Formation and evolution of macrotidal chenier ridges

- Experimental and in-situ approaches -

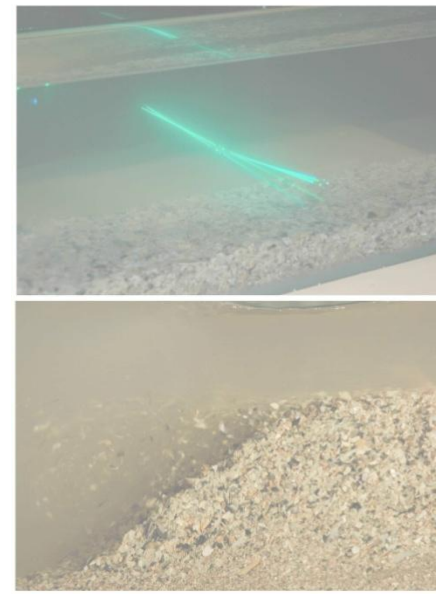
Doctorat de l'Université de Caen

-Terre solide et enveloppes superficielles -

Pierre Weill

Lab. M2C (UMR CNRS/INSU 6143)
Université de Caen Basse-Normandie

Directed by : **Bernadette Tessier**
Dominique Mouazé



Université de Caen Basse-Normandie

CONSEIL RÉGIONAL

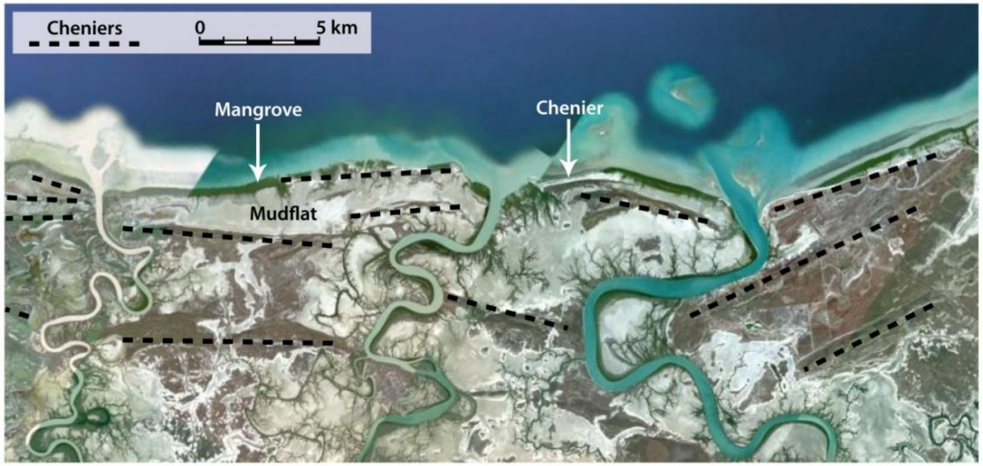
Chenier

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

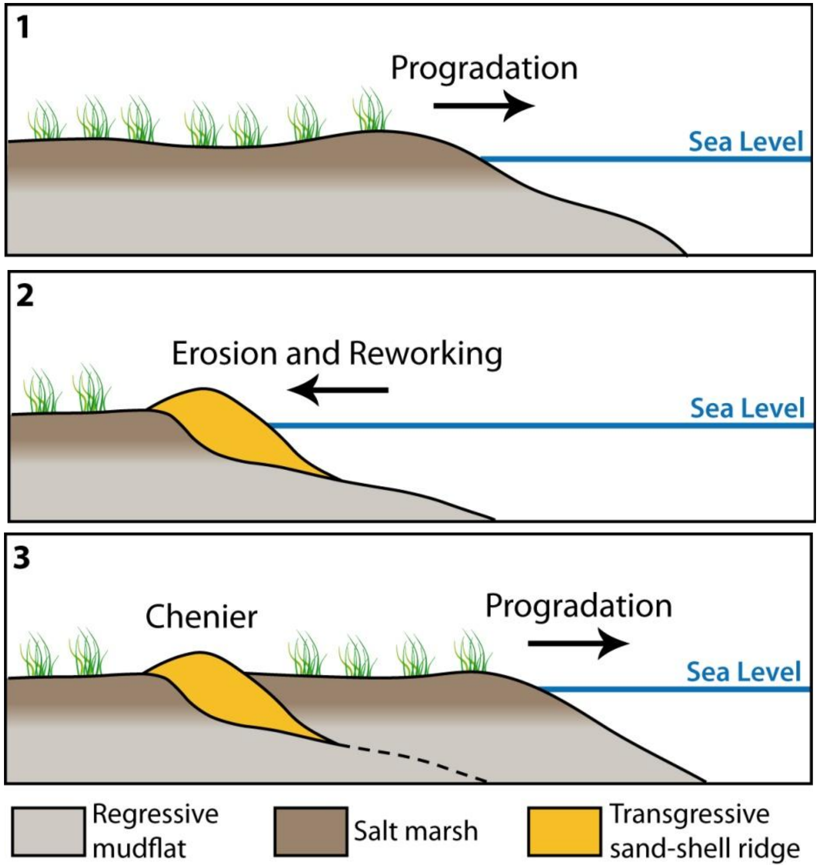
Chenier construction implies a **balance** between :

-**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**
(Augustinus 1980, Penland & Suter 1989, Anthony 1989...)

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

2 types of cheniers

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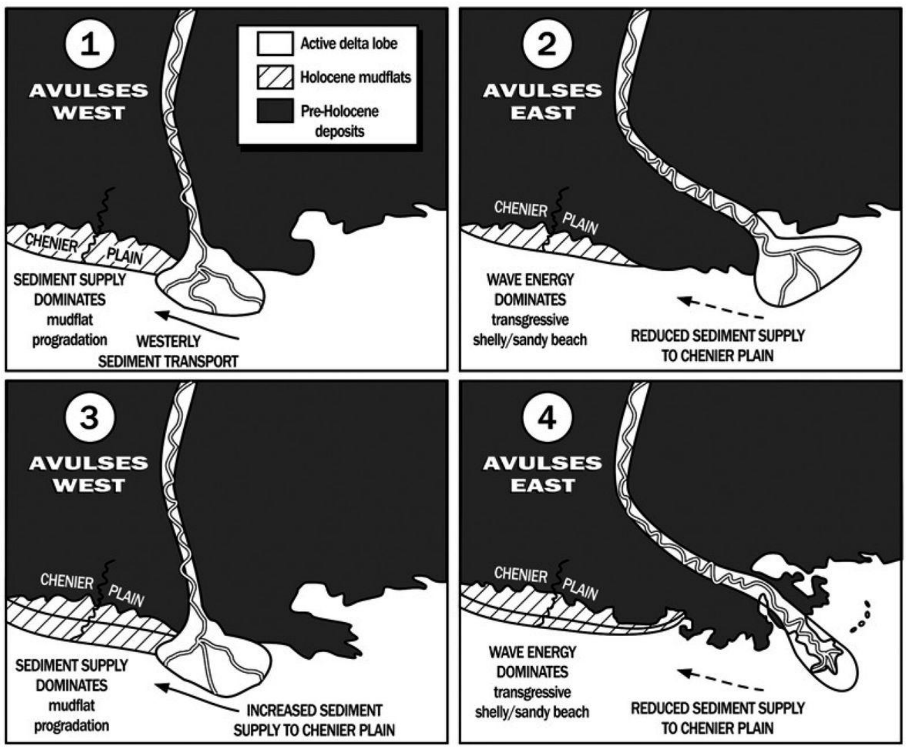
Archetypal exemple – Louisiana chenier plain

Chenier plain progradation controlled by Mississippi distributaries avulsion



McBride et al. (2007)

Chenier plain in Louisiana

(source : R.L. Watson, Consulting Geologist, Texas)

2 types of cheniers

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

Gulf of California, Mexco (max. tidal range 6.5 m)

Firth of Thames, New Zealand (max. tidal range 3 m)

Essex, UK (max. tidal range 5 m)

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

Formation and evolution of macrotidal chenier ridges

- Experimental and in-situ approaches -

Objectives

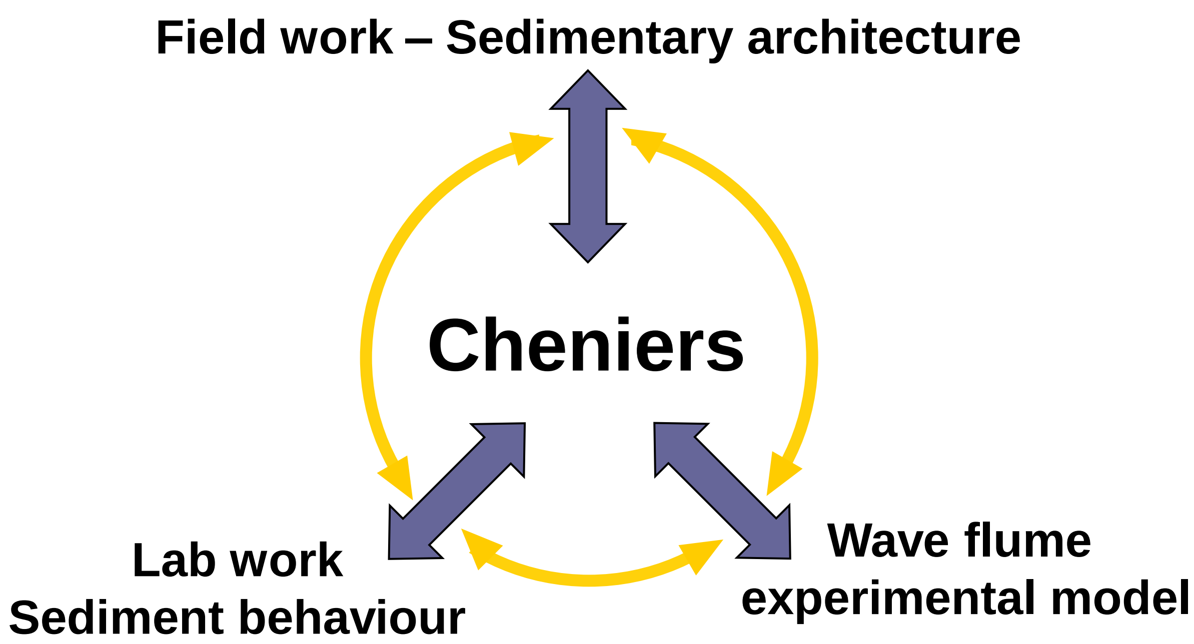
- Identify the main parameters controlling chenier dynamics in tidal environments

- 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

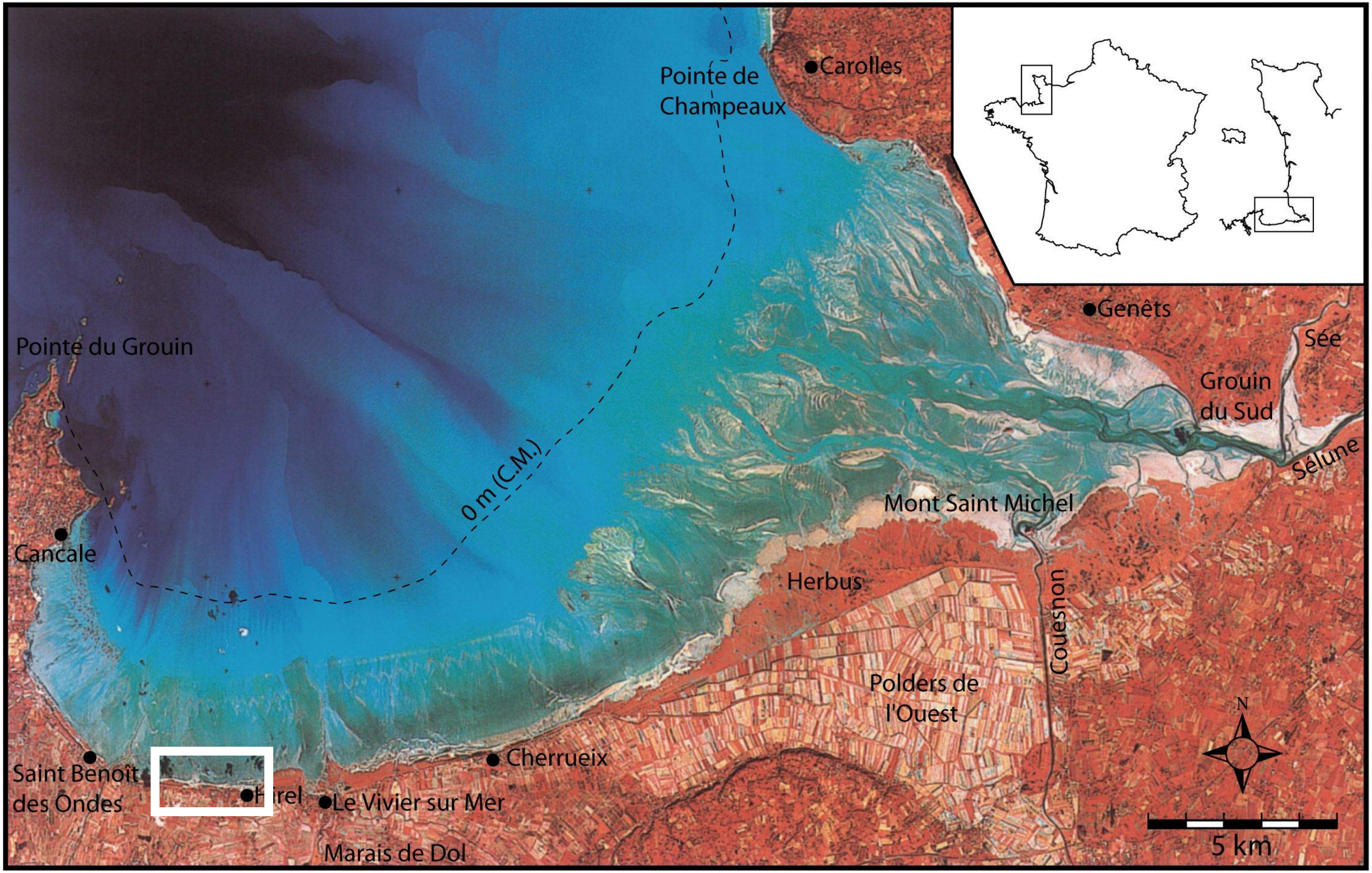
→ Mont-Saint-Michel bay



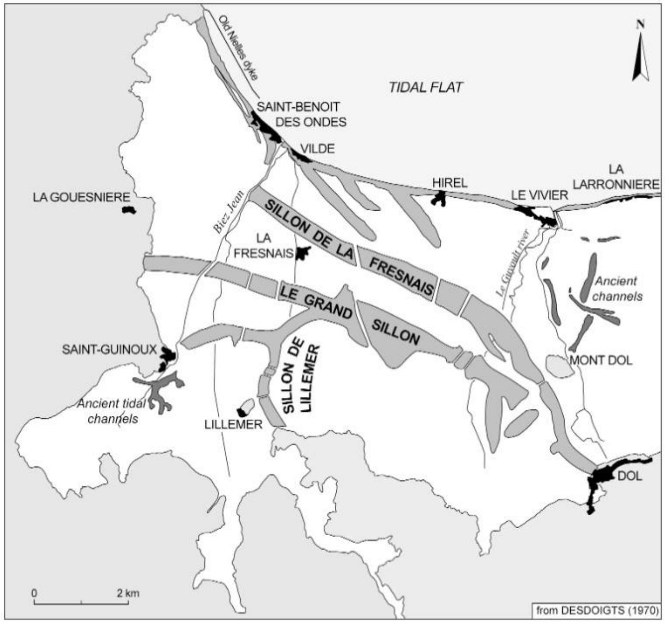
Integrating time and space scales…
…from grain motion to coastal evolution

 →  → 

Mont-Saint-Michel bay - SPOT satellite image (1994)



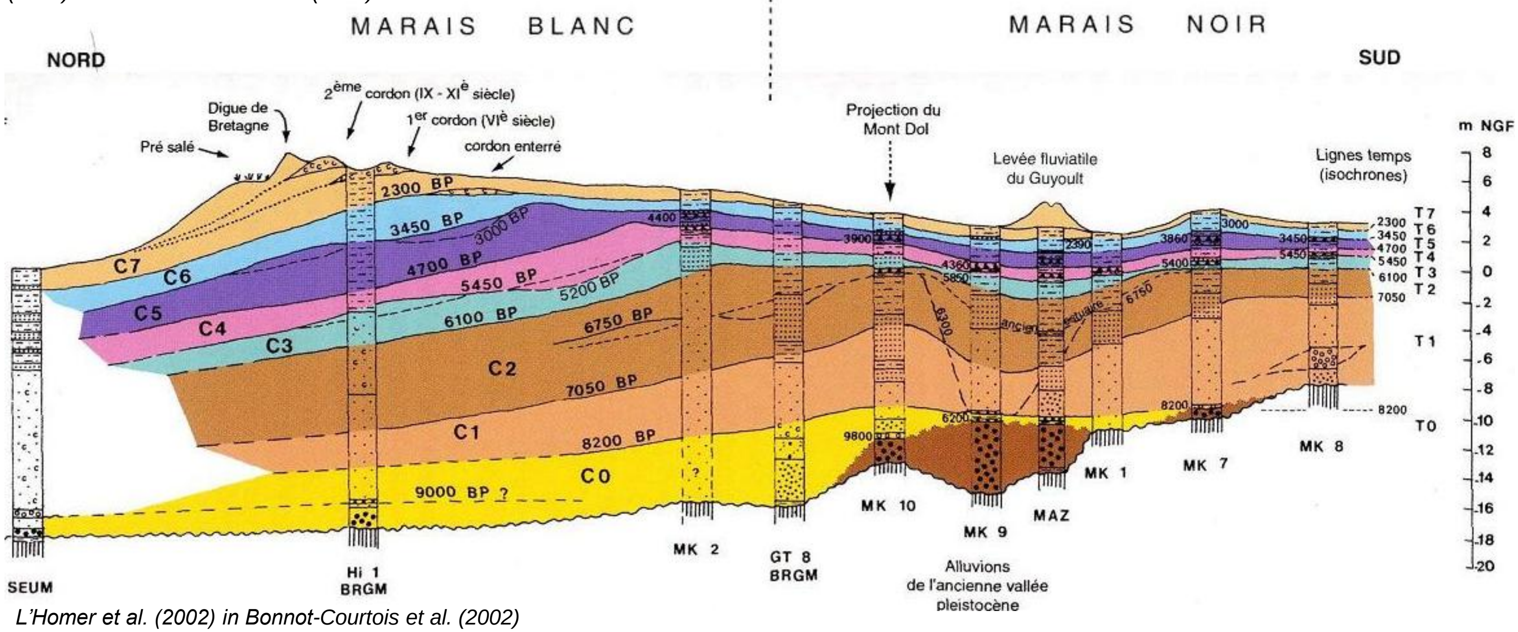
Hirel - Photographie aérienne (Bruno Caline – 1993)



from Desdoigts (1970) in Bonnot-Courtois et al. (2004)

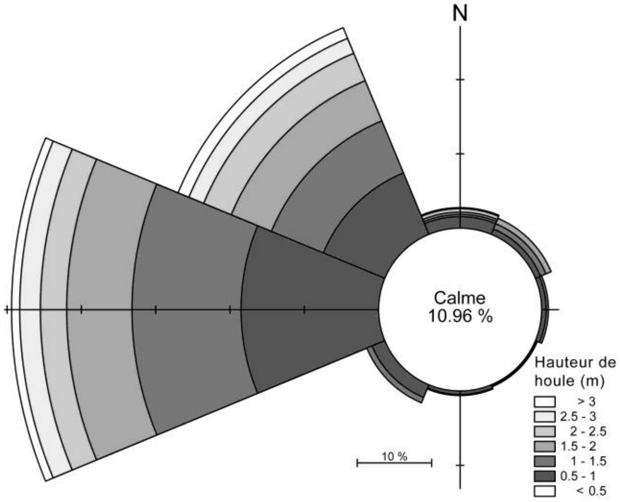
The Dol Marshes

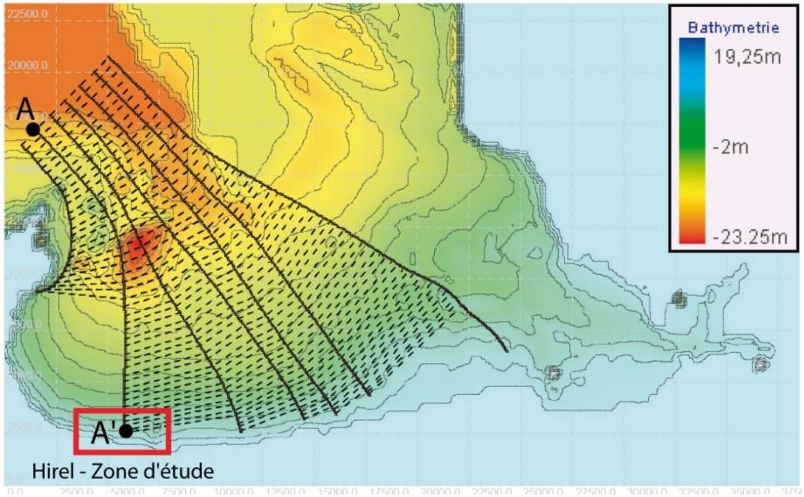
Last episode of sedimentary infilling (progradation) periodically interrupted from 3 500 y. BP by coarse shelly littoral barriers



L'Homer et al. (2002) in Bonnot-Courtois et al. (2002)

Hydrodynamic conditions - Waves



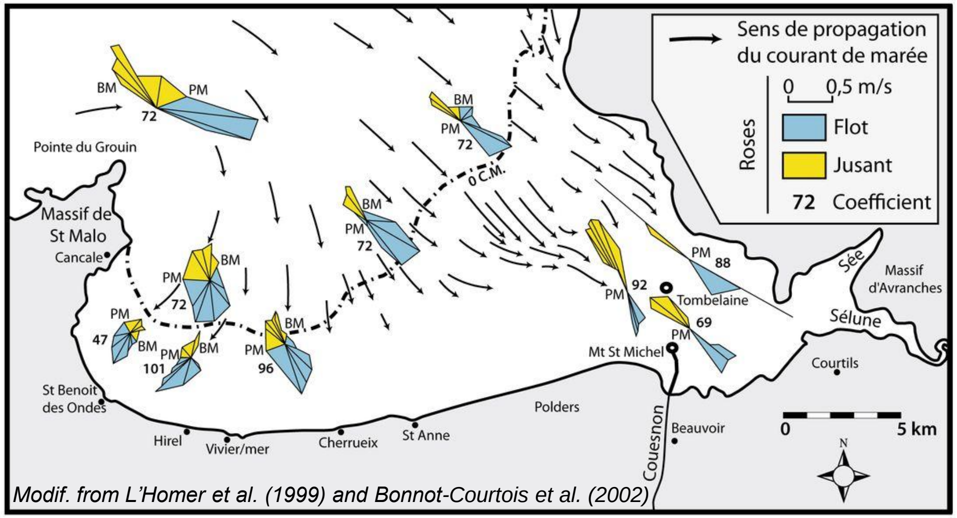


Shallow and protected embayment → Low wave environment

Fair weather conditions (13/03/2009)

Storm conditions (10/02/2009)

