Formation and evolution of macrotidal chenier ridges

- Experimental and in-situ approaches -

Doctorat de l’Université de Caen
-Terre solide et enveloppes superficielles -

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P. Weill  22nd October 2010
Chenier

Coarse littoral barrier anchored in a prograding mudflat sequence (Otvos & Price, 1979).

Chenier construction implies a balance between:

- Fine-grained sediment supply (fluvial or tidal origin)
- Coarse-grained sediment concentration (marine or continental, wave dynamic)

Cheniers in the Gulf of Carpentaria, Northern Australia

Modified from Hoyt (1969)
2 types of cheniers

- siliclastic cheniers at the outflow of large rivers

- bioclastic cheniers in meso to macrotidal bays and estuaries
  (Greensmith & Tucker 1968, Neal et al. 2002, Vilas et al. 1999, ...)
2 types of cheniers

- siliclastic cheniers at the outflow of large rivers

Archetypal exemple – Louisiana chenier plain

Chenier plain progradation controlled by Mississippi distributaries avulsion

Chenier plain in Louisiana
(source : R.L. Watson, Consulting Geologist, Texas)
• Introduction

2 types of cheniers

- bioclastic cheniers in meso to macrotidal bays and estuaries
  (Greensmith & Tucker 1968, Neal et al. 2002, Vilas et al. 1999, ...)

Several deposition models for chenier plains
  in tidal influenced bays and estuaries
  (climatic changes, sea level fluctuation, storms, ...)

→ No investigation on the role of tides in cheniers construction
Objectives

- Identify the main parameters controlling chenier dynamics in tidal environments
- Dissociate the action of waves and tide
- Identify sedimentary facies of chenier at the scale of the sedimentary body
- Link the hydrodynamic processes to the chenier sedimentary structures

→ Mont-Saint-Michel bay
Field work – Sedimentary architecture

Lab work
Sediment behaviour

Wave flume
experimental model

Cheniers

Integrating time and space scales...
...from grain motion to coastal evolution
Mont-Saint-Michel bay - SPOT satellite image (1994)
• Study site ➔ Localisation

Hirel - Photographie aérienne (Bruno Caline – 1993)

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The Dol Marshes

Last episode of sedimentary infilling (progradation) periodically interrupted from 3 500 y. BP by coarse shelly littoral barriers
Hydrodynamic conditions - Waves

**Shallow and protected embayment ➔ Low wave environment**

- **Fair weather conditions (13/03/2009)**
- **Storm conditions (10/02/2009)**
Hydrodynamic conditions - Tides

Spring tidal range: 14 m

Strong alternating currents in the estuary

Weak rotating currents in the embayment

Level of tidal flooding

Modif. from L'Homer et al. (1999) and Bonnot-Courtois et al. (2002)
Hydrodynamic settings

Hydrodynamic conditions - Tides

Spring tidal range: 14 m

Strong alternating currents in the estuary

Weak rotating currents in the embayment

Level of tidal flooding

(data: C. Bonnot-Courtois)
Introduction → Hydrodynamic settings

Wave and tide conjunction

Variations in cumulated time of chenier flooding per year

→ 4.4 years tidal cycles
→ 18.6 years tidal cycles

Waves

Multi-annual climatic variations
Field work – Sedimentary architecture
Observation during high spring tide
Trenching and coring
GPR survey

Cheniers

Lab work
Sediment behaviour

Wave flume
experimental model
Ground Penetrating Radar (GPR)

Propagation of high-frequency electro-magnetic waves

GPR antennas - 400, 900 MHz and 2.6 GHz

6.5 km of radar profiles (cross-shore and longshore)

+ Trenching and coring

GPR Equipment: GSSI, distributed by MDS Paris
Localisation of GPR profiles and cores

- **Box 1**: 20 x 55m, 1 core
- **Box 2**: 12 x 44m, 7 cores
- **Box 3**: 20 x 60m, 1 core

Legend:
- 500 m
- N
GPR Profile n° 1 (cross-shore) – 900 MHz

Weill et al. (in press)
GPR Profile n° 1 (cross-shore) – 900 MHz

- Sedimentary Architecture → GPR data and interpretation

Eroded salt marsh deposits

Eroded tidal flat

Erosion surface

Basal unit

Beach lamination (swash built)

