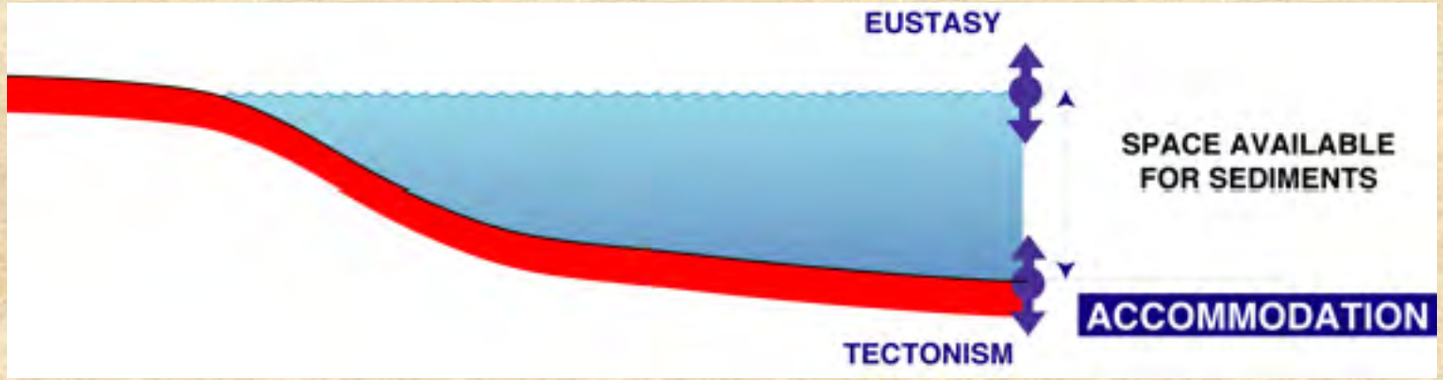
Seismic and Sequence Stratigraphy

EOL - Master Class
Romain Pellen

THE CONCEPT OF ACCOMMODATION: Jervey, 1988



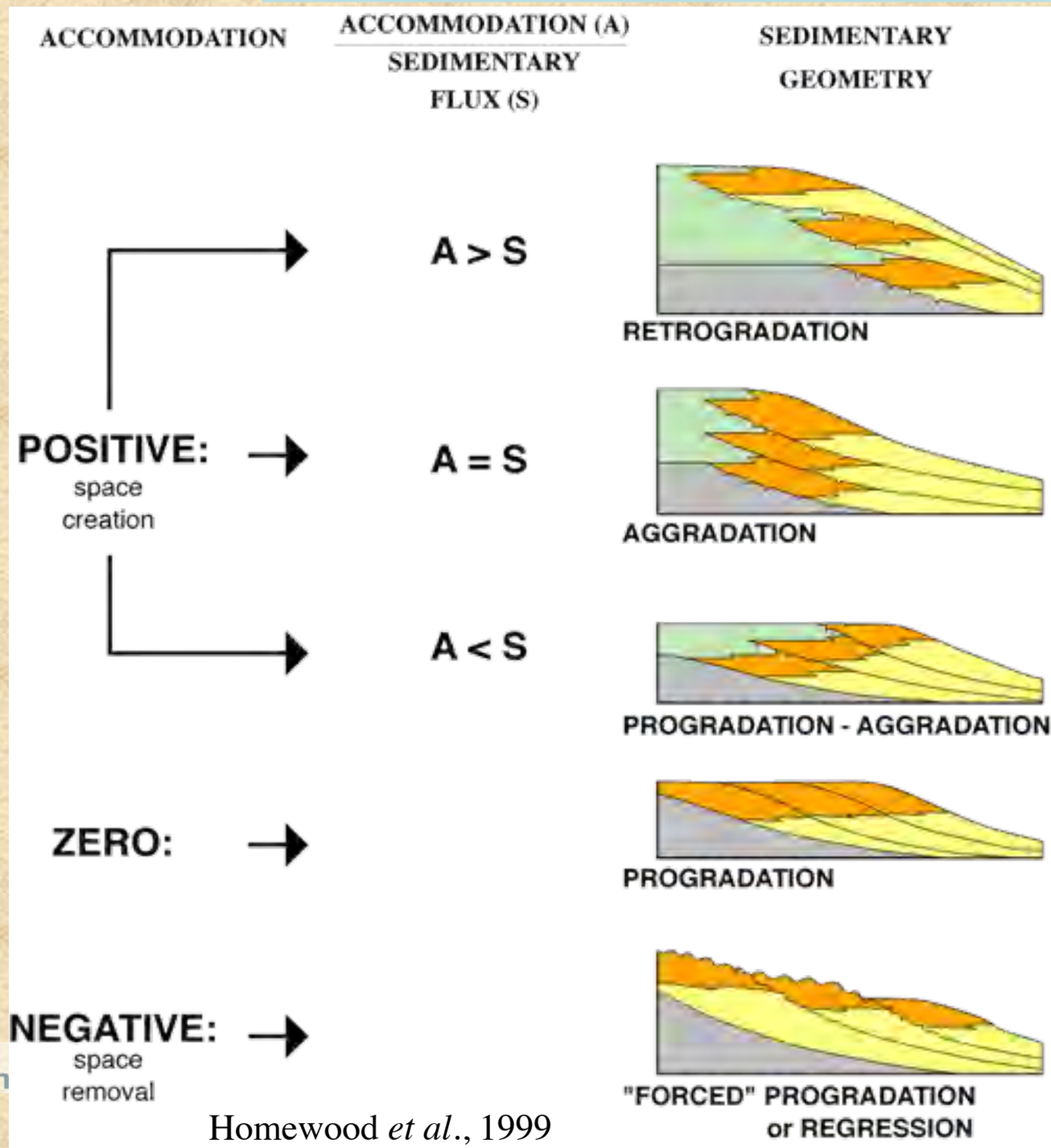
- **Accommodation is space made available for potential sediment accumulation**
- **It is a function of both sea-level change and local subsidence (or emergence) of seafloor or coastal plain**
- **It includes old space left over from the previous cycle as well as the new space created**
- **Base level is the lowest surface up to which a river can flow and up to which subaerial erosion can proceeds; thus it generally equals sea level.**
- **Base level controls accommodation, and thus, whether erosion or deposition will occur at any given location.**

Guillocheau, 1995

Useful Source:

- « Blue book » Exxon, AAPG, Mitchum et al. 1977
- Emery & Myers ed. (1996)
- Guillocheau et al., 1995 ; Catuneau et al. 2006
- Posamentier et al., 2003
- http://www.sepmstrata.org/Page.aspx?pageid=1
- https://www.youtube.com/watch?v=RPf7aKQFKcY (FW Schroeder)
- https://www.youtube.com/watch?v=kKXd0dv6ae4

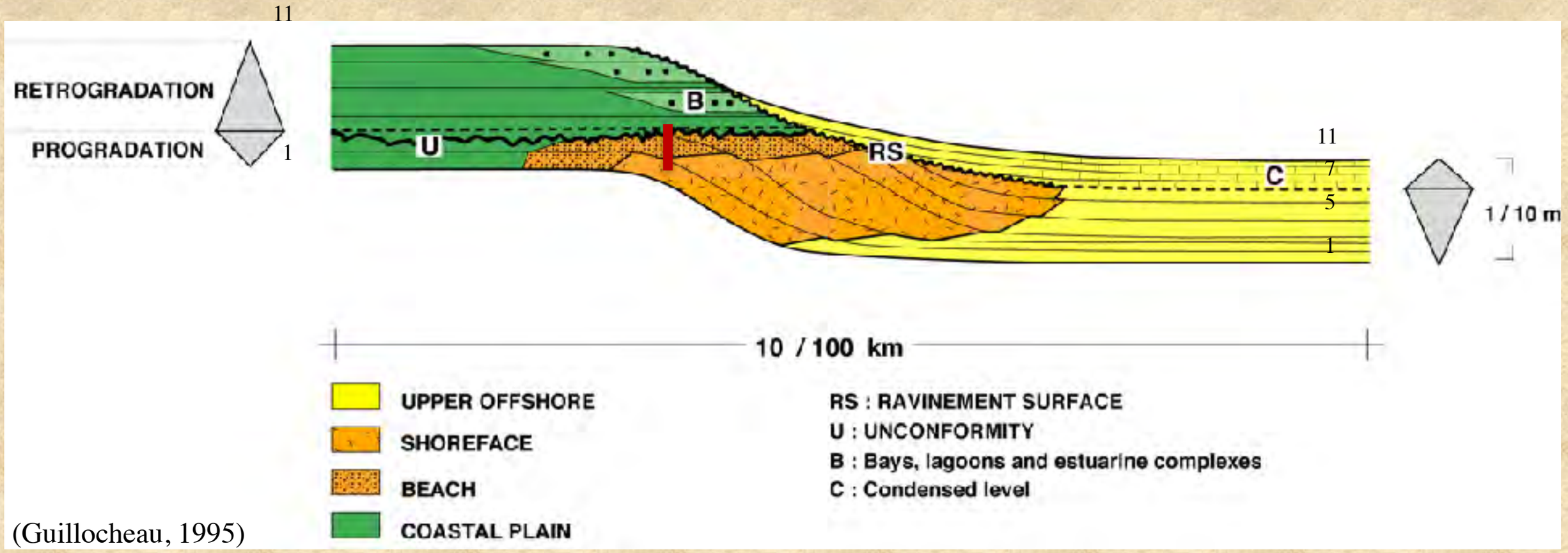
Shoreline geometries and A/S cycles



Homewood *et al.*, 1999

a DEPOSITIONAL SEQUENCE or a STRATIGRAPHIC CYCLE is defined as a A/S variation cycle (i.e. **progradation/retrogradation cycle)**

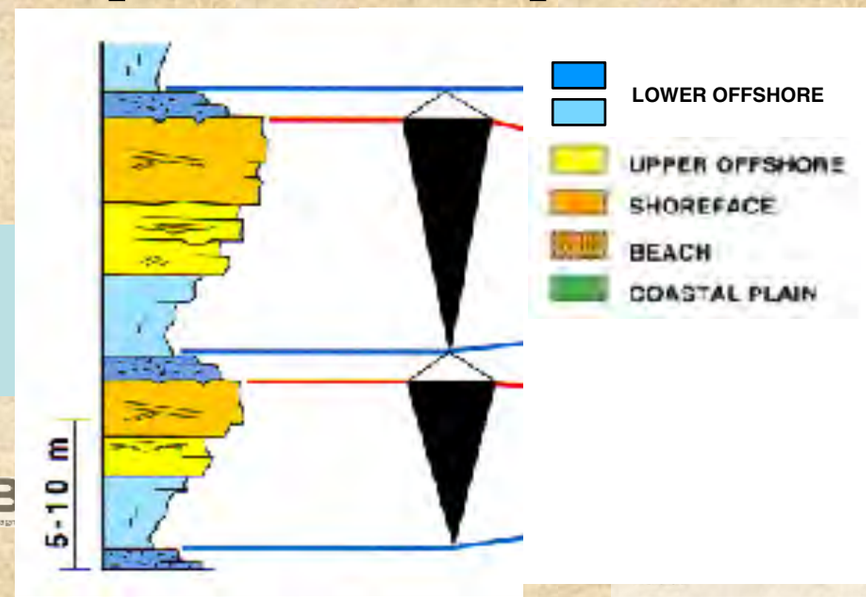
2D geometry of a genetic unit



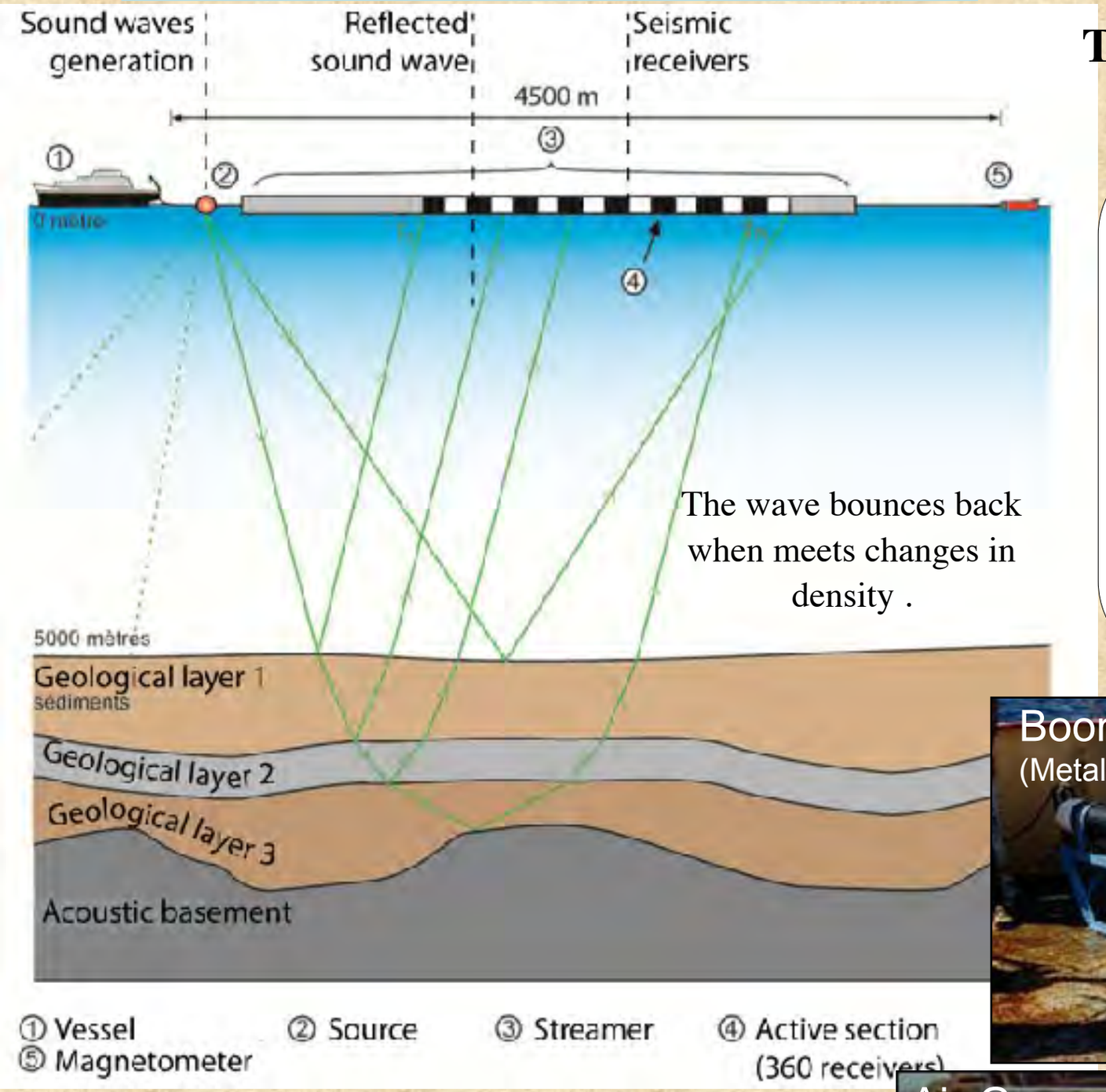
(Guillocheau, 1995)

These accommodation successions can be related to systems tracts, depositional sequences, sequence sets, and megasequences and used to **describe and interpret a basin's depositional fill.**

Example of lithological log and A/S cycle (red line of the 2D section)



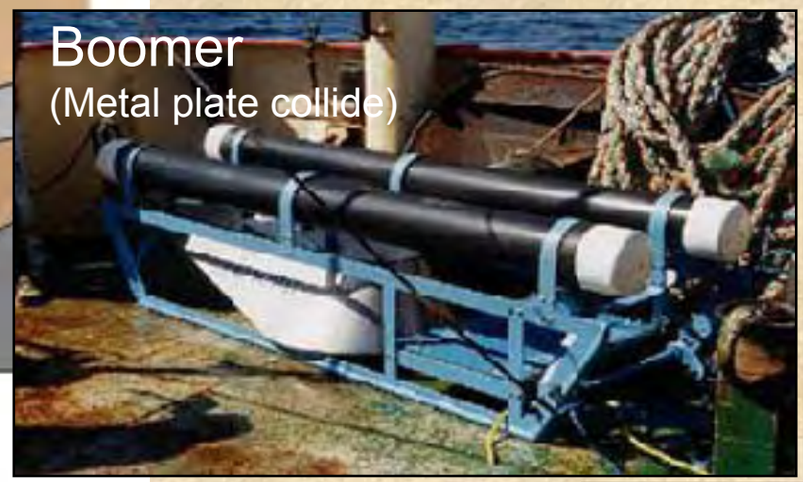
Seismic reflexion : Principle and method

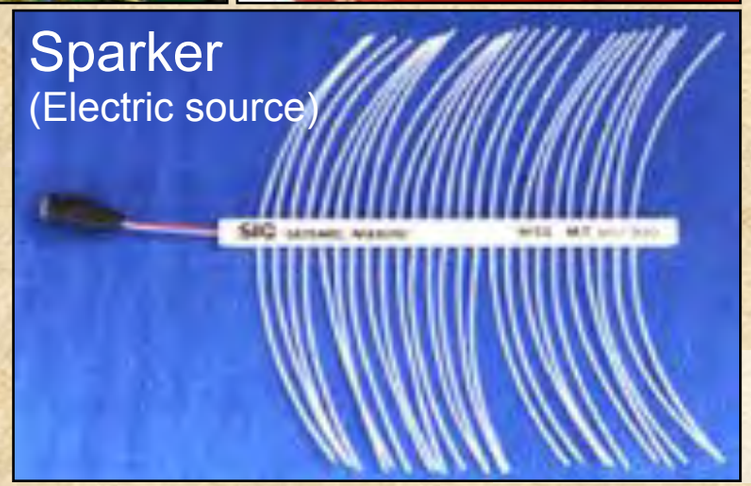


The law of propagation of these waves follows the law of Snell-Descartes (optics)

Source

- ~~Explosives (expansive and destroy all)~~
- Air gun, Water gun, …
- Electric system (sparker)
- Electro-mecanic system (boomer)
- piezo-electric system (Chirp)





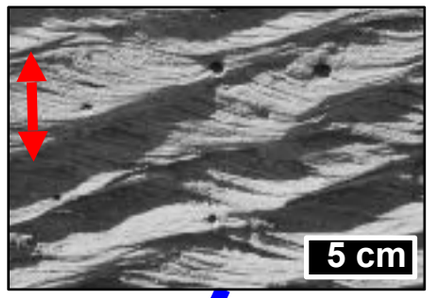
FIELD APPROACH

1280 × 720 - youtube.com

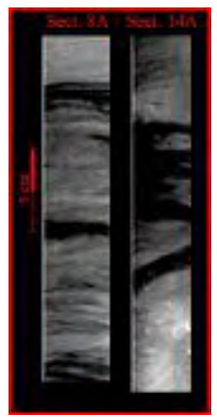
+ SPATIAL SCALE :

Surface

Microscope, Sed. Structure mm-cm-m

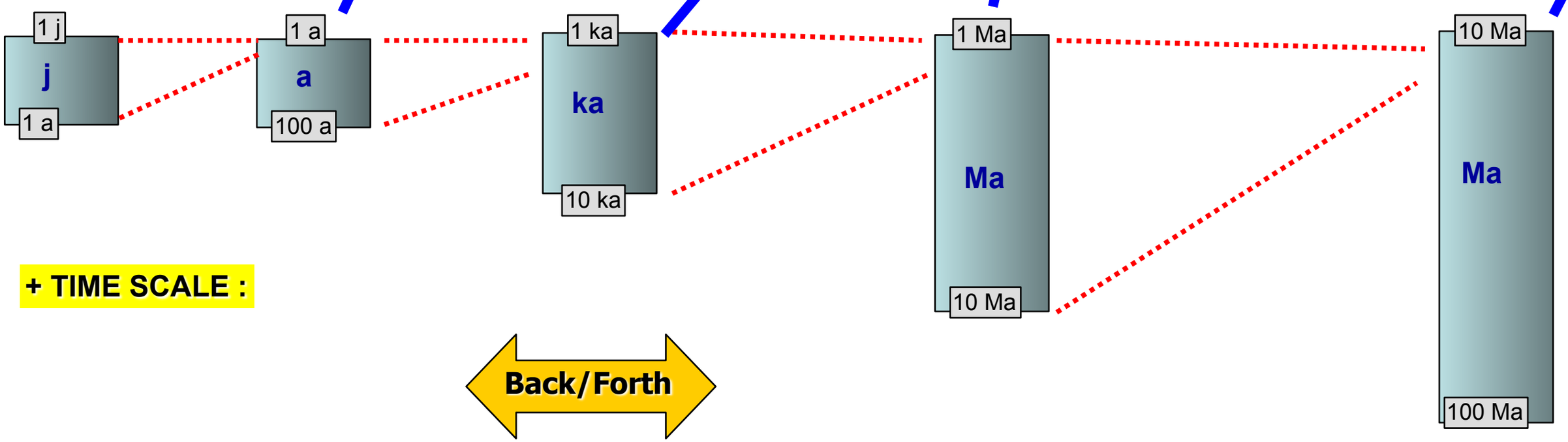


Cores, outcrops 1-20 m



Outcrops 100 m

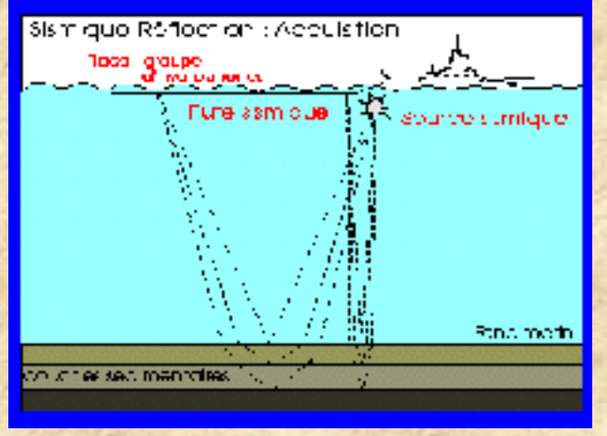
Basin Drills 10 km



+ TIME SCALE :