Hydrodynamic conditions - Tides



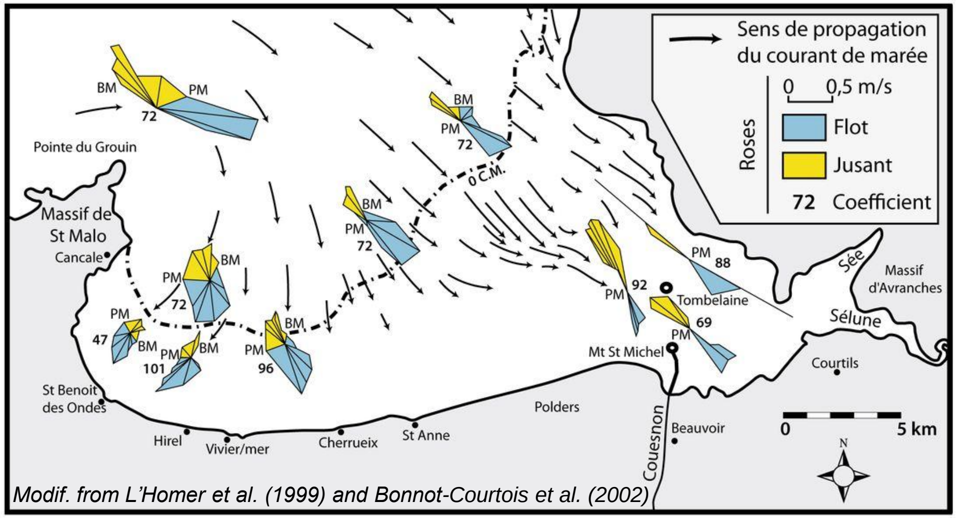
Spring tidal range : 14 m

Strong alternating currents in the estuary

Weak rotating currents in the embayment

Level of tidal flooding

Hydrodynamic conditions - Tides



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

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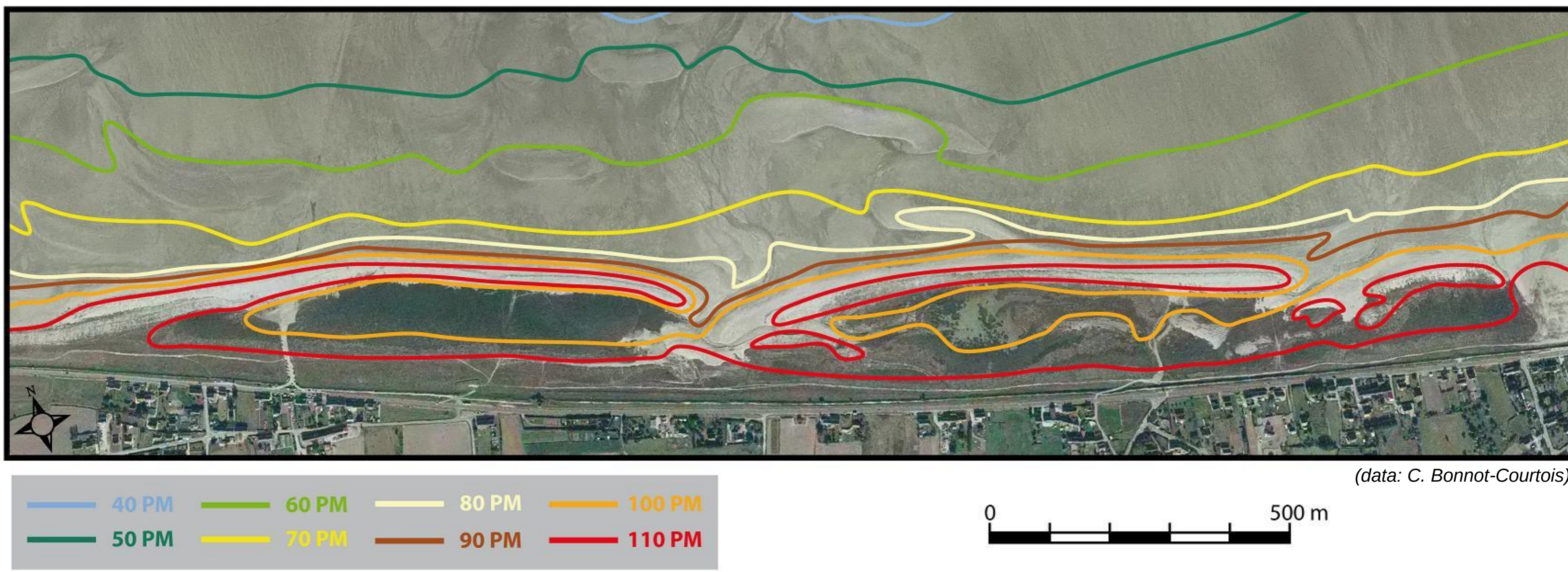
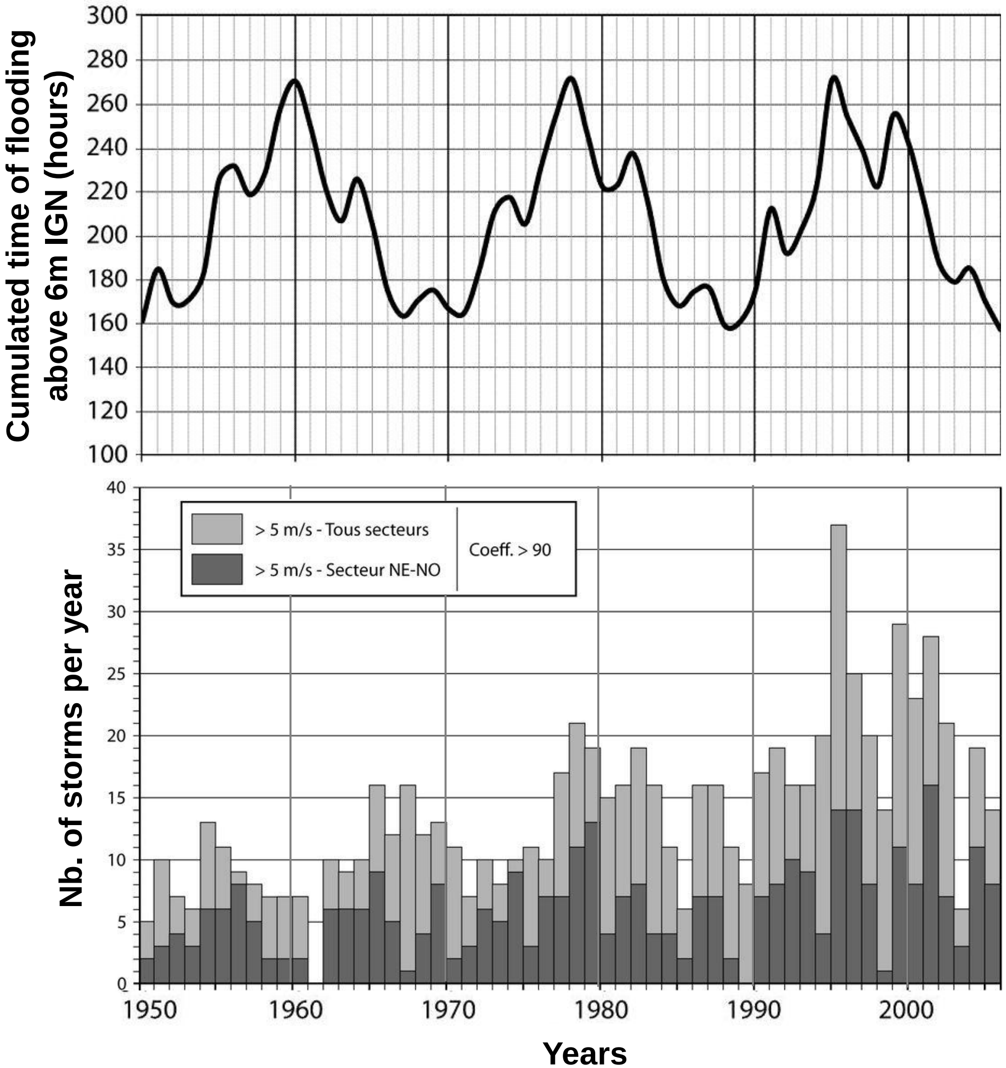


(data: C. Bonnot-Courtois)

Wave and tide conjunction



Variations in cumulated time of chenier flooding per year

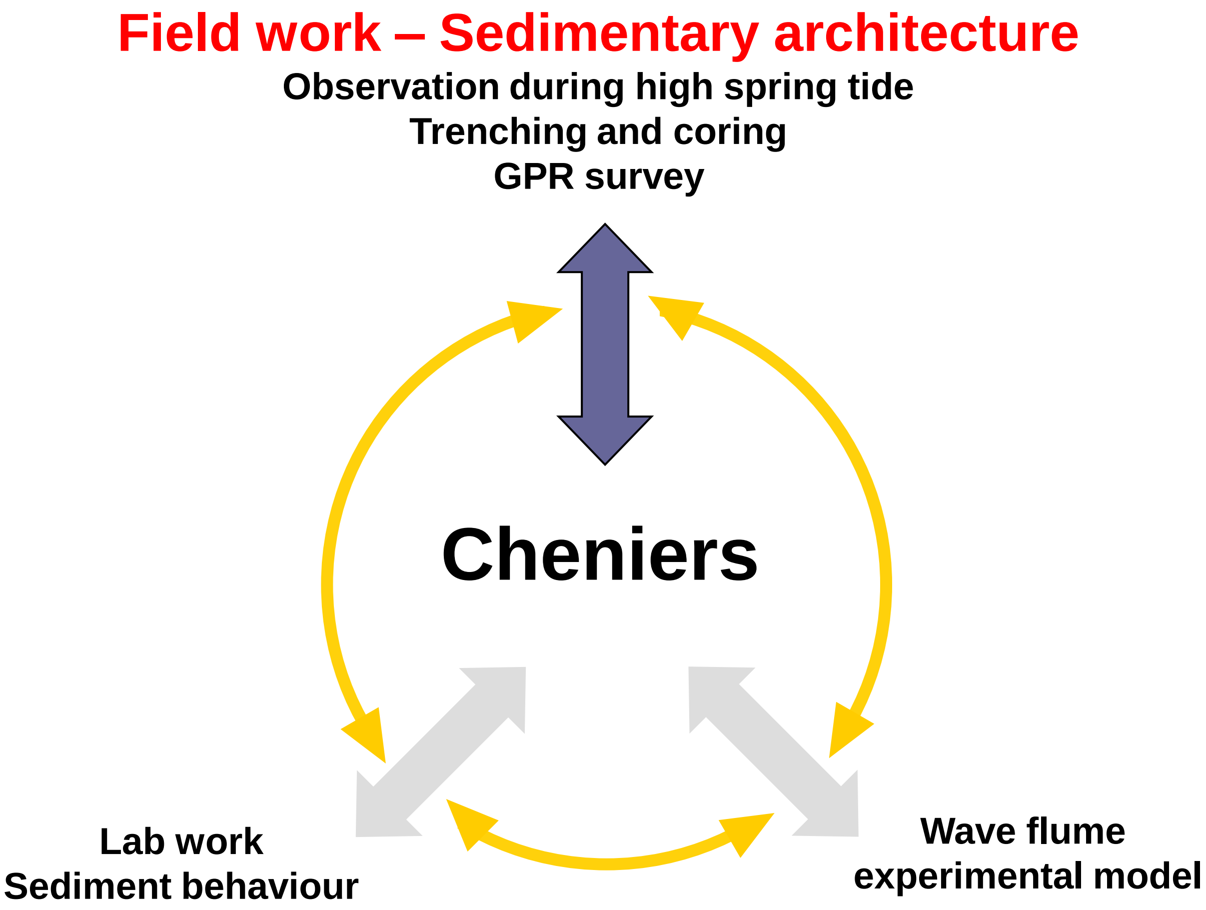
→ **4.4 years tidal cycles**

→ **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)

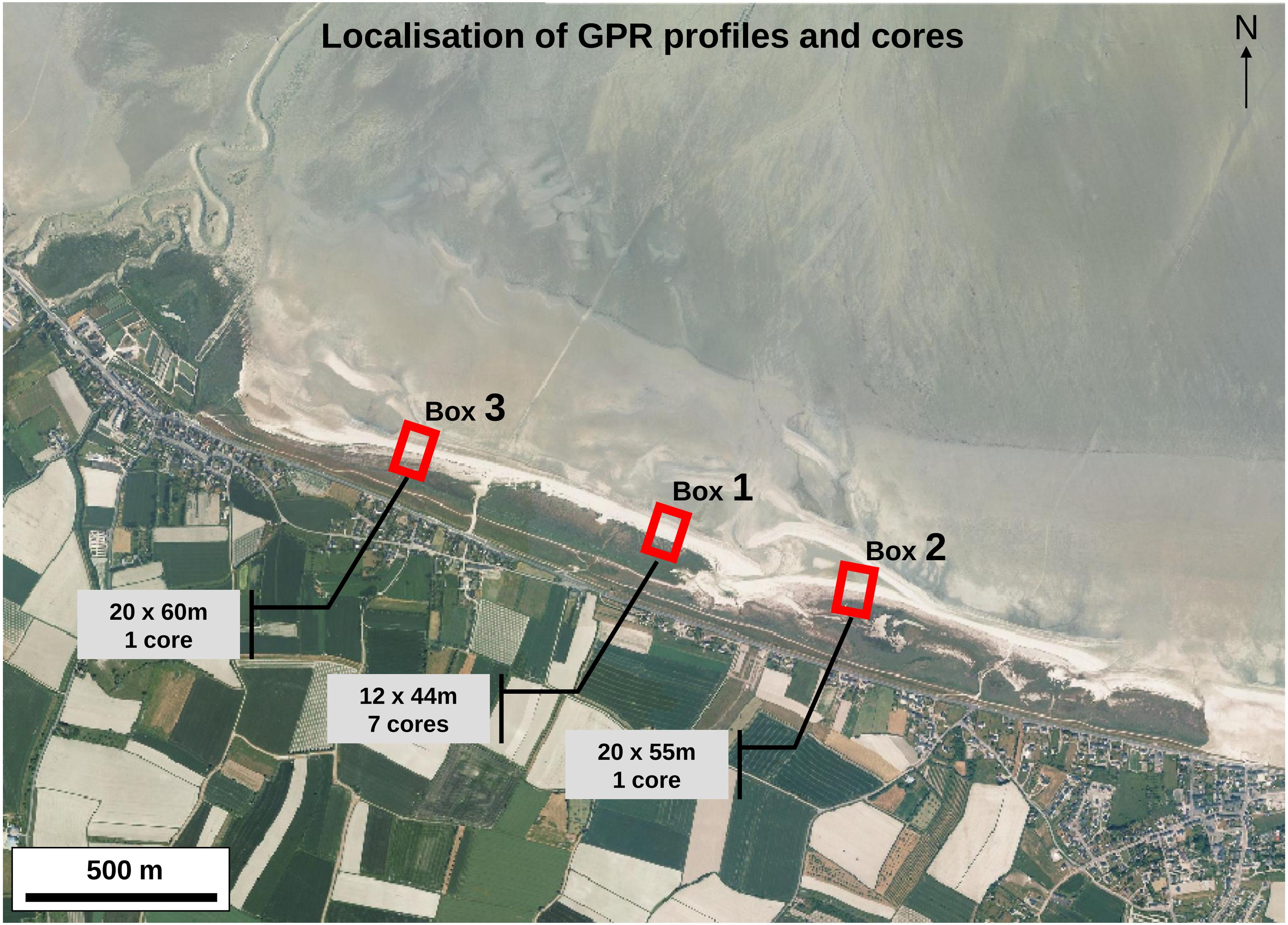
Propagation of high-frequency electro-magnetic waves

GPR antennas - 400, 900 MHz and 2.6 GHz

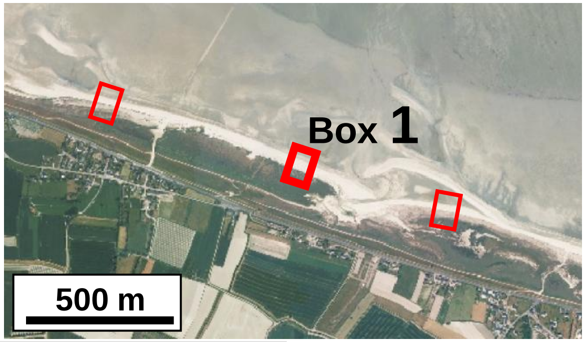
6,5 km of radar profiles
(cross-shore and longshore)

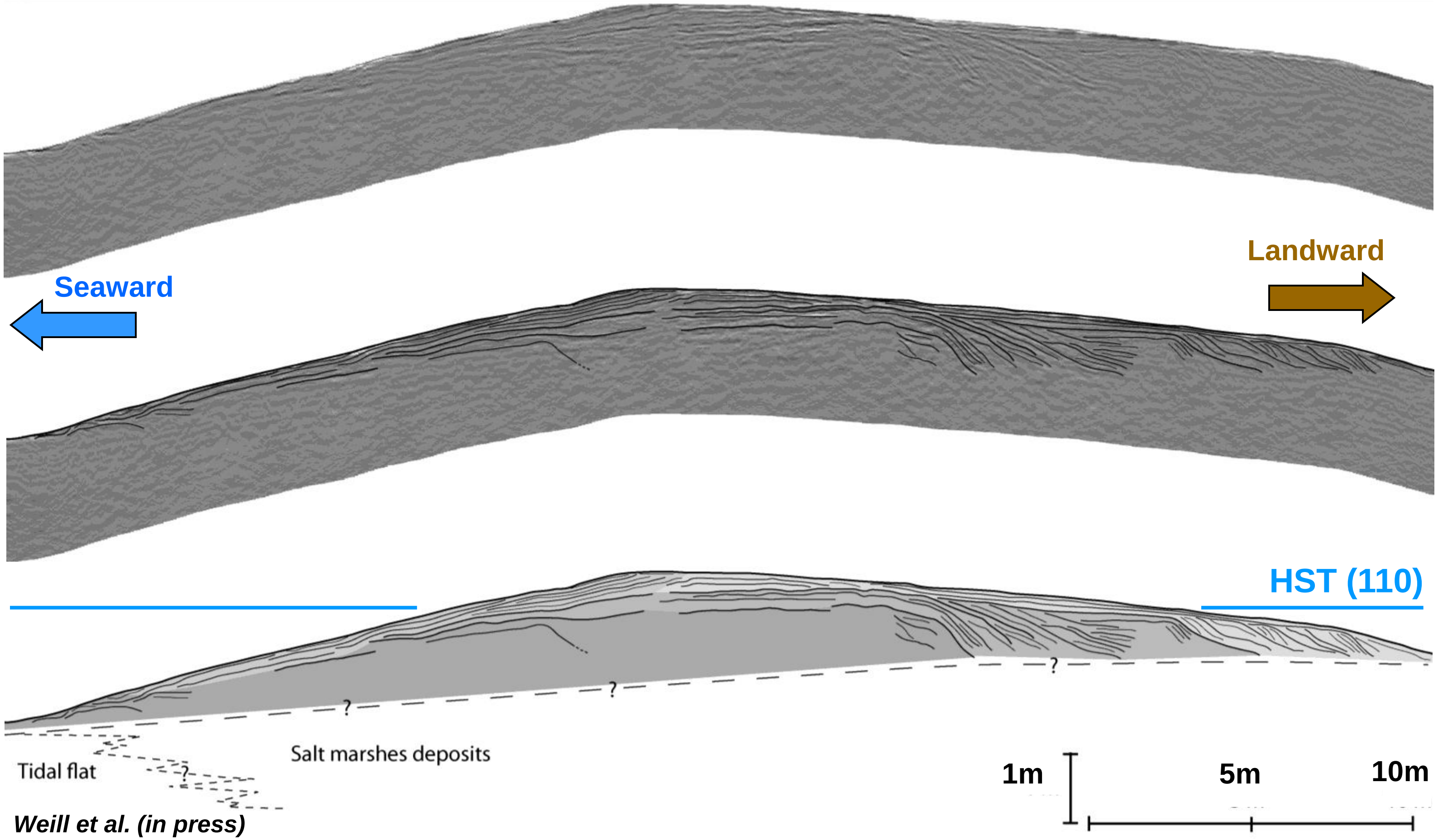
+ Trenching and coring

GPR Equipement : GSSI, distributed by MDS Paris


Localisation of GPR profiles and cores
N
Box 3
Box 1
Box 2
20 x 60m
1 core
12 x 44m
7 cores
20 x 55m
1 core
500 m

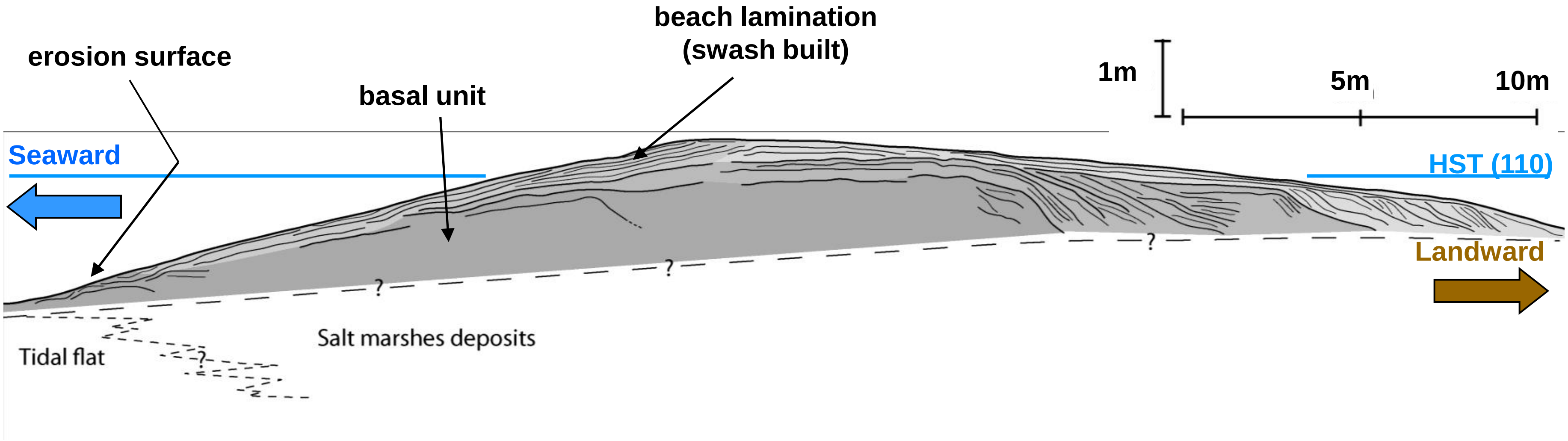
GPR Profile n° 1 (cross-shore) – 900 MHz





Weill et al. (in press)

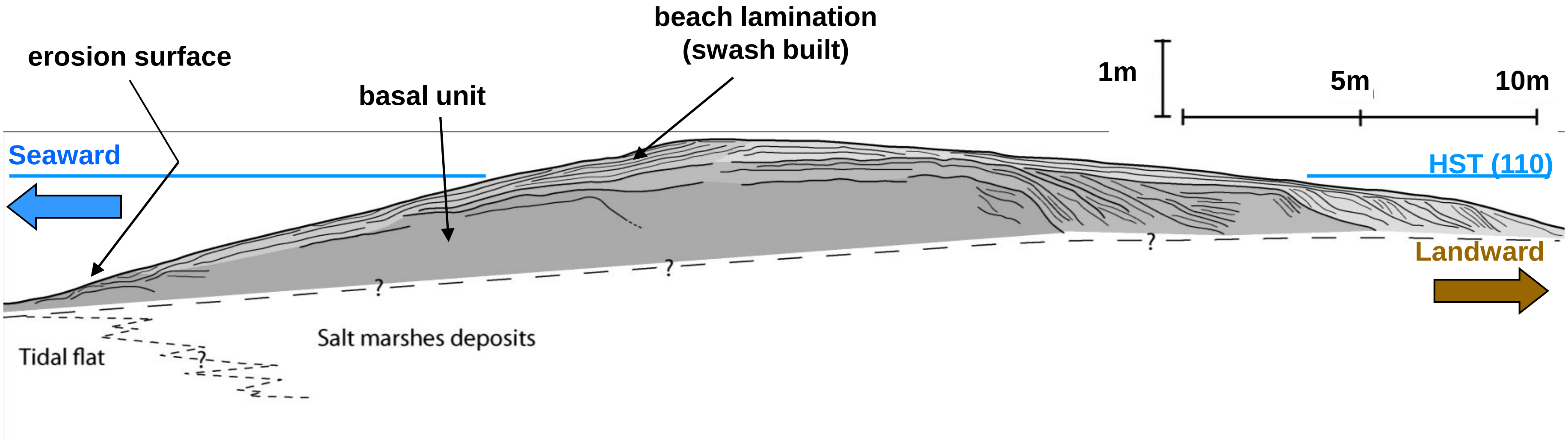
GPR Profile n° 1 (cross-shore) – 900 MHz



Eroded salt marsh deposits

Eroded tidal flat

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



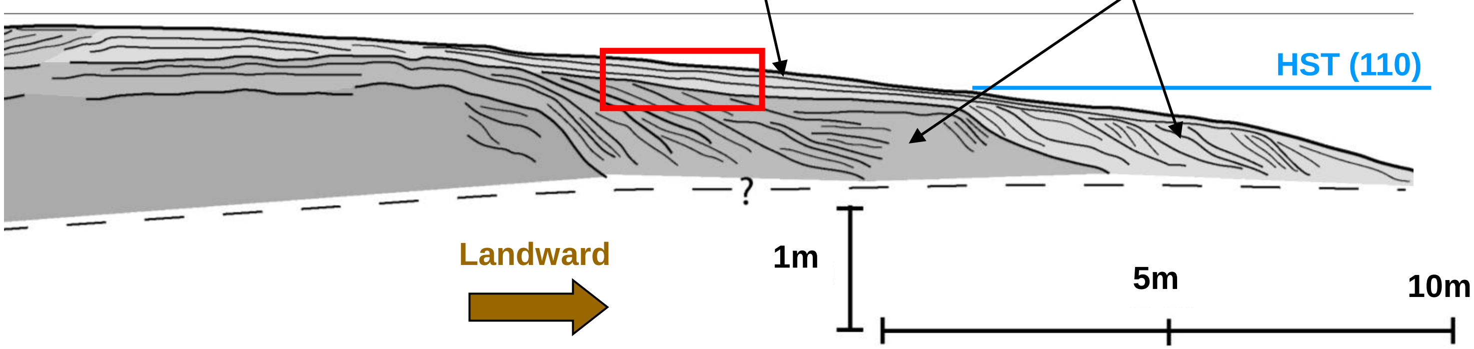
Millimetric beach lamination

Centimetric beach lamination

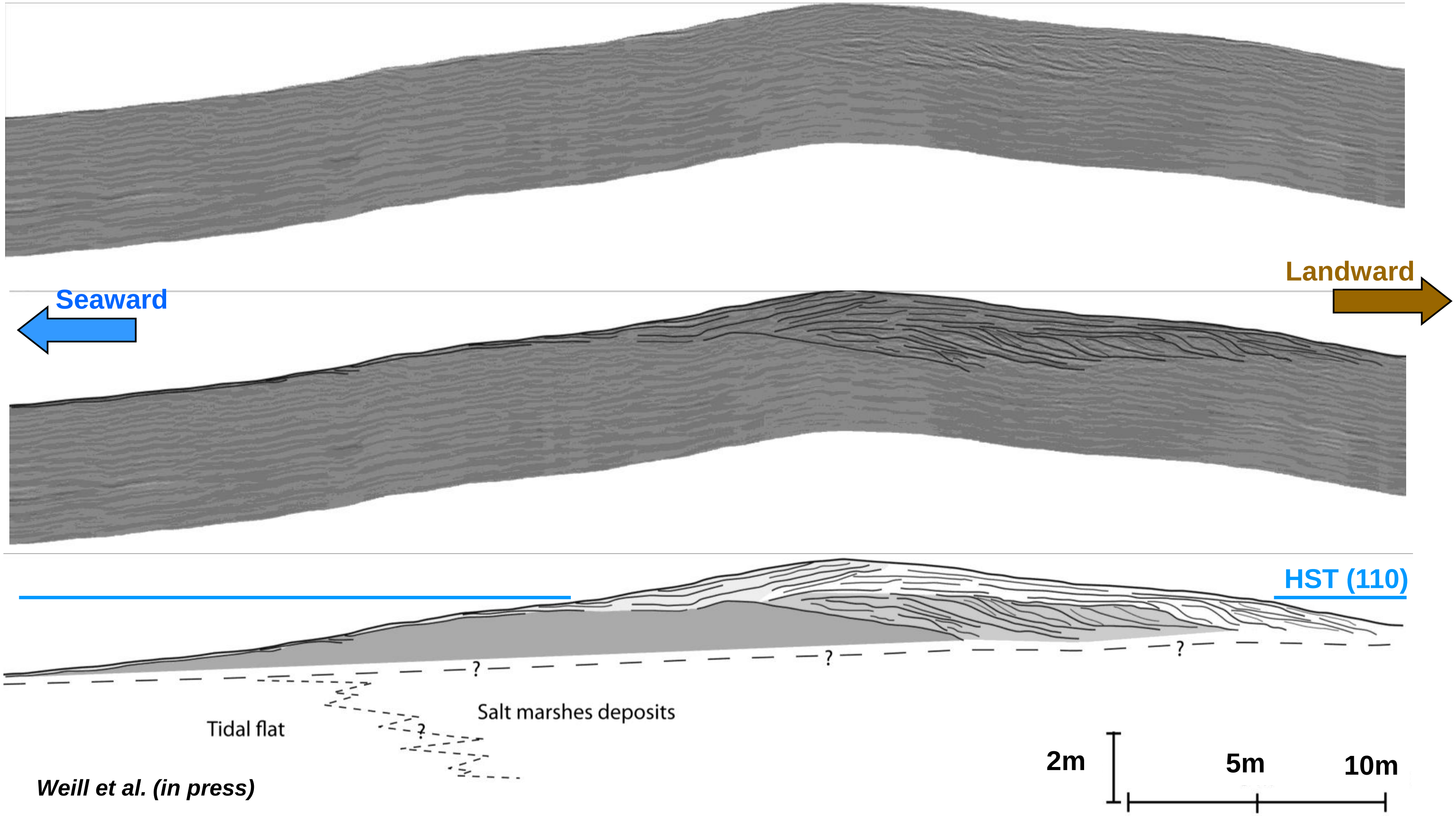
GPR Profile n° 1 (cross-shore) – 900 MHz

