Variation of Quaternary Stratigraphic Pattern along an Incised Valley-fill Revealed by Very High Resolution Seismic Profiling: The Paleo-Charente River (French Atlantic Coast)

By
Nicolas Weber[1], Eric Chaumillon[2], and Michel Tesson[3]
Search and Discover y Article #30021 (2004)

[1]EPSHOM, Cellule Sédimentologie, Brest, France
[2]Université de La Rochelle, La Rochelle, France
[3]Université de Perpignan, Perpignan, France

Introduction

The aim of this contribution is to show the longitudinal evolution of a mixed-tide- and wave-dominated incised valley-fill (Charente incised valley), based on very high resolution (VHR) seismic profiling. The very dense seismic grid (total seismic profile length: 2060 km / study area: 1600 km^2) allows us to depict the detailed three-dimensional internal organization of the valley-fill. Geometric pattern and seismic-facies analysis are used to reconstruct the main depositional phases and to correlate them to the last Holocene sea-level rise.

General Setting

The study area is located in the inner part of the Bay of Biscay along the French Atlantic coast. The present-day Charente River flows into the “Marennes - Oléron Bay,” and the “Pertuis d’Antioche” between Ré and Oléron islands (Figure 1). The area is characterized by rocky peninsula and marsh, which extend 40 km landward. Morphology of the “Pertuis d’Antioche” is characterized by a relatively deep (-40 m) trough, the “Antioche trough,” isolated from the shelf by a crescent-like shoal (-20 m), the “inter-island shoal.” This feature has been interpreted as a remnant of the drowned Charente paleo-valley. The Charente River drains a basin of approximately 10,000 km^2. The mean annual water discharge is $3.1x10^9$ m^3 (Tesson, 1973). In the estuary mouth, tidal range is between 2 m and 6 m. Another essential hydrodynamic feature of this environment is its exposure to the west-northwest large-amplitude and long-period swells.

Methods

For our studies, we have used two kinds of seismic-acquisition packages: (1) an explosive Sparker source (50 J) with a mono-channel streamer for the main regional survey; (2) the “IKB SEISTEC” with Boomer source which is incorporated into a three-meter long catamaran for shallow targets (Simpkin and Davis, 1993). Bathymetric data were extracted from the database of French Hydrographic Office (SHOM). From these data, digital elevation models were developed. A vibracore cruise was conducted to collect core samples where the main seismic units are supposed to crop out.

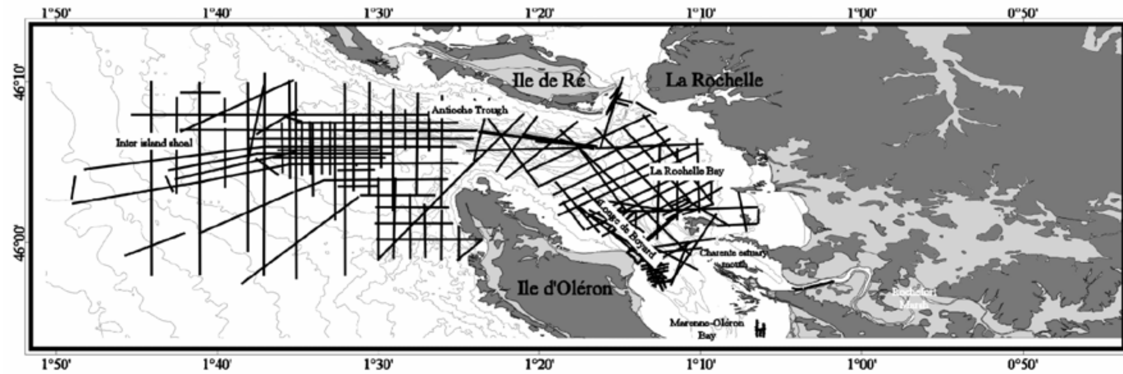

Figure 1. Simplified bathymetric map (SHOM data) showing the general location of the study area. Seismic profiles are indicated by line segments.

Incision Morphology

Reflectors of basal unit U0 crops out close to the shore and consist of folded and faulted Mesozoic strata (Chaumillon et al., 2002; Weber et al., 2002). U0 upper boundary, R1, is a regional erosional surface that also forms the base of the different channels. Moreover, R1 is interpreted as a typical sequence boundary, SB1, that formed during the last sea-level lowstand (Würm III) and probably was a reactivation of previous Quaternary lowstands. Both the meandering pattern of incised channels and their connection with the Antioche Trough revealed by seismic data allows us to propose a fluvial origin for this present-day submarine feature as well as for newly identified incisions located below the inter-island shoal and La Rochelle Bay infill. These wide and deep incisions correspond to a typically large valley type described on the U.S. Atlantic margin (Ashley and Sheridan, 1994).

