transgressive flooding on the southern coast of Brittany. Zones that are under the control of waves (W), Tides (T), waves and tides (W+T) are shown in the Fig.; see the text for discussion.

change in relative sea level, leading to a sudden transformation from wave to tidal dominance as reported from different regions such as the Bay of Fundy (Canada), and the Channel Sea, eastern China (Shaw et al. 2010, Tessier 2012, Zhang et al. 2014).

In south Brittany, about 10,000 years ago, when the shoreline was located at the foot of the rocky barrier, the littoral zone was under the influence of wave and wind processes (Menier et al. 2010). For most parts, the coast was probably wave-dominated. When sea level approached the upstream of the basement shoal, a new hydrodynamic regime that was both tidal and wave dominated formed between submerged downstream parts and upstream parts of the valley (Menier et al. 2010, Proust et al. 2010, Estournes et al. 2012). Communication between the sea and the bays depended on a deep and narrow "inlet". Strong tidal currents occurred and associated with them were significant unsettling of sediments that explain the present day thin transgressive vertical succession within the incised valley segment (e.g. Etel, Vilaine and Artimon valleys) (Fig. 2; table 1) cutting the central parts of the basement shoal (Menier et al. 2010). The rapid change in terms of hydrodynamics and wave to tide dominance did not facilitate circulation of large volumes of previously deposited sediment stocks (on/offshore). These hydrodynamic conditions were existent and operative within the narrow corridor. A schematic diagram illustrating various sub-environments during the last stage of Holocene transgressive flooding on the southern coast of Brittany is proposed in order to summarize the sedimentary context in this particular case (Fig. 3).

The present day south Brittany coast is dominated by pocket beaches and rocky coast (Pian et al. 2011, Pian et al. 2014, Dubois et al. 2014) as a consequence of obstruction of marine transgressive sand flux by the Hercynian shoal.

5. Conclusion

Dynamics of sedimentation and their subsequent preservation are governed by the shape of the valley and exposure to coastal weather action. The coastal topography and structural inheritance are critical factors determining volume of sediments transferred between seaward and landward regions in the dispersion of post-glacial sediments from the offshore zone to present-day coast of south Brittany.

The present day littoral system in south Brittany is severely sediment-starved; appear immensely vulnerable and extremely sensitive in relation to climate change and increasing frequency of storm surges.

Given cognizance are also modern climate warming and resultant attenuated sea level rise in the context of coastal zone management

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Conflict of interest. Authors declare that they are no conflict of interest.

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