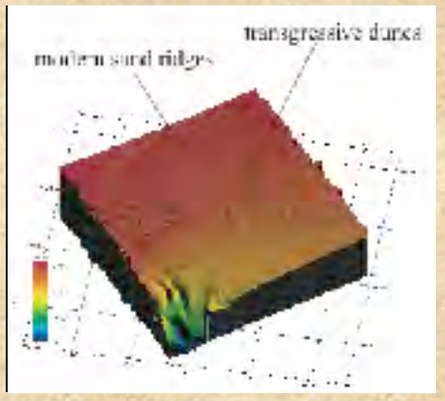
Back/Forth

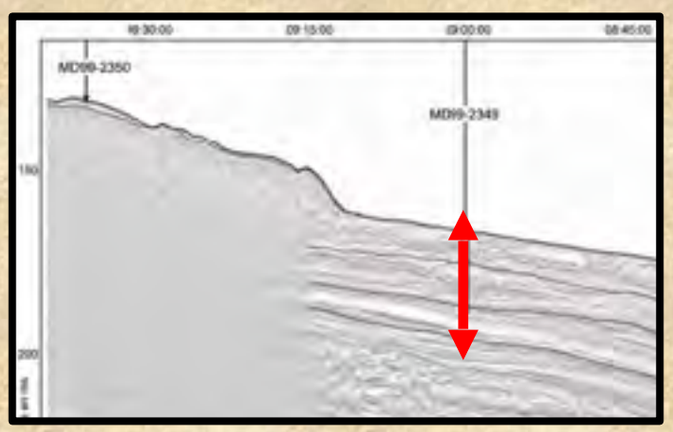
GEOPHYSICAL APPROACH

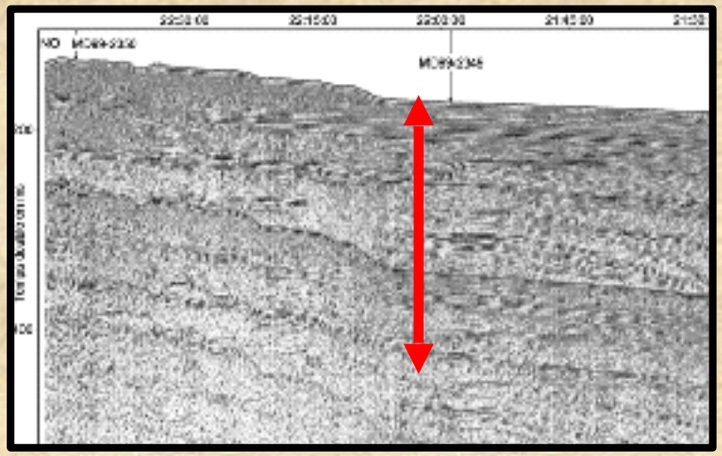


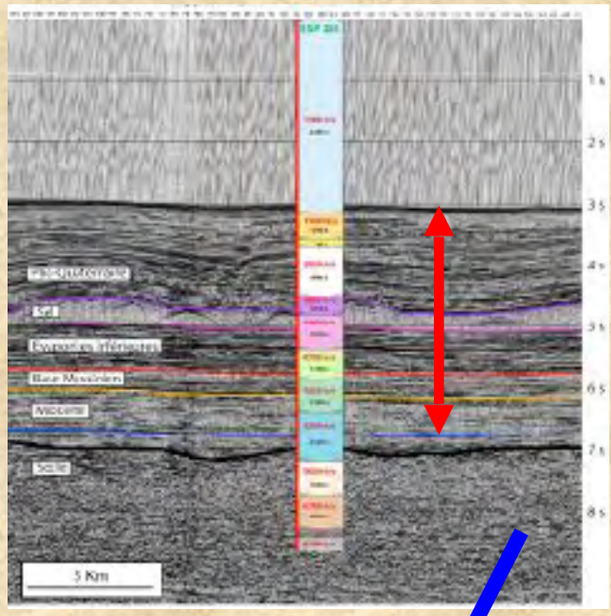
+ SPATIAL SCALE

Surface **mm-m** **Sed. Bodies 1-20 m** **Stack sedimentary Sequences 100-500 m** **Basin-Drill 10 km**





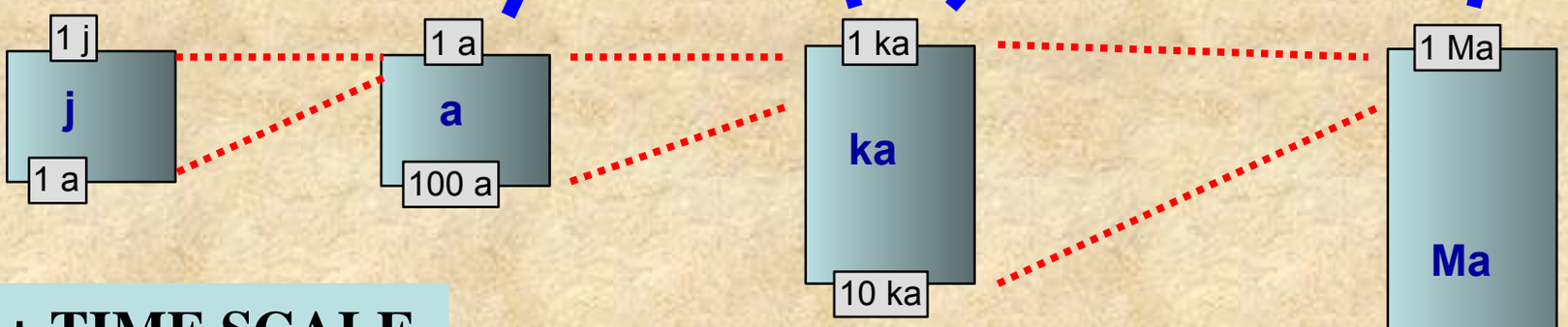




Bathymetry Imagery

Chirp

Sparker

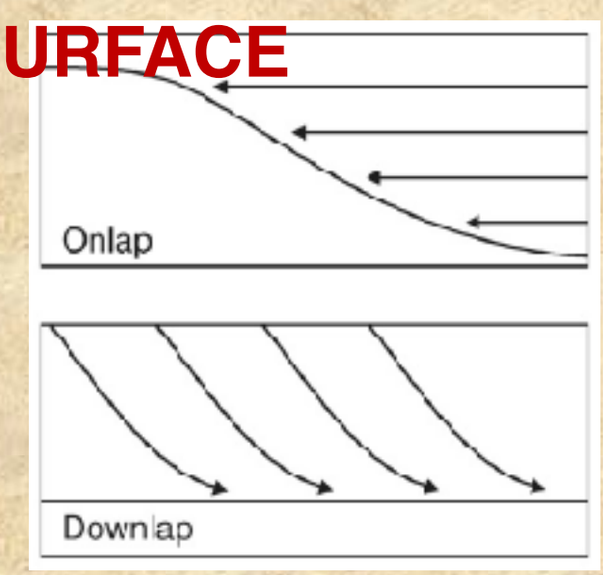


+ TIME SCALE

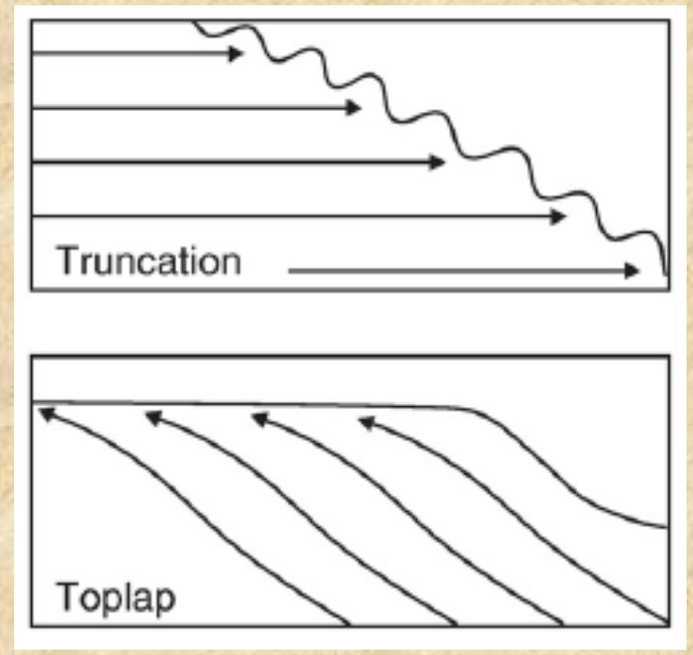
Back/Forth

SEISMIC TRATIGRAPHY

TERMINATIONS ABOVE A SURFACE

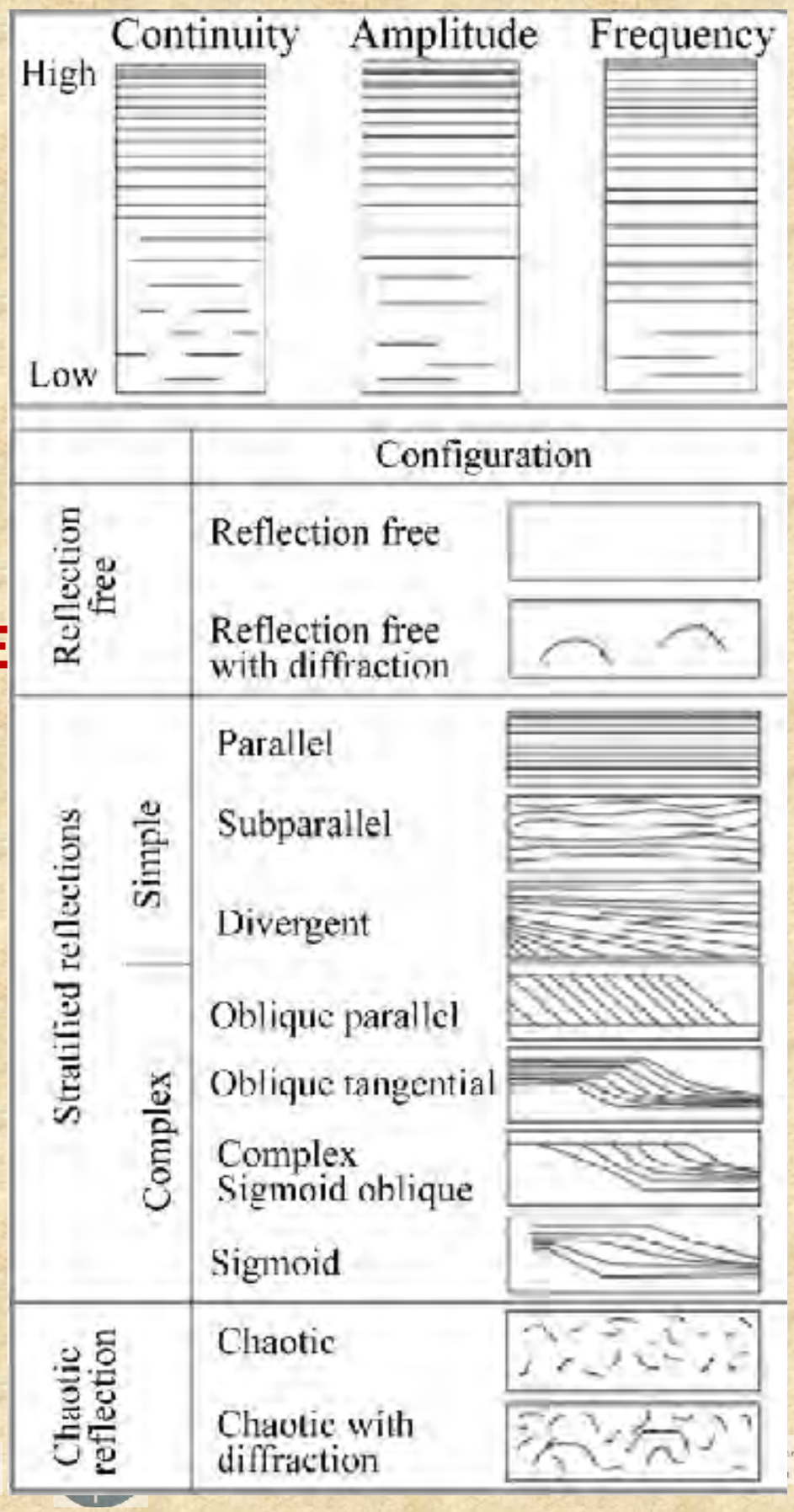


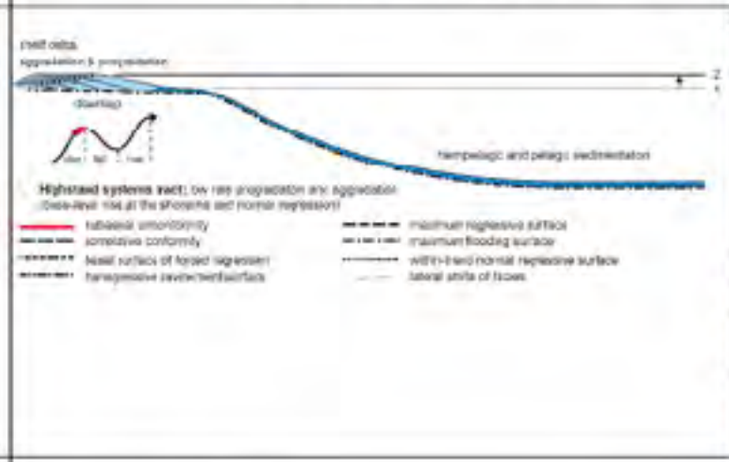
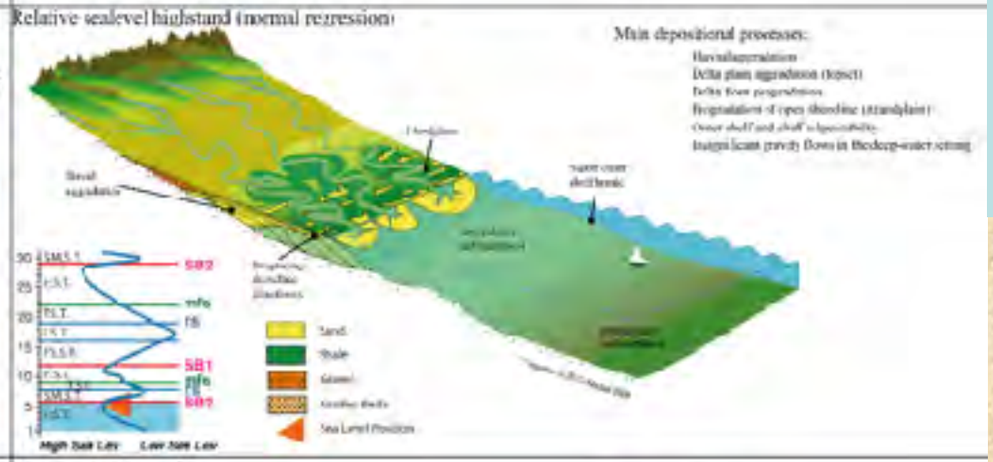
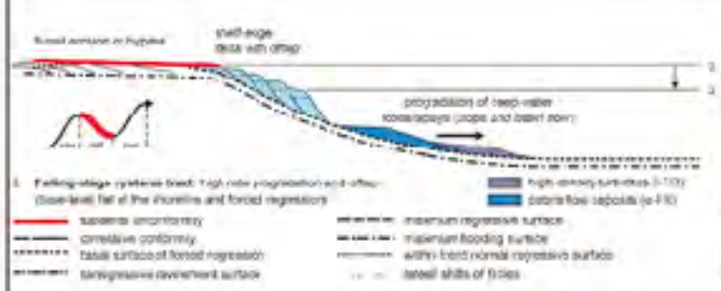
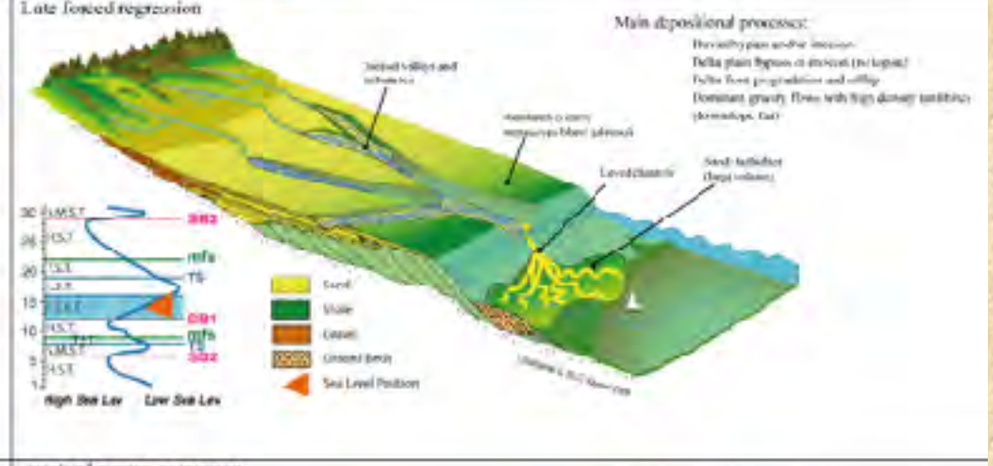
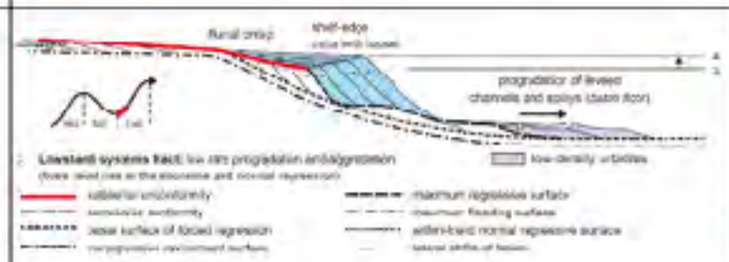
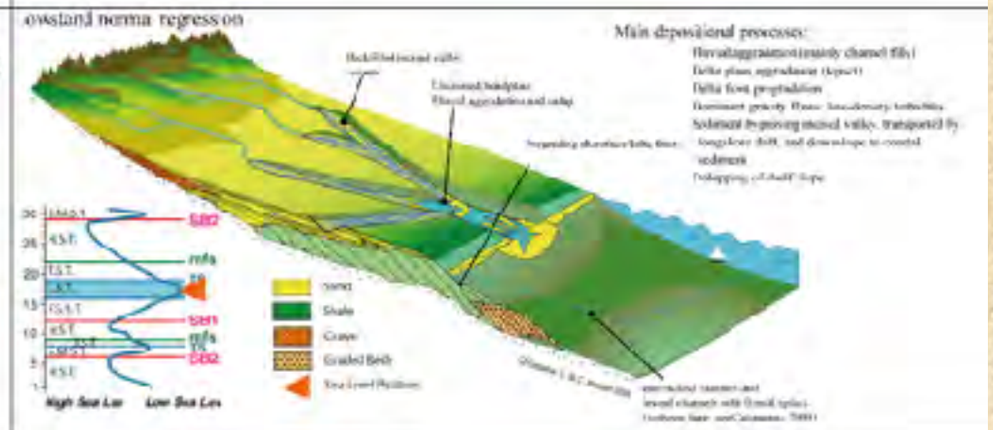
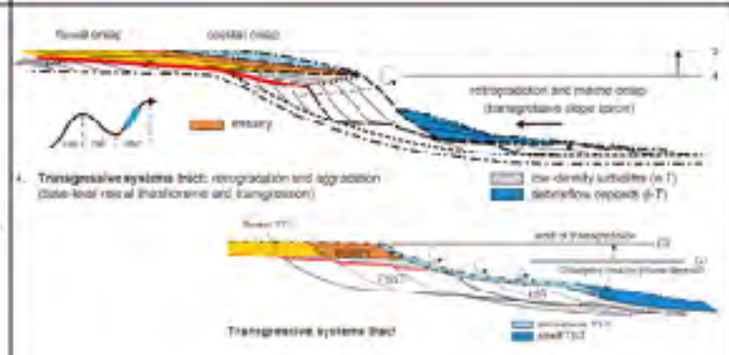
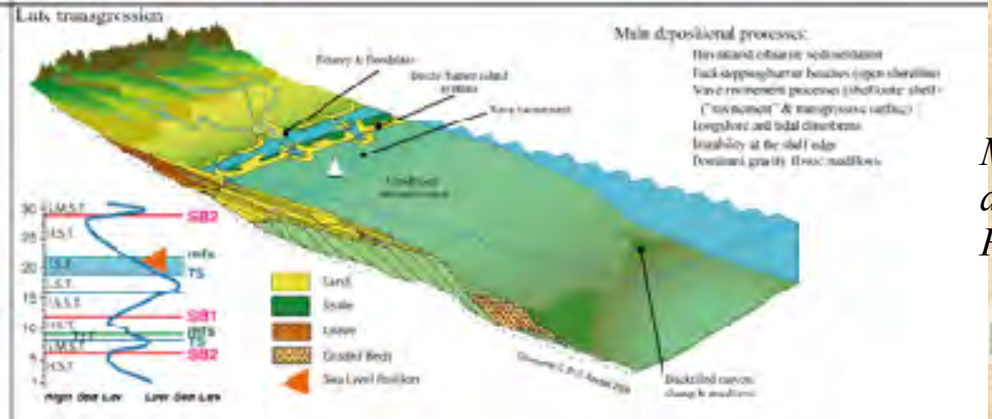
TERMINATIONS BELOW A SURFACE