The Charente paleo-valley exhibits a seaward distributary pattern with a main shoreward channel, which bifurcate in many valleys. We propose that this incision pattern is under lithological and/or tectonic control (Weber et al., 2002).

Incised valley between Antioche Trough and present-day estuary mouth is characterized by many secondary channels connected with the main Charente incised valley. Moreover, these incisions are identified landward below marshes (Carbonel et al., 1998; Decker et al., 2001). Connection between the “Pertuis d’Antioche” and “Marenne-oléron bay” southward is thought to have been by narrow and deep channels. Northward, a large valley was probably the connection between the “Pertuis d’Antioche” and the northern “Pertuis Breton.”

Despite large differences in catchment and discharge between the Charente and Gironde rivers (located less than 100 km southward), similarities in incised-valley morphologies are known concerning their depth (20 to 25 m) and width (4.5 to 5.5 km). This observation supports the idea that valley dimensions are strongly constrained by their age rather than their hydrodynamic parameters (Schumm and Ethridge, 1994).

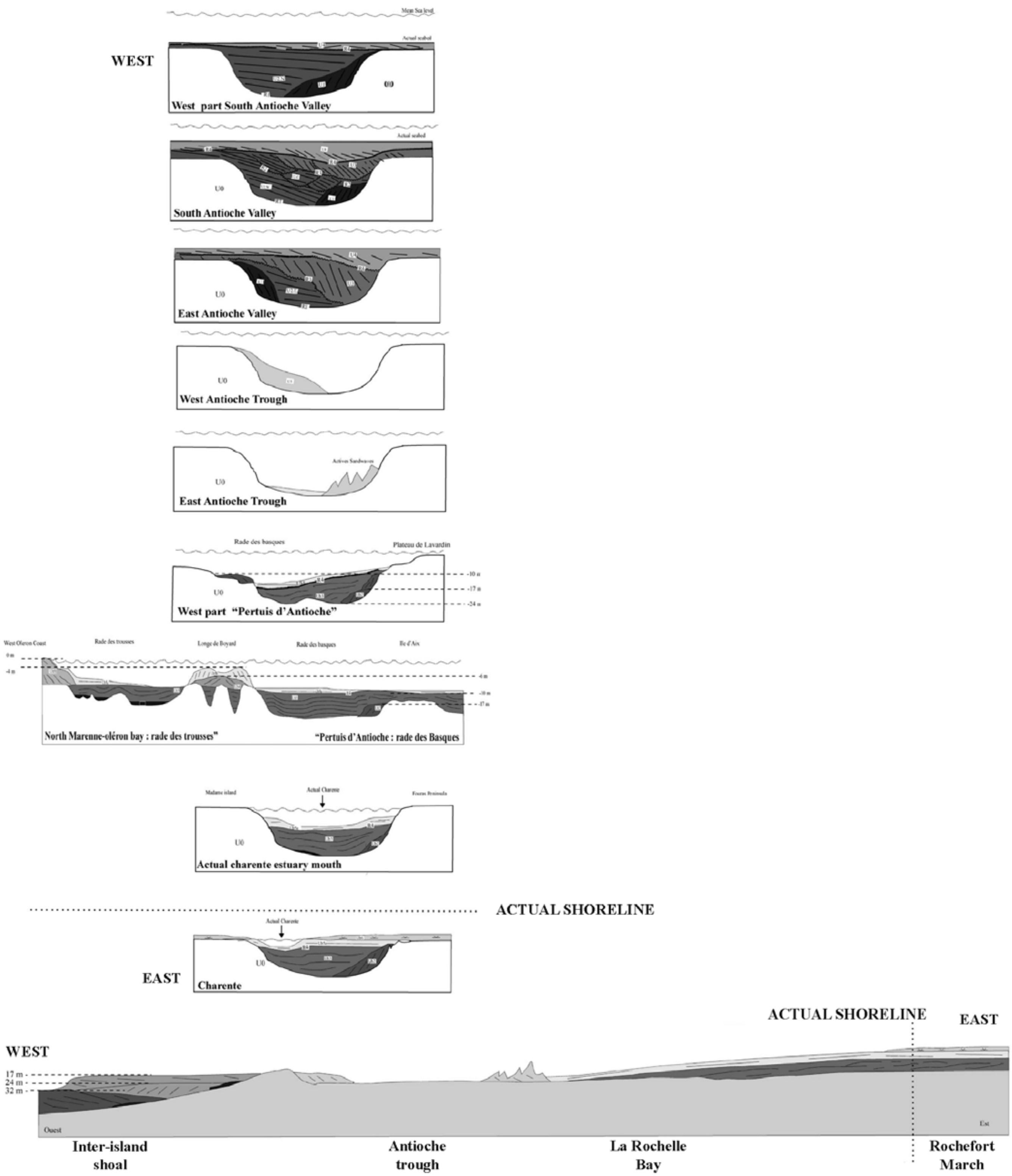

Figure 2. Schematic valley-fill pattern for the Charente incised valley

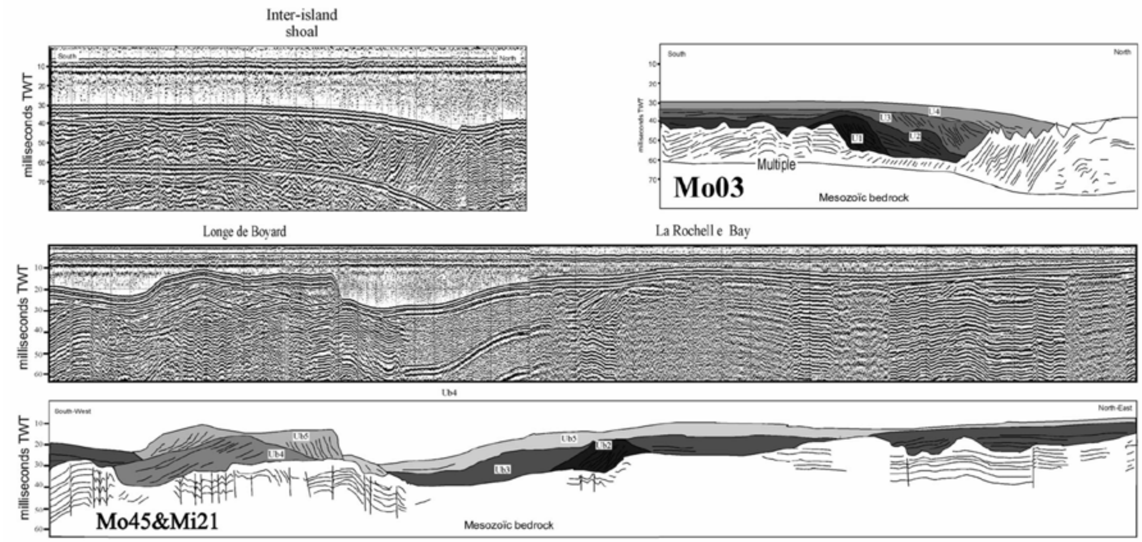

Figure 3. Processed seismic profiles and their interpretation, showing a transverse cross-section of the inter-island shoal (Mo03), and La Rochelle Bay (Mo45&Mi21).

Description of Sedimentary-infill

Inter-island Shoal