Sub-aerial washover sheets
(aggradation)

Washover deltas
(progradation)

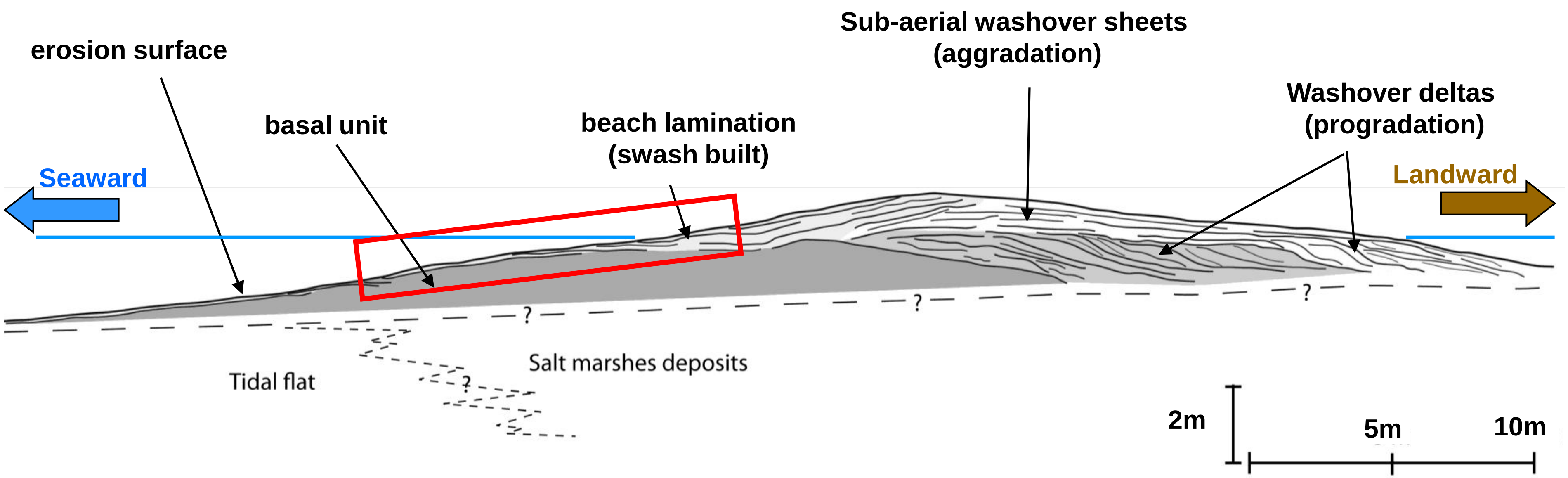


GPR profile n° 2 (cross-shore) – 900 MHz

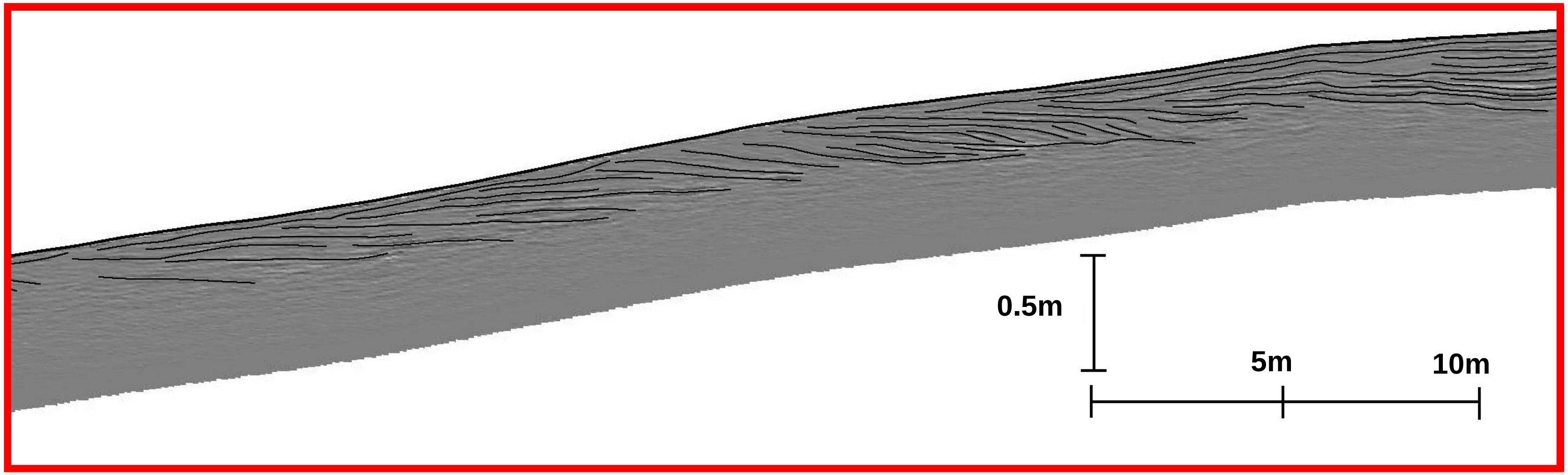


Weill et al. (in press)

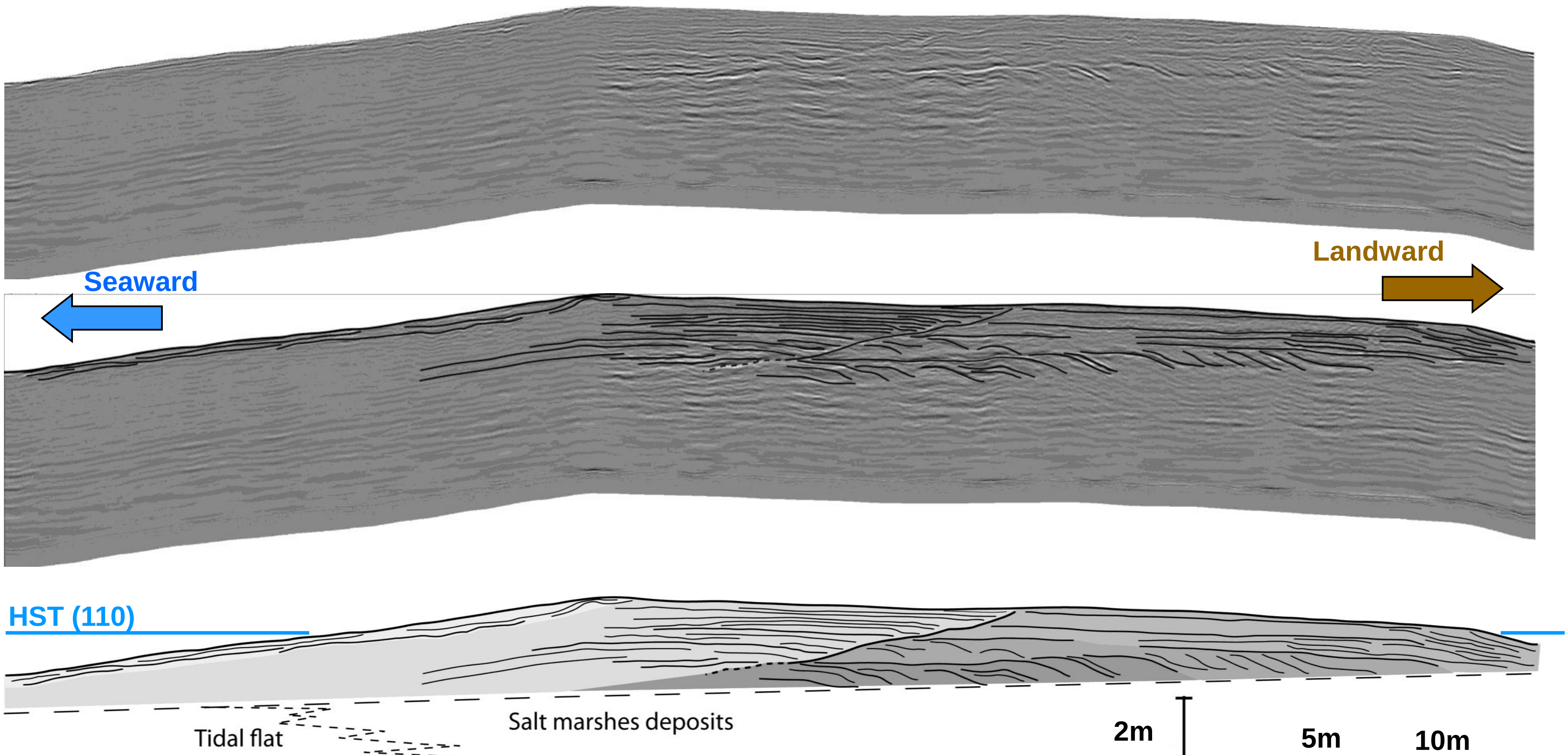
GPR profile n° 2 (cross-shore) – 900 MHz



High-resolution cross-shore profile – 2.6 GHz

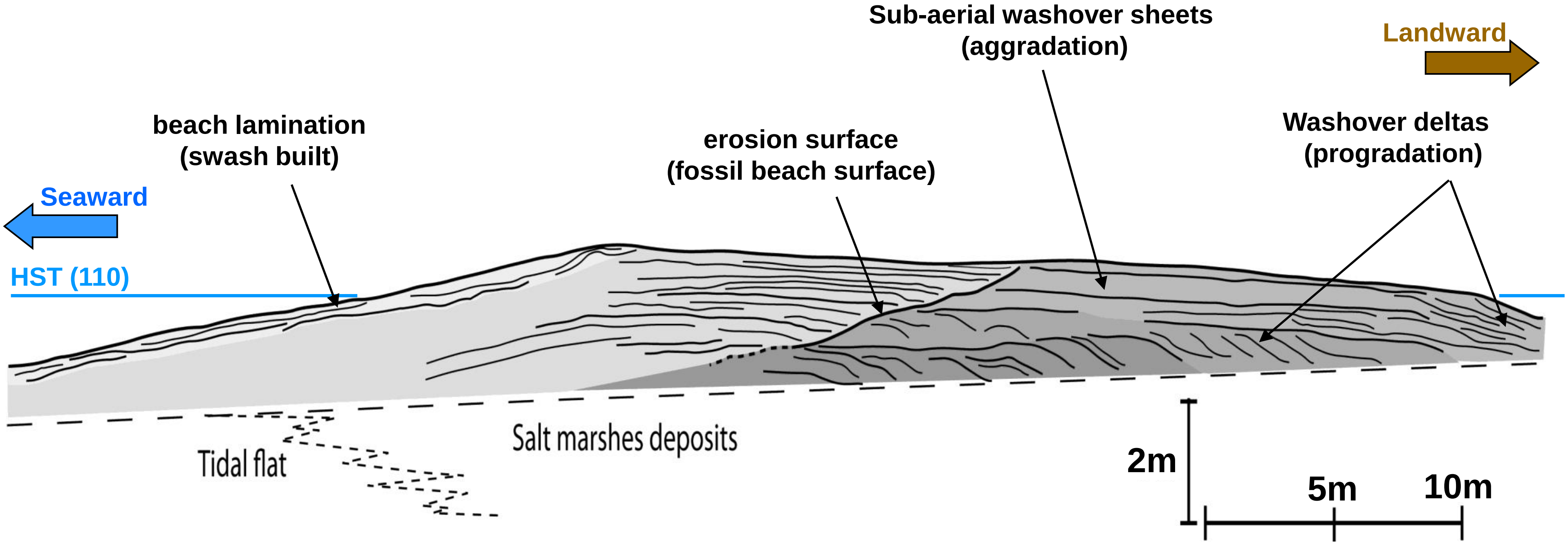


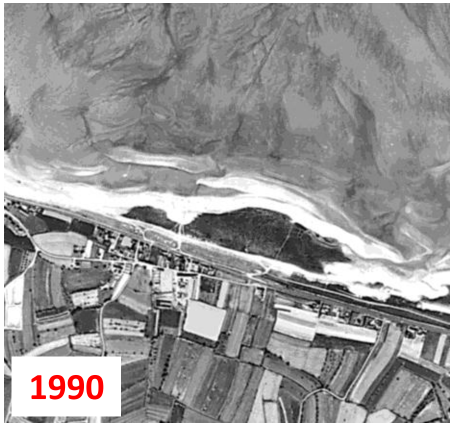
GPR profile n° 3 (cross-shore) – 900 MHz

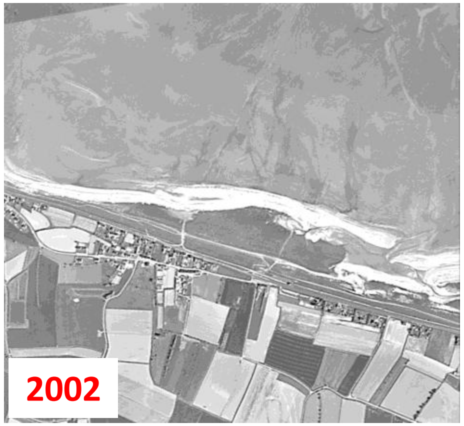


Weill et al. (in press)