Catuneanu et al., (2006)

INTERNAL DESCRIPTION IN A SEQUE



Main A/S cycles evolution (Fluvial siliciclastic system)	Regional architecture sketch of depositional sequence and main boundaries (according to the nomenclature of Hunt & Tucker, 1992) (and modified from Catuneanu, 2006)	Main paleo-environmental characteristics
Depositional sequence when S>A during High Relative marine level (RML). *Highstand System Tract (H.S.T.)*		
Depositional sequence when A>S negative, with relative RML fall. *Falling-Stage-systems Tract (F.S.S.T.)*		
Depositional sequence when A>S, with relative RML rise. *Lowstand Systems Tract*		
Depositional sequence when A>S vs A<S, with relative RML rise/end of transgression. *Transgressive Systems Tract (T.S.T.)*		

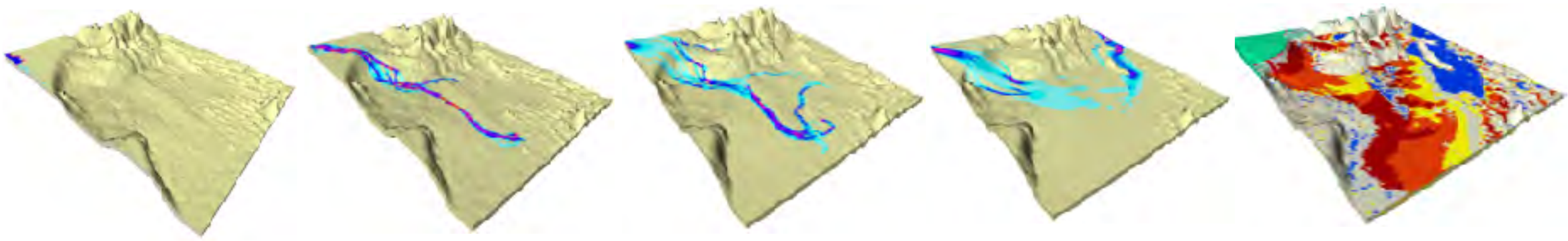
Example of palaeo-environmental interpretation from sequence stratigraphy

1. Surface and Seismic Units, sequences mapping.
2. Build Maps : depth of reflectors,
3. Thickness of units and sequences.
4. Tie to wells to have age control
5. Think (well, you have to think also during 1, 2, 3, 4…)

CAREFUL: it's a model and there is a lot of different models..

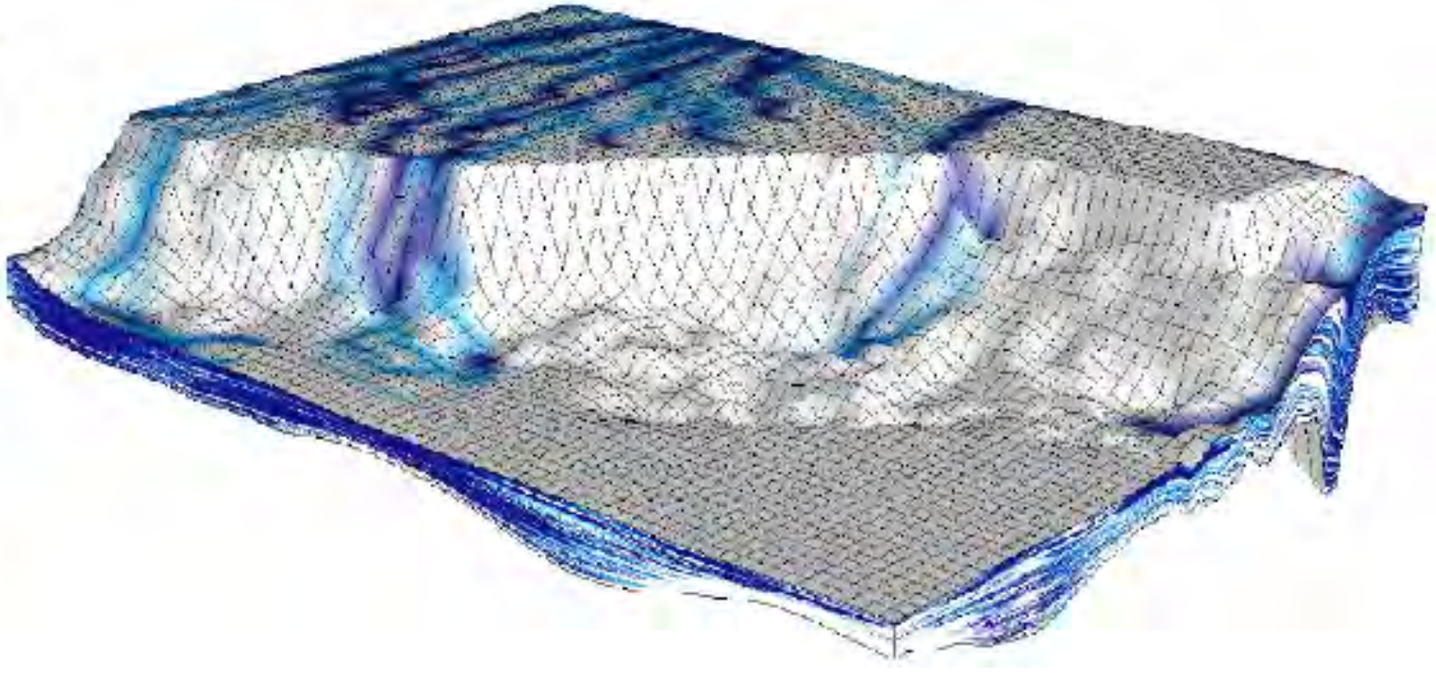
Here an example of regional sedimentary Architecture evolution related of relative Sea level variation.

Modified from Catuneanu, 2006; and website SEPMSTRATA (in Pellen, 2016)



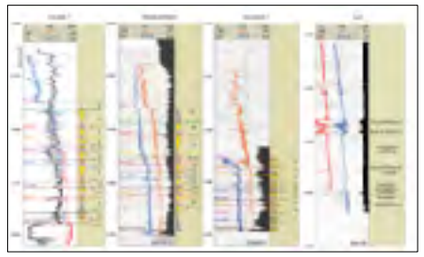
NUMERICAL STRATIGRAPHIC MODELINGS applied to the western Mediterranean

Estelle Leroux,
et
Marina Rabineau, Daniel Aslanian, Christian Gorini, Didier Granjeon, Jean-Loup Rubino, Jean-Pierre Suc, Spéranta Popescu, Maryline Moulin, Jeffrey Poort, Christian Blanpied, Laurence Droz, Philippe Schnurle, Cécile Robin, Stéphane Molliex, Romain Pellen et al.

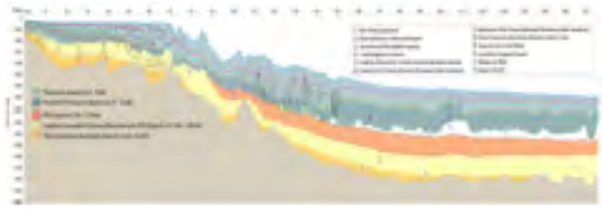


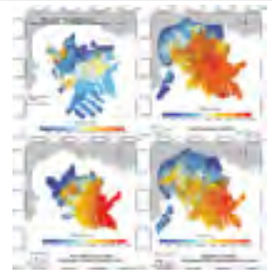
2021-10, Earth Ocean Link, Accra-Ghana

WORKFLOW



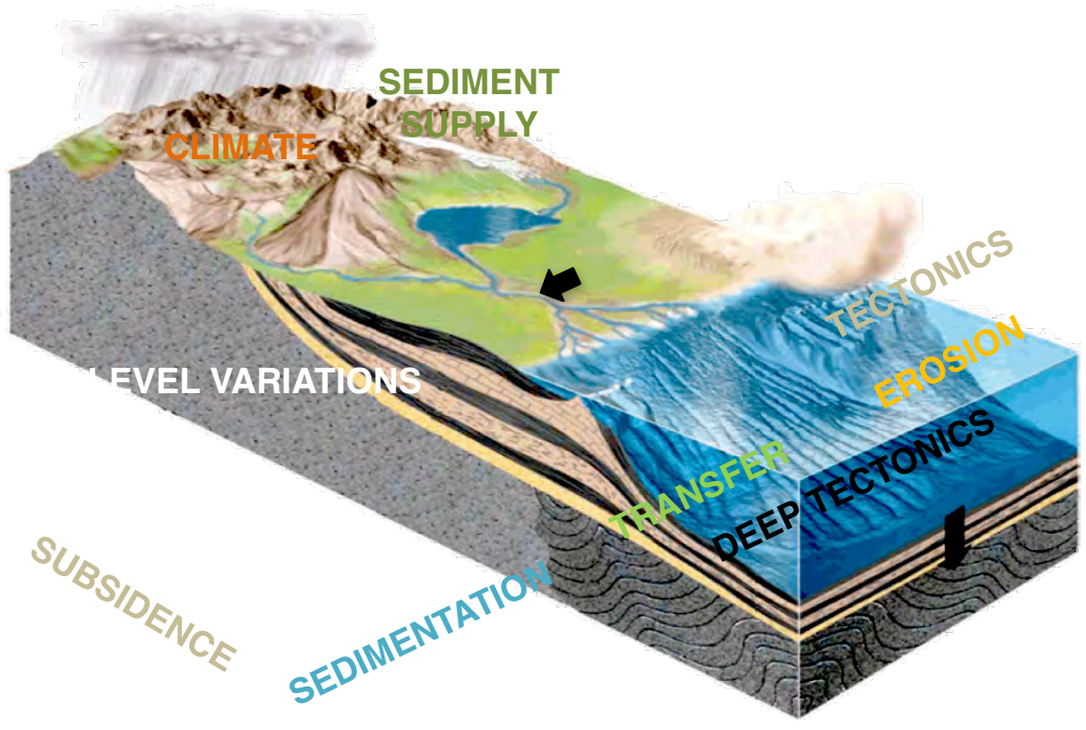
Analyses (seismic, litho-, bio-stratigraphy) from multiple data





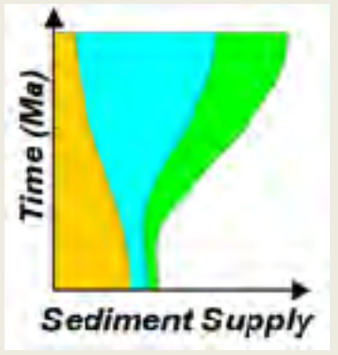
Geological model & Cartographies

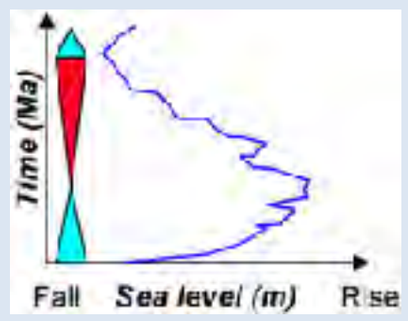
CLIMATE



QUANTITATIVES ANALYSES

Vertical movements





Sea-level variations

STRATIGRAPHIC MODELING

- Refine input parameters
- Test hypothesis of geological model
- Predictions of facies, paleobathymetries, sediment thicknesses, sediment architecture …

Validation or not quantifications of respectives forcings

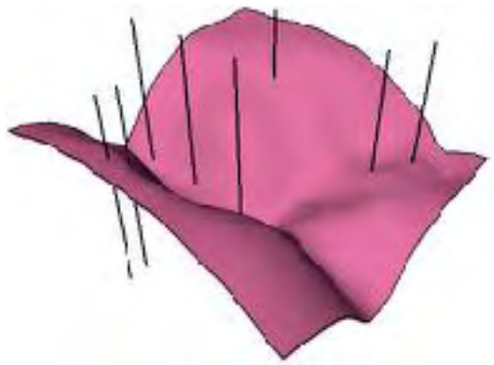
Relation to surface processes (climate)

Relation to deep tectonics processes

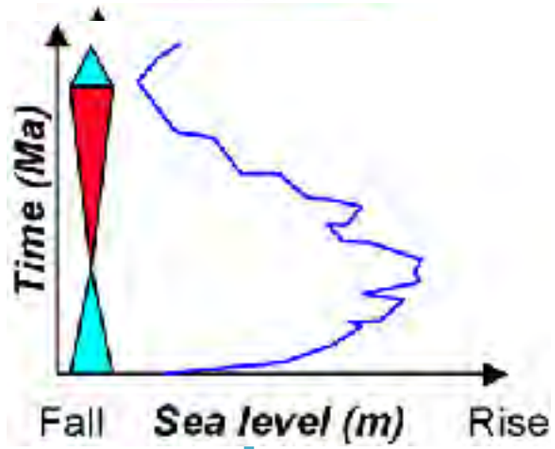
MAIN INPUT PARAMETERS

PRINCIPLE

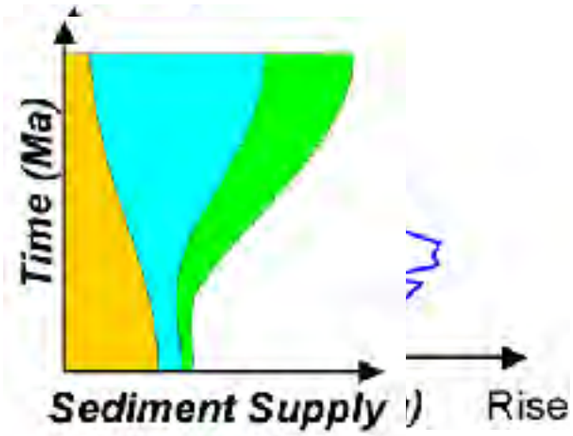
VERTICAL MOVEMENTS
defined with
-sequence thickness & paleobathymetries
-or subsidence maps



SEDIMENT SUPPLY
defined with:
-Thickness maps
-Paleogeographic maps
-Volumes and concentrations supplied by rivers



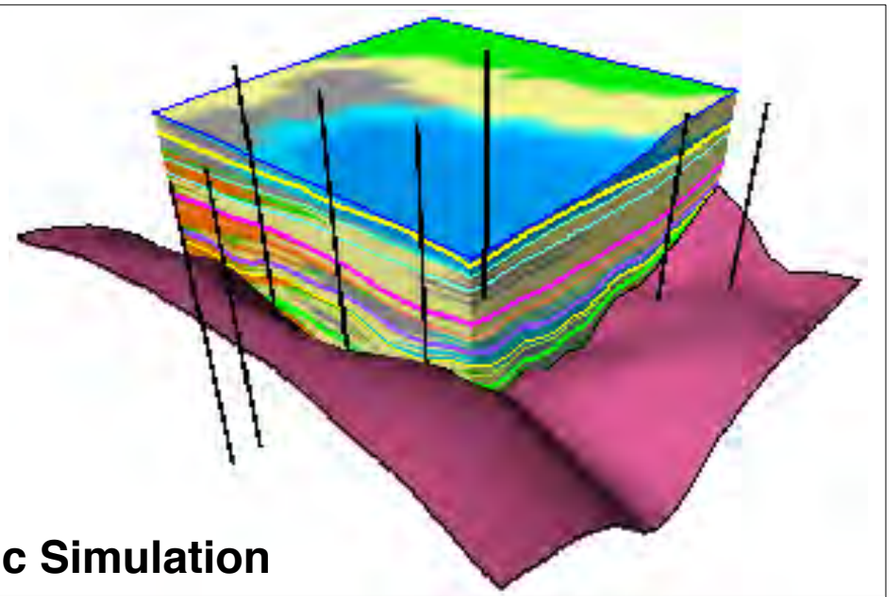
EUSTACY
defined with:
- Sea-level curve



Environmental parameters (diffusion coefficient)

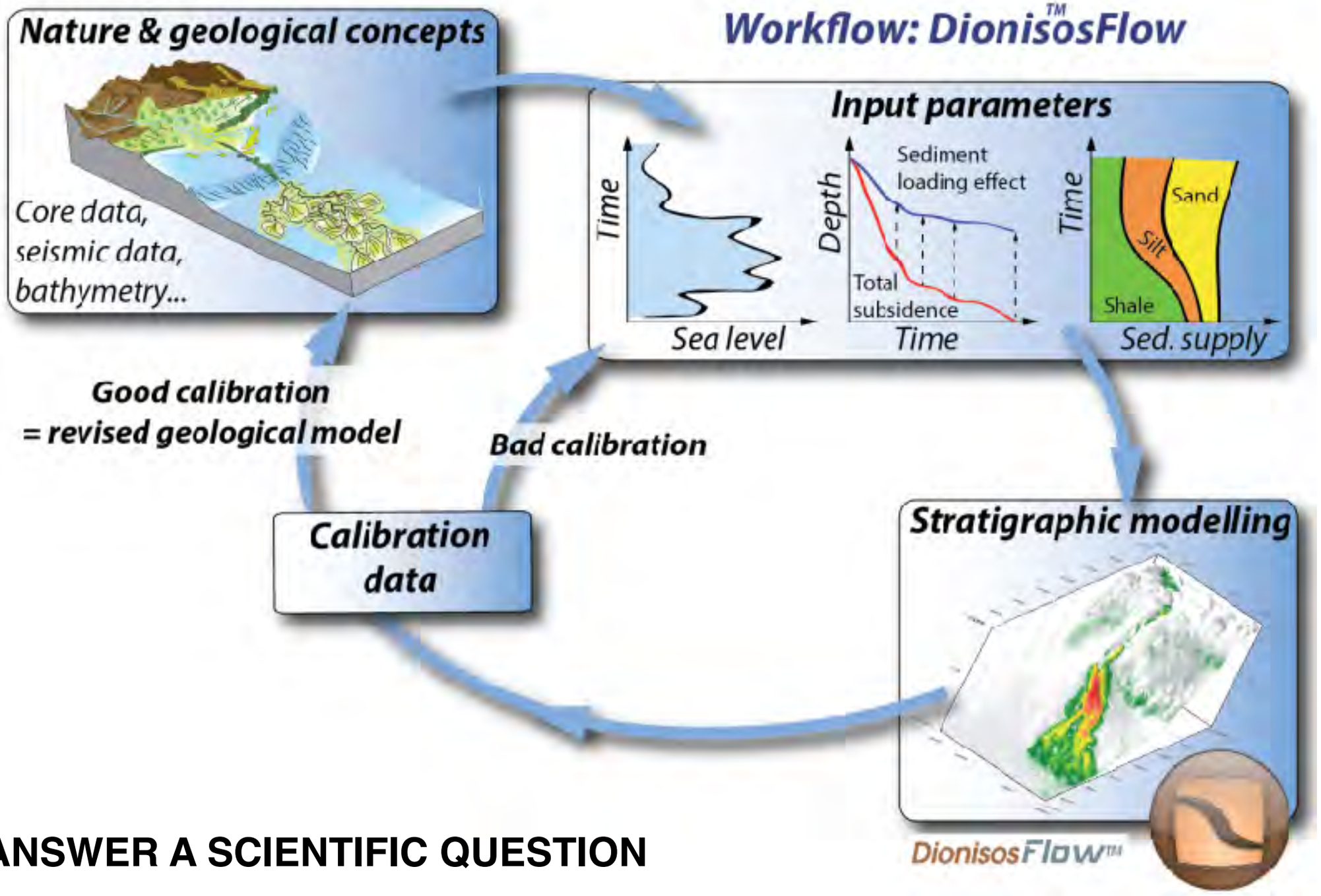
DIFFUSIVE EQUATION:
Qs = K Qw S

Qs = sediment flow
K = diffusive coefficient for each environment
Qw = water flow
S = slope