From bottom to top four seismic units are recognized. The internal valley-fill always shows the same internal-reflection-pattern evolution: high- to moderate-angle-dipping reflectors at the base (U1) and top (U3 and U4) of sequence with intervening horizontal to low-angle-dipping reflectors (U2) (Weber et al., 2002).

Antioche Trough

The Antioche trough is characterized by a lack of sediment, except along its western wall, where Unit U5 displays a large progradational package. We infer that this stratigraphic pattern records the incipient infill of the Antioche trough.

La Rochelle Bay and Present-day Estuary Mouth

Five main seismic units are recognized:

- Unit Ub1: Discontinuous lenses located along the axis of the thalweg (coarse sand - gravel inferred).
- Unit Ub2: Middle amplitude, oblique subparallel. This unit is localized both on the insides of meander bends and along the valley walls. Vibracores show that it is composed of medium to coarse sand with marine shells. Two superposed seismic subunits bounded by a planar erosional unconformity are identified. The upper subunit is systematically offset outward from the valley axis. Those subunits lie between -24m and -13m. This depth range is similar to the basal marsh infill onland, where radiocarbon dating gives ages of 8380 BP +/- 250 (Decker et al., 2001).
- Unit Ub3: Low-amplitude, low-angle, and seaward-aggrading sigmoid. It constitutes the bulk of the valley-fill. Cores within this unit contain from bottom to top: a (1) alternation of fine sand and fine sand with mud layers; (2) muds with fine-sand layers at the top.