GPR profile n° 3 (cross-shore) – 900 MHz

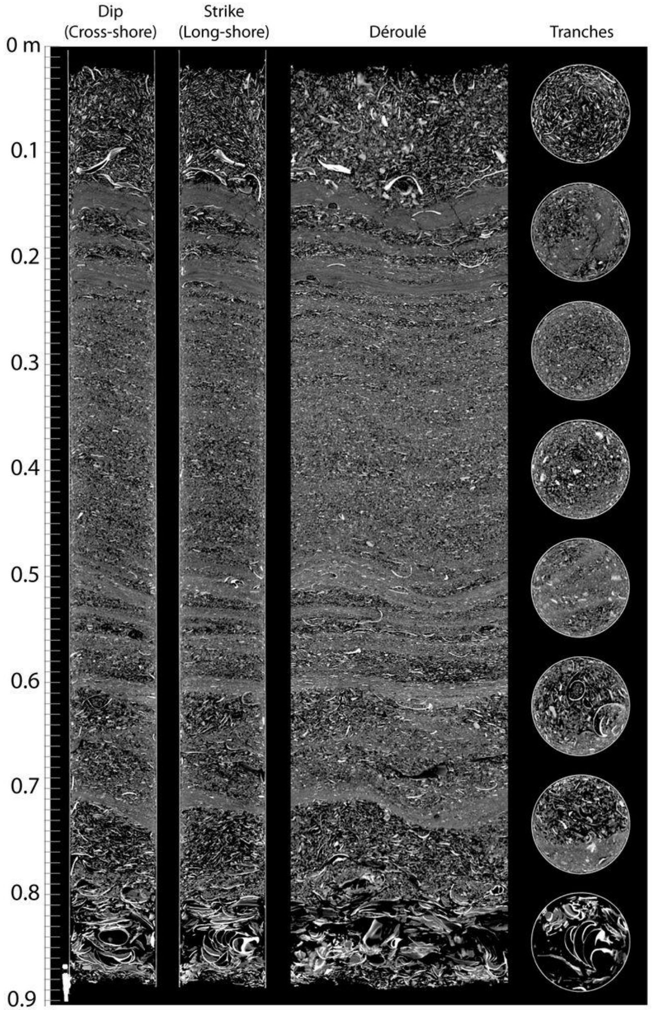




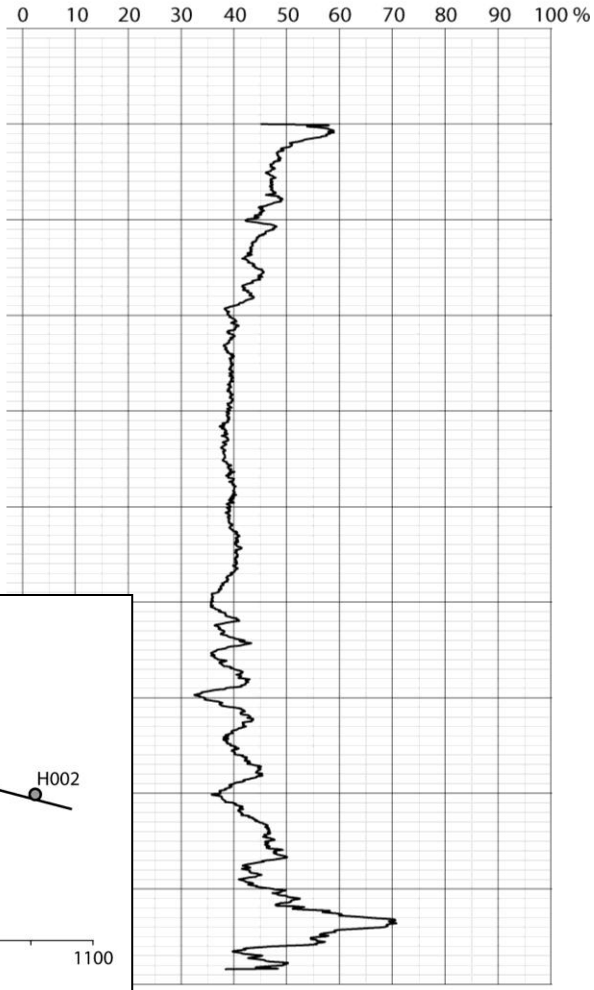


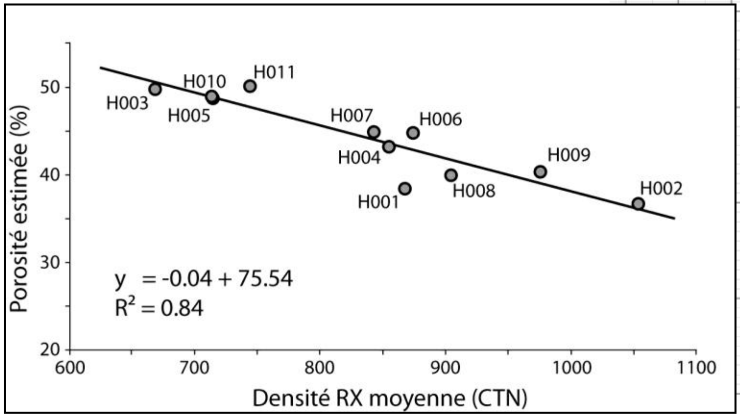
Core analysis

X-ray slices and virtual sections



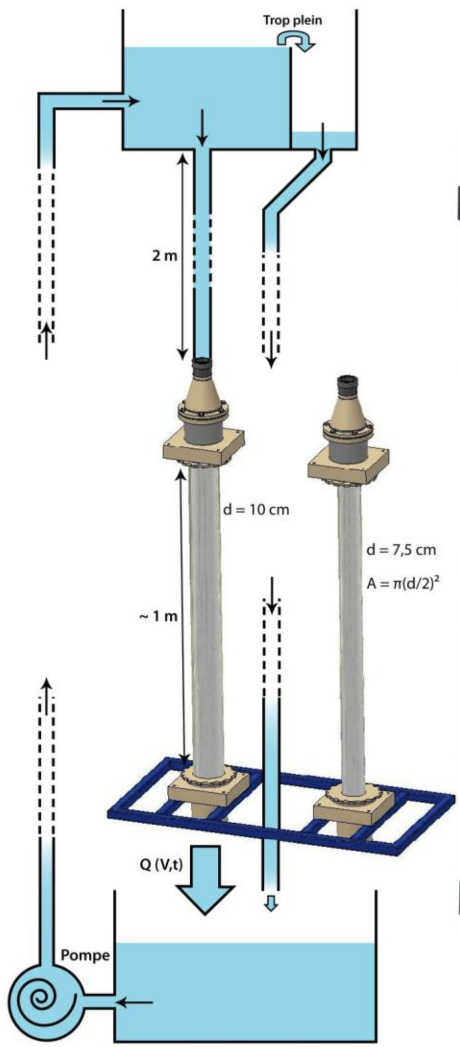
Porosity log

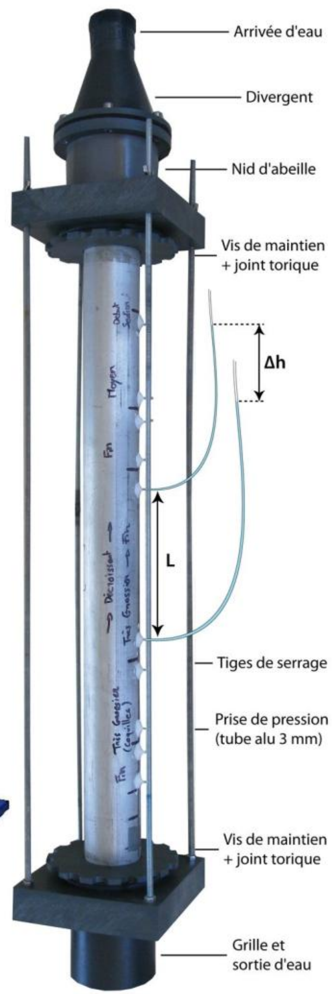




X-ray density / porosity correlation

Constant head permeameter

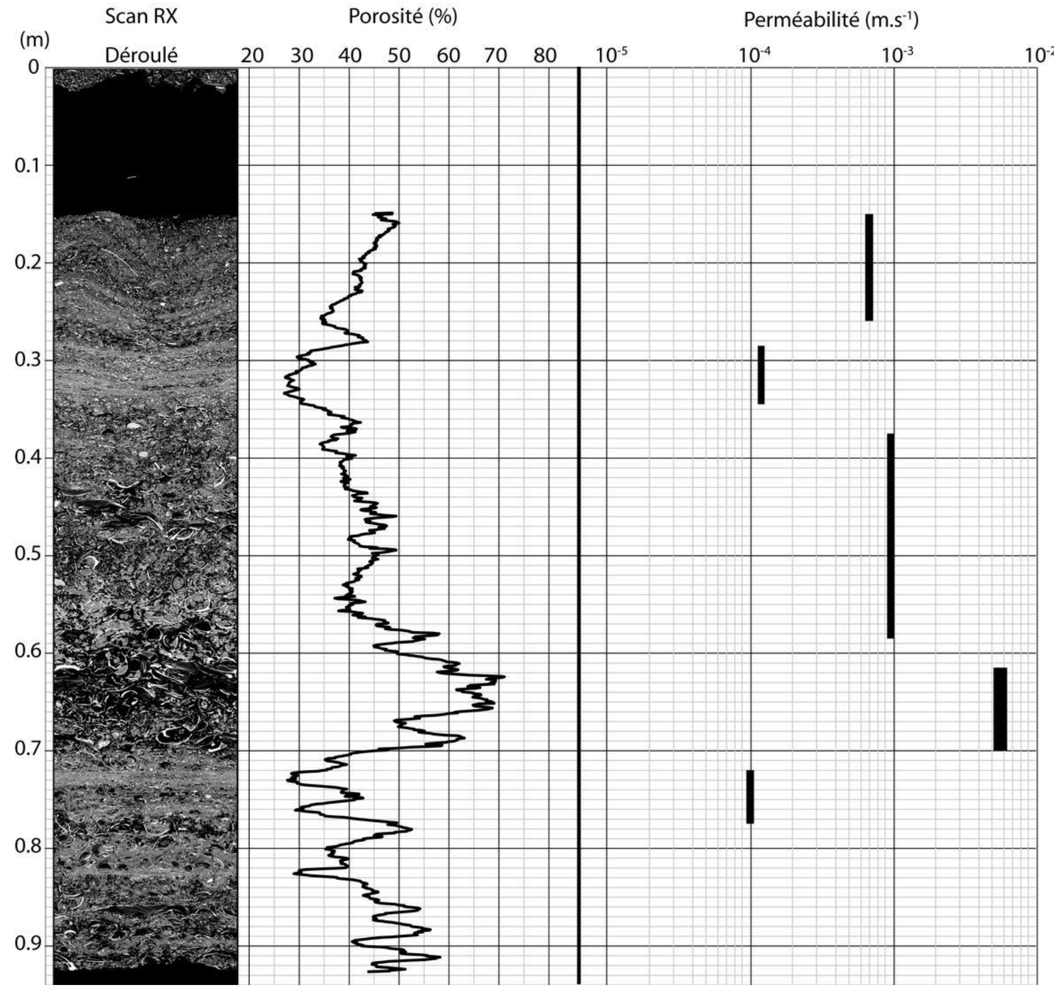




Design: Sylvain Haquin

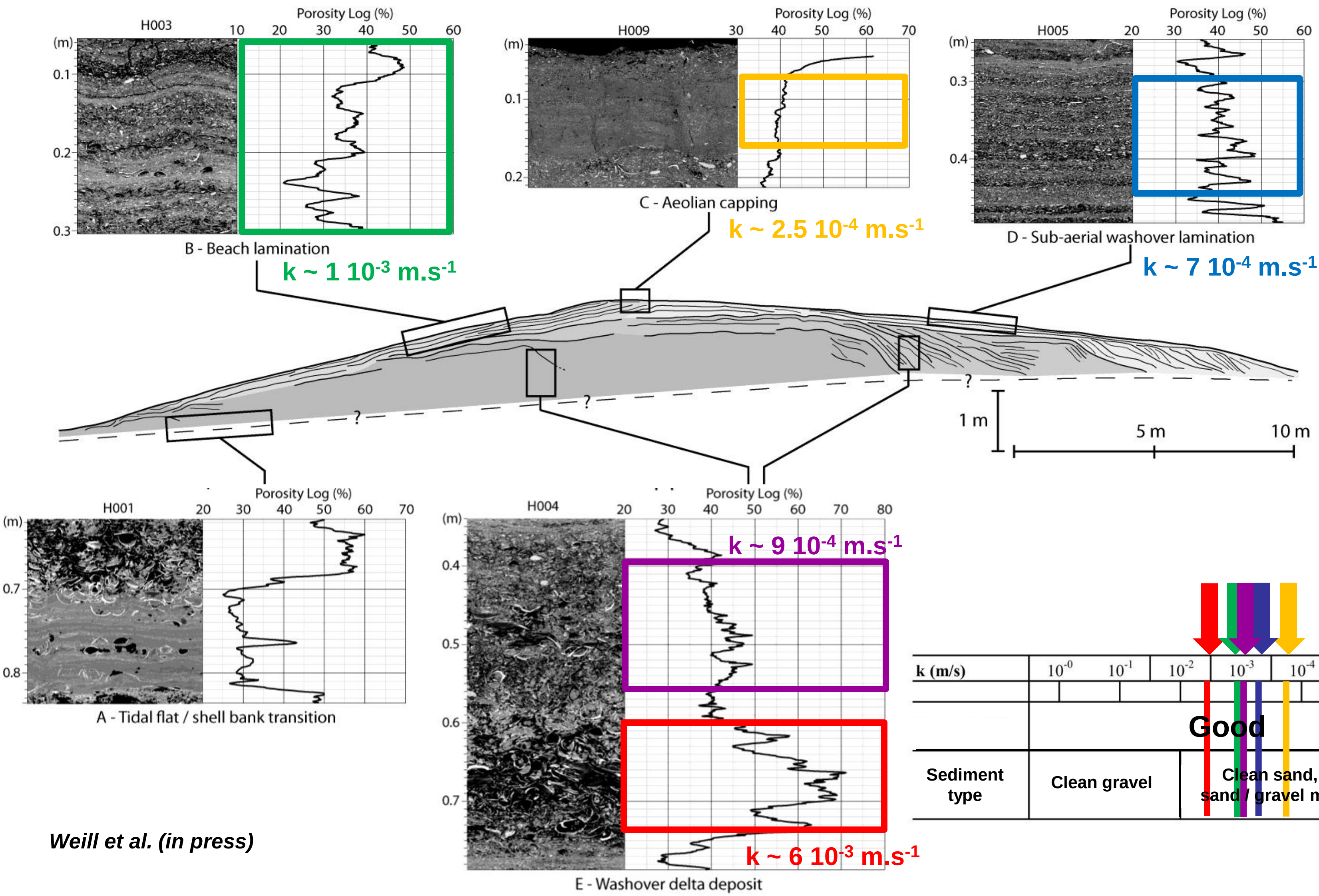
$$k = \frac{Q.L}{A.\Delta h}$$

Porosity and permeability log



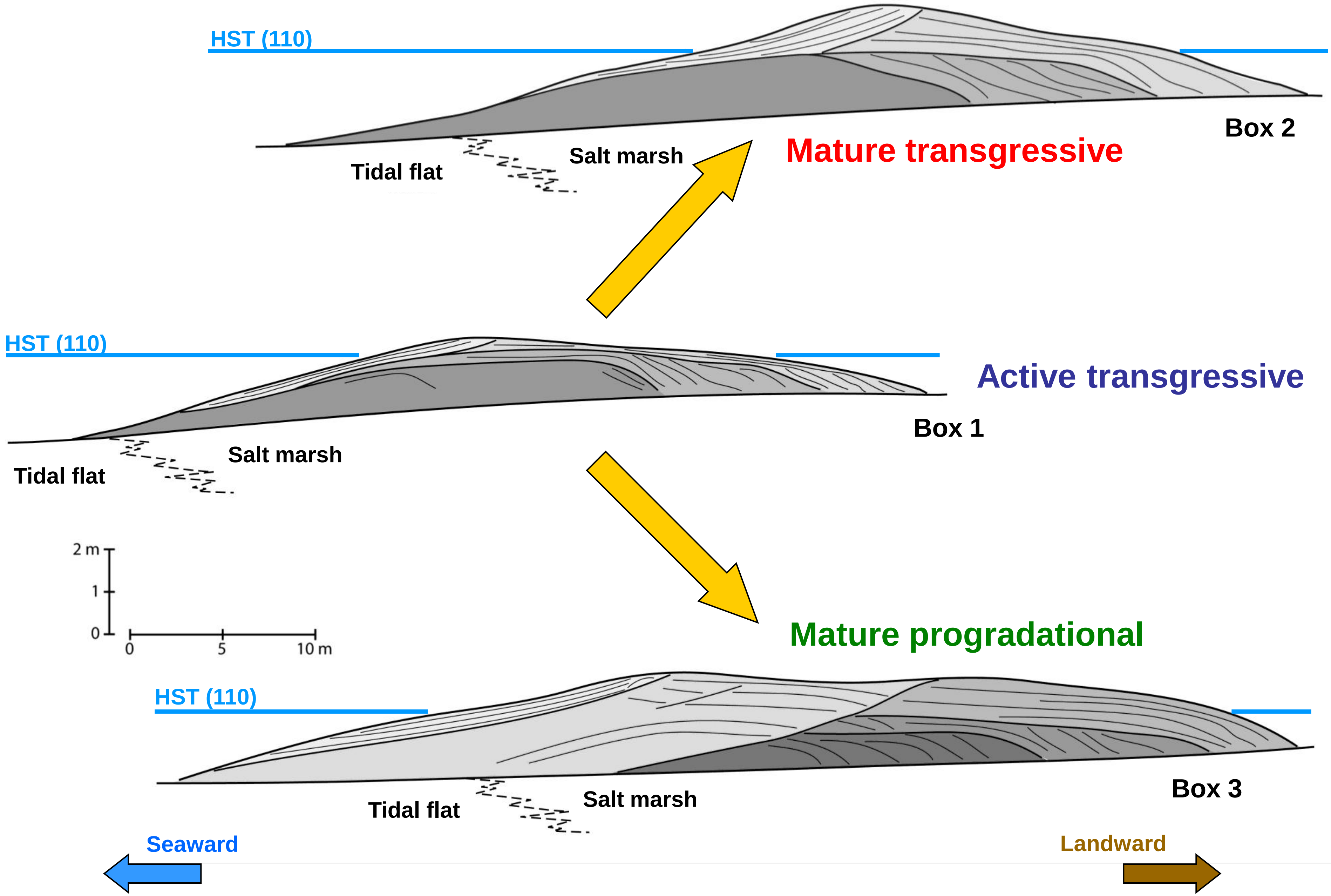
k (m/s)	10^{-0}	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
Permeability				Good				Low		Null	
Sediment type	Clean gravel			Clean sand, sand / gravel mix				Very fine sand, silt, silt and clay			Clay

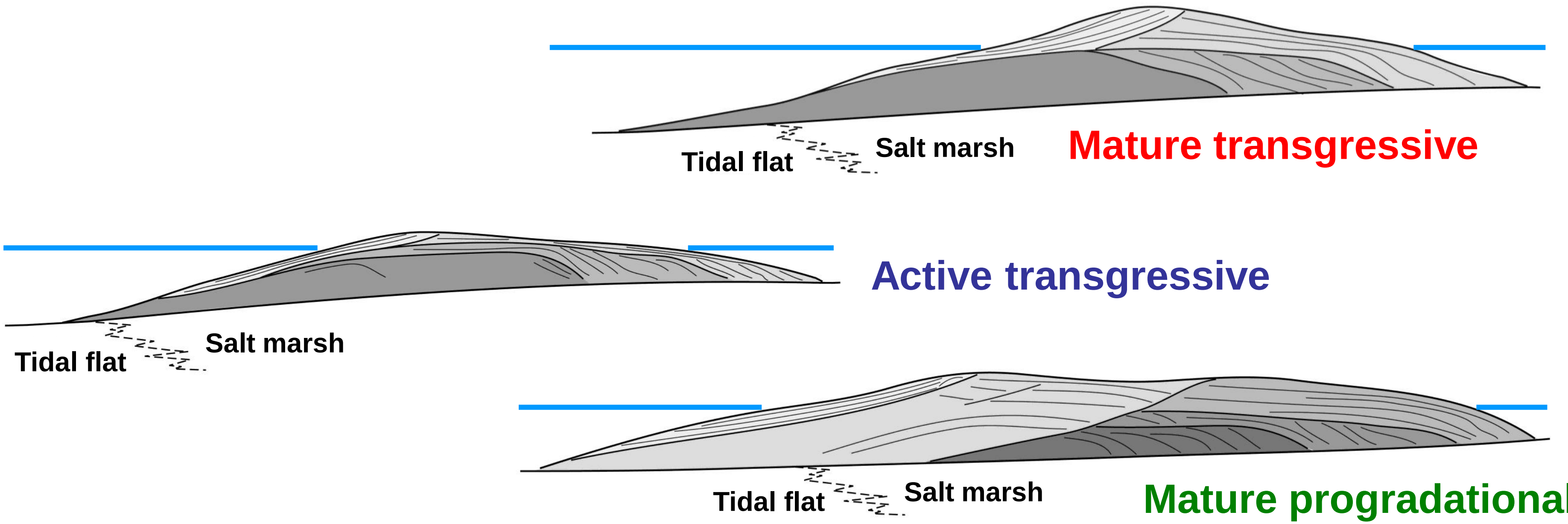
Geotechnical and lithological facies of radar units

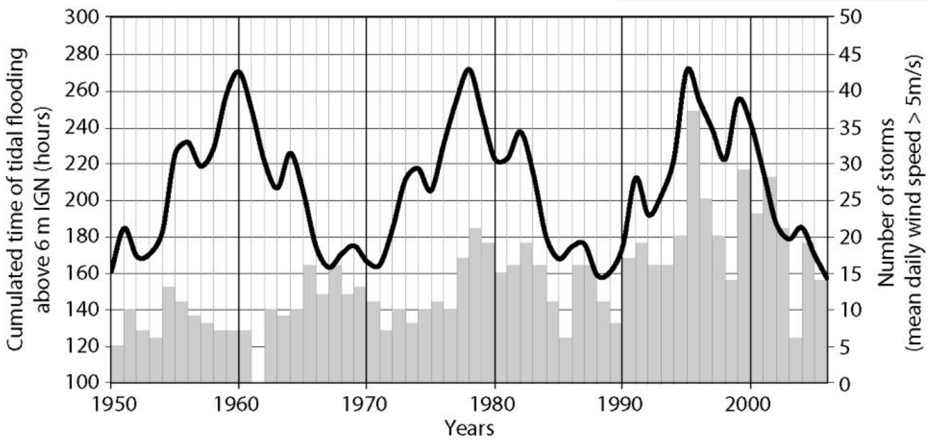


Weill et al. (in press)

k (m/s)	10^{-0}	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
	Good						Low	
Sediment type	Clean gravel		Clean sand, sand / gravel mix			Very fine sand, silt, silt and clay		


HST (110)
Box 2
Mature transgressive
Salt marsh
Tidal flat
HST (110)
Active transgressive
Box 1
Salt marsh
Tidal flat
2 m
1
0
0
5
10 m
Mature progradational
HST (110)
Box 3
Salt marsh
Tidal flat
Seaward
Landward





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

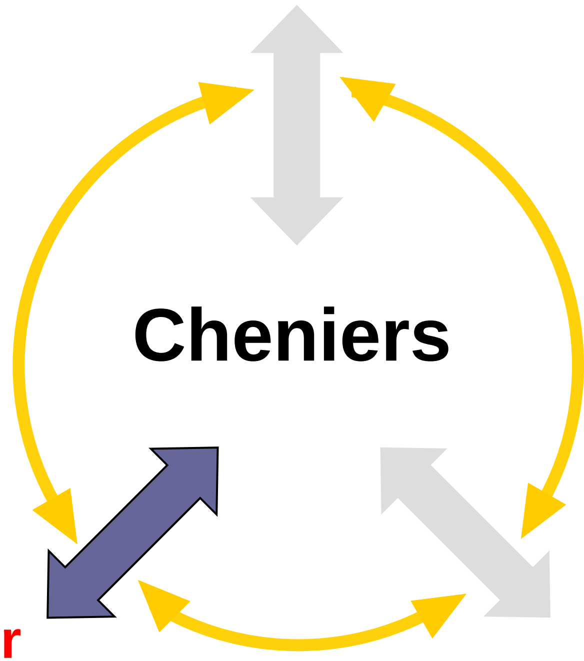
Influence of low frequency tidal cycles (4.5 and 18.6 years) ?
(peak periods → massive sediment reworking by waves)

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



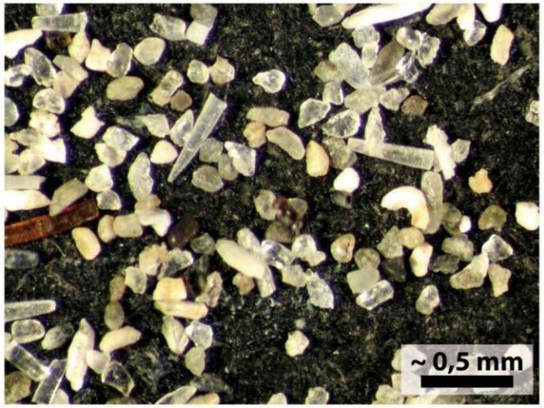
Wave flume
experimental model

Lab work
Sediment behaviour
Settling velocity
Threshold of motion

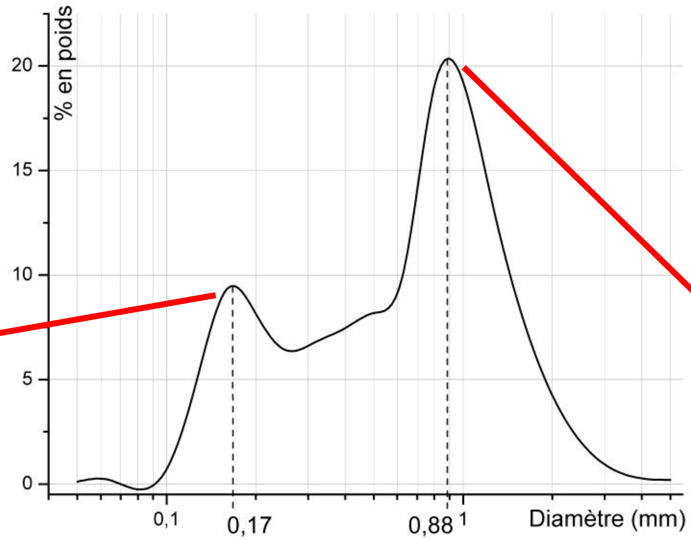
Sediment composition and sieve size distribution

Sediment sampled in the field

Bimodal distribution



Fine silicoclastic fraction



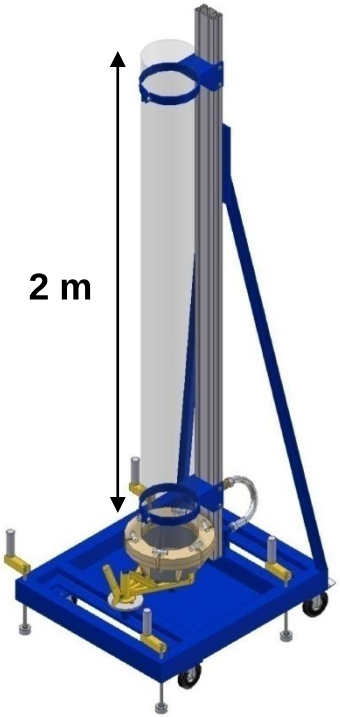
Coarse bioclastic fraction

Meaning of the sieve diameter for shell debris ?

Settling velocities converted into **equivalent settling diameters**

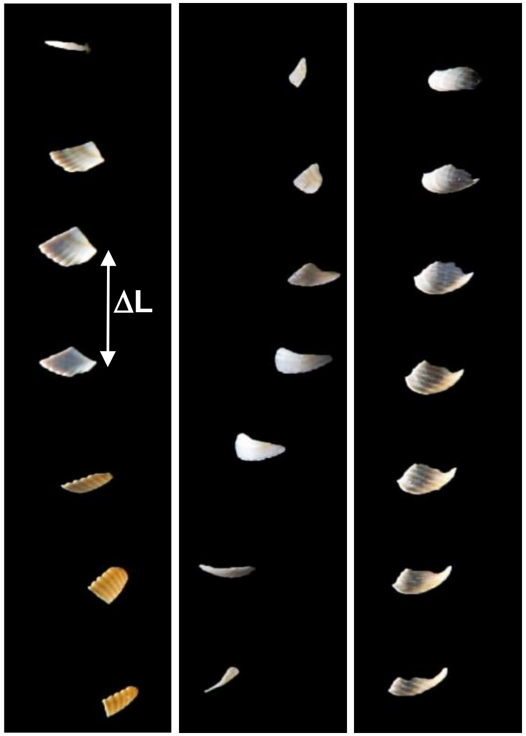
Bioclastic particles : **flat** shape

→ **Small settling velocity** and equivalent diameter

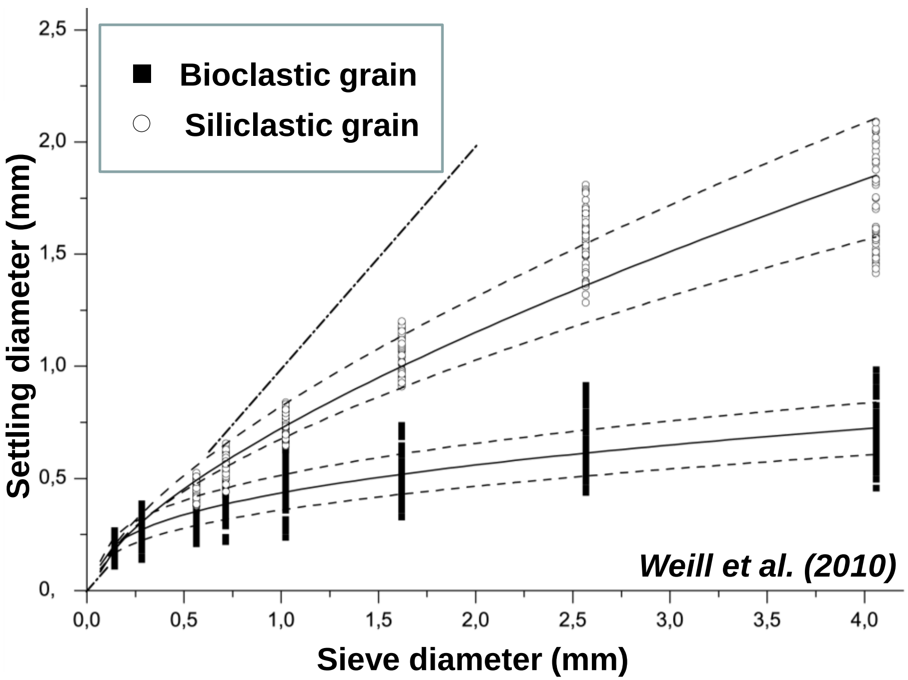


Design: Sylvain Haquin

Stroboscopic photographs (5 Hz)



→ $V = \Delta L / \Delta t$

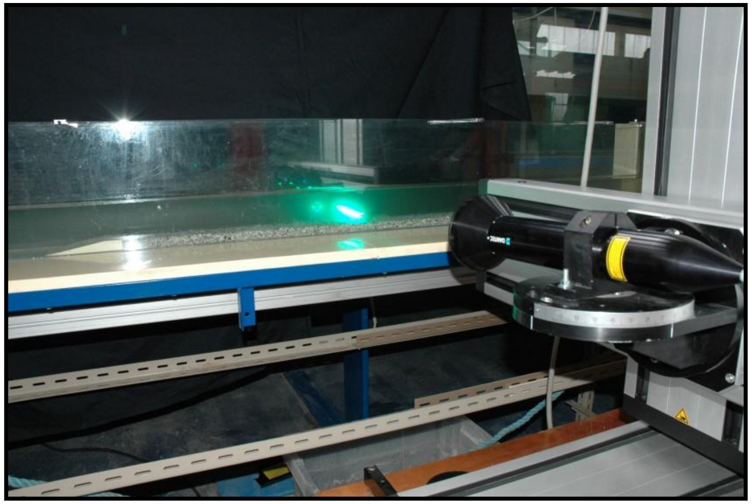


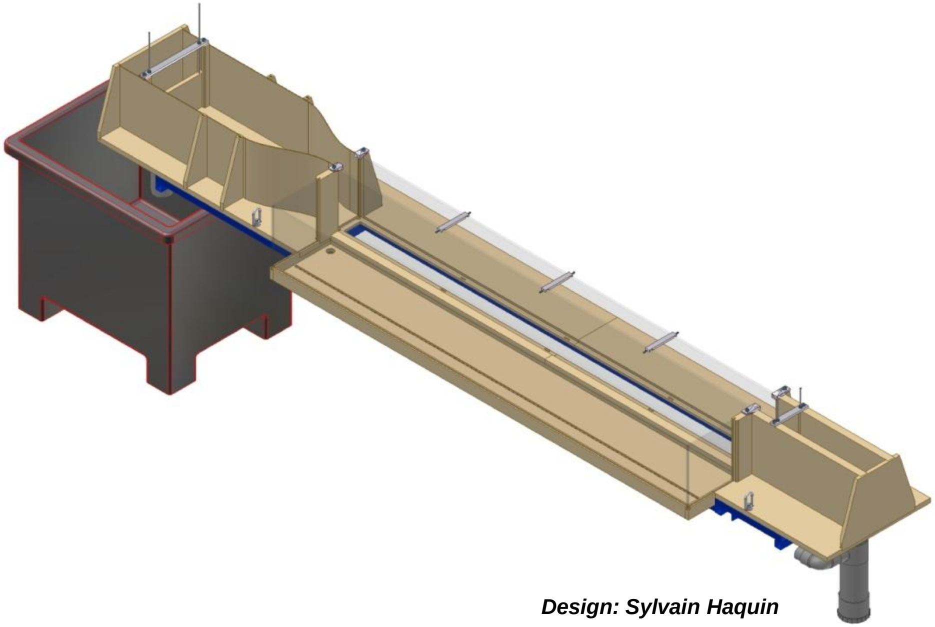
Threshold of motion under unidirectional current

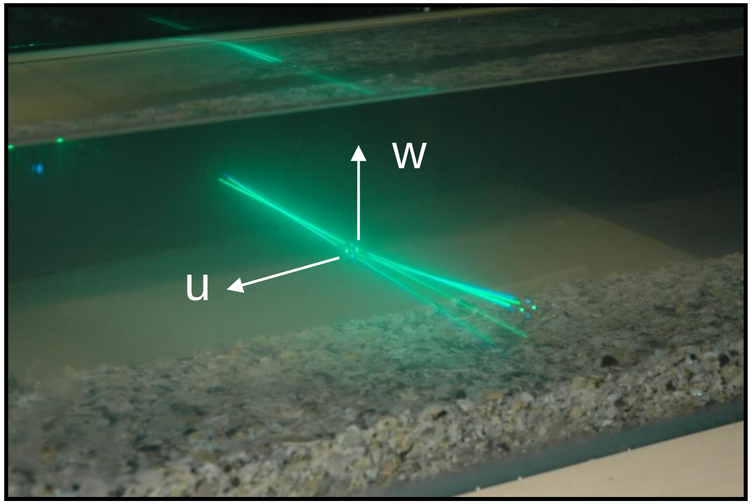
Sieved sediment in flat bed

Unidirectional current generated

Velocity and turbulence profiles using Laser Doppler Anemometry (LDA)







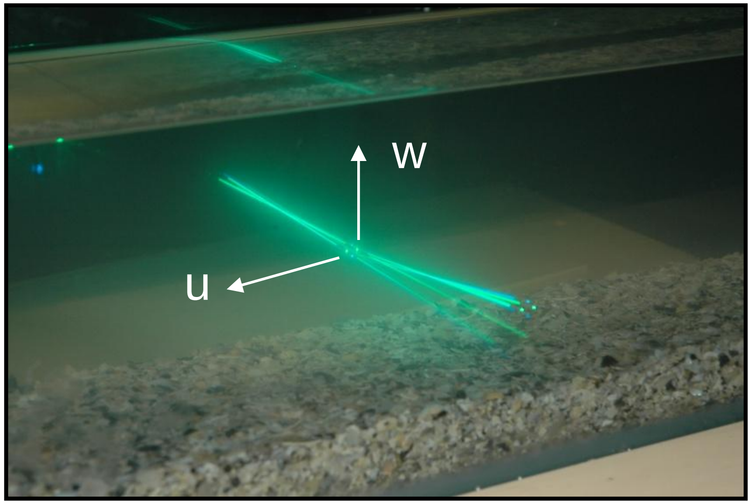
Design: Sylvain Haquin

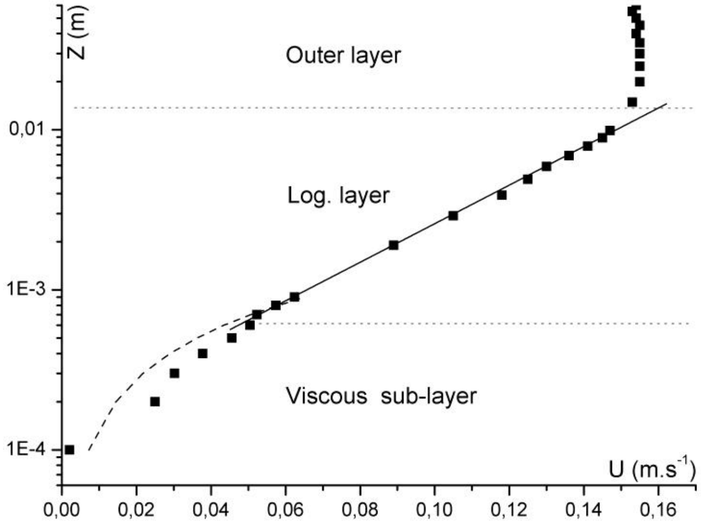
Threshold of motion under unidirectional current