Stratigraphic Simulation

PRINCIPLE



AIM: ANSWER A SCIENTIFIC QUESTION

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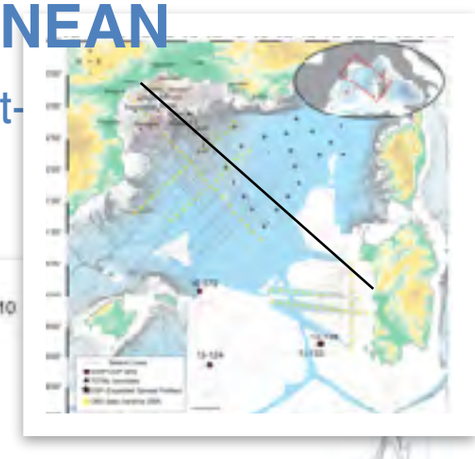
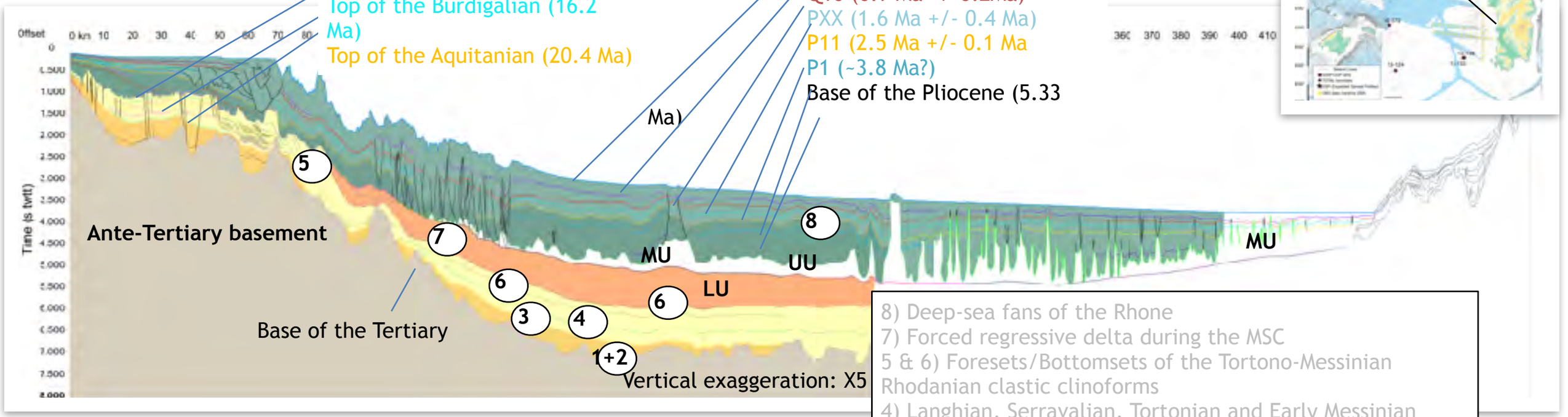
The interdisciplinary graduate school for the blue planet

AMBASSADE DE FRANCE AU GHANA

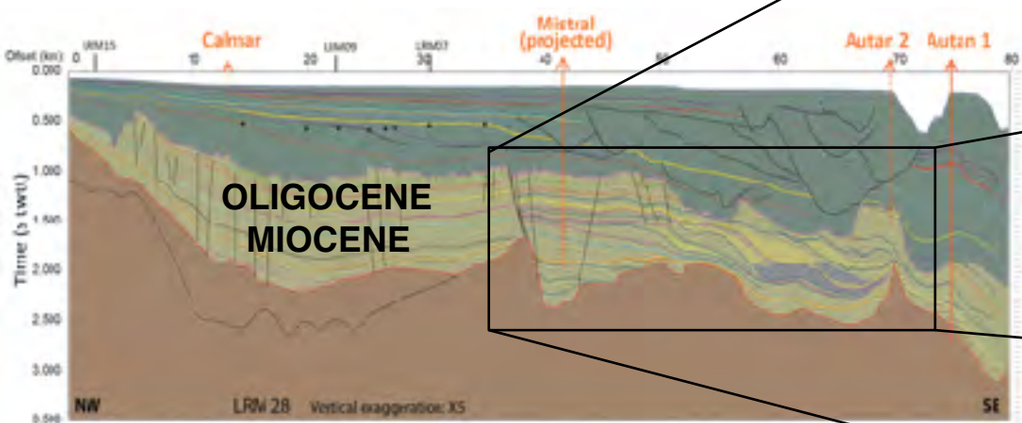
NUMERICAL STRATIGRAPHIC MODELING… APPLIED TO THE WESTERN MEDITERRANEAN

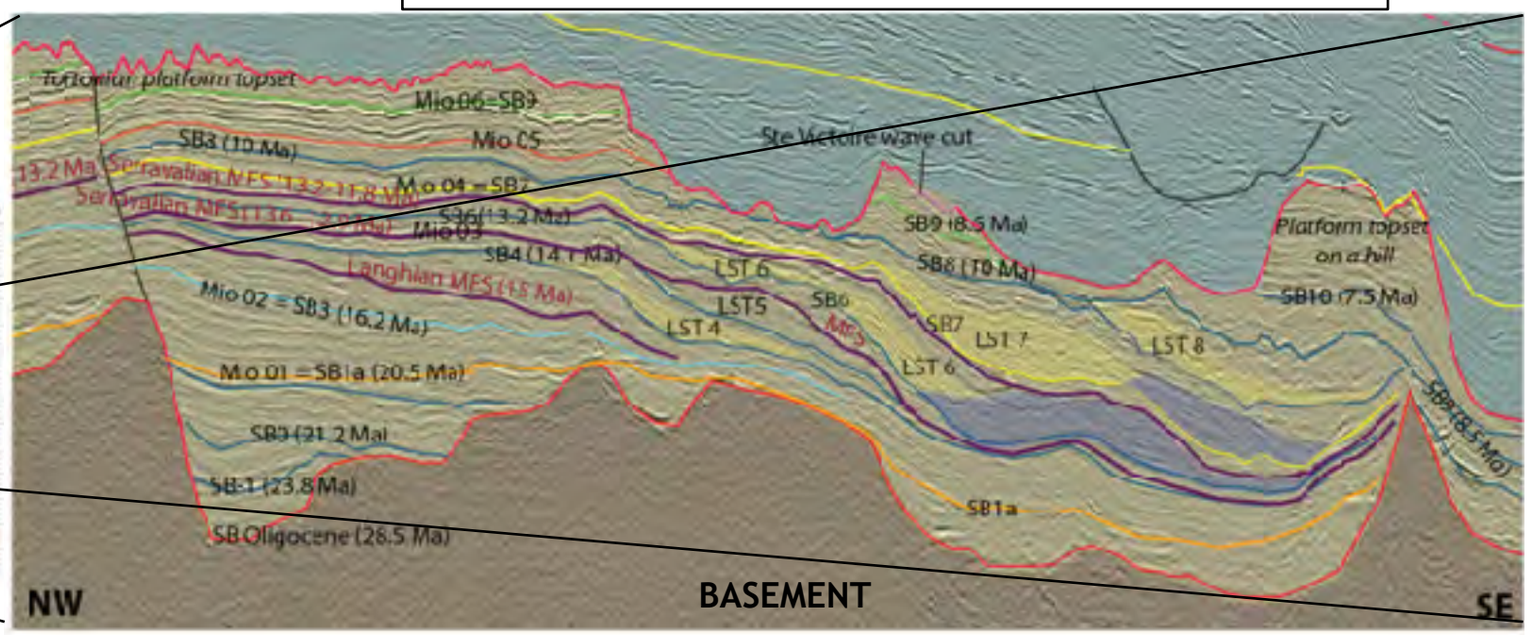
Geological model of the post-





8) Deep-sea fans of the Rhone
7) Forced regressive delta during the MSC
5 & 6) Foresets/Bottomsets of the Tortono-Messinian Rhodanian clastic clinoforms
4) Langhian, Serravalian, Tortonian and Early Messinian deposits
3) Late Burdigalian carbonate
2) Aquitanian and Burdigalian deposits
1) Oligo-Aquitanian continental deposits



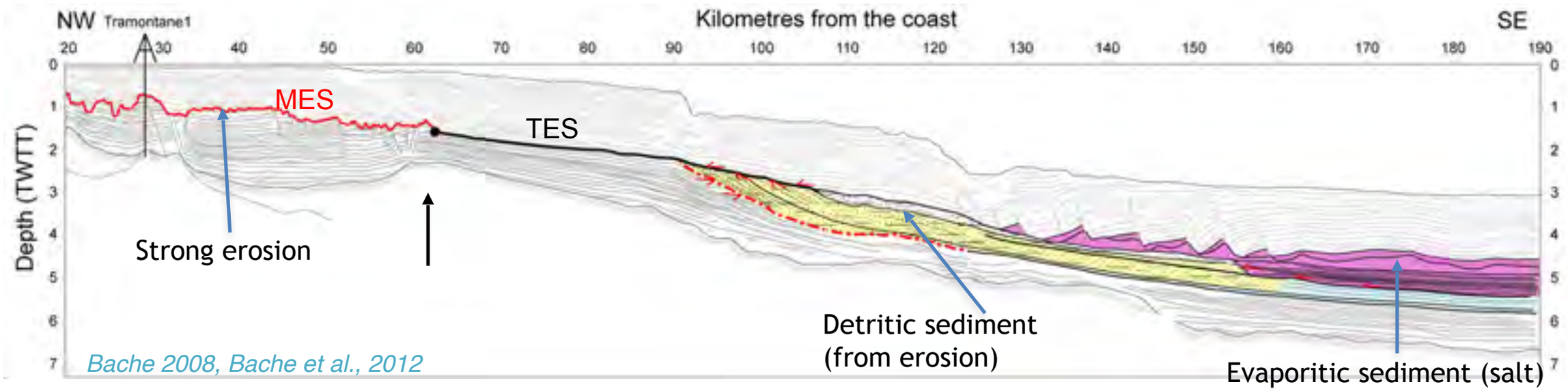


SHELF: 28.5 Ma, 23.8 Ma, 21.2 Ma, 20.5 Ma, 16.2 Ma, Langhian MFS (~15 Ma), 2 Serravalian MFS[13.6 Ma-11.8 Ma], 10 Ma, 8.5 Ma-

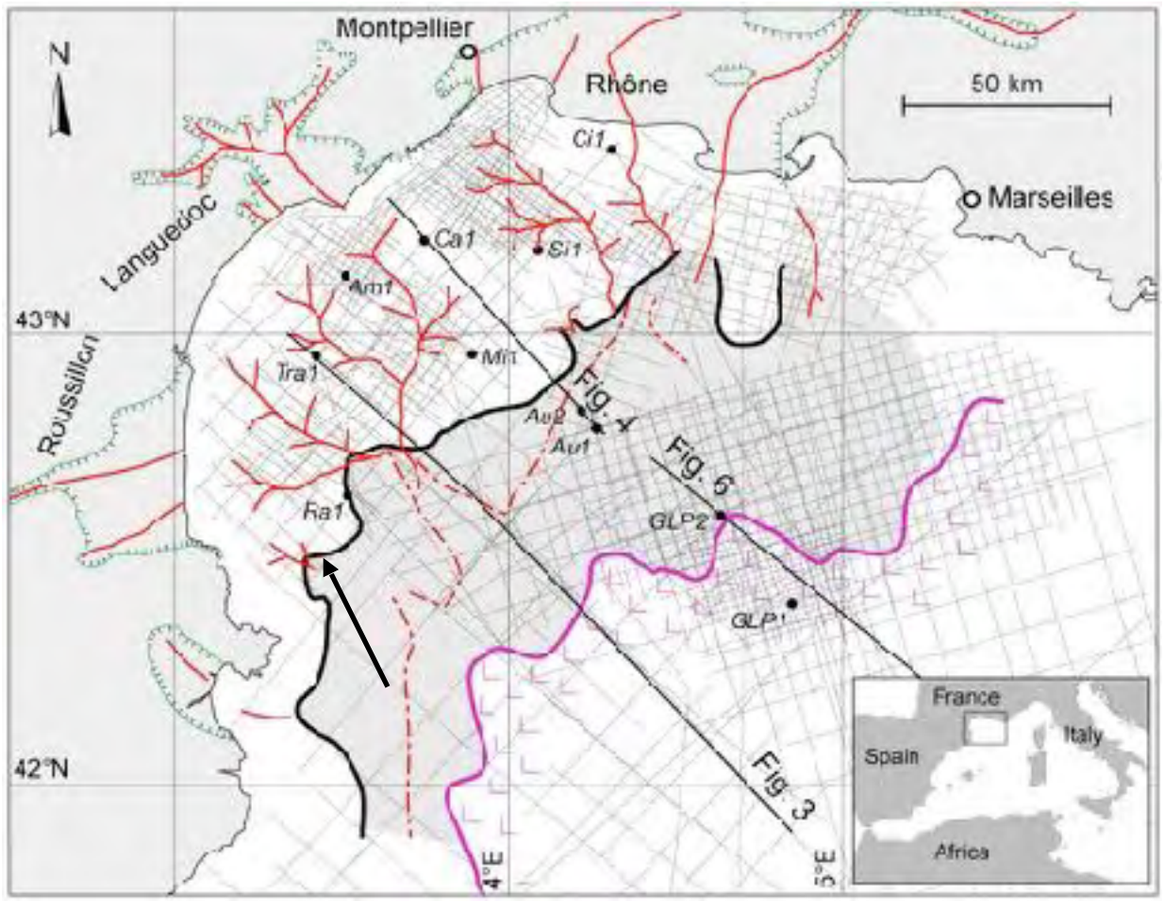
The Mediterranean Messinian (5.96-5.33 Ma) : A very brief but highly complex event!
1500 m sea level drop in 600 000 years!

NUMERICAL STRATIGRAPHIC MODELING… APPLIED TO THE WESTERN MEDITERRANEAN

Modeling the Messinian Salinity Crisis

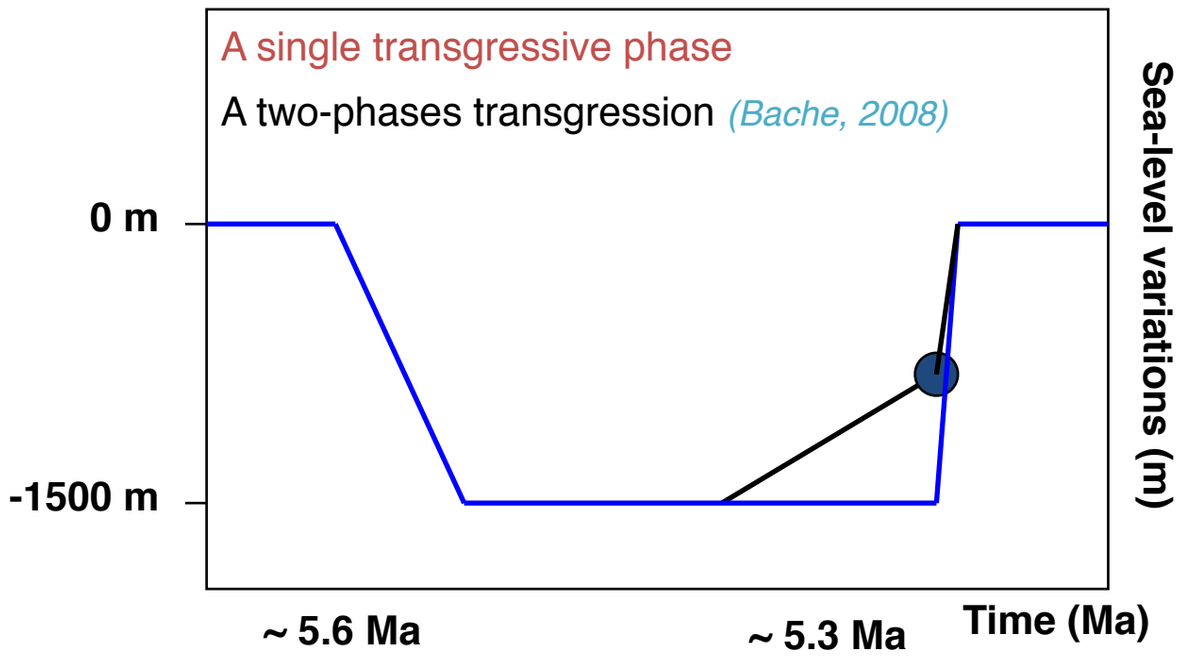


Bache 2008, Bache et al., 2012

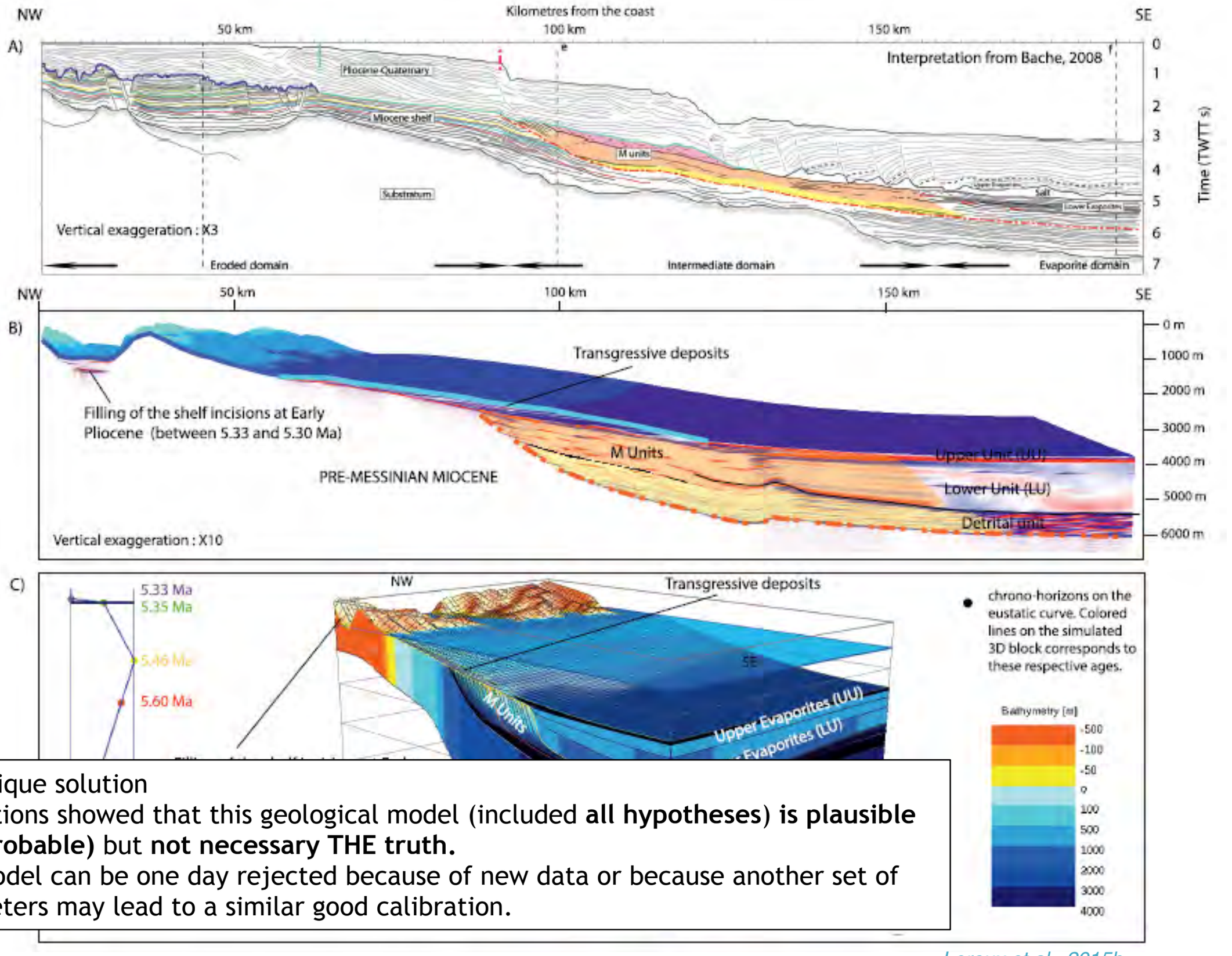


Bache 2008, Bache et al., 2012

TES = smooth topography (ravinement surface)
=> slow sea-level rise
MES = rough topography
=> Fast sea-level rise



Modeling the Messinian Salinity Crisis



Non unique solution
Simulations showed that this geological model (included **all hypotheses**) **is plausible (and probable)** but **not necessary THE truth.**
This model can be one day rejected because of new data or because another set of parameters may lead to a similar good calibration.