Onland (Rochefort marsh) this unit shows a progradational pattern with decreasing sediment ages seaward (5400 to 3870 BP, Decker et al., 2001).
- Unit Ub3: Upper unconformity appears as a flat erosional truncation on seismic profiles and coincides with a typically condensed shell bed (with oyster or various marine broken shells).
- Unit Ub4: Middle amplitude, oblique parallel and composed of medium to coarse sand. It is located in the western part of the La Rochelle bay (Longe de Boyard) and along eastern coast of Oleron Island,
- Unit Ub5: This unit constitutes recent (last two centuries) and present-day deposits observed from comparison of successive bathymetric charts (1824, 1882, 1960 and 2000). Two subunits are identified:
  - (1) (Ub5a)—low-frequency, aggrading reflectors, corresponding to fluvial and biogenic mud with abundant organic matter, which fills active channel.
  - (2) (Ub5b)—high-frequency, strong amplitude and oblique parallel reflectors. It is composed of marine fine sands and is located only in area where swell propagates.

Interpretation of Sedimentary-infill

Depositional Environment

Inter-island shoal

The valley infill (high- to moderate-angle-dipping reflectors (U1, U3, U4) at the base and at the top of sequence with an intervening horizontal to low-angle-dipping-reflector unit (U2)) is comparable to the sedimentary sandwich depicted within large valleys of the U.S. Atlantic continental margin: There are sands and gravels at the base, sands at the top with an intervening mud unit (Ashley and Sheridan, 1994). Basal sands and gravels are interpreted as fluvial deposits, the intervening mud unit would represent inner basin facies, and upper sands would correspond to estuary-mouth and marine sands (Weber et al., 2002).

Antioche trough

Taking into account that the present-day seabed of this area consists of Mesozoic strata, this valley segment has been a non-depositional area during many sea-level cycles. Such interpretation is supported by strong present-day tidal currents (>1 m/s), which could be explained by the entrenched morphology.

The incipient sand fill (Unit U5) of the western part of this trough is interpreted as the result of present-day transport under waves and tidal current action because such processes are present westward within the inter-island shoal.

La Rochelle Bay and present day estuary mouth

Basal infill of both the La Rochelle Bay (U1b, U2b, Ub3) and inter-island shoal (U1, U2) shows a similar upward decrease of reflector dips. This is interpreted as recording a decrease in energy environment. Basal lenses (U1 and Ub1) are interpreted as alluvial sands and gravels. The intervening aggradational unit (U2 and Ub3) is interpreted as tidal, mixed mud and sand deposits.

The upper high-angle units are poorly developed in the La Rochelle Bay and are restricted to coastal progradational areas and estuary-type sand banks ("Longe de Boyard," Chaumillon et al., 2002). In the La Rochelle Bay a general decrease in energy is observed in every area, but now, sedimentary facies and hydrodynamic action are well separated. Fine-sand dominates the area of swells (western Antioche Trough and west part of La Rochelle Bay), with mud in tide-dominated active channel (La Rochelle Bay). Moreover, the present-day Charente shows a straight-meander-straight pattern, typical of a tide-dominated estuary (Dalrymple et al., 1992).

Sequence Stratigraphy Interpretation
Despite the major sedimentary discontinuity represented by the Antioche trough, we note internal seismic-pattern and sedimentary-facies similarities both in the western (inter-island shoal) and eastern (La Rochelle Bay) valley-fill areas. Such a valley-fill pattern leads us to propose an interpretation for the Charente incised-valley in terms of sequence stratigraphy related to sea-level changes.
The channel fills always show small alluvial discontinuous lenses interpreted as a condensed LST.

As in typical incised valleys, we interpret the bulk of the Charente valley-fill as belonging to the TST. We note that it consists of two units:
- An early TST, which mainly corresponds to aggradational mixed sand and mud facies (U2 in the inter-island shoal and Ub3 in La Rochelle Bay).
- A late TST, which is well developed in the inter-island shoal (sand units U3 and U4) and condensed in the La Rochelle Bay (Ub4).

Based on sedimentary-facies similarities, we propose that La Rochelle Bay retrogradational sand banks (Ub2) are similar to the Rochefort marsh basal fill (8380 BP +/- 250; Decker et al., 2001). Thus, they would correspond to the final period of rapid sea-level rise (Lambeck, 1997). U3b seismic package (bulk of La Rochelle Bay valley-fill) also shows similarities with the bulk of the Rochefort marsh (6000 BP); then U3b would correspond to a period of decrease in sea-level rise.
The top of Ub3 unit corresponds to a typical condensed shell bed, which could correspond to the maximum flooding surface (Zaitlin et al., 1994).
Modern to present-day sedimentary evolution is used to define the HST. It corresponds to U5 in the western Antioche trough and Ub5 in La Rochelle Bay. Seaward, the HST is absent because this area experiences submarine erosion.