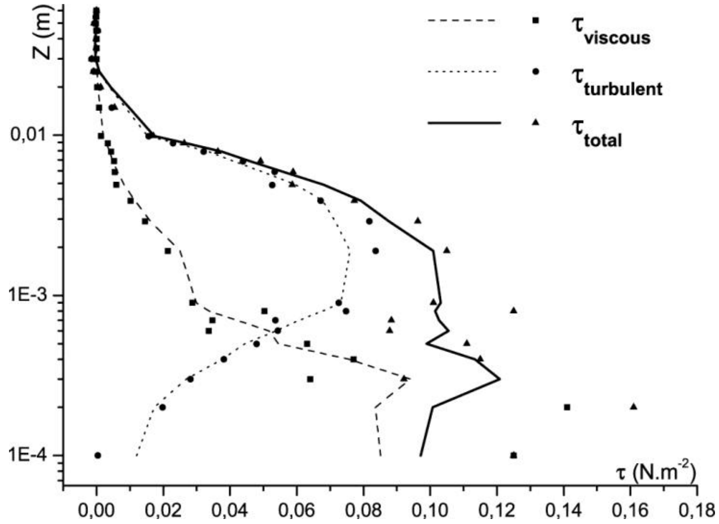
Velocity and turbulence profiles using Laser Doppler Anemometry (LDA)

Velocity and stress profiles

Critical velocity and shear stress for sediment motion







Threshold of motion for bioclastic sediment :

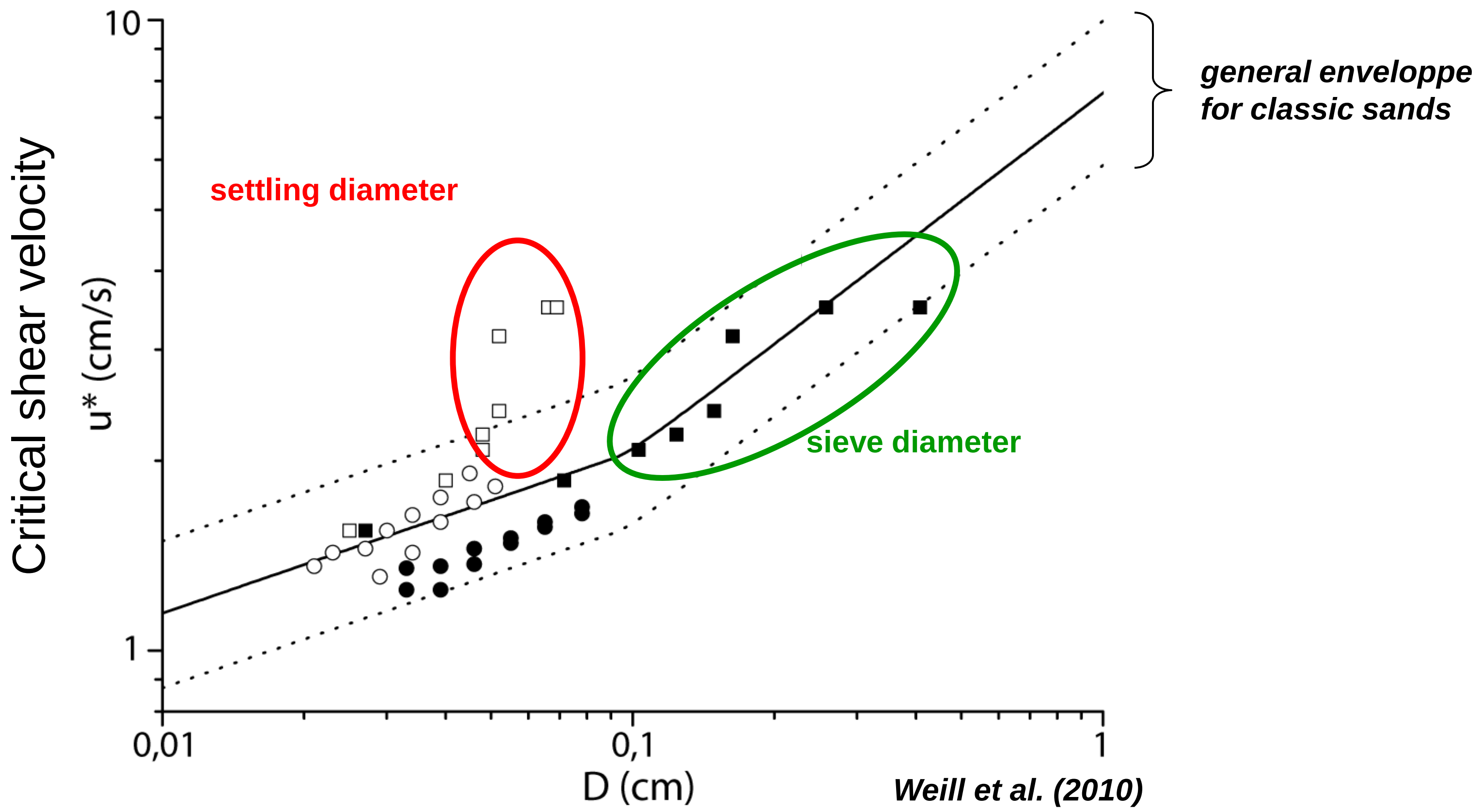
- close to common values with sieve diameter

- 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

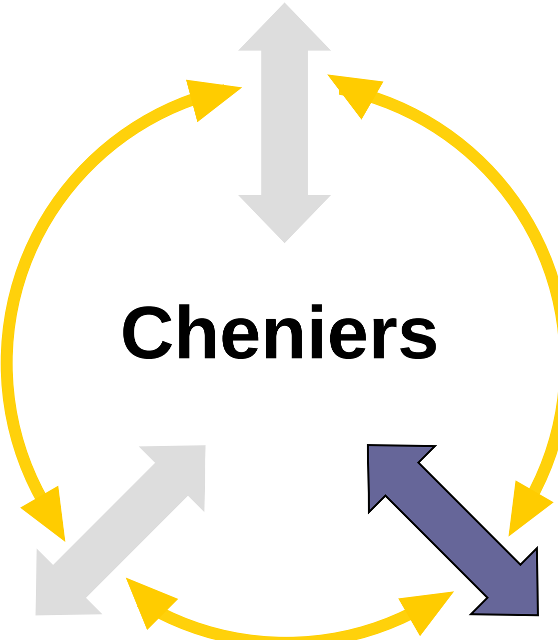


Weill et al. (2010)

Questions...

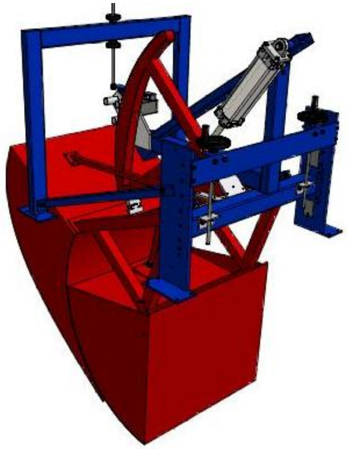
Sediment behaviour in breaker zone, swash zone, overwash ?

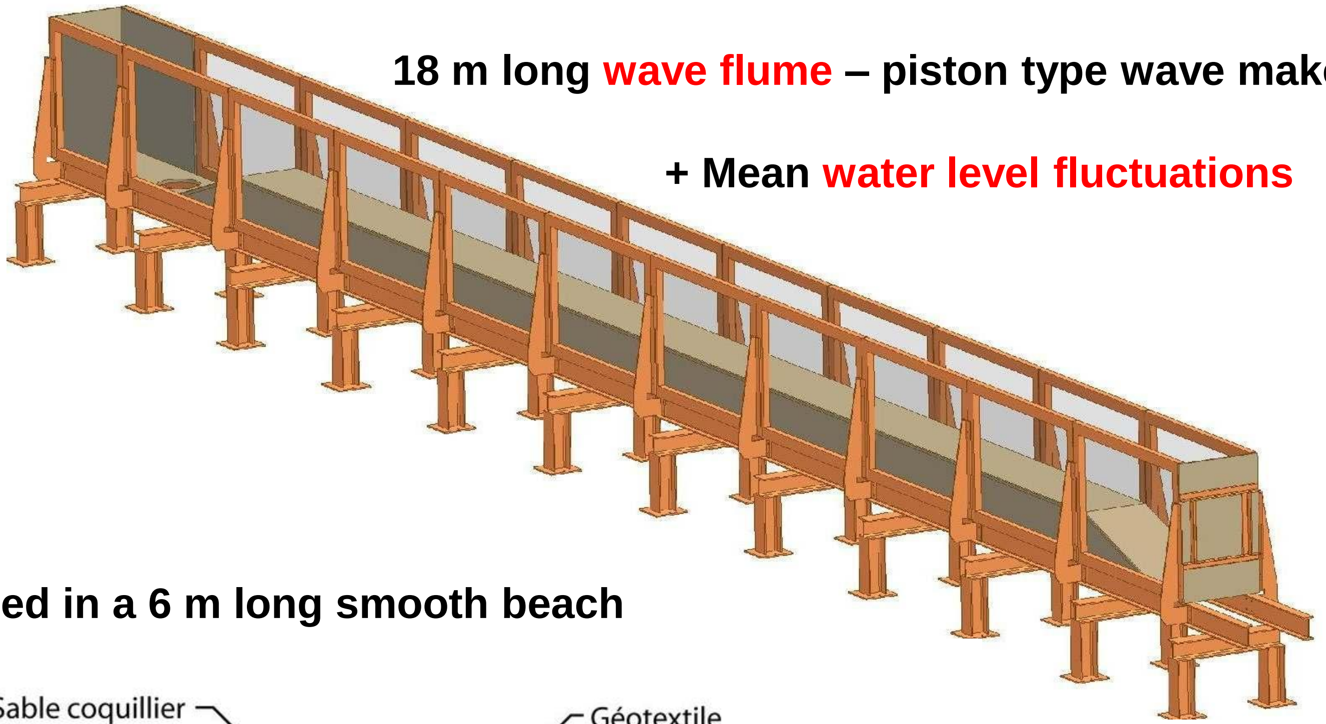
Field work – Sedimentary architecture



Lab work
Sediment behaviour

Wave flume
experimental model

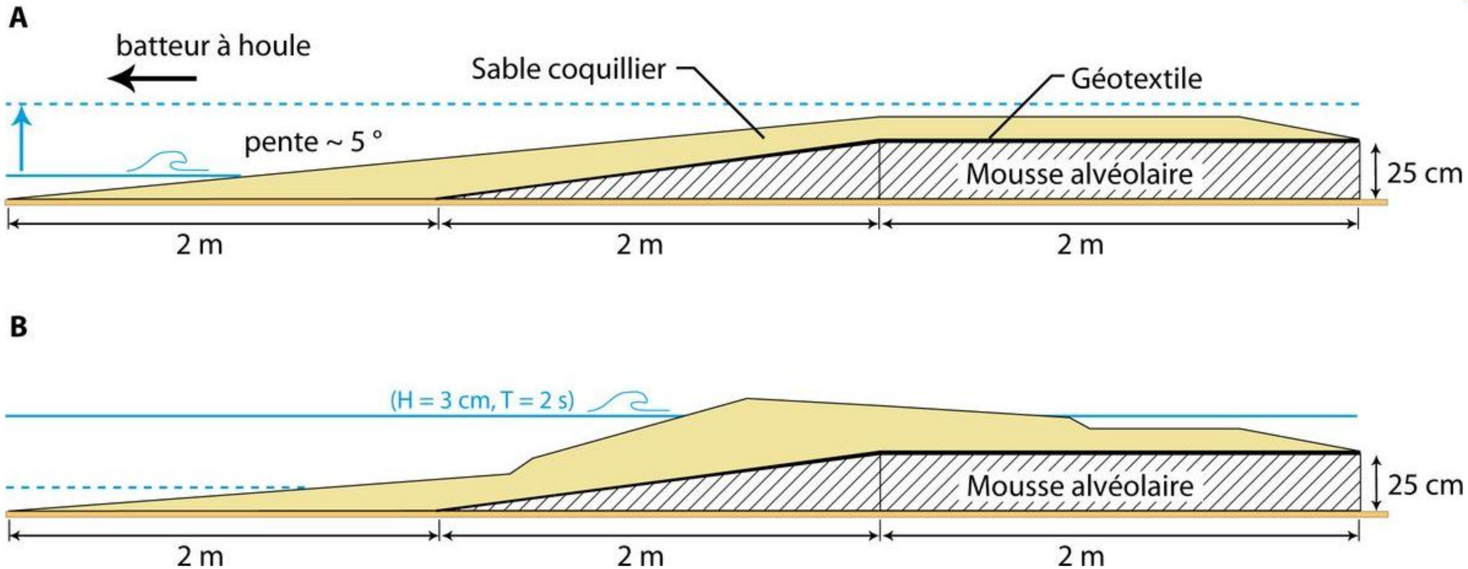




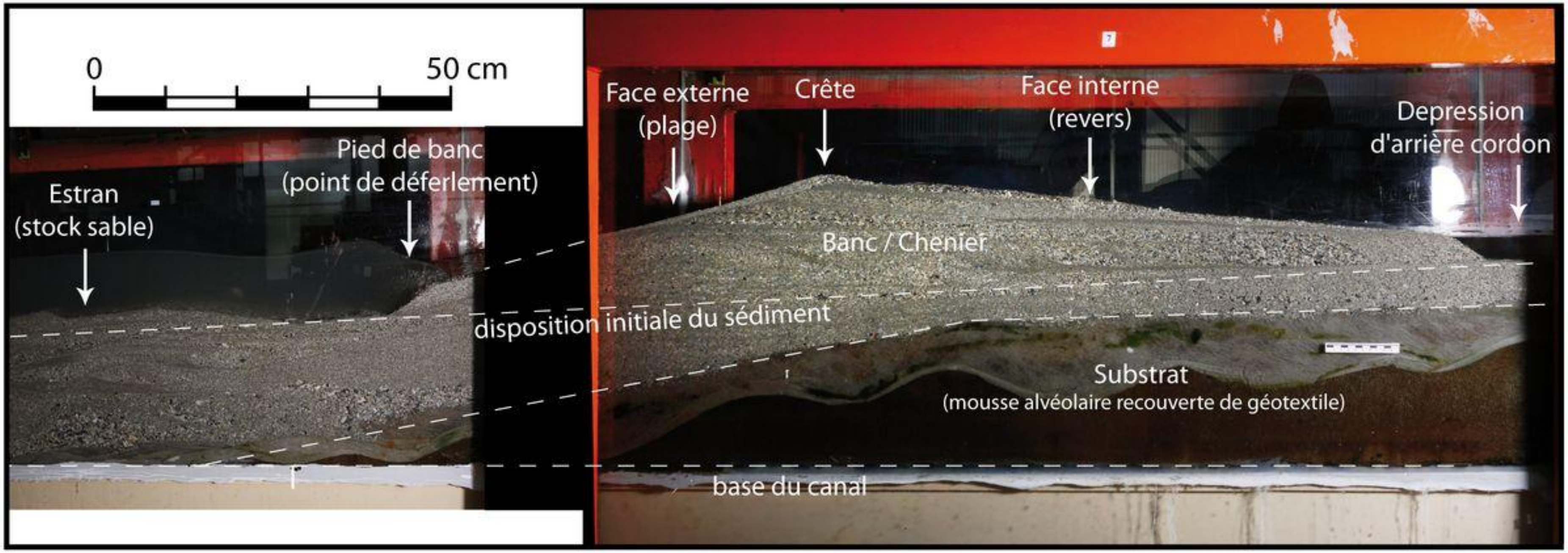
18 m long wave flume – piston type wave maker

+ Mean water level fluctuations

Natural sediment shaped in a 6 m long smooth beach

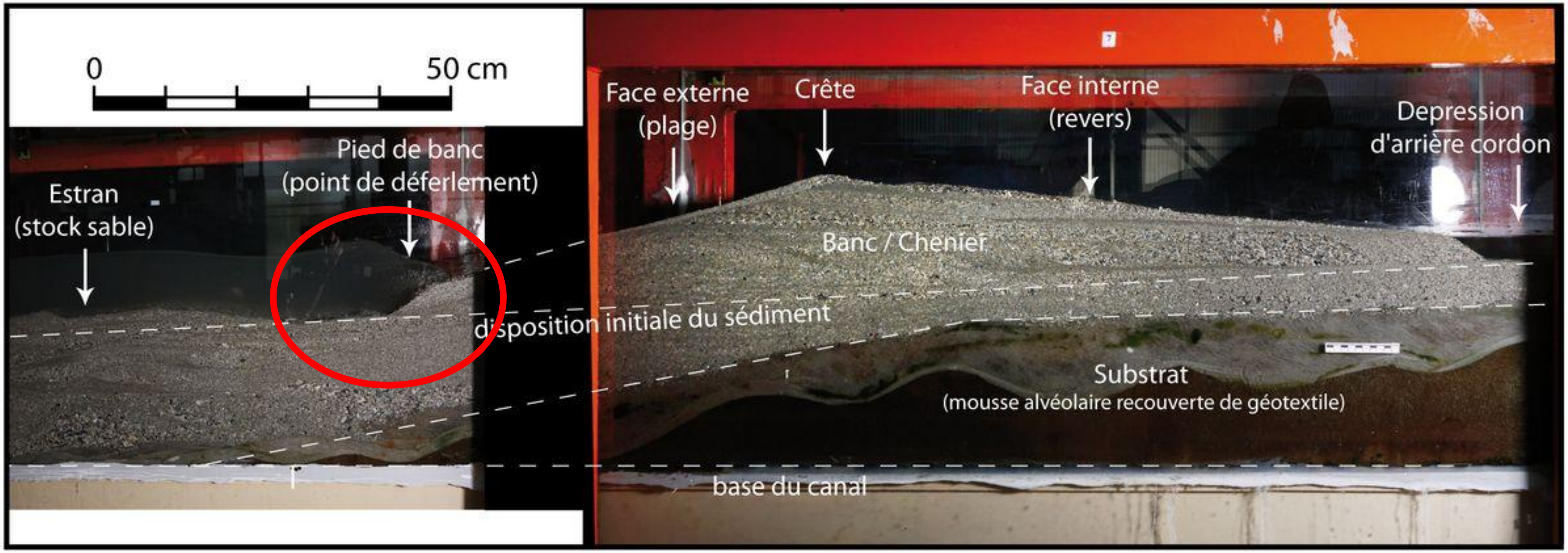


Equilibrium morphology



Montage of 2 photographs taken through the side glass of the flume

Breaker zone → Chenier foot



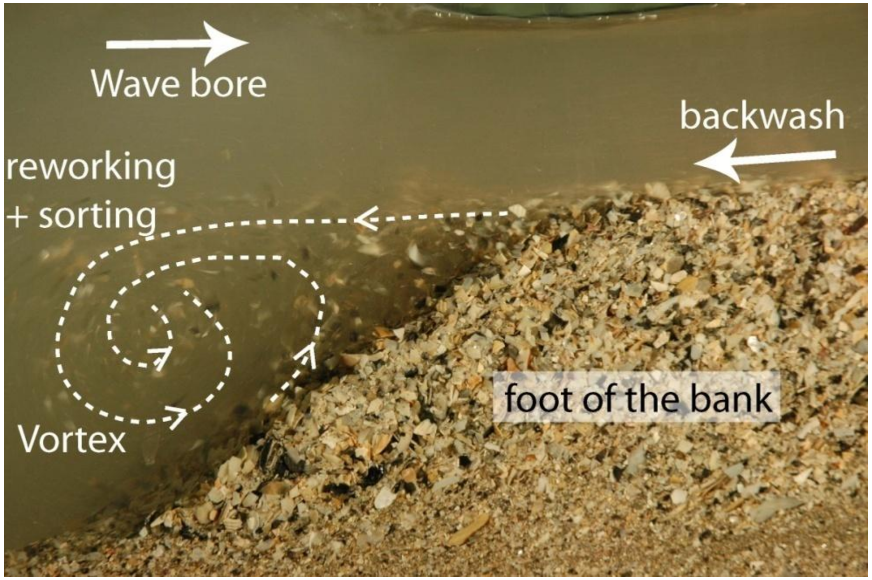
Breaker zone

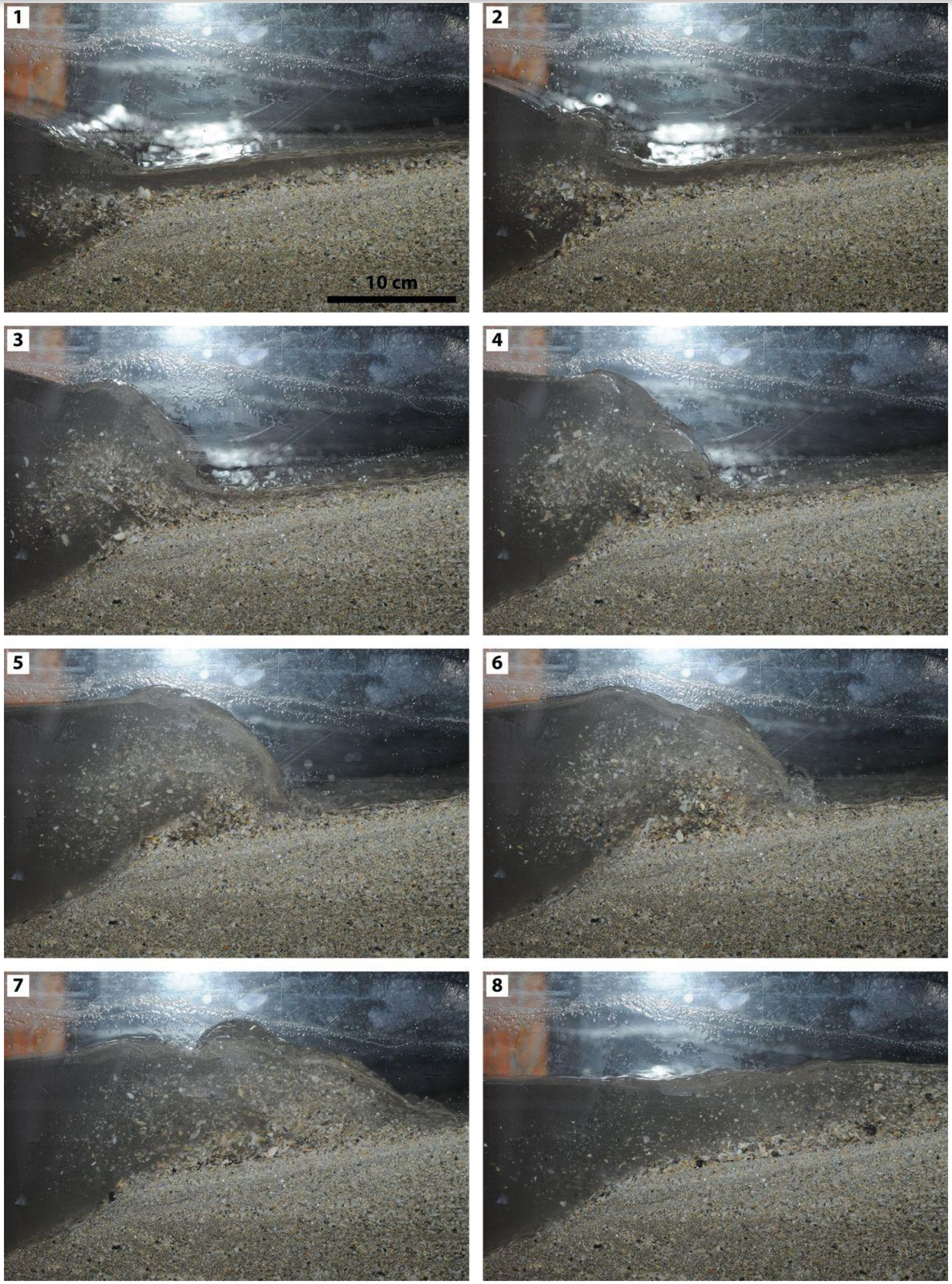
No surf zone – Surging breaker

Intense erosion – Topographic step

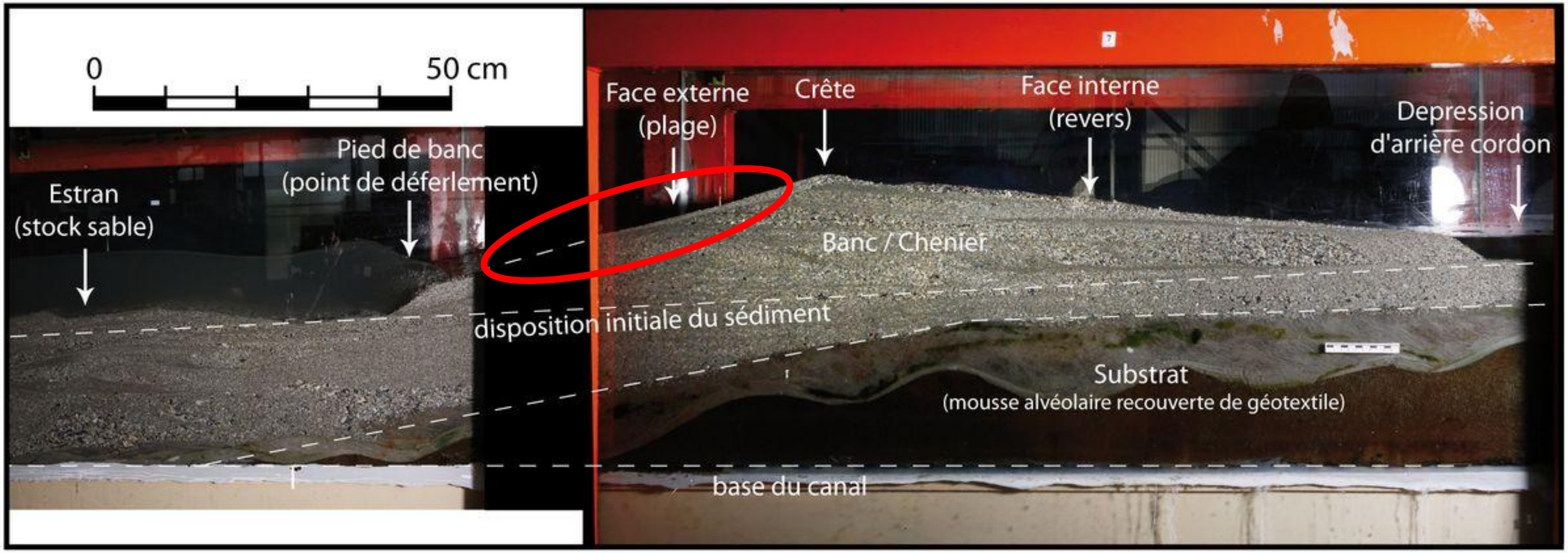
Sediment eroded, sorted and transported in the swash zone