Leroux et al., 2015b

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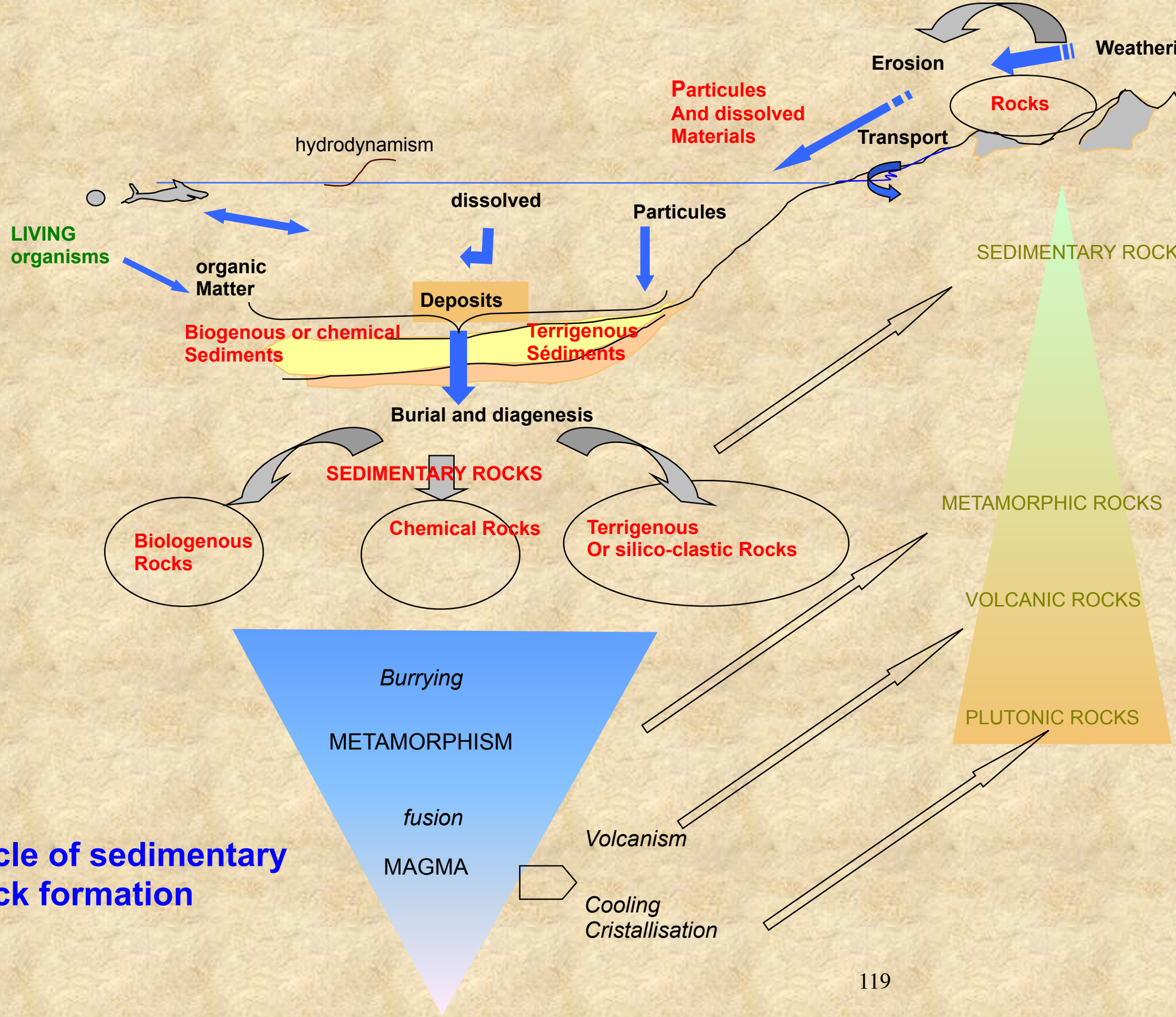
…

SEA-LEVEL CYCLES andSEDIMENTARY RECORD at differentscales

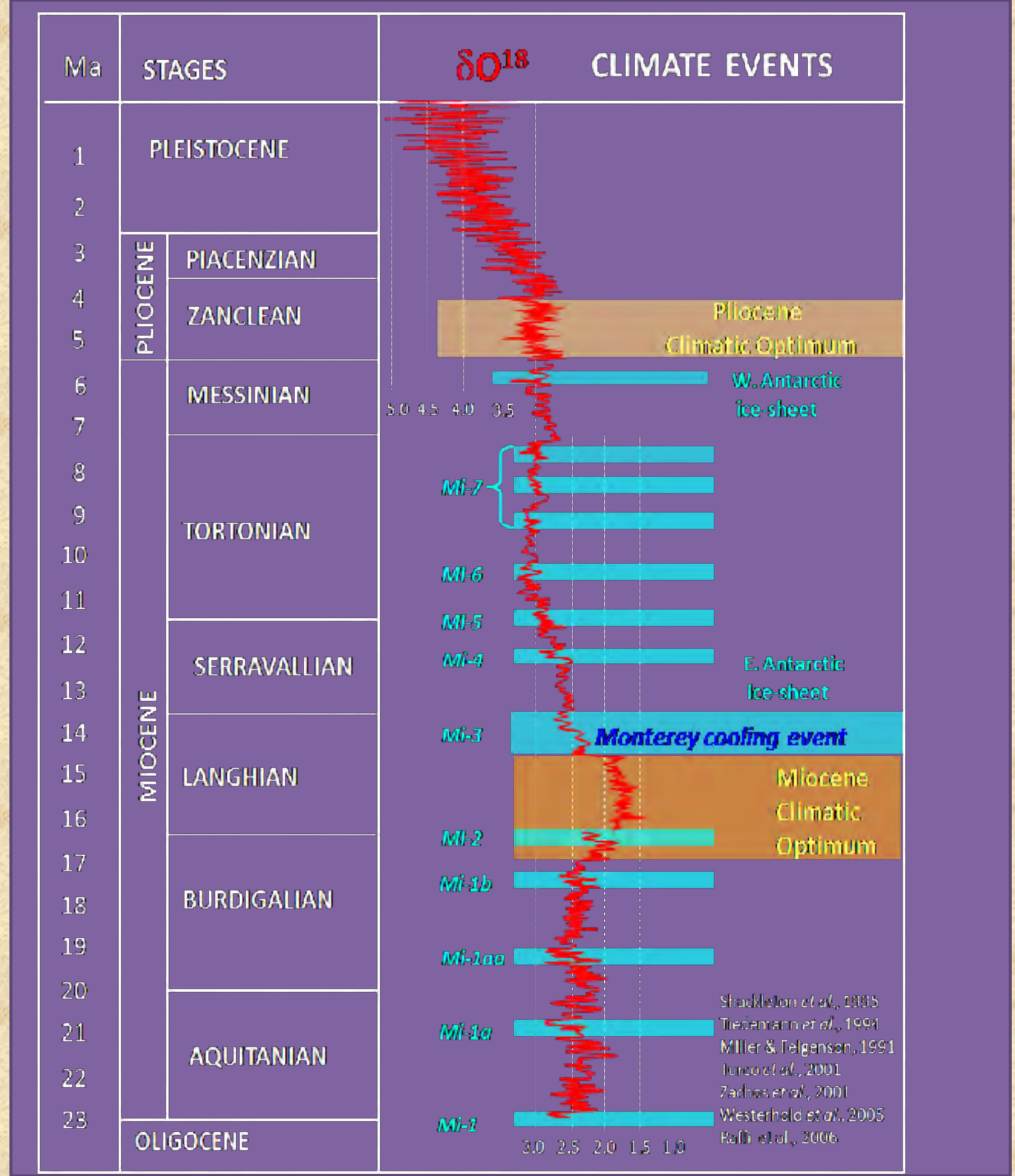
Examplesfrom European Recent basins

Accra, Ghana Univ., AEON-ESSRI, UBO,
IFREMER EOL SCHOOL

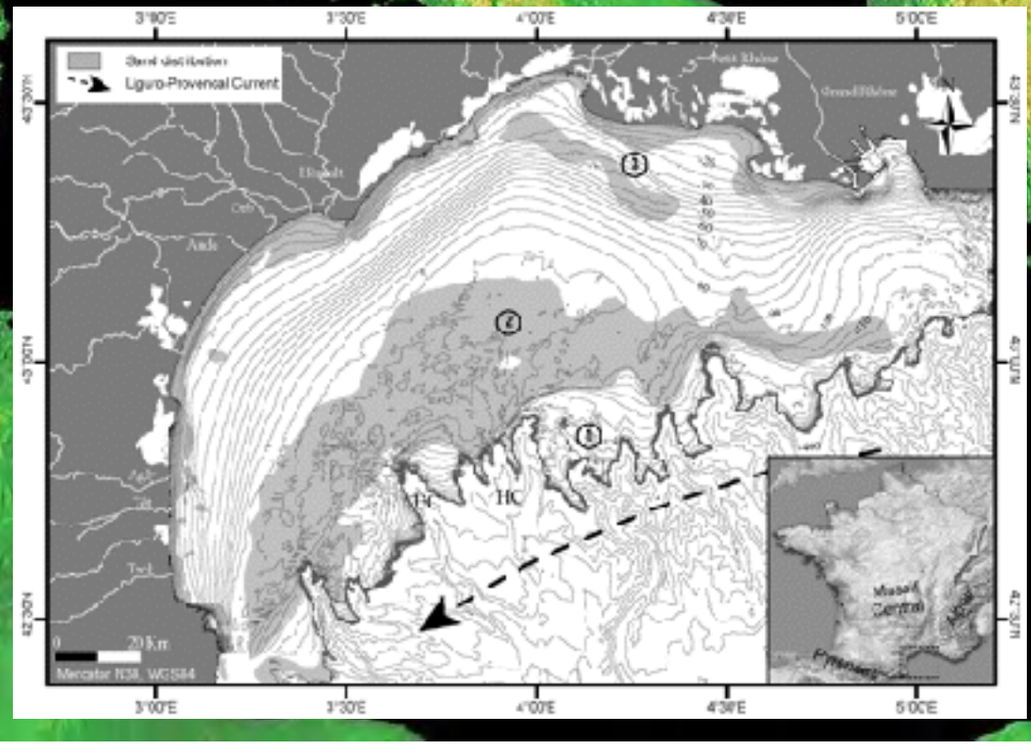


Cycle of sedimentary rock formation

Climate variations
During the formation
of the Gulf of Lion



A- Drainage basin and Modern Gulf of Lion

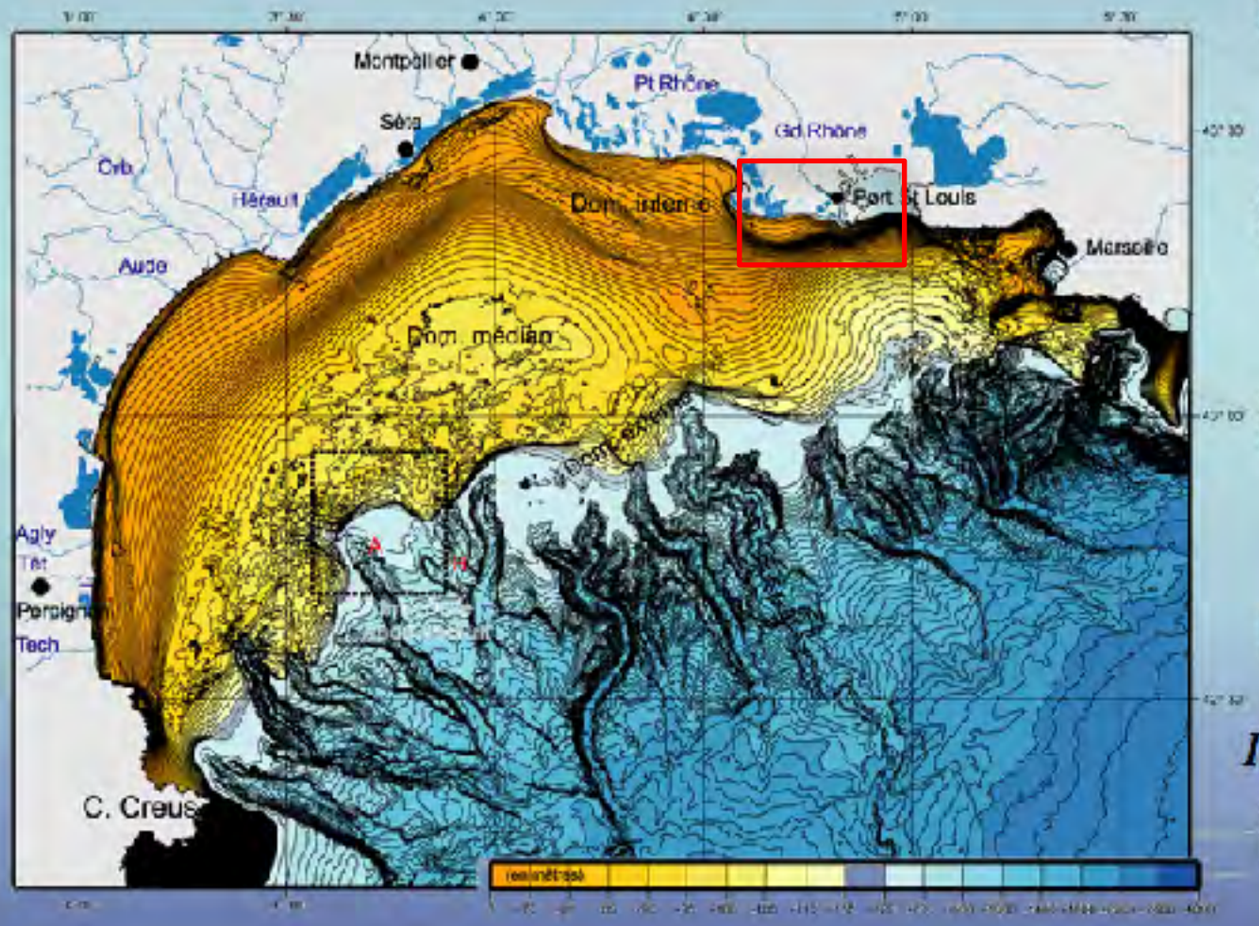


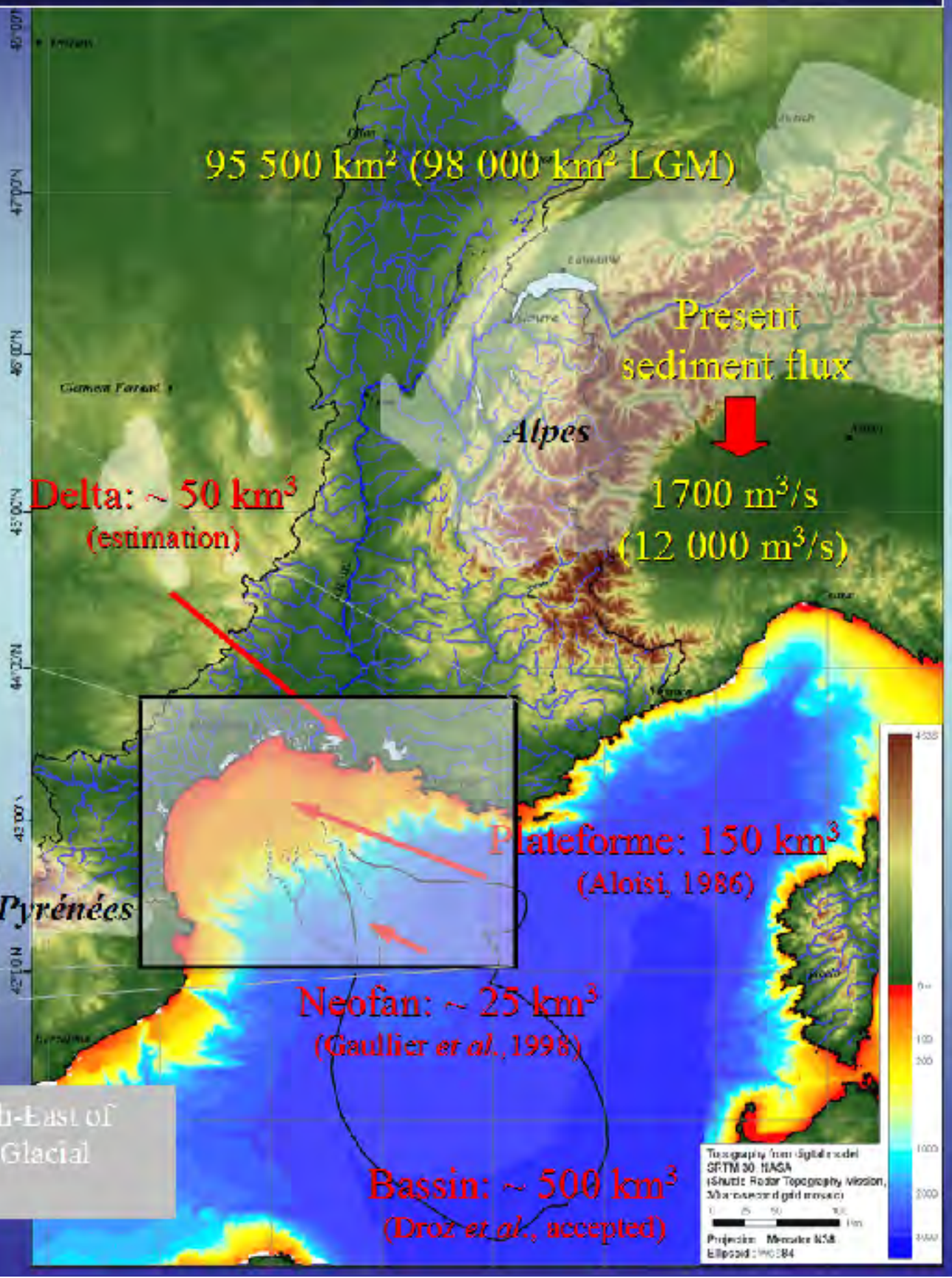
The Western Mediterranean

The Gulf of Lions

Passive margin:

- *High sediment supply*
- *Continuous subsidence (250 m/Ma)*



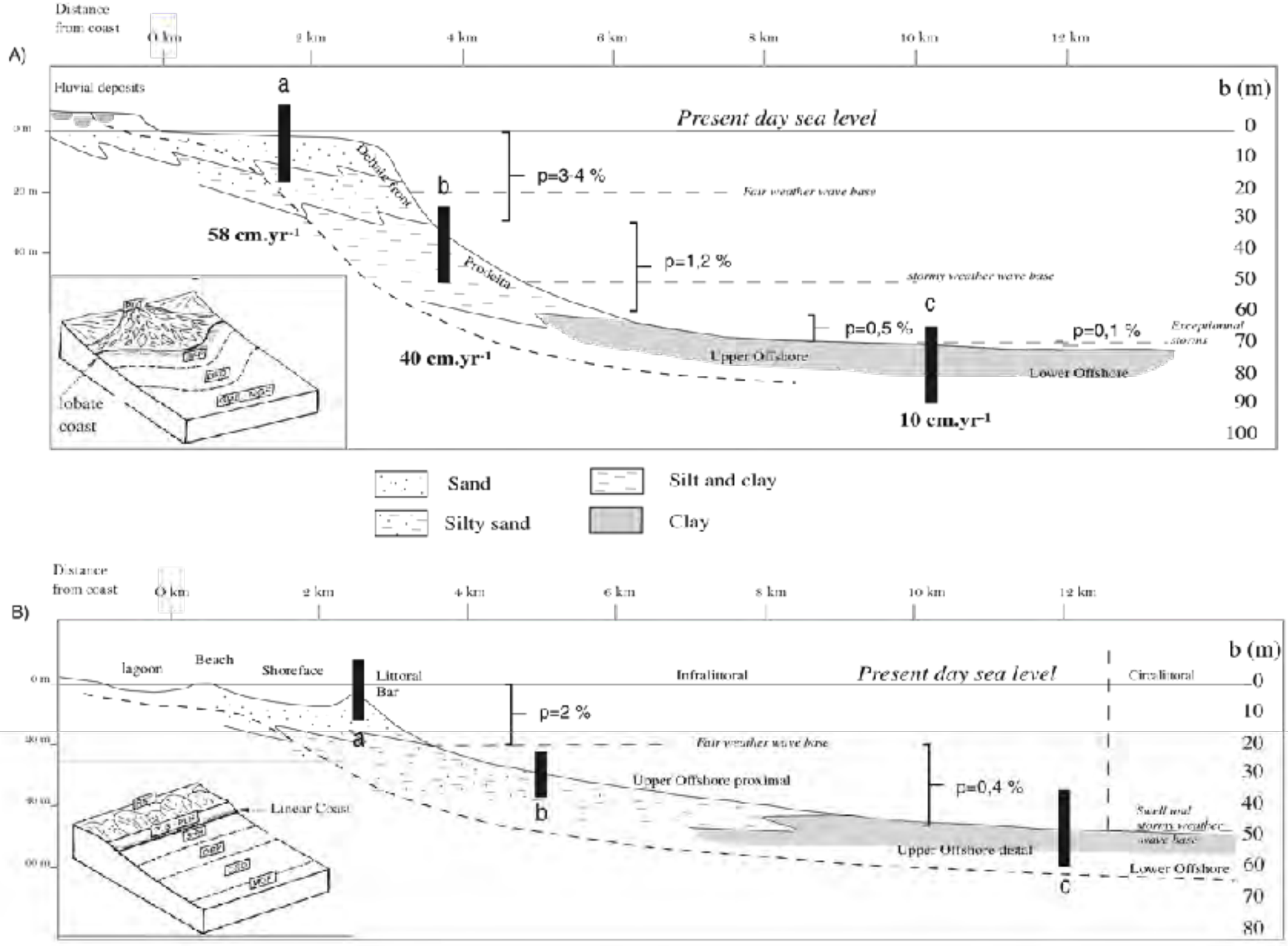


Geographic, morpho-bathymetric and hydrographic settings in South-East of France and maximum extension of the alpine glaciers during Last Glacial maximum (redraw from Antoine *et al.*, 1999).