Conclusion

The use of a very dense, high-resolution seismic grid brings new and crucial constraints concerning the morphology and three-dimensional architecture of the Charente incised-valley.
(1) Alluvial origin for the Antioche trough is confirmed and its seaward and landward extensions are documented for the first time. Incised-valley dimensions support the idea they are constrained by their age rather than present-day hydrodynamic parameters.

(2) Valley-fill is characterized by two disconnected areas, separated by a non-depositional area (Antioche trough), which is explained by entrenched morphology and a subsequent hydrodynamic-forcing increase.
(3) The seaward part of the valley is similar to a typical transgressive valley-fill pattern; the bulk of the valley-fill consists of transgressive estuarine sediments. The TST can be divided in an early and a late TST.
(4) The landward part of the valley-fill consists mainly of the early TST unit.
(5) Comparison between the seaward and the landward parts of the valley shows that differences observed between the two valley-fills can be interpreted as the result of differences in hydrodynamic environments: mixed tide and wave environment in the seaward part of the valley and tide dominated environment in the landward part of the valley.
(6) In both the landward and seaward parts of the valley, reduced LST and HST are observed. This is interpreted as the consequence of small sedimentary input due to the reduced Charente river discharge.

References

Ashley, G.M., and R.E. Sheridan, 1994, Depositional model for valley-fills on a passive continental margin, *in* R.W. Dalrymple, R.J. Boyd, B.A. Zaitlin, eds., Incised valley systems: Origin and sedimentary sequences: SEPM Special Publication. 51, p. 285-301.

Carbonel, P., H. Dartevelle, J. Evin, Y. Gruet, L. Laporte, L. Marambat, J.P. Tastet, C. Vella, and O. Weber, 1998, Evolution paléogéographique de l'estuaire de la Charente au cours de l'Holocène: In: Laporte, L. (Eds.), L'estuaire de la Charente de la Protohistoire au Moyen Age. La Challonnière et Mortantambe (Charente Maritime). 1998, Paris MSH, Daf No.72, p. 15-25.

Chaumillon, E., H. Gillet, N. Weber, and M. Tesson, 2002, Evolution temporelle et architecture interne d'un banc sableux estuarien: La longe de Boyard (Littoral Atlantique, France): Comptes Rendus de l'Acade´mie des Sciences, v. 334, p. 119-126.

Dalrymple, R.W., B.A. Zaitlin, and R. Boyd, 1992, Estuarine facies models: conceptual basis and stratigraphic implications: Journal of Sedimentary Petrology, v. 62, p. 1130-1146.

Decker, L., and L. S. P., 2001, Géométries et dynamique de remblayage de l'incision Holocène dans le marais de Rochefort: Modélisation géologique, Orleans, BRGM.

Lambeck, K., 1997, Sea-level change along the French Atlantic and Channel coast since the time of Last Glacial Maximum: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 129, p. 1-22.

Simpkin, P.G., and Angela Davis, 1993, For Seismic profiling in very shallow water, a novel receiver, *in* Sea Technology, v. 34, no. 9, September 1993.

Schumm, S.A., and F.G. Ethridge, 1994, Origin, evolution and morphology of fluvial valley, *in* R.W. Dalrymple, R.J. Boyd, B.A. Zaitlin, eds., Incised valley systems: Origin and sedimentary sequences: SEPM Special Publication. 51, p. 11-27.

Tesson, M., 1973, Aspects dynamiques de la sédimentation dans la baie de Marennes-Oléron (France): thesis, University Bordeaux I, Bordeaux.

Weber, N., E. Chaumillon, M. Tesson, and T. Garlan, 2002, Architecture and morphology of the outer segment of a mixed tide and wave dominated incised-valley, revealed by pseudo 3D seismic reflection profiling: The paleo-Charente River, France: submitted to Marine Geology.

Zaitlin, B.A., R.W. Dalrymple, and R. Boyd, 1994, The stratigraphic organisation of incised valley systems associated with relative sea-level change, *in* R.W. Dalrymple, R.J. Boyd, B.A. Zaitlin, eds., Incised valley systems: Origin and sedimentary sequences: SEPM Special Publication. 51, p. 45-60.