Seaward

Tidal flat

Salt marshes deposits

Landward

HST (110)

1m 5m 10m
GPR Profile № 1 (cross-shore) – 900 MHz

- Sedimentary Architecture
- GPR data and interpretation

**Millimetric beach lamination**

**Centimetric beach lamination**

- Erosion surface
- Basal unit
- Beach lamination (swash built)

Tidal flat

Salt marshes deposits

Seaward

Landward

1m

5m

10m

HST (110)
GPR Profile n° 1 (cross-shore) – 900 MHz

Sub-aerial washover sheets (aggradation)

Washover deltas (progradation)

Landward

1m

5m

10m

50 cm

HST (110)
GPR profile n° 2 (cross-shore) – 900 MHz
GPR profile n° 2 (cross-shore) – 900 MHz

- Basal unit
- Beach lamination (swash built)
- Sub-aerial washover sheets (aggradation)
- Washover deltas (progradation)

High-resolution cross-shore profile – 2.6 GHz
GPR profile n° 3 (cross-shore) – 900 MHz
GPR profile n° 3 (cross-shore) – 900 MHz

- Sedimentary Architecture → GPR data and interpretation

- Beach lamination (swash built)
- Erosion surface (fossil beach surface)
- Sub-aerial washover sheets (aggradation)
- Washover deltas (progradation)

- HST (110)
- Seaward
- Landward
- Tidal flat
- Salt marshes deposits

- 1982
- 1990
- 2002
- 2006

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Core analysis

X-ray slices and virtual sections

Porosity log

X-ray density / porosity correlation

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**Constant head permeameter**

\[ k = \frac{Q.L}{A.\Delta h} \]

**Porosity and permeability log**

<table>
<thead>
<tr>
<th>Permeability</th>
<th>Good</th>
<th>Low</th>
<th>Null</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment type</td>
<td>Clean gravel</td>
<td>Clean sand, sand / gravel mix</td>
<td>Very fine sand, silt, silt and clay</td>
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Design: Sylvain Haquin

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Geotechnical and lithological facies of radar units

- **Sedimentary Architecture** → **Core Analysis**

**Porosity Log (%)**

- **B** - Beach lamination: $k \sim 1 \times 10^{-3} \text{ m.s}^{-1}$
- **C** - Aeolian capping: $k \sim 2.5 \times 10^{-4} \text{ m.s}^{-1}$
- **D** - Sub-aerial washover lamination: $k \sim 7 \times 10^{-4} \text{ m.s}^{-1}$

**Porosity Log (%)**

- **A** - Tidal flat / shell bank transition: $k \sim 9 \times 10^{-4} \text{ m.s}^{-1}$
- **E** - Washover delta deposit: $k \sim 6 \times 10^{-3} \text{ m.s}^{-1}$

**Table of Permeability**

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<tr>
<td>$k$ (m/s)</td>
<td>$10^0$</td>
<td>$10^1$</td>
<td>$10^2$</td>
</tr>
</tbody>
</table>

**Weill et al. (in press)**

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Different progradation or accretion units identified (2-3) over the period of chenier construction on the upper tidal flat (30-40 years)

Influence of low frequency tidal cycles (4.5 and 18.6 years) ?
(peak periods → massive sediment reworking by waves)

Influence of low frequency tidal cycles (4.5 and 18.6 years) ?
(peak periods → massive sediment reworking by waves)
Questions...

How can coarse material be concentrated in a low energy environment?

How can we explain the grain sorting observed in the beddings?