Coarse bioclastic particles easily sorted





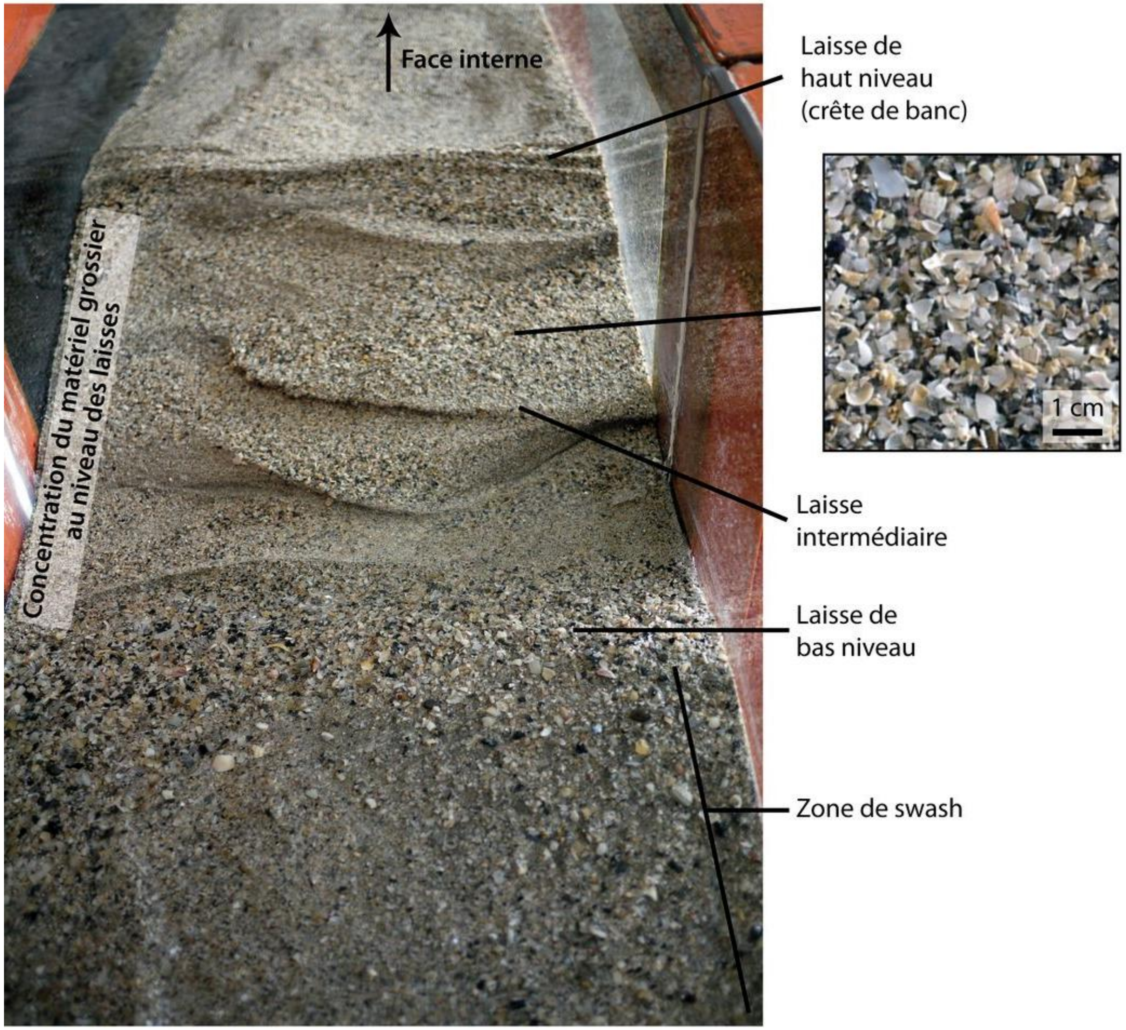
Swash zone – Chenier seaward face (beach)



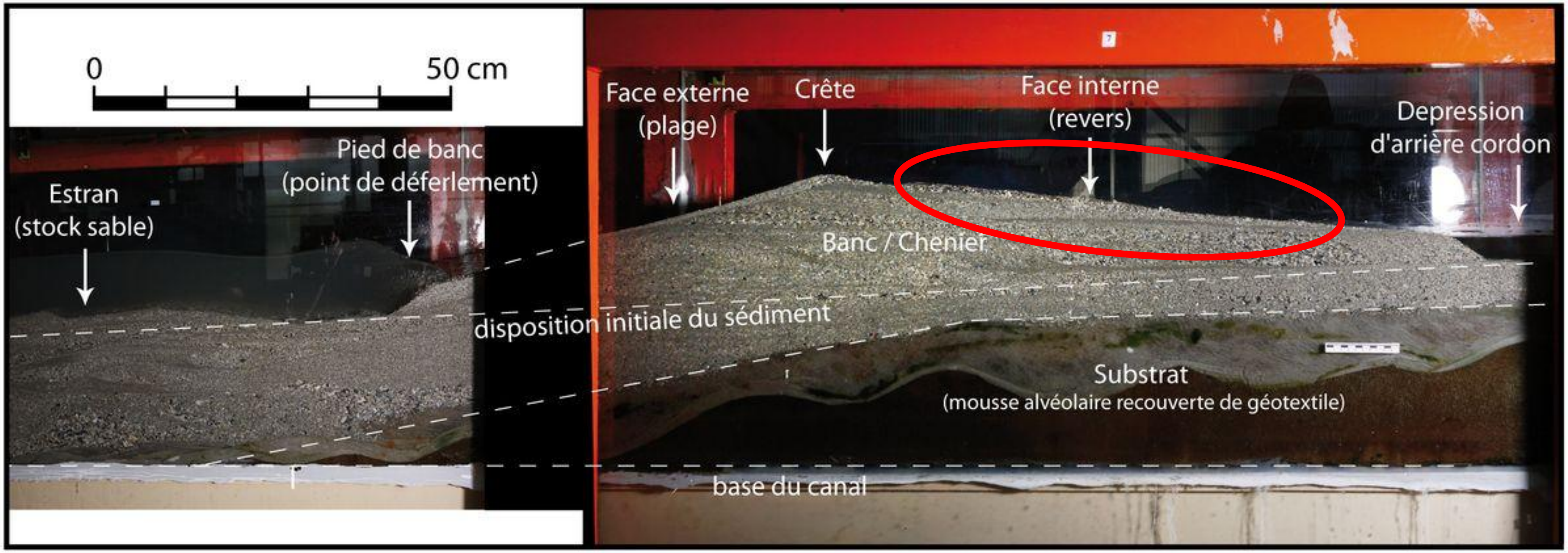
Swash zone
Chenier seaward face (beach)

Coarse sediment transported and deposited in the upper swash zone

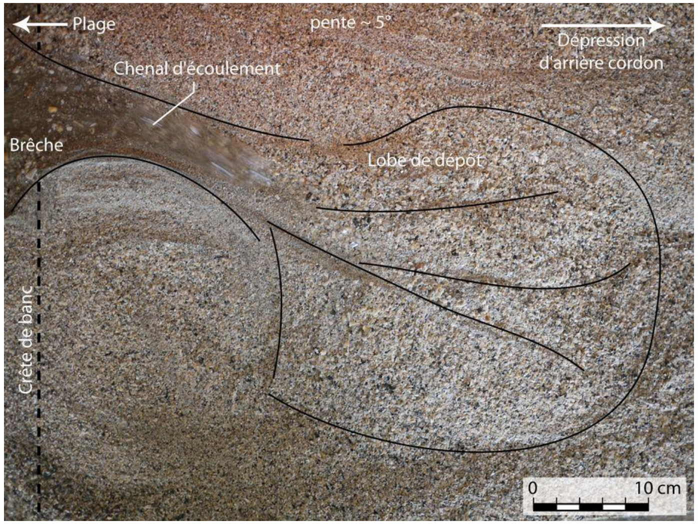
Fine sediment left in the lower swash zone

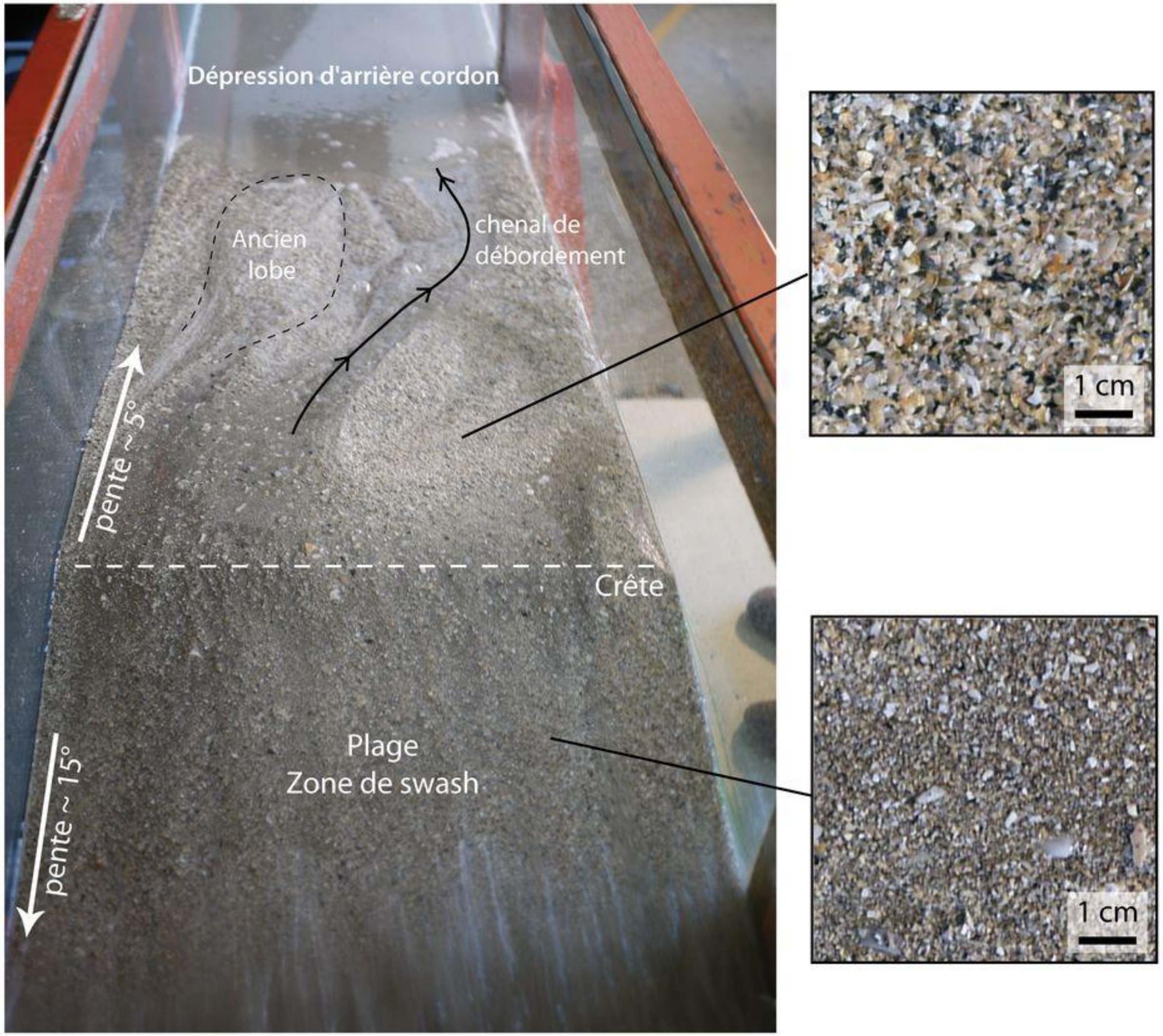


Washover zone – Chenier landward face

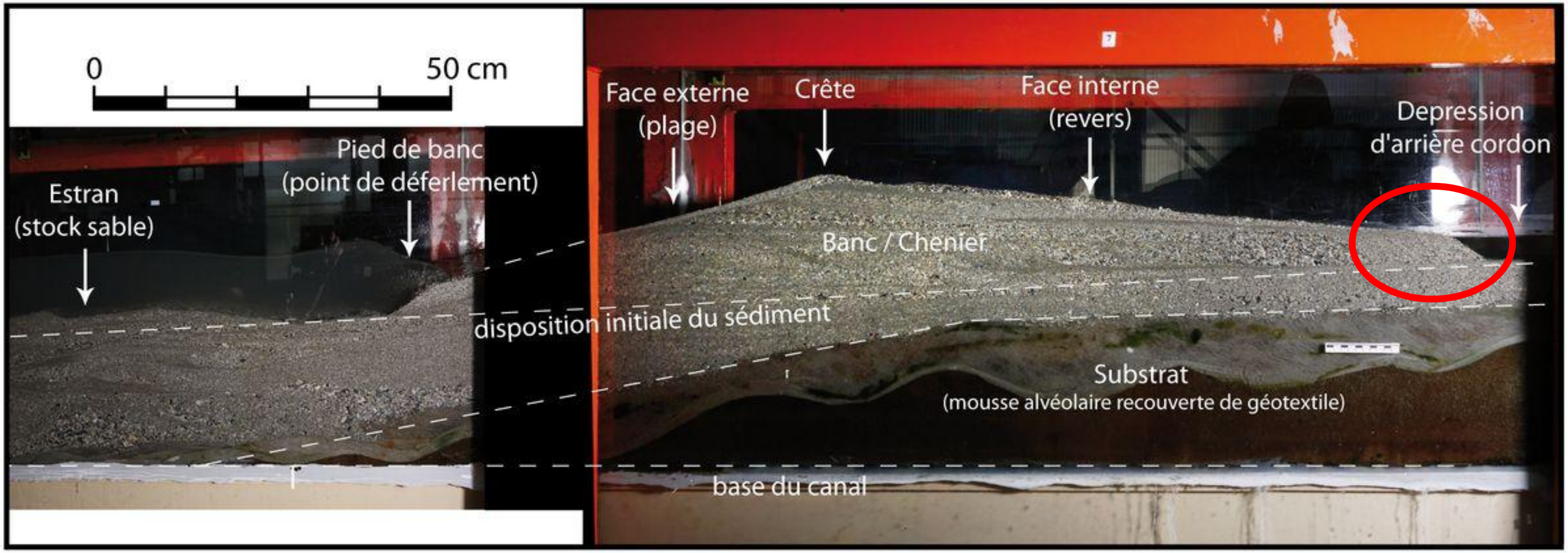


Washover zone – Chenier landward face

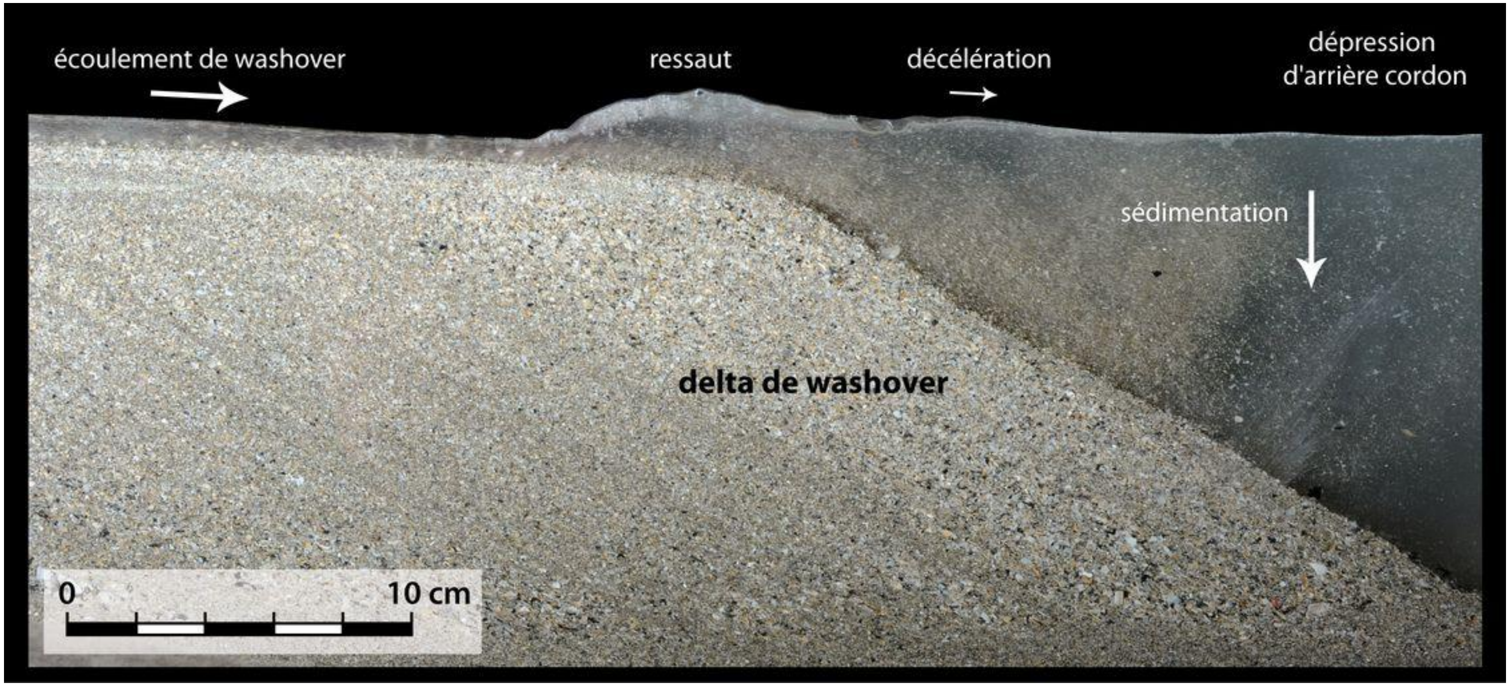




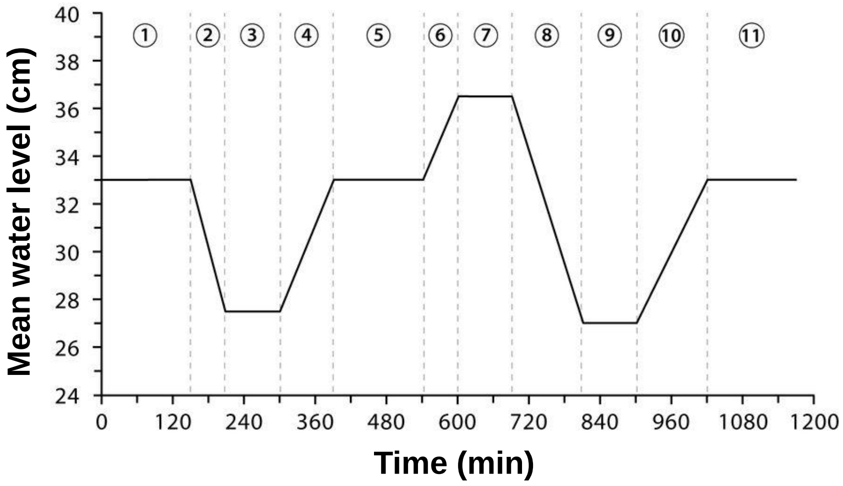
Washover zone – Chenier landward face

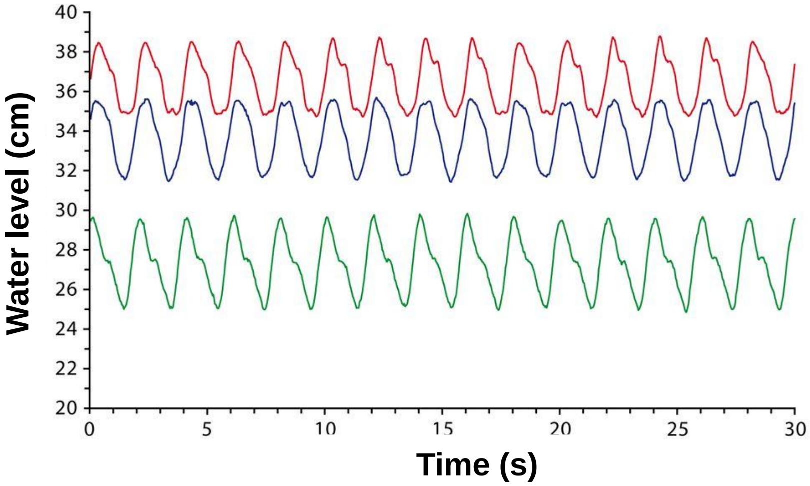


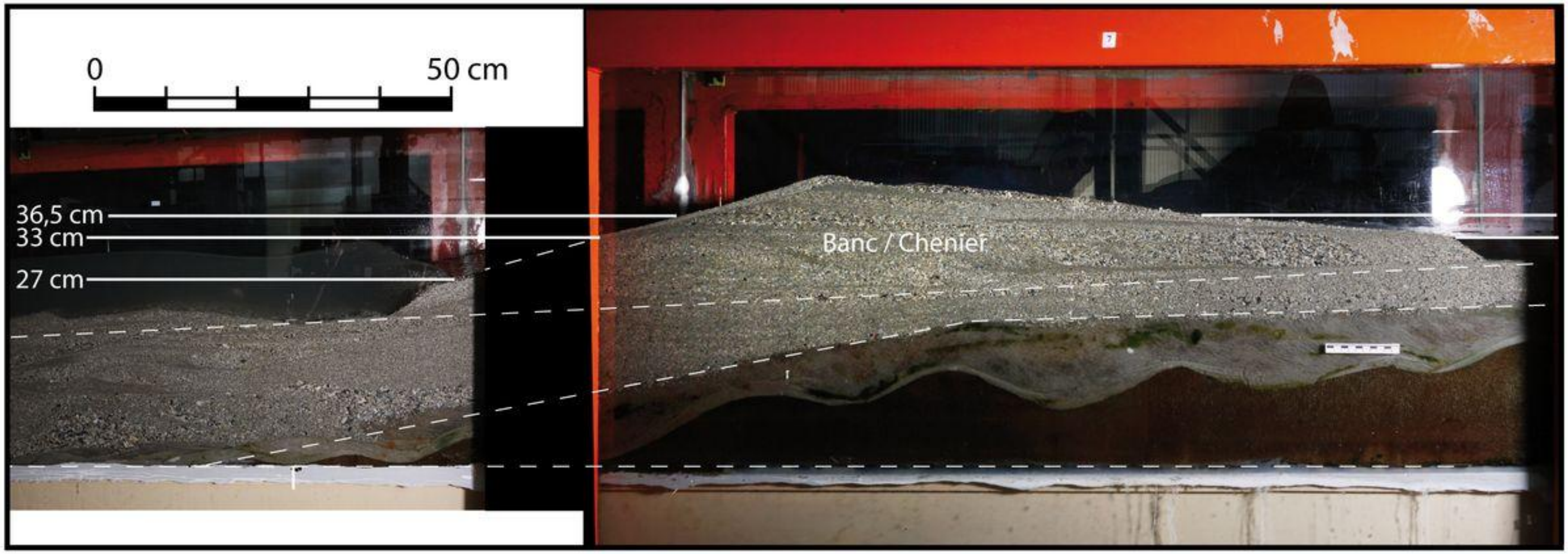
Washover zone – Chenier landward face



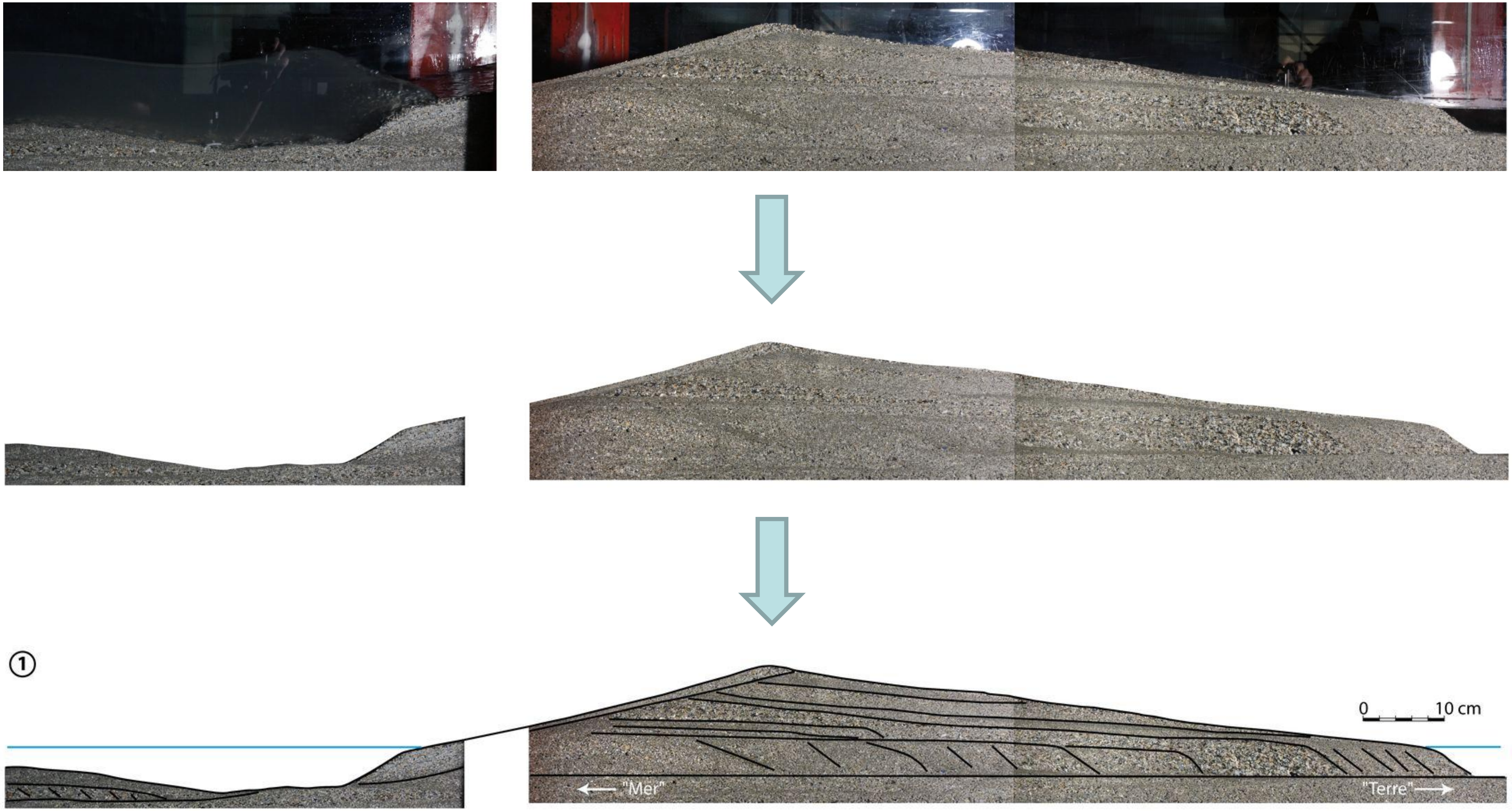
Morphological response to mean water level fluctuations