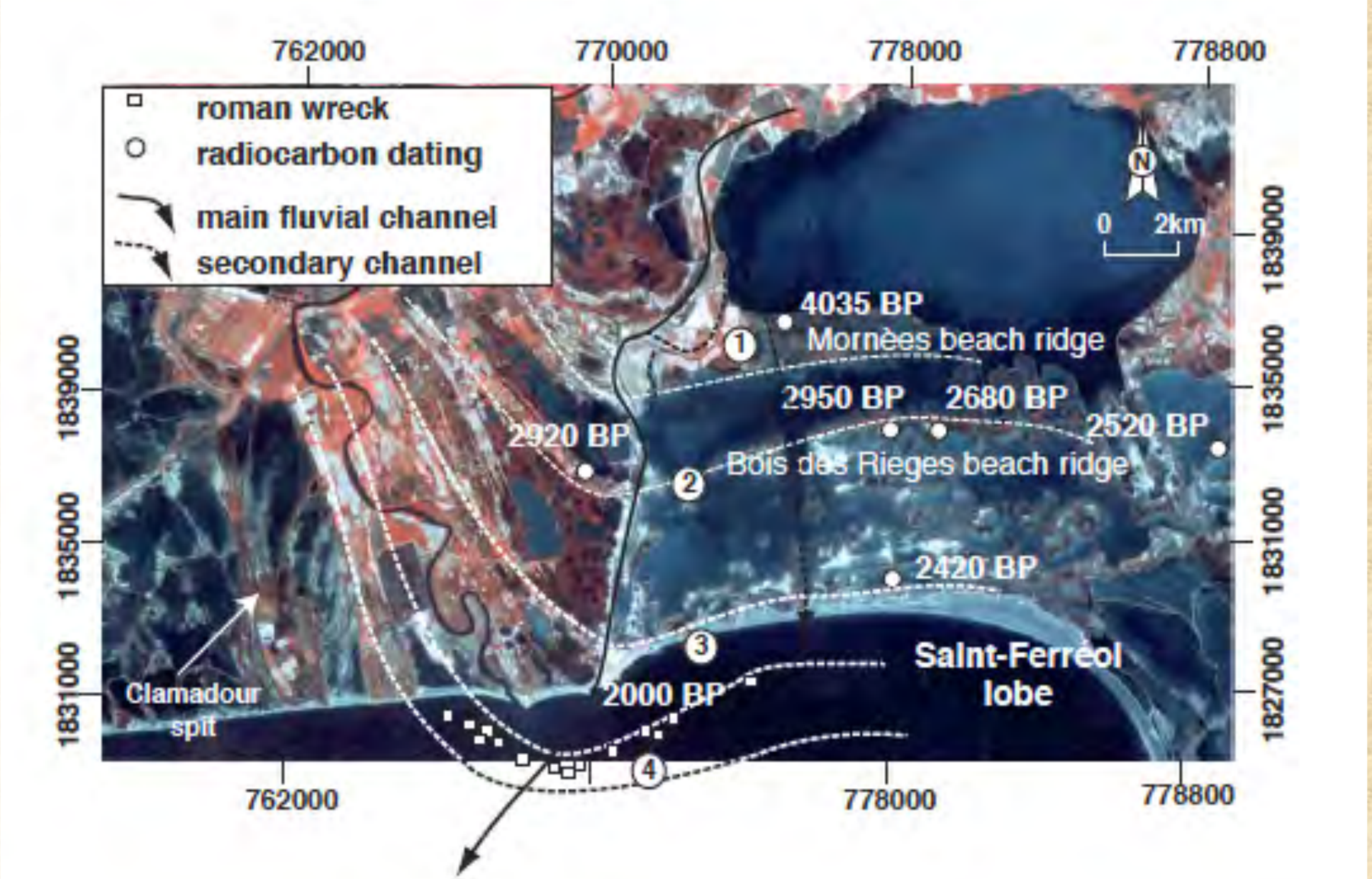
(Jouet et al., 2006)

What kind of Delta ?

Geographical position of the studied area: the Rhone delta. The green lines represent palaeo-channels of the Rhone. Pleistocene gravel of Crau and fresh water marsh on the
eastern margin of the delta are superimposed on the landsat image. (Vella et al., 2006)

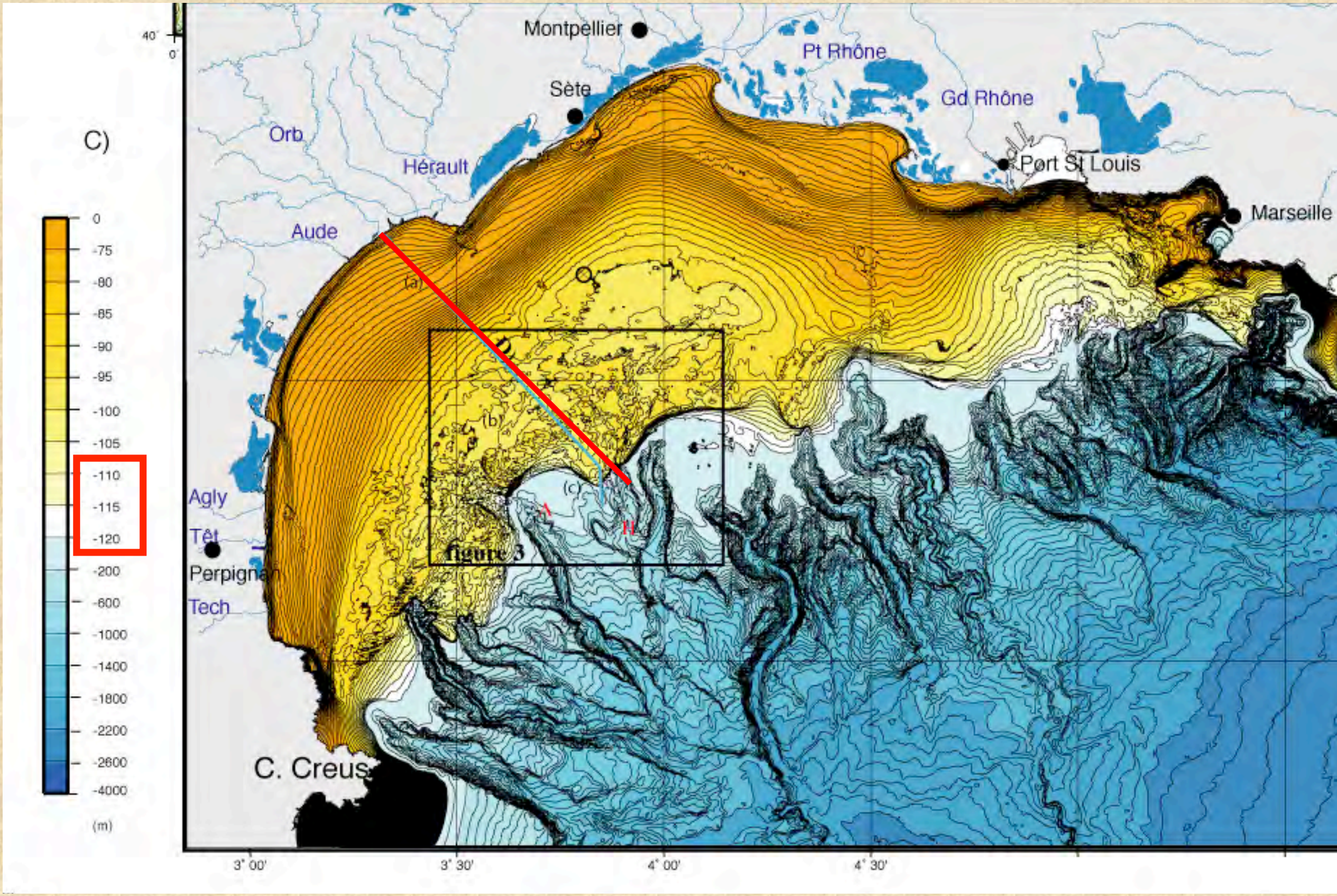

A)
Distance
from coast
0 km
2 km
4 km
6 km
8 km
10 km
12 km
Fluvial deposits
a
b
c
Present day sea level
b (m)
0
10
20
30
40
50
60
70
80
90
100
Delta front
Pro-delta
p=3-4 %
Fair weather wave base
58 cm.yr-1
p=1,2 %
storm weather wave base
p=0,5 %
p=0,1 %
Exceptional storms
40 cm.yr-1
Upper Offshore
Lower Offshore
10 cm.yr-1
lobate
coast
Sand
Silty sand
Silt and clay
Clay
B)
Distance
from coast
0 km
2 km
4 km
6 km
8 km
10 km
12 km
lagoon
Beach
Shoreface
Littoral
Bar
Infralittoral
Present day sea level
Circalittoral
b (m)
0
10
20
30
40
50
60
70
80
p=2 %
Fair weather wave base
a
b
Upper Offshore proximal
p=0,4 %
Swell and
storm weather
wave base
Upper Offshore distal
Lower Offshore
c
Linear Coast

Evolution through time

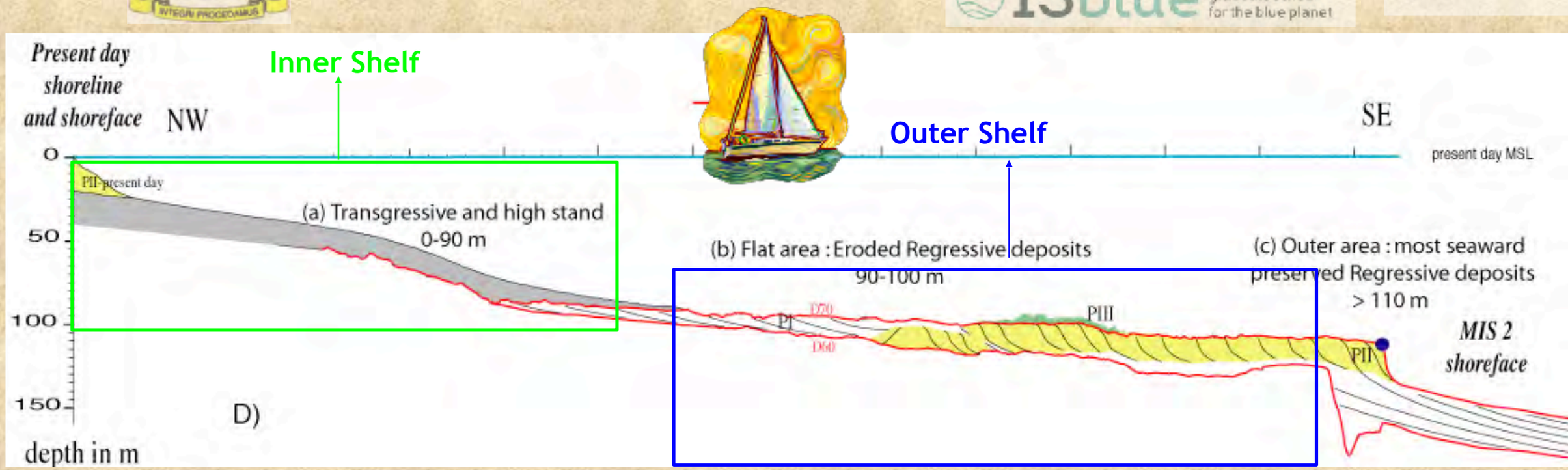


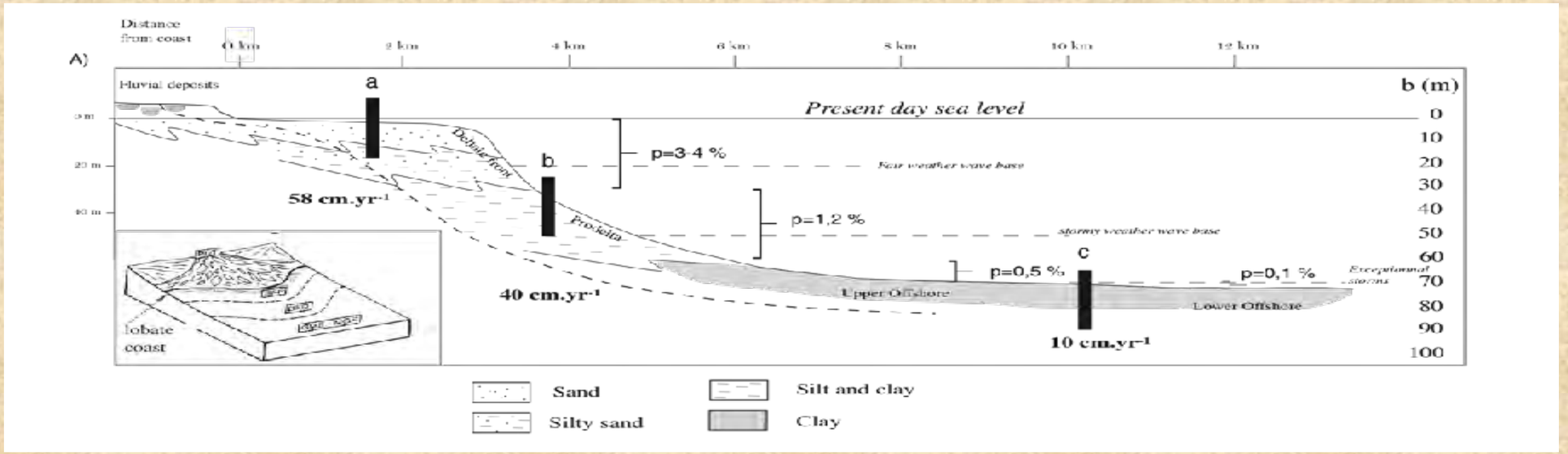
Progradation of Rhône's deltaïc plain since 4000 BP (Vella et al., 2008)

The Gulf of Lion shelf

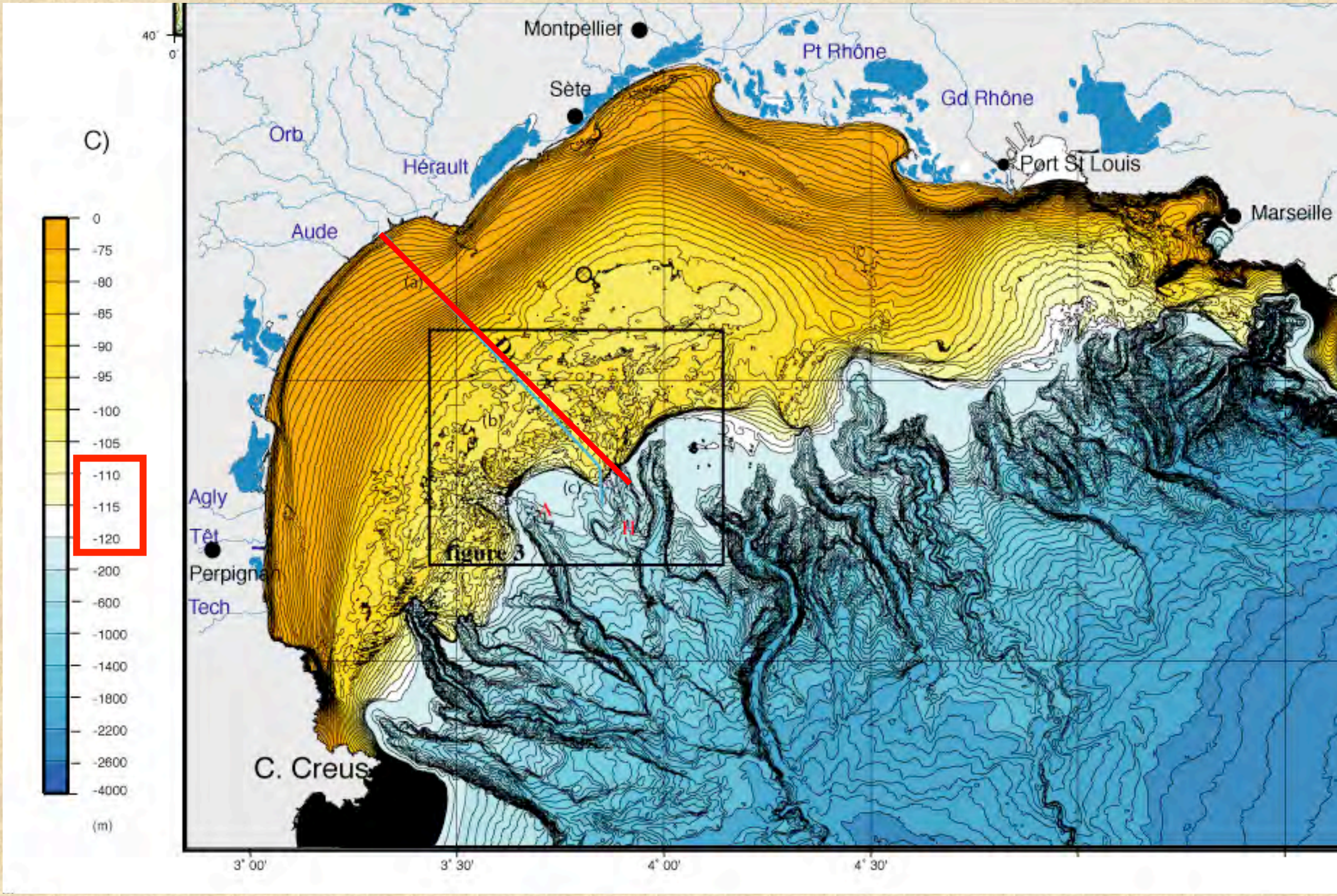


… From the coast to the shelf break


Present day shoreline and shoreface
NW
SE
Inner Shelf
Outer Shelf
present day MSL
0
50
100
150
depth in m
PII-present day
(a) Transgressive and high stand
0-90 m
(b) Flat area : Eroded Regressive deposits
90-100 m
(c) Outer area : most seaward preserved Regressive deposits
> 110 m
PI
PIII
PII
D20
D60
MIS 2 shoreface
D)

