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Distinguishing natural evolution and human impact on estuarine morpho-sedimentary development: A case study from the Vilaine Estuary, France

C. Traini [a], J.-N. Proust [b], D. Menier [a, c, *], M.J. Mathew [c]

[a] UMR CNRS 6538, Géosciences Marine & Géomorphologie littorale, Université de Bretagne Sud, rue Yves Mainguy, 56017 Vannes cedex, France
[b] Géosciences (UMR 6118), CNRS and Université de Rennes 1, 35042 Rennes, France
[c] Universiti Teknologi PETRONAS Tronoh, Perak, Malaysia

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ABSTRACT

Estuaries are coastal areas controlled by hydrodynamic factors such as sea-level changes, waves and tidal currents, and river discharge. This study focuses on the Vilaine Estuary which is strongly impacted by human activity after construction of Arzal dam in 1970. The purpose of this research is to differentiate the role of natural from anthropogenic factors on sediment dynamics within the Vilaine Estuary. We are proposing a hypothetical model based on the hydrodynamic modification and morpho-sedimentary development by analyzing the natural estuarine evolution and the impact of human alteration to the natural system by utilizing datasets including river discharge, tidal currents, winds and wave activities to further combine with photographic, bathymetric, topographic and sedimentary surveys. Results show that waves carry sediment from the sea and rework local sediments. The river damming is reducing the tidal prims and leads to the fall of tidal currents. This new situation supports the sediment deposition and reduces at the same time the accommodation space which decrease tidal currents in feed-back. The Vilaine Estuary is therefore coming close to a bay-type functioning which leads to a channel narrowing, a drastic increase of the tidal flat zone, an acceleration of erosional processes affecting the main channel, salt marsh and all associated depositional systems. We propose a hypothetical model showing that this evolution took place in two steps and we show that the dam has an effect to accelerate a natural infilling of the estuary.

1. Introduction

Estuaries are remnants of ancient fluvial valleys that have succumbed to flooding due to eustatic variations. Estuarine environments are of profound interest to human population due to their intense biological (habitat, reproduction, nursery, migration path) and economical relevance (fishing, fish trade, tourism, harbour). Anthropological impacts strongly modify the natural (pre-human) balance of the environment in various ways (e.g. modification of river flow, degradation of the habitat, depletion of aquatic resources, pollution, etc.). Since 1960s, there has been a significant increase in research pertaining to estuaries (Guilcher, 1958; Cameron and Pritchard, 1963; Bowden, 1967; Caspert, 1967; Pritchard, 1967; Fairbridge, 1980; Pethick, 1984; Day et al., 1989; Bird, 1993; Geyer et al., 2000; Woodruff et al., 2001; Guo and Levinson, 2007) with quite a few estuaries being thoroughly explored and utilized as references to elucidate hydrodynamics (Bilgili et al., 2005; Ji et al., 2007; Levasseur et al., 2007), sedimentology (Dalrymple et al., 1992; Allen and Posamentier, 1993, 1994; Martinsen and Hellandhansen, 1994; Estournès et al., 2012) and ecological balance (Caspert, 1967; Azevedo et al., 2008). However, integrated studies taking into account the role of human activities within these environments are scarce (Ferrier and Anderson, 1997; Winterwerp et al., 2001; Tagliani et al., 2003). This form of studies are often difficult to generalize (Hart and Long, 1990; Wolanski et al., 2001; Kim et al., 2006) as observed in the main natural estuary classifications, which never take into account the influence of human developments on sediment budget (Bowden, 1967; Fairbridge, 1980; Dalrymple et al., 1992).

* Corresponding author. Universiti Teknologi PETRONAS Tronoh, Perak, Malaysia.
E-mail addresses: camille.traini@yahoo.com, ct@gpi.uni-kiel.de (C. Traini), jean-noel.proust@univ-rennes1.fr (J.-N. Proust), dmenier5@gmail.com, david.menier@univ-ubs.fr, david.menier@petronas.com.my (D. Menier), manoj_mathew7@yahoo.com (M.J. Mathew).

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The Vilaine Estuary (Fig. 1), located on the French Atlantic coast, is a good example of a Holocene natural evolution strongly impacted by the human activity after construction of Arzal dam in 1970. The dam is situated at a distance of 8 km from the river mouth. The dam is responsible for estuarine infilling and major changes to the surrounding environment.

The aim of this study is to propose a hypothetical model based on the hydrodynamic modification and morpho-sedimentary development by analysing the natural estuarine evolution and the impact of human alteration to the natural system after 1970. To achieve this, we collected data on river discharge, tidal currents, and wind and wave activities to further combine with photographic, bathymetric, topographic and sedimentary surveys. The comparison of these data with annual resolution will enable a precise understanding of relationships linking each hydrodynamic parameter to each other and their effects on sedimentary processes during the last 50 years in the estuary.