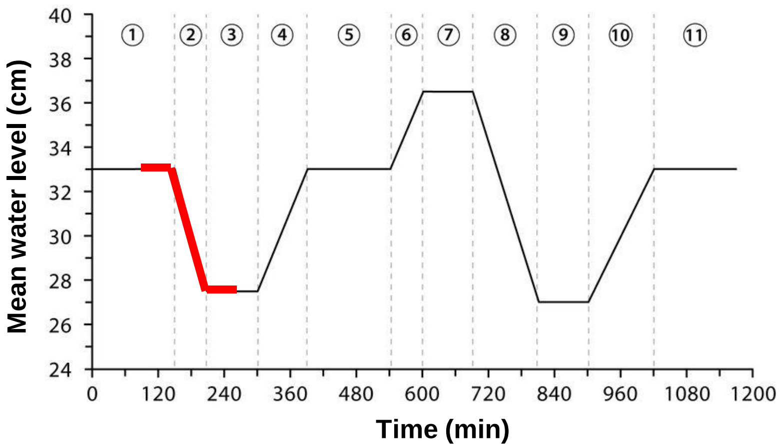




Morphological response to mean water level fluctuations

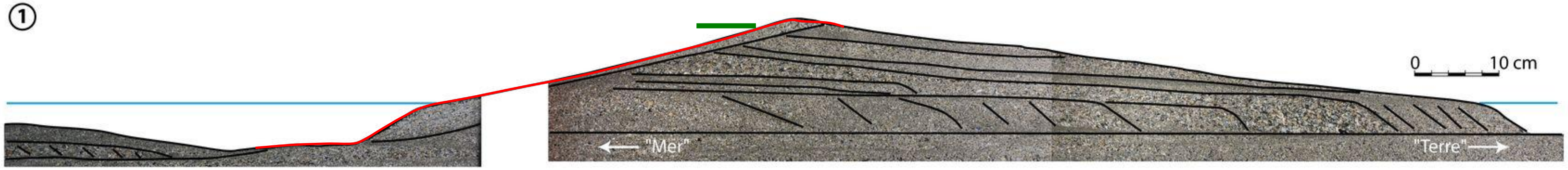


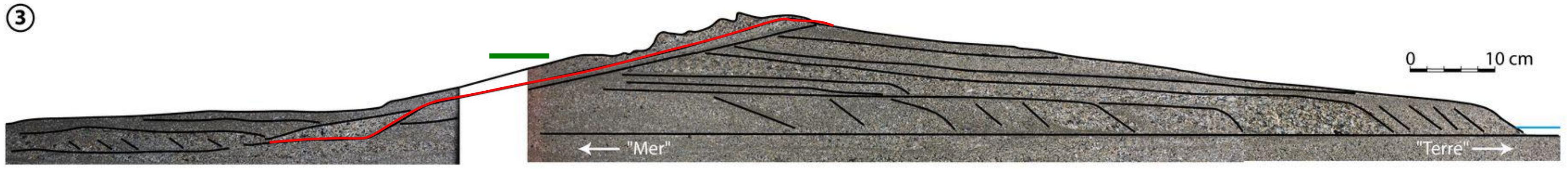
Falling water level



→ **Small ridge formation seaward of the chenier**

→ **New sediment stock at the chenier foot**

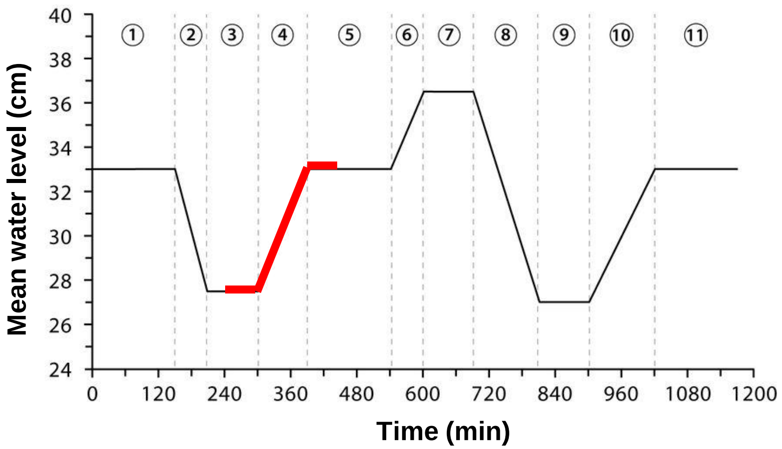


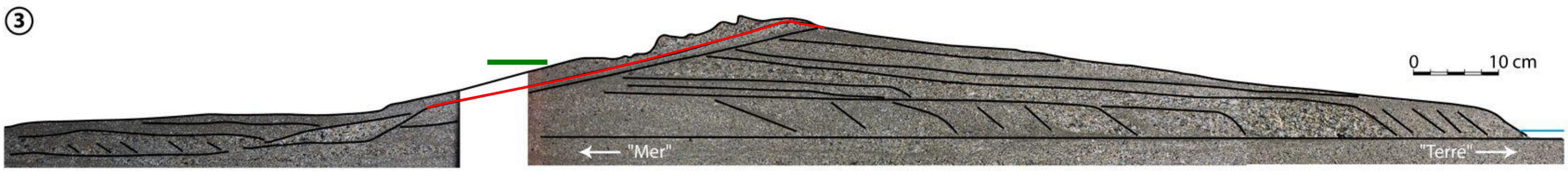


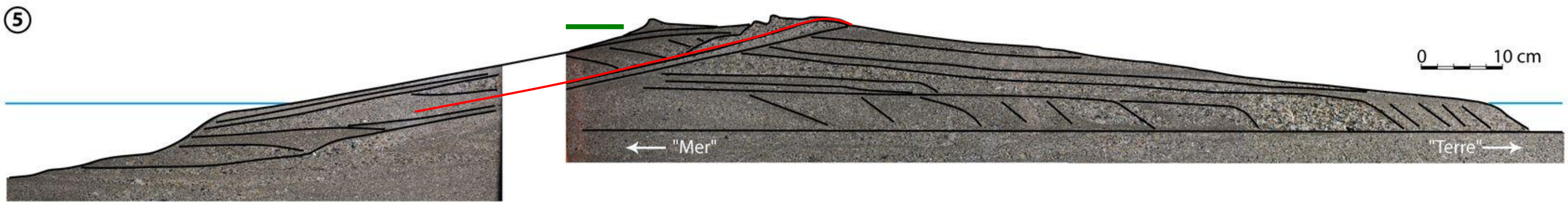
Rising water level

→ **Sediment stock reworked**

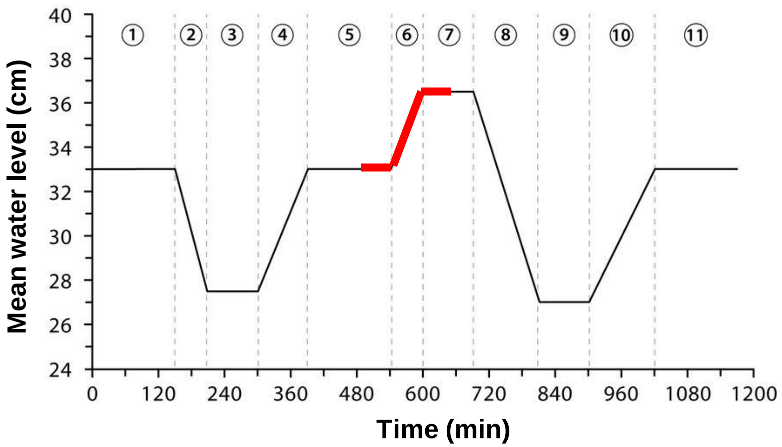
→ **Beach accretion**





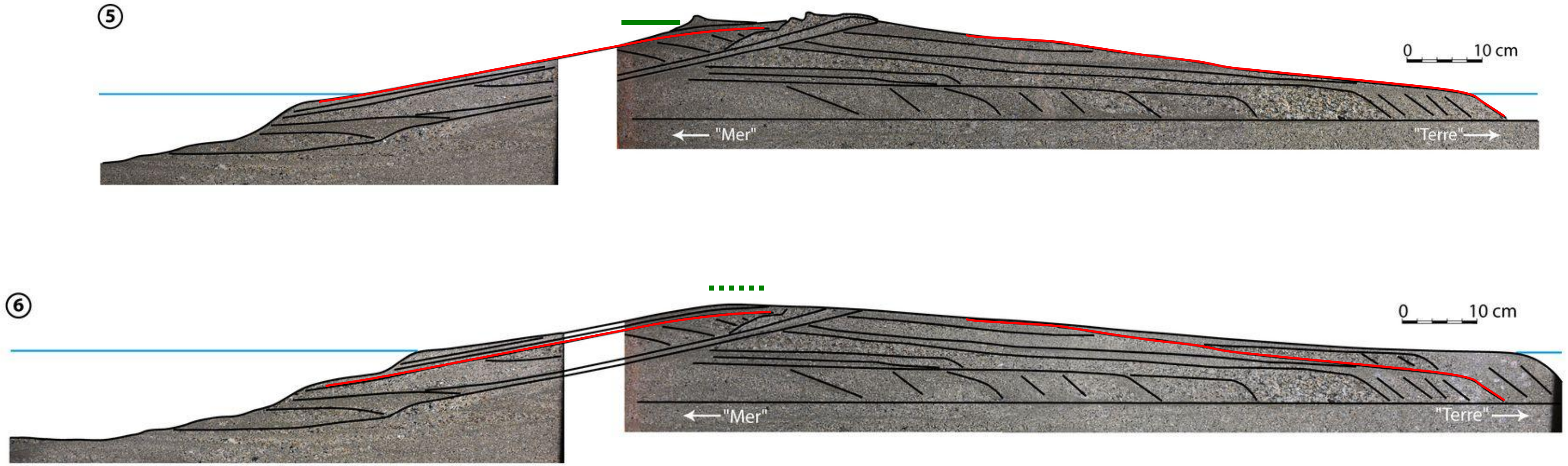


Rising water level

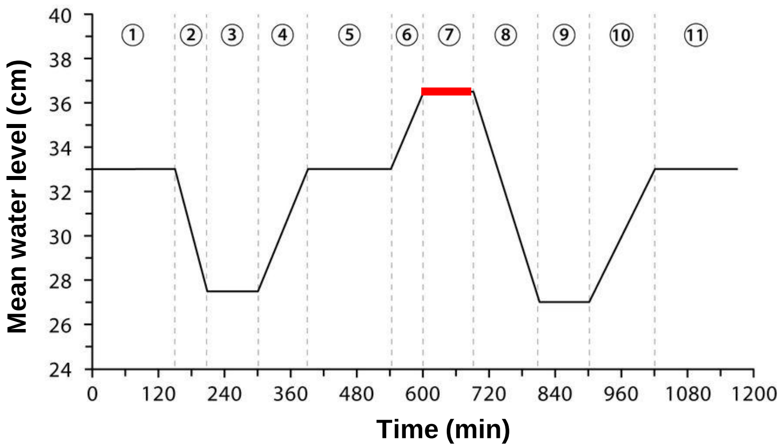


→ **Chenier foot erosion and migration**

→ **Washover**

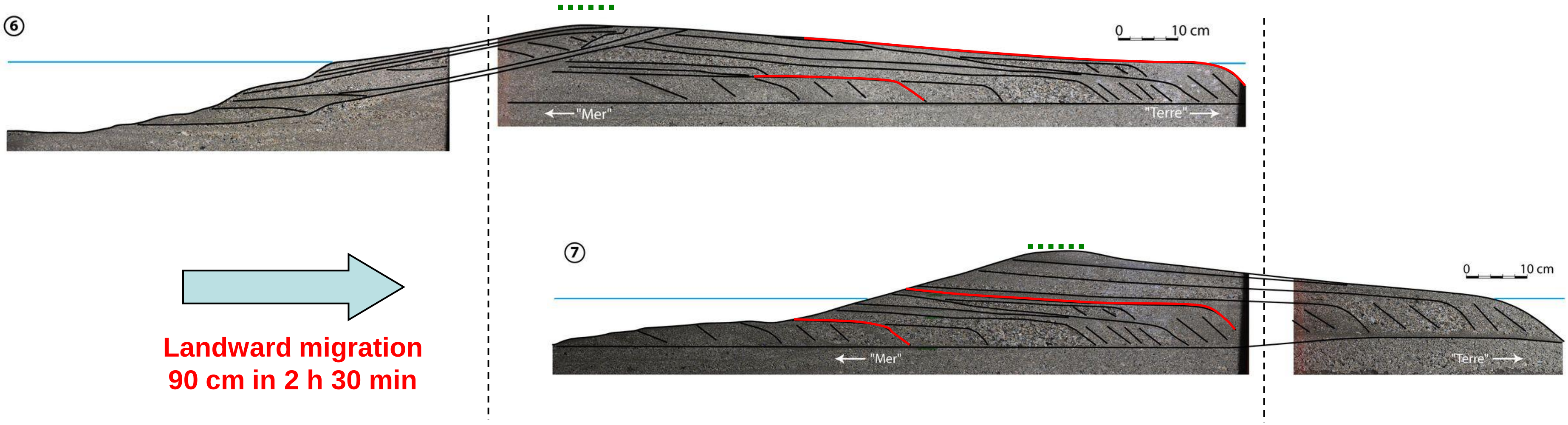


Very high water level



→ Large washover

→ Chenier landward migration and vertical aggradation

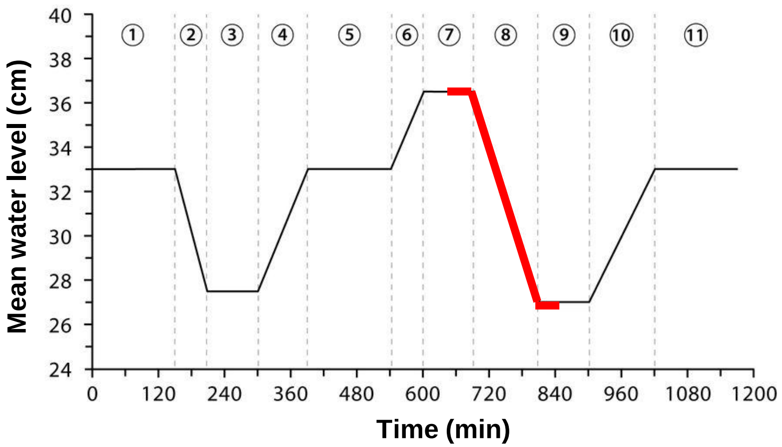


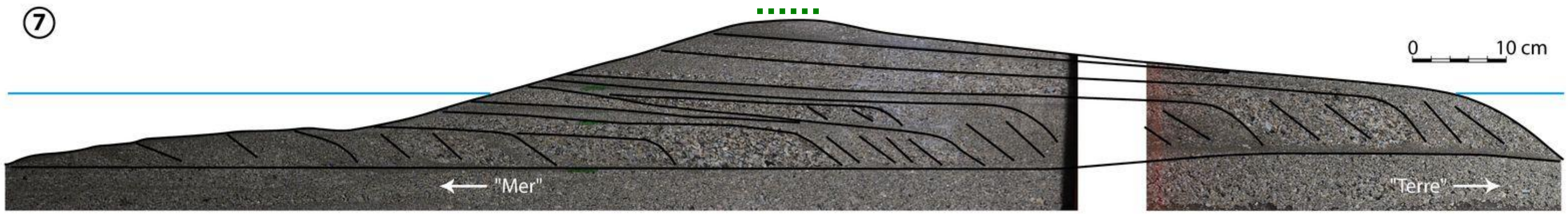
Landward migration
90 cm in 2 h 30 min

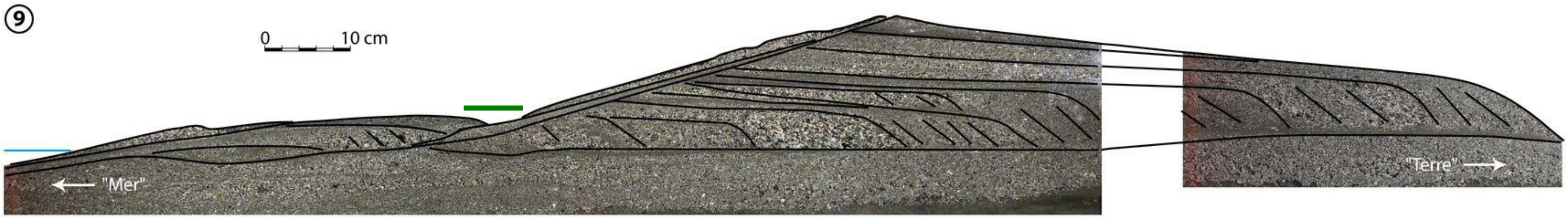
Falling water level

→ **Chenier stabilization**

→ **Sediment accumulation at the foot of the chenier**



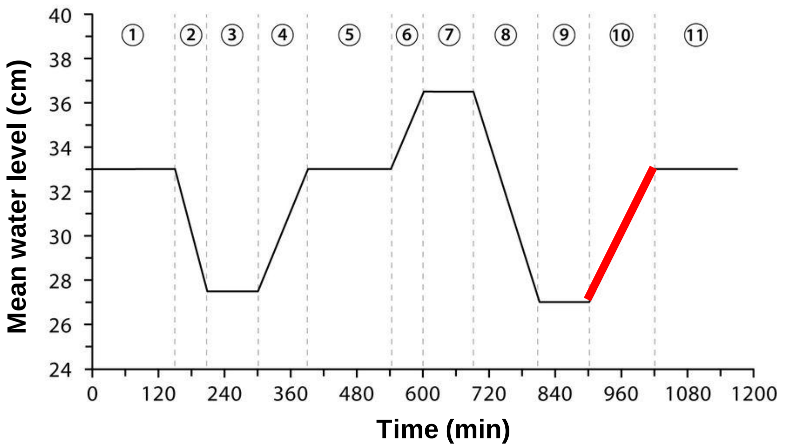


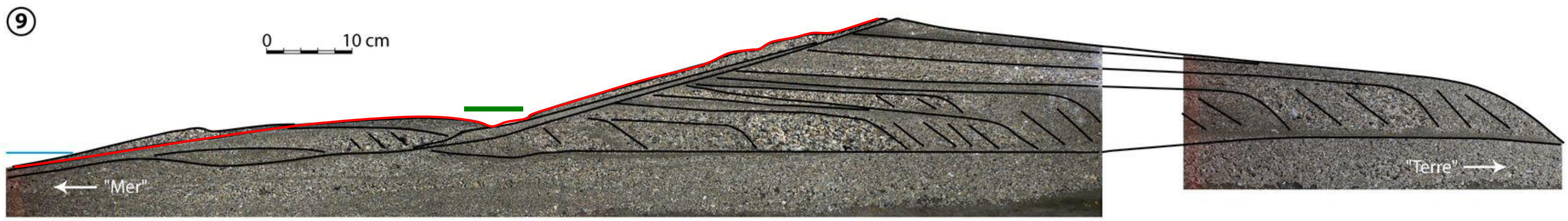


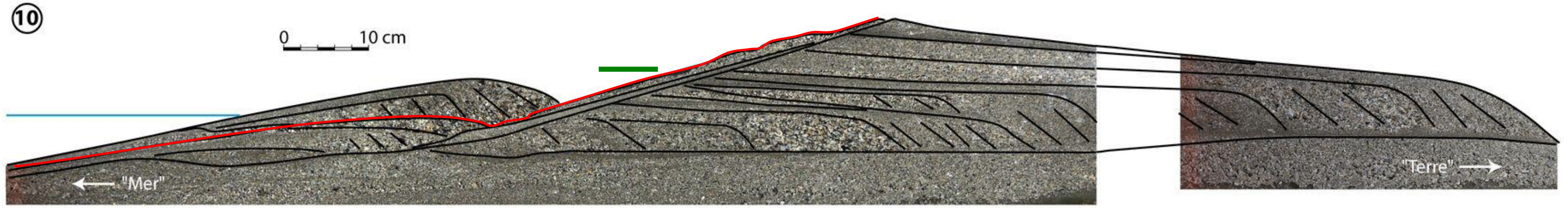
Rising water level

→ **Sediment stock reworked**

→ **Formation of a new ridge at the chenier foot**



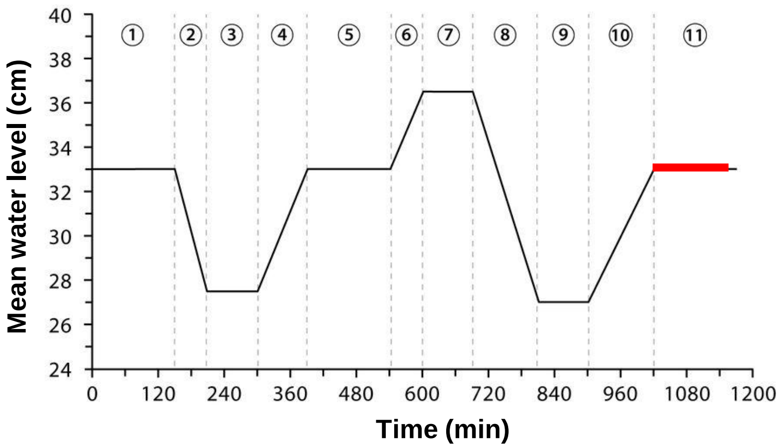


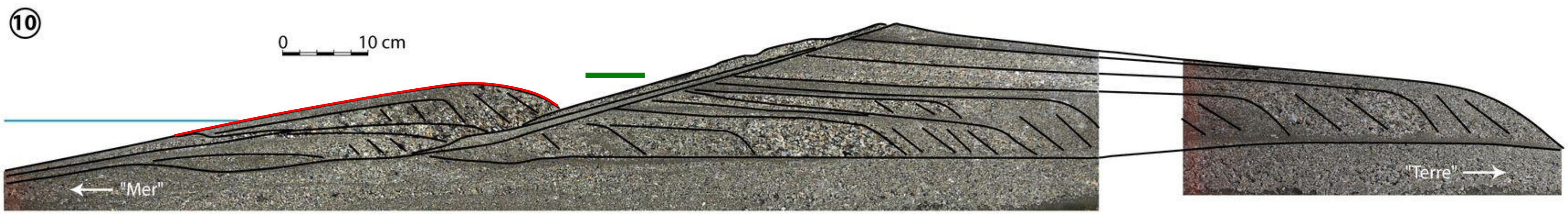


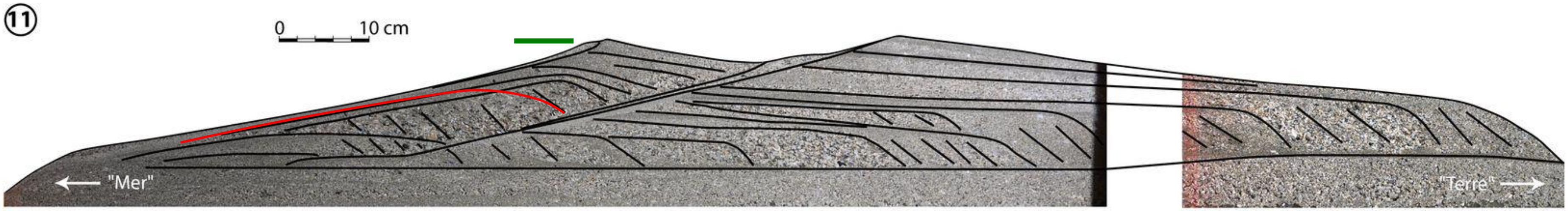
High water level

→ Migration of the new ridge on the chenier beach face

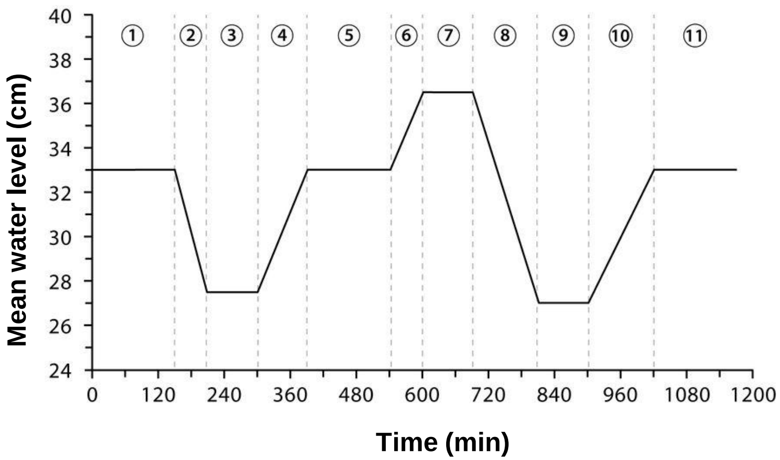
→ Stabilization of the ridge
Seaward progradation of the chenier