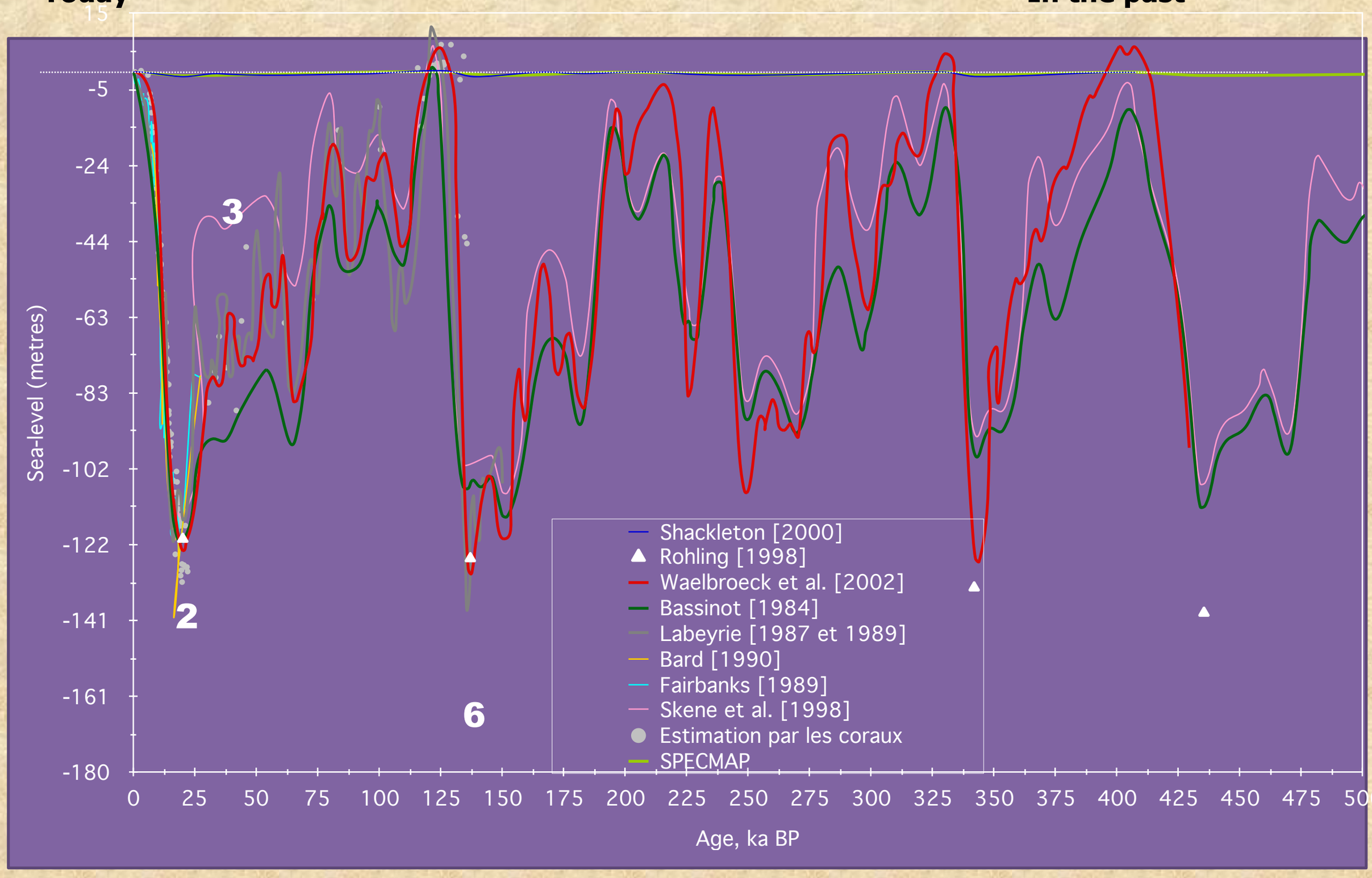

A)
Distance from coast
0 km
2 km
4 km
6 km
8 km
10 km
12 km
Fluvial deposits
a
b
c
Present day sea level
b (m)
0
10
20
30
40
50
60
70
80
90
100
p=3-4 %
p=1,2 %
p=0,5 %
p=0,1 %
Near weather wave base
Storm weather wave base
Exceptional storms
58 cm.yr-1
40 cm.yr-1
10 cm.yr-1
Prodelta
Upper Offshore
Lower Offshore
lobate coast
Sand
Silty sand
Silt and clay
Clay

The Gulf of Lion shelf



Where is the LGM coastline ?