2. Geographical setting

The Vilaine Estuary is located in a particularly well and unique sheltered position along the French Atlantic coast (Fig. 1). The estuary opens on the southern coast of Brittany at the back of Vilaine Bay. The bay is protected behind a belt of highs (trending N130°) consisting in the Quiberon peninsula, the Island Houat and Hoëdic, and the "Plateau du Four" rise, closed to the South by the headland of the Croisic (Fig. 1). The Vilaine Estuary drains a catchment of 10.530 km^2 and collects 800 mm/yr rainfall (typical of a temperate oceanic climate regime). Its infilling is less than 10,000 years old (Traini et al., 2013) and developed at the same time as most estuaries around the world (Pritchard, 1967; Russell, 1967; Boyd et al., 1992) when the last marine transgression slowed down ca. 6.000 years ago. Seawater flooded first the downstream part of the valley, which was rapidly filled up before the stabilization of the dynamic balance between river and marine inputs (Proust et al., 2001; Menier et al., 2010; Sorrel et al., 2010; Traini et al., 2013; Menier et al., 2014). Prior to the construction of the Arzal dam, tidal influence extended to a distance of 80 km onshore (Morzadec-Kerfourn, 1974).

This structural pattern of the Vilaine Estuary shows numerous areas of weakness promoting incision of depressions filled up by Quaternary sediments. The present day shape of the estuary correlates with three geomorphological parts tightly related to the geological heritage (Fig. 1).

- The inner part, 500 m wide, between the dam of Arzal and the haven of Tréhiguier, is incised into the prehercynian micaschists and orthogneisses through the Cadomian and Hercynian fault network;
- the central part, 2000 m wide, between the haven of Tréhiguier and the headlands of Penn-Lann (north) and Halguen (south),

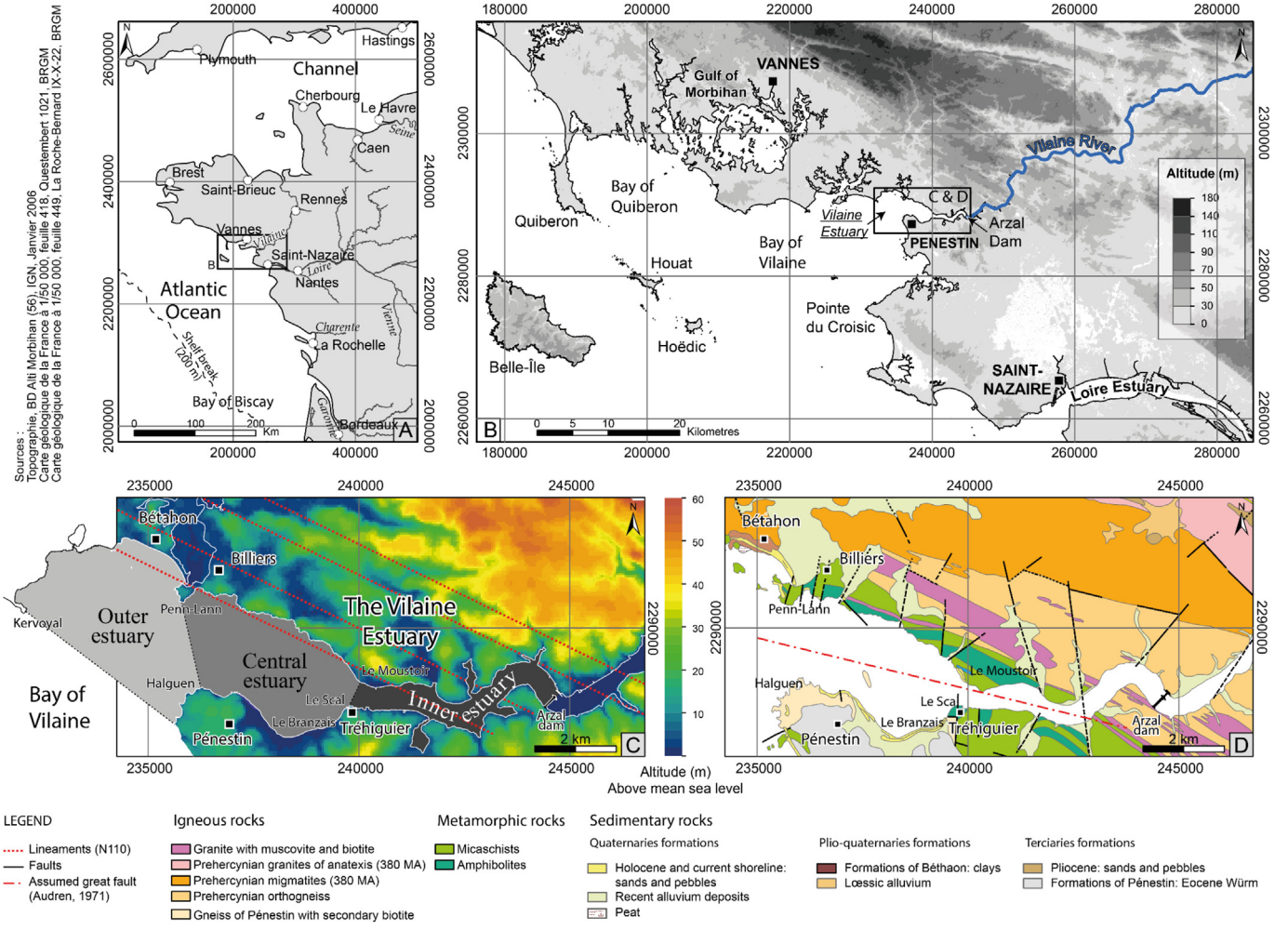

Fig. 1. Location map of the Vilaine Estuary. The figure shows the Vilaine Estuary location and its regional (A and B), geomorphological (C) and geological (D) contexts.