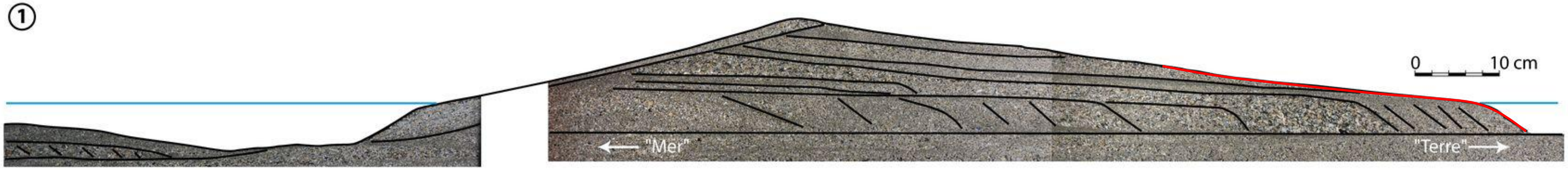
With constant monochromatic waves
+
Mean water level fluctuation



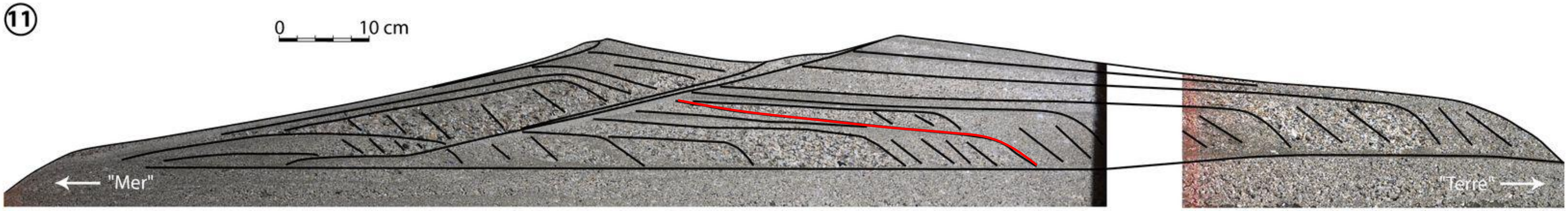
- → **Chenier ridge morphology**
- → **Washover dynamic**
- → **Sedimentation style controlled by water level**
- → **Chenier landward migration**
- → **Chenier progradation**

→ **Striking similarities with field data**

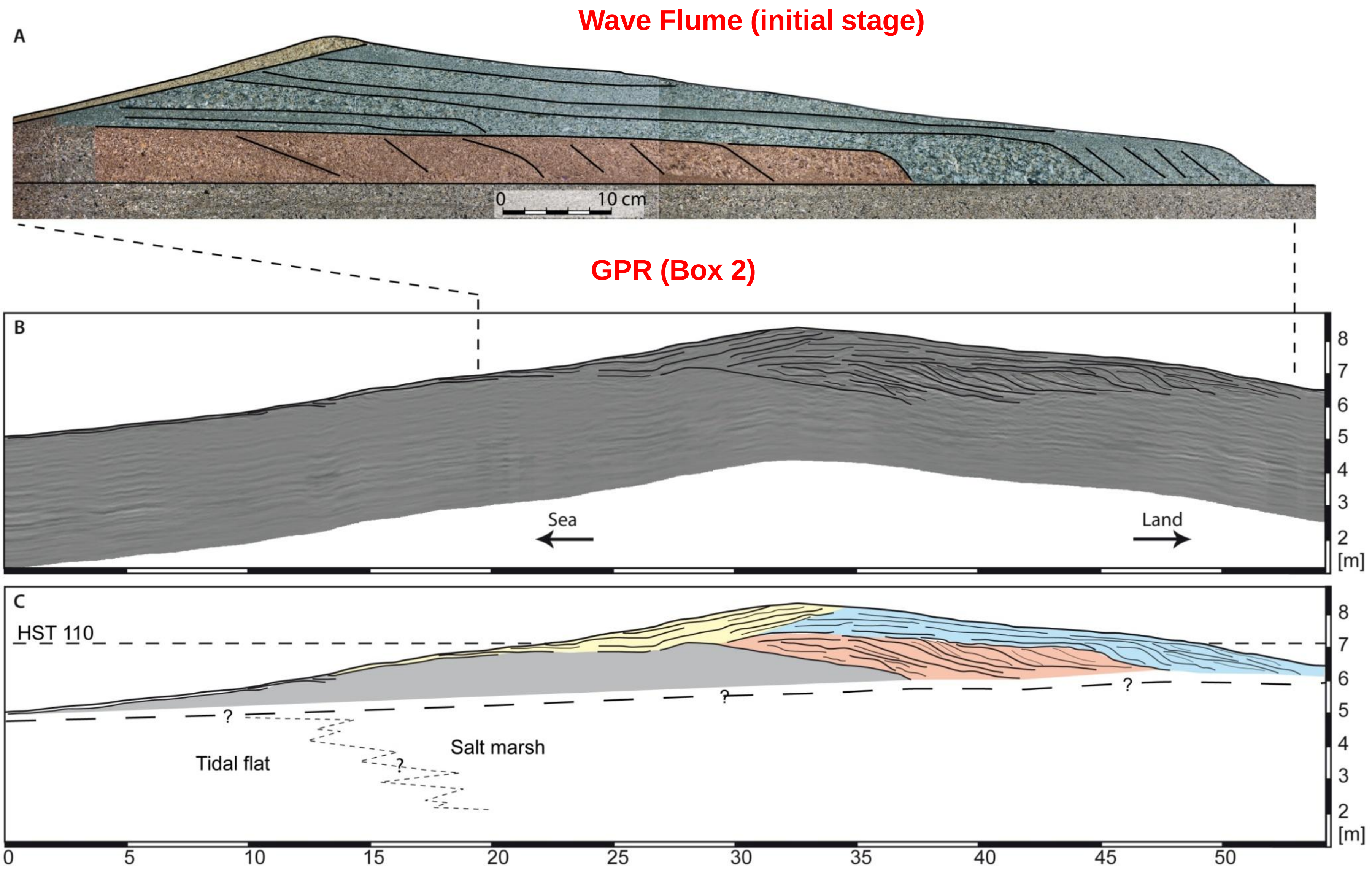
①



⑪



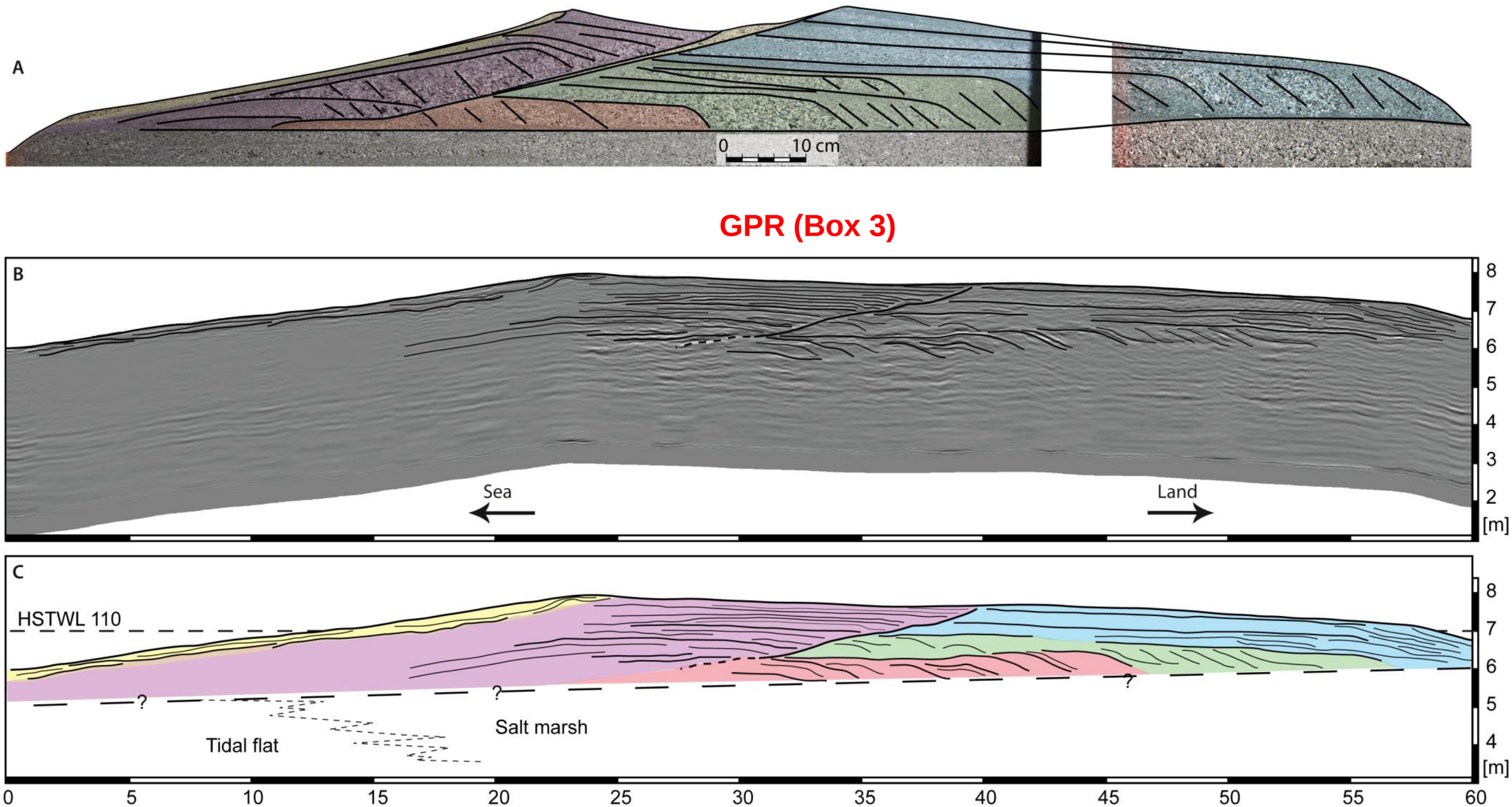
Transgressive chenier morphology



Prograding chenier morphology

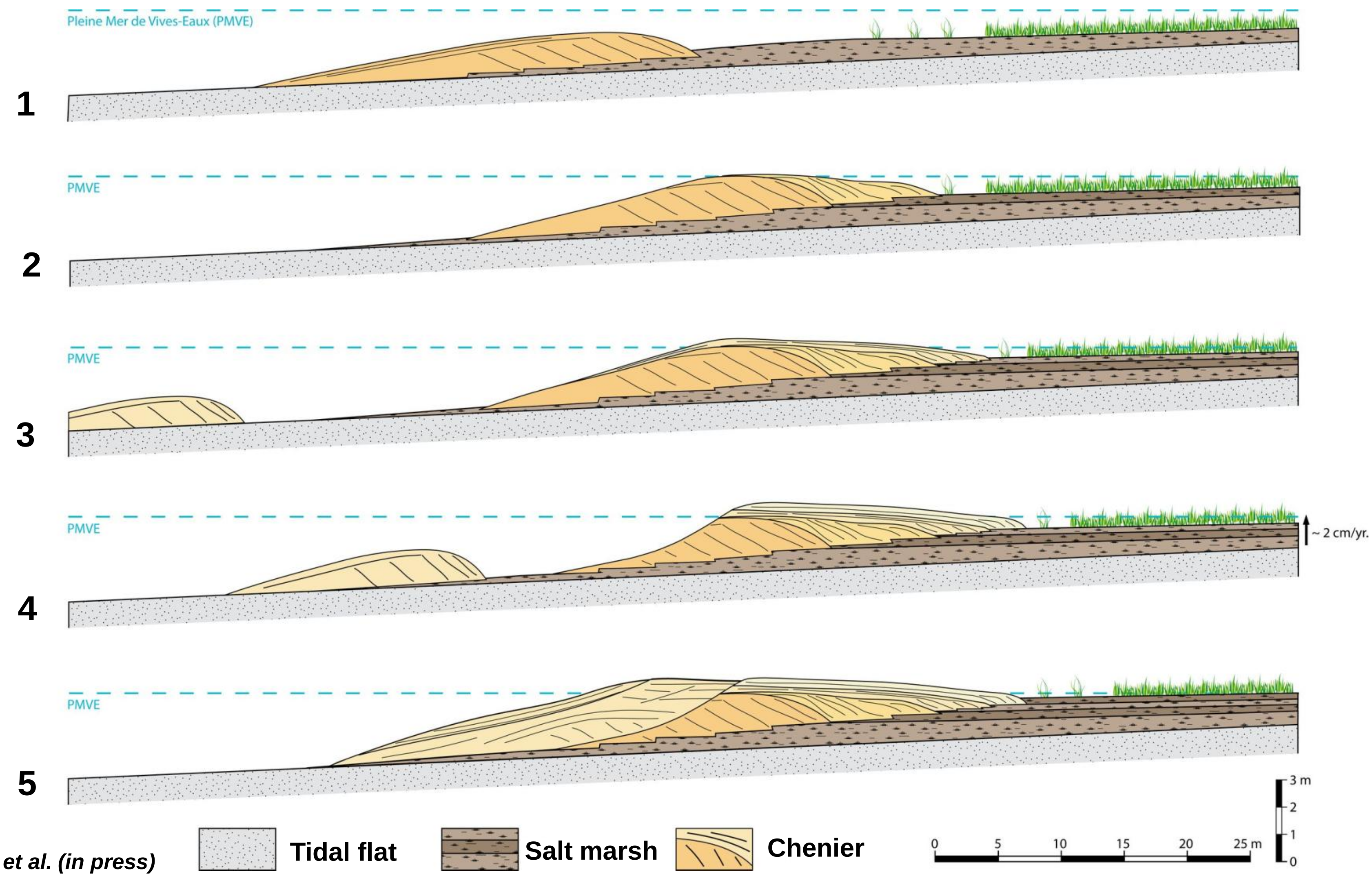
Wave Flume (final stage)

GPR (Box 3)



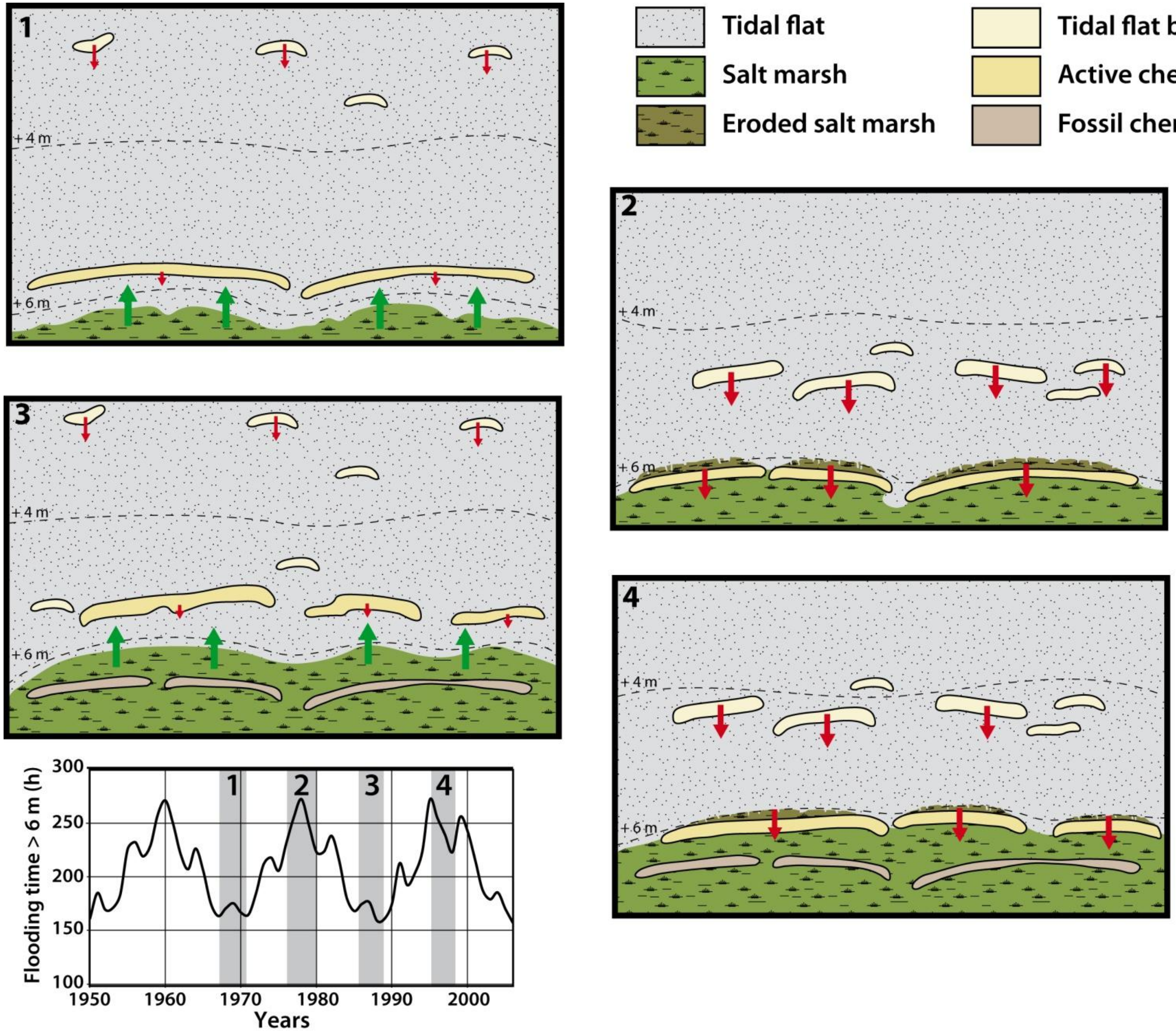
A depositional model controlled by tides

Internal architecture and stages of evolution



Weill et al. (in press)

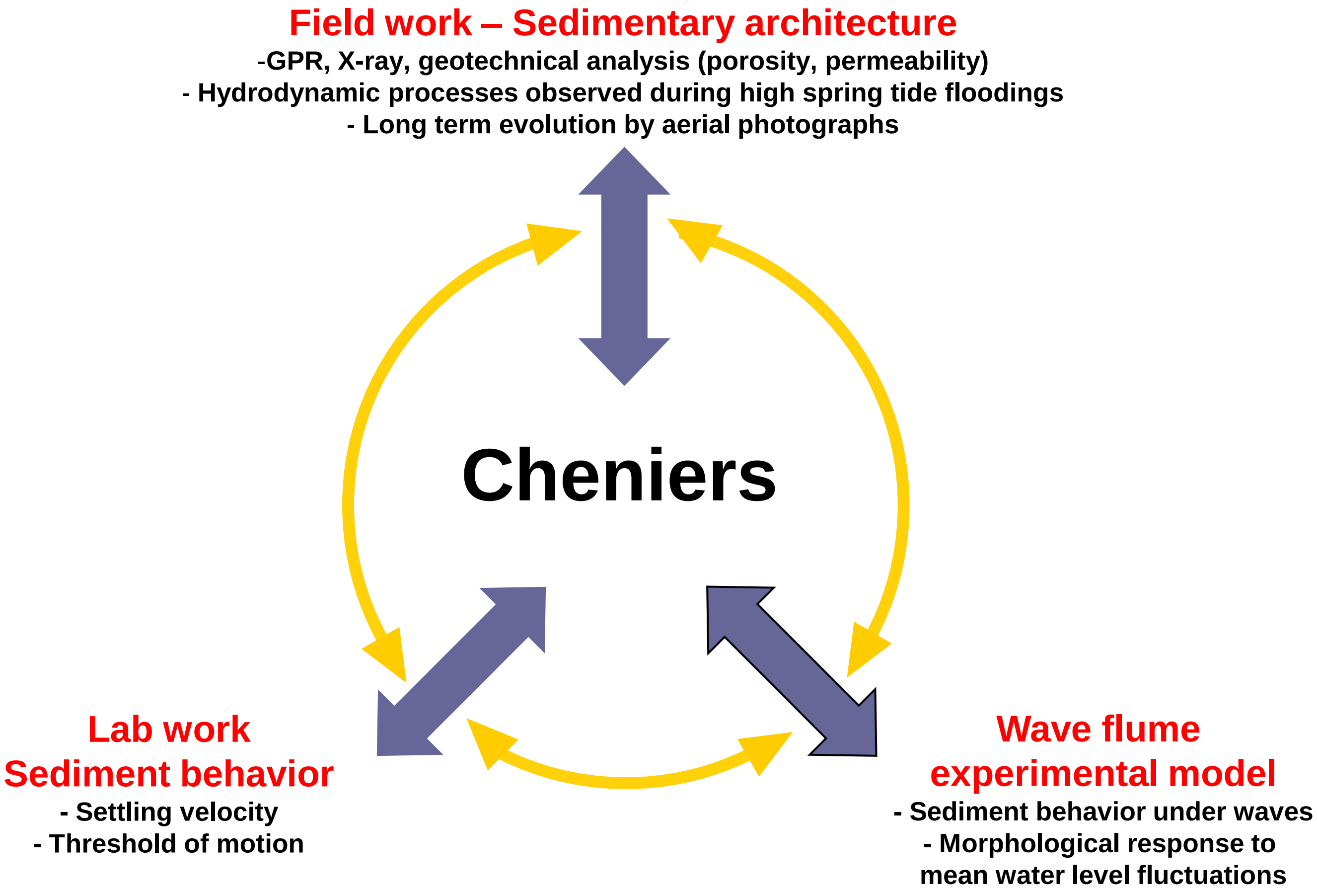
A depositional model controlled by tides



Goals

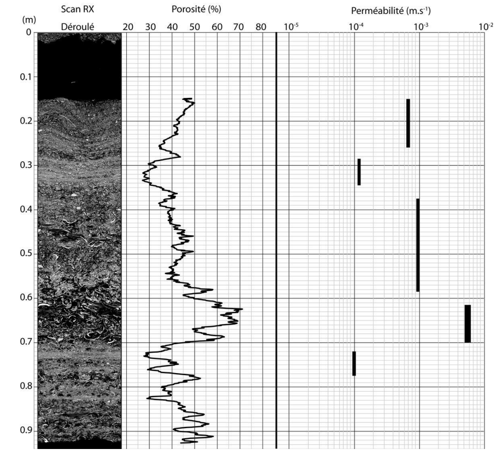
- To characterize the genesis, growth and stabilization of cheniers in macrotidal environments

Methods

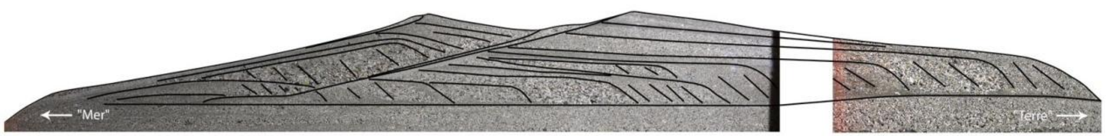


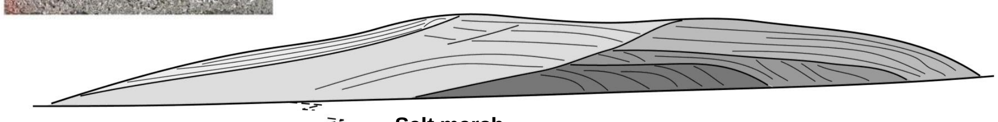
Results

1- A peculiar sediment behaviour

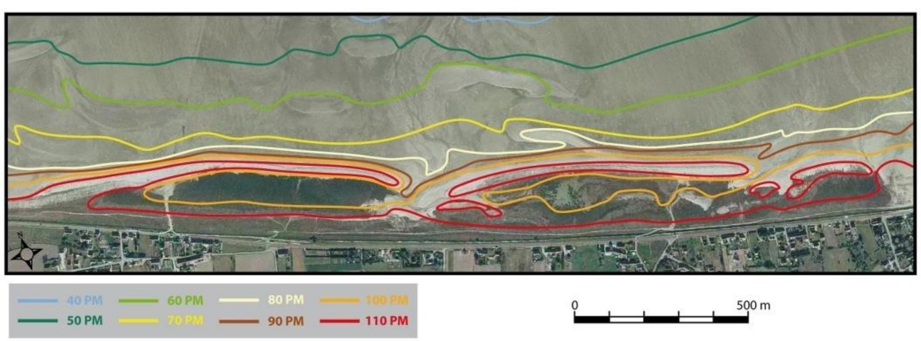


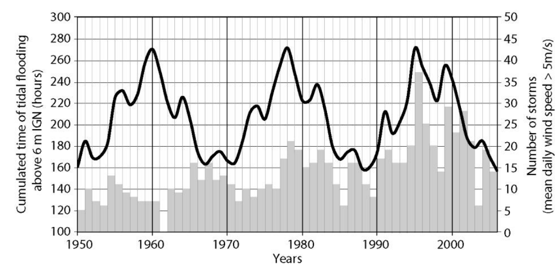
2- A revealed internal architecture





3- A deposition model controlled by tides





Merci de votre attention !