Field work – Sedimentary architecture

Cheniers

Lab work
Sediment behaviour
Settling velocity
Threshold of motion

Wave flume
experimental model

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Sediment composition and sieve size distribution

Sediment sampled in the field

Bimodal distribution

Meaning of the sieve diameter for shell debris?
Settling velocities converted into equivalent settling diameters

Bioclastic particles: flat shape

→ Small settling velocity and equivalent diameter

\[ V = \frac{\Delta L}{\Delta t} \]
Threshold of motion under unidirectional current

Sieved sediment in flat bed

Unidirectional current generated

Velocity and turbulence profiles using Laser Doppler Anemometry (LDA)

Design: Sylvain Haquin
Threshold of motion under unidirectional current

Velocity and turbulence profiles using Laser Doppler Anemometry (LDA)

Velocity and stress profiles

Critical velocity and shear stress for sediment motion
Threshold of motion for bioclastic sediment:
- close to common values with sieve diameter
- over estimated with settling diameter

Need to dissociate behaviour of:
- isolated particles suspended in highly turbulent flows
- imbricated particles and armoured bed under unidirectional flows

Diagram showing the relationship between critical shear velocity and particle diameter, with curves for settling diameter and sieve diameter comparison. The general envelope for classic sands is also indicated.
Questions...

Sediment behaviour in breaker zone, swash zone, overwash?

Field work – Sedimentary architecture

Cheniers

Lab work
Sediment behaviour

Wave flume
experimental model
Natural sediment shaped in a 6 m long smooth beach
Equilibrium morphology

Montage of 2 photographs taken through the side glass of the flume
Breaker zone → Chenier foot
Breaker zone

No surf zone – **Surging breaker**

Intense **erosion** – Topographic step

Sediment eroded, sorted and transported in the swash zone

**Coarse bioclastic particles easily sorted**
Swash zone – Chenier seaward face (beach)
Swash zone
Chenier seaward face (beach)

**Coarse sediment** transported and deposited in the **upper swash zone**

**Fine sediment** left in the **lower swash zone**
Washover zone – Chenier landward face
Washover zone – Chenier landward face
Washover zone – Chenier landward face
Washover zone – Chenier landward face
Morphological response to mean water level fluctuations

Time (min)

Mean water level (cm)

Time (s)

Water level (cm)

0 50 cm

36.5 cm

33 cm

27 cm

Banc / Chenier
Morphological response to mean water level fluctuations
Experimental modelling  → Morphological response

Falling water level

→ Small ridge formation seaward of the chenier

→ New sediment stock at the chenier foot
Rising water level

→ Sediment stock reworked

→ Beach accretion
Rising water level

→ Chenier foot erosion and migration

→ Washover
• Experimental modelling  ➔ Morphological response

Very high water level

→ Large washover

→ Chenier landward migration and vertical aggradation

Landward migration 90 cm in 2 h 30 min
Falling water level

- Chenier stabilization
- Sediment accumulation at the foot of the chenier
Rising water level

→ Sediment stock reworked
→ Formation of a new ridge at the chenier foot
High water level

→ Migration of the new ridge on the chenier beach face

→ Stabilization of the ridge
Seaward progradation of the chenier

![Graph showing mean water level over time](image-url)
With constant monochromatic waves

+ Mean water level fluctuation

→ Chenier ridge morphology
→ Washover dynamic
→ Sedimentation style controlled by water level
→ Chenier landward migration
→ Chenier progradation

→ Striking similarities with field data
Transgressive chenier morphology

Wave Flume (initial stage)

GPR (Box 2)
Prograding chenier morphology

Wave Flume (final stage)

GPR (Box 3)
A depositional model controlled by tides

Internal architecture and stages of evolution

Weill et al. (in press)

Tidal flat  Salt marsh  Chenier
A depositional model controlled by tides

1. Tidal flat
2. Salt marsh
3. Eroded salt marsh
4. Tidal flat bank
5. Active chenier
6. Fossil chenier

Flooding time > 6 m (h)


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Goals

- To characterize the genesis, growth and stabilization of cheniers in macrotidal environments

Methods

Field work – Sedimentary architecture
- GPR, X-ray, geotechnical analysis (porosity, permeability)
- Hydrodynamic processes observed during high spring tide floodings
  - Long term evolution by aerial photographs

Lab work
- Sediment behavior
  - Settling velocity
  - Threshold of motion

Wave flume
- Experimental model
  - Sediment behavior under waves
  - Morphological response to mean water level fluctuations
Results

1- A peculiar sediment behaviour

2- A revealed internal architecture

3- A deposition model controlled by tides
Merci de votre attention !