Today **In the past**

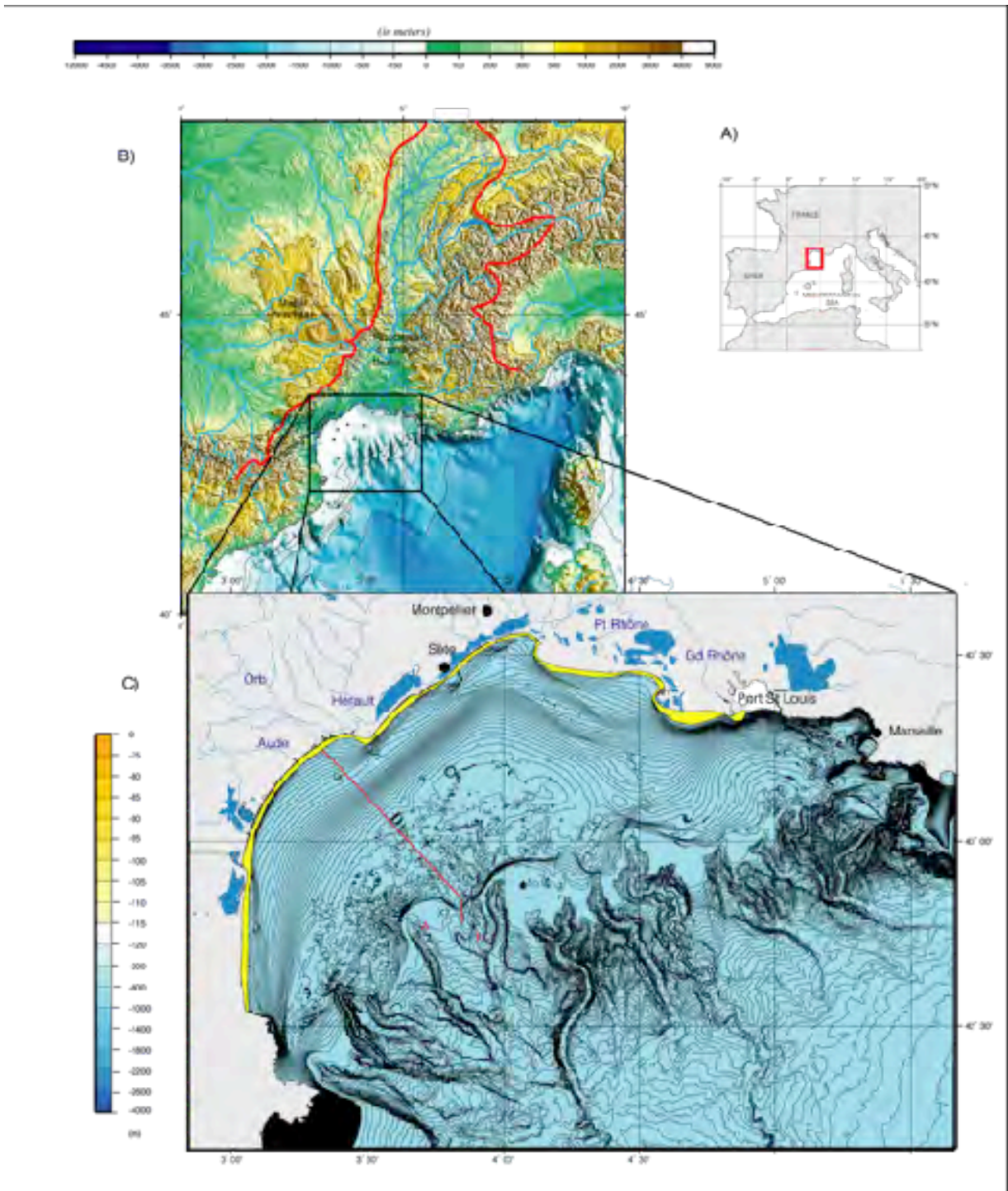


Synthesis by Waelbrock, Rabineau and Jouet

Present : High Sea Level

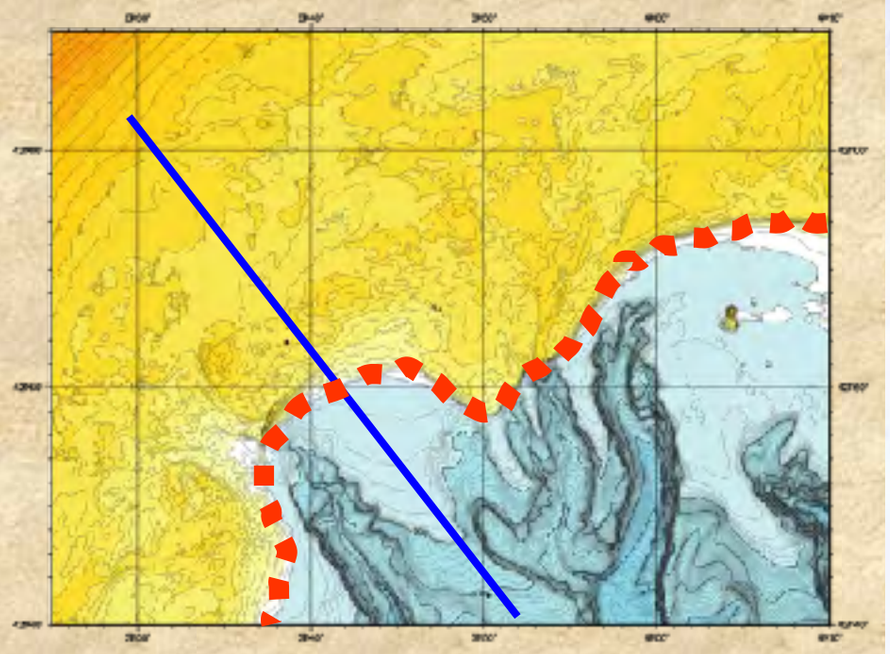
Last Glacial Maximum
Low Sea Level

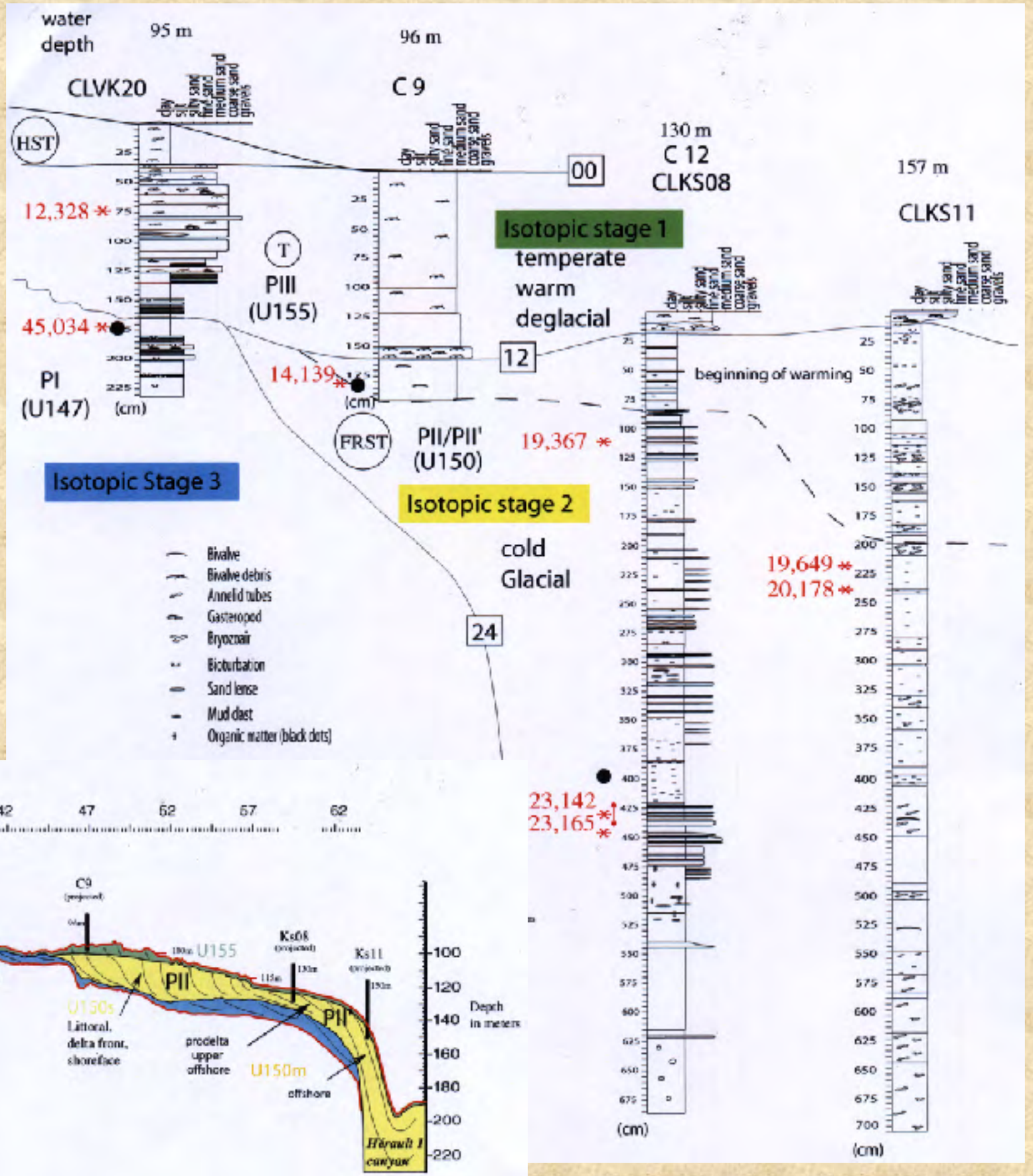
Rabineau et al., 2006



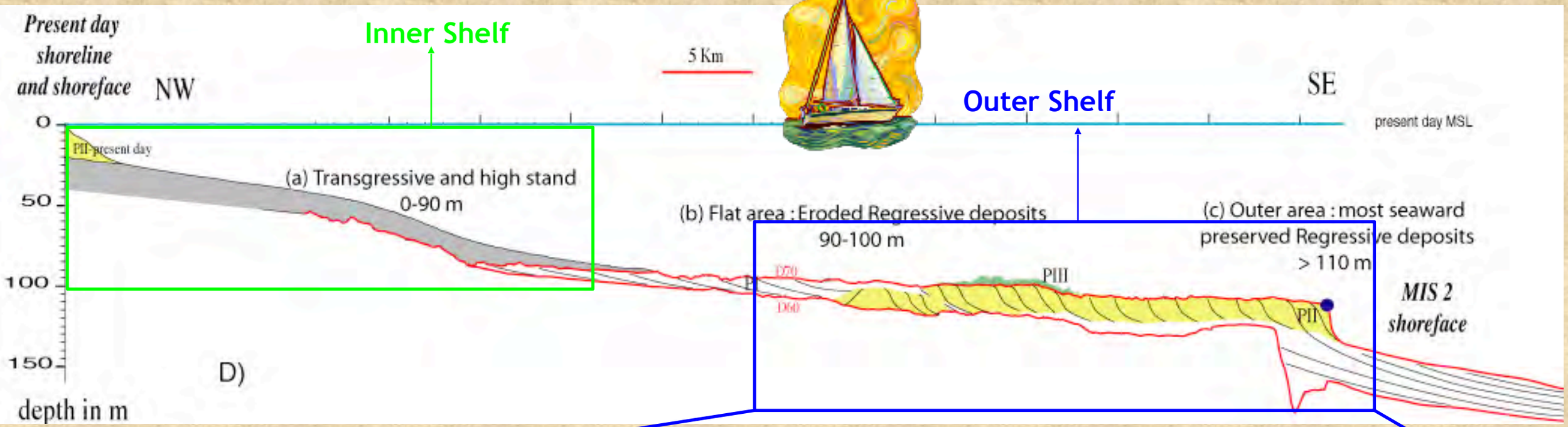
Lithoseismic correlations

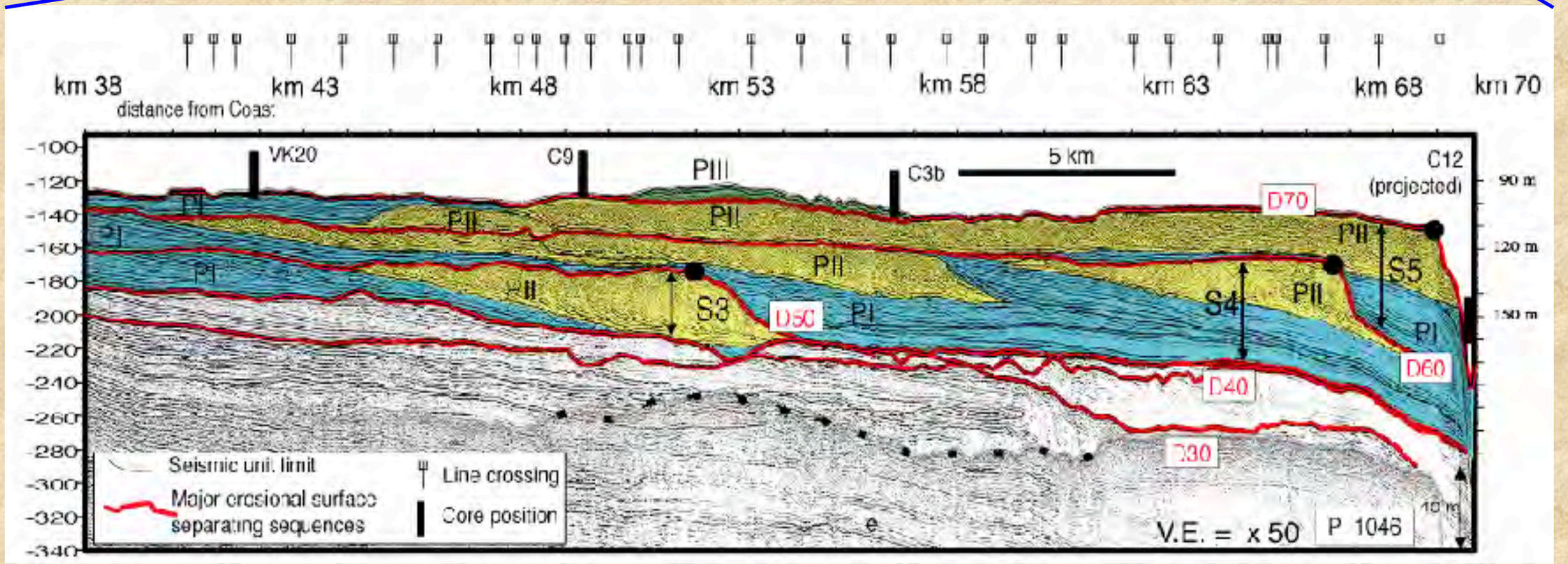
Rabineau et al., 2005

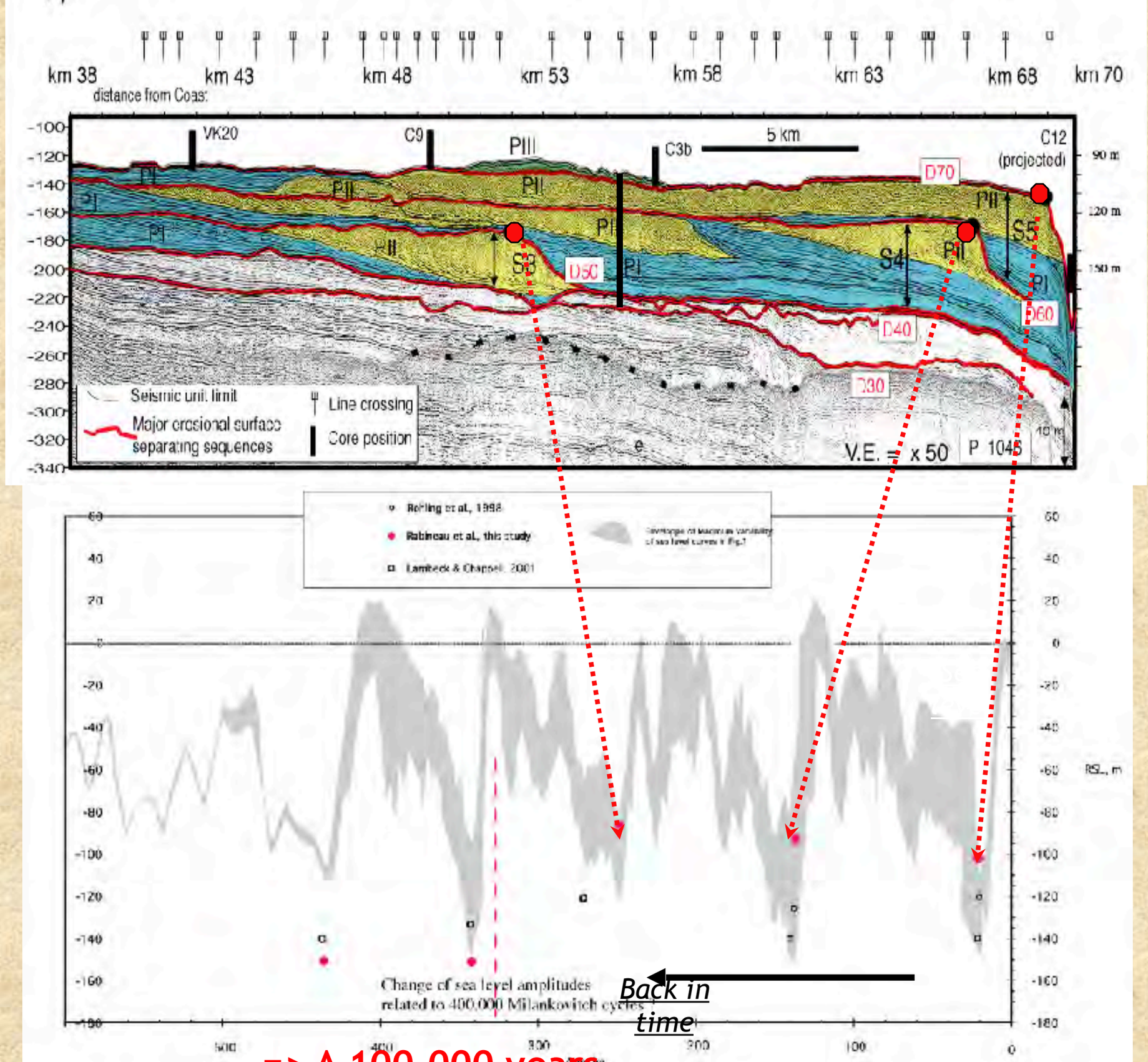




Architecture of Quaternary deposits : HST et FRSST-LST partitionning

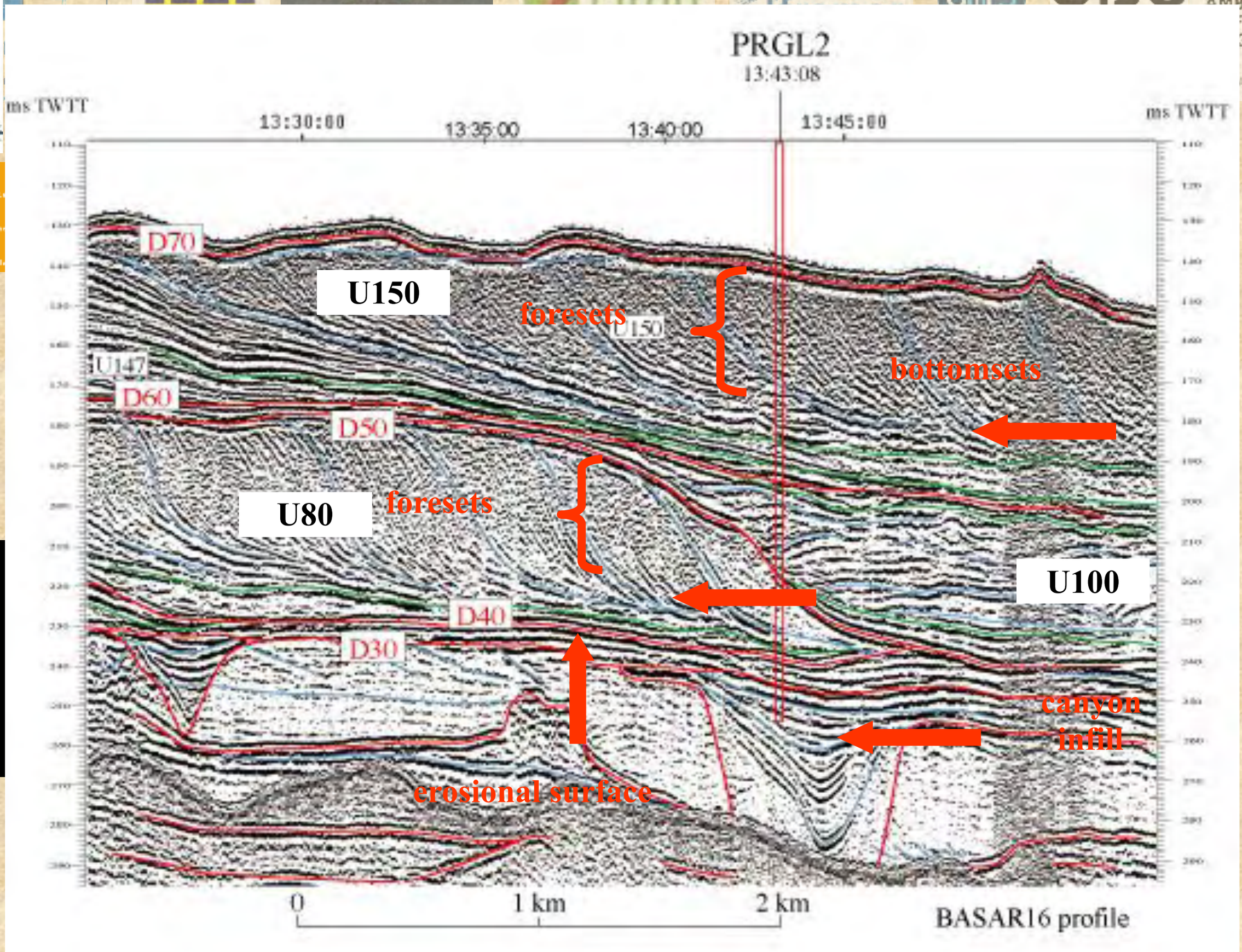






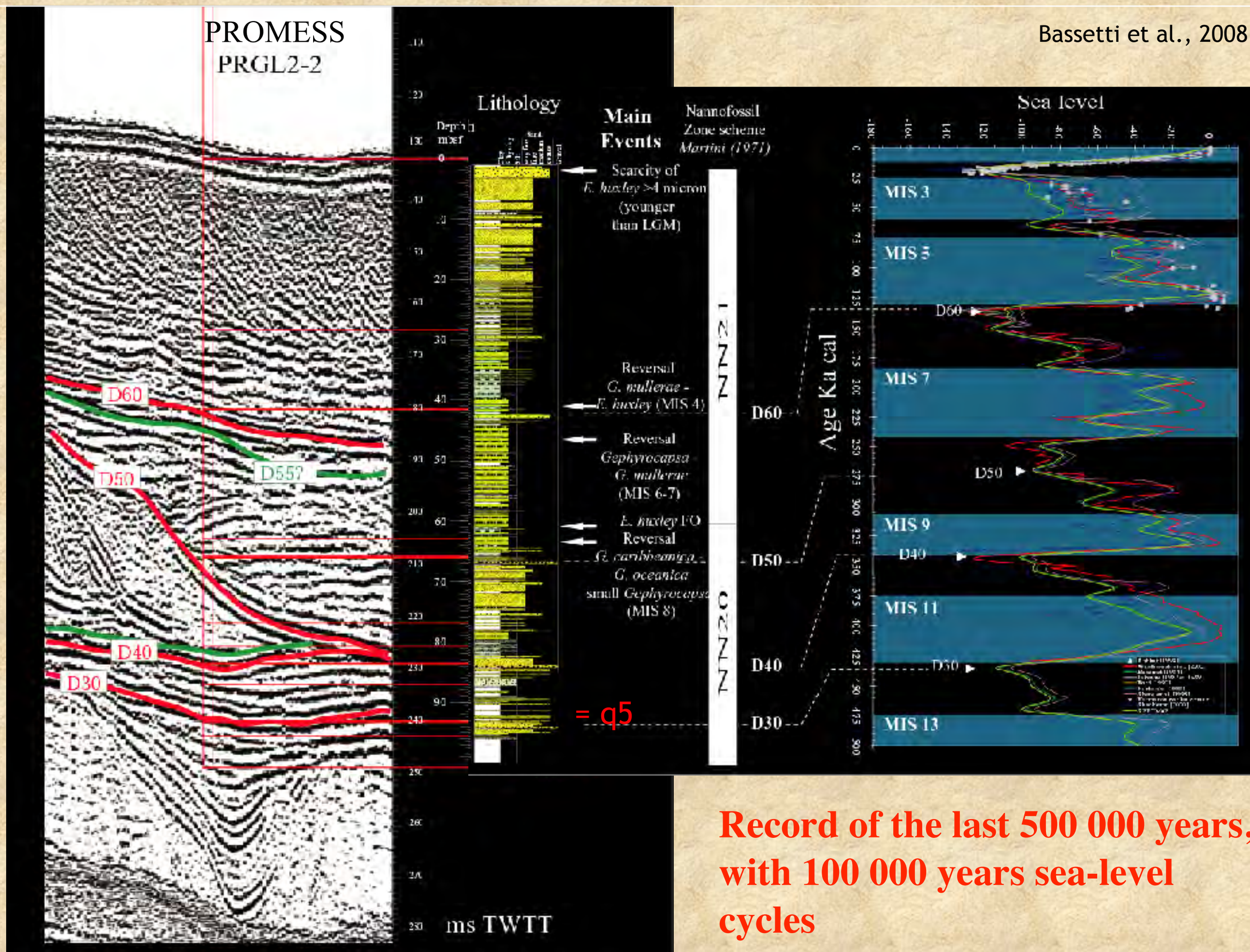
=> A 100,000 years cyclicity

Rabineau et al., EPSL 2006



(Seismic interpretation: Rabineau et al. 2005, in Bassetti et al. 2008)

Bassetti et al., 2008



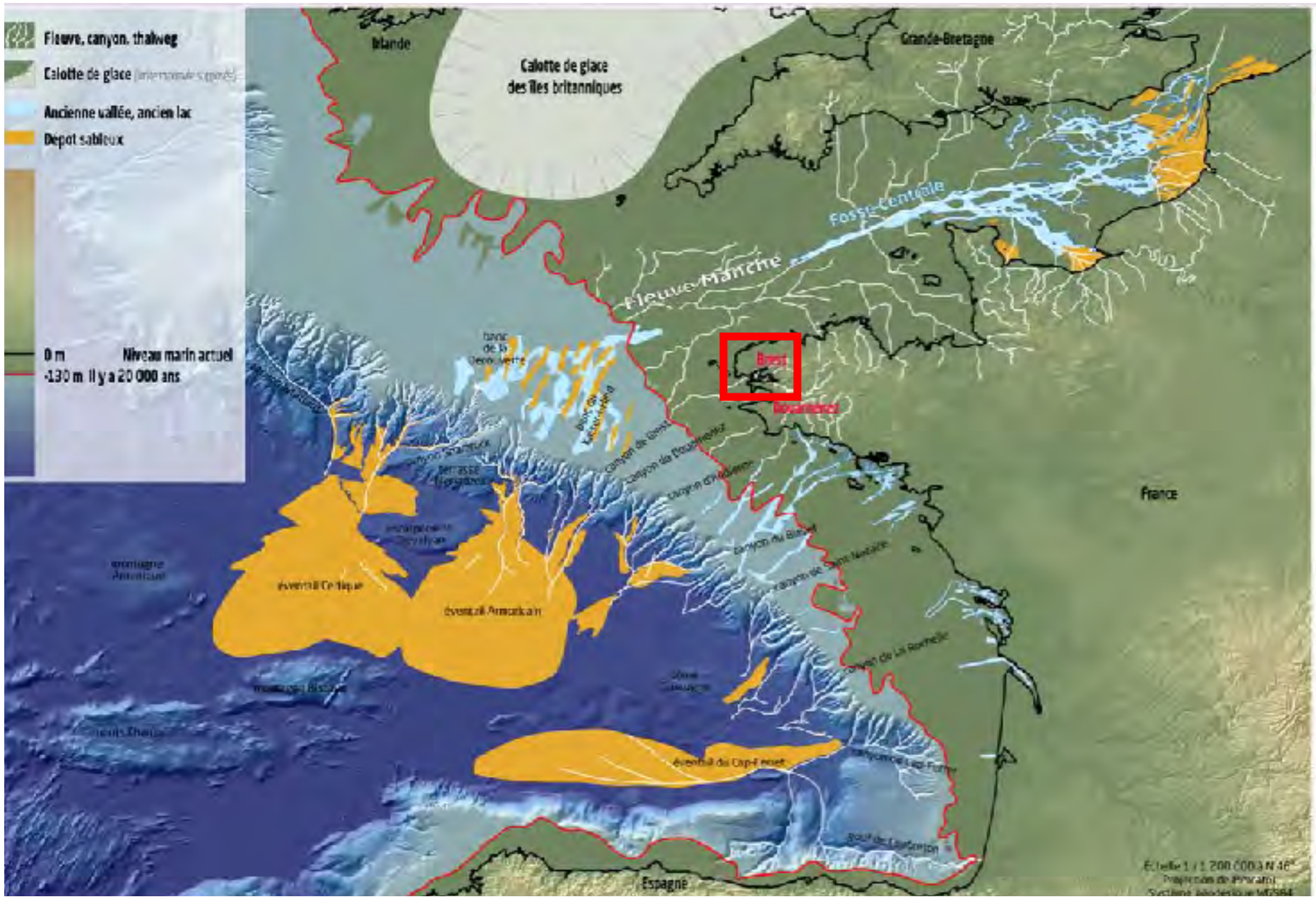
Record of the last 500 000 years, with 100 000 years sea-level cycles

20 000 years ago : Last Glacial Maximum

Icehouse climate

North Europe covered by ice-sheet

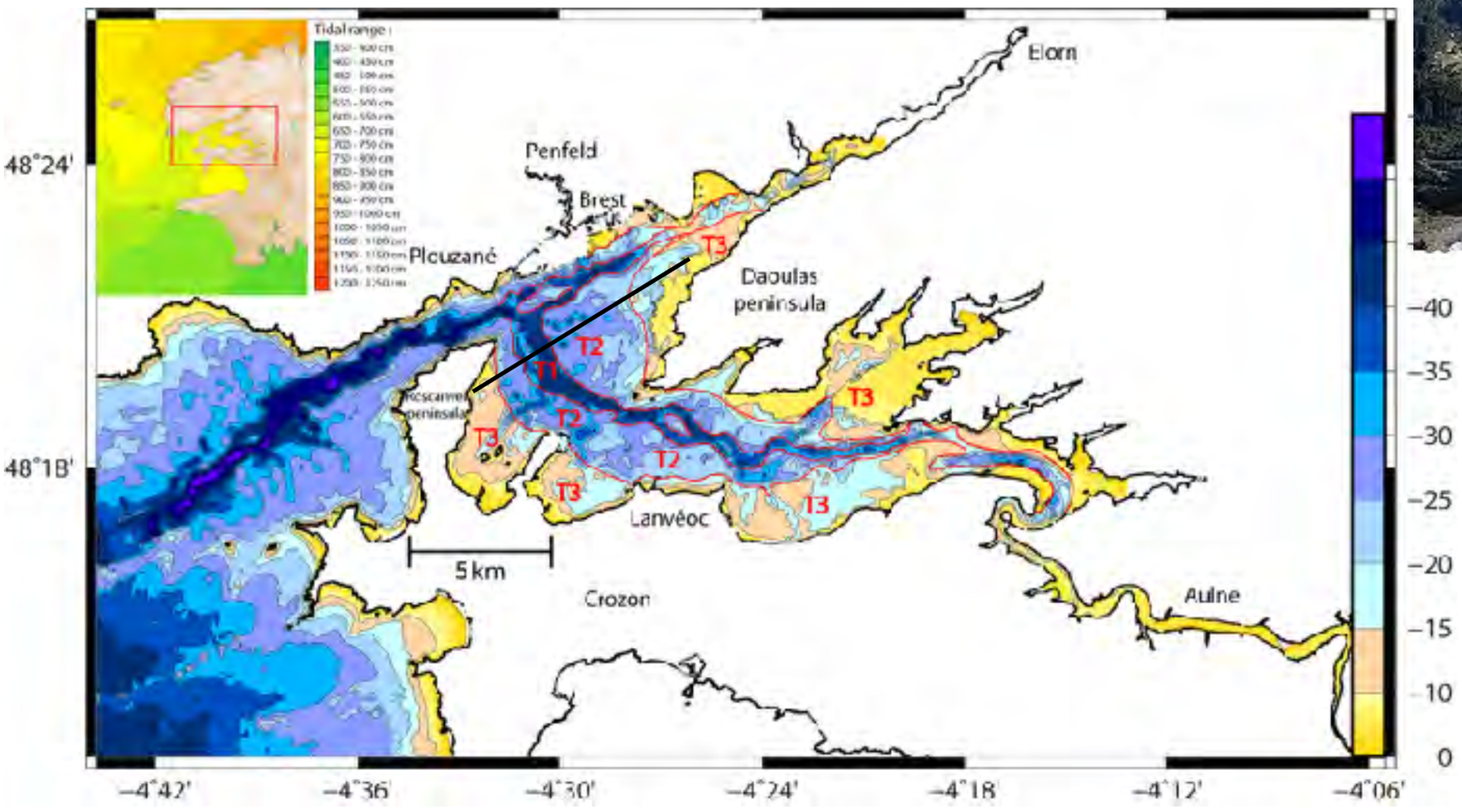
English Chanel (Present-day Sea between France and England) was reduced to a River

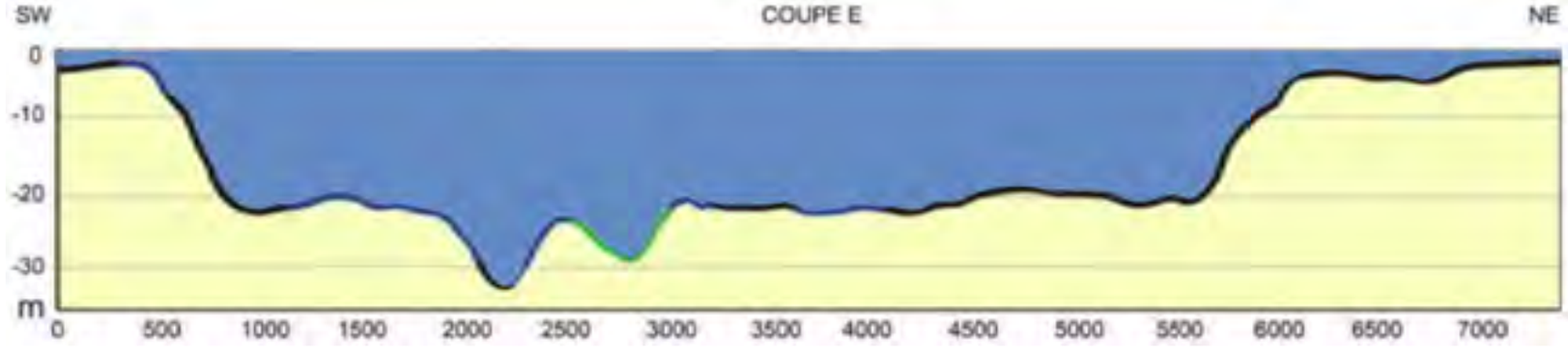


We could walk from France to go to England

Before the Holocene transgression, English Channel (Between France and England)

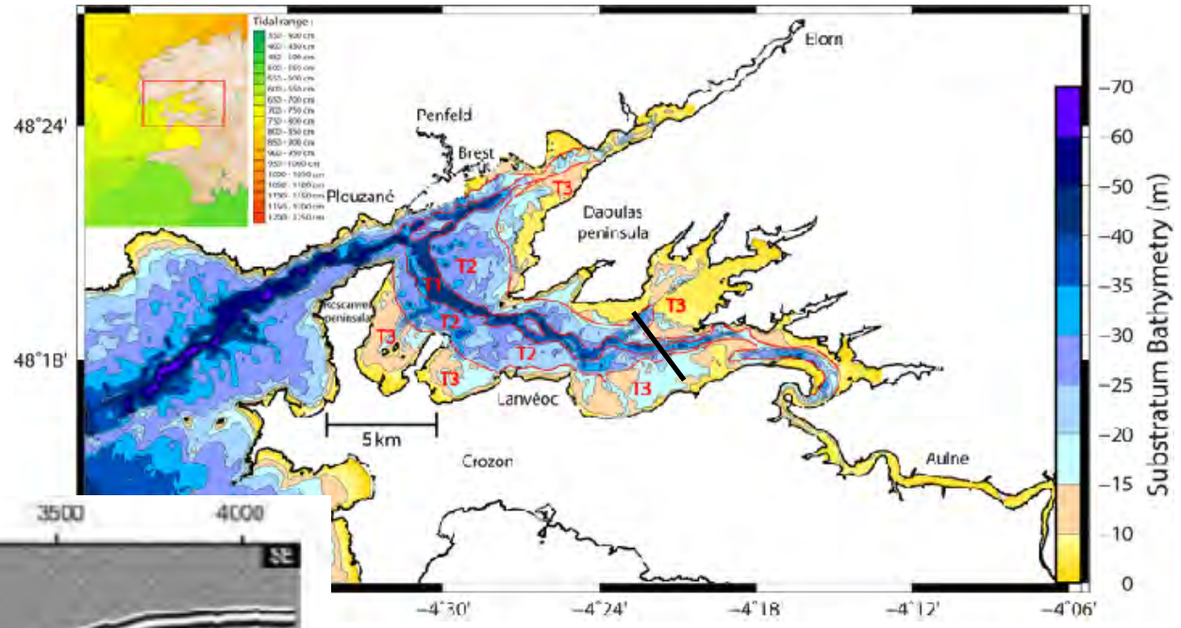
Bay of Brest (estuary), Britany, West of France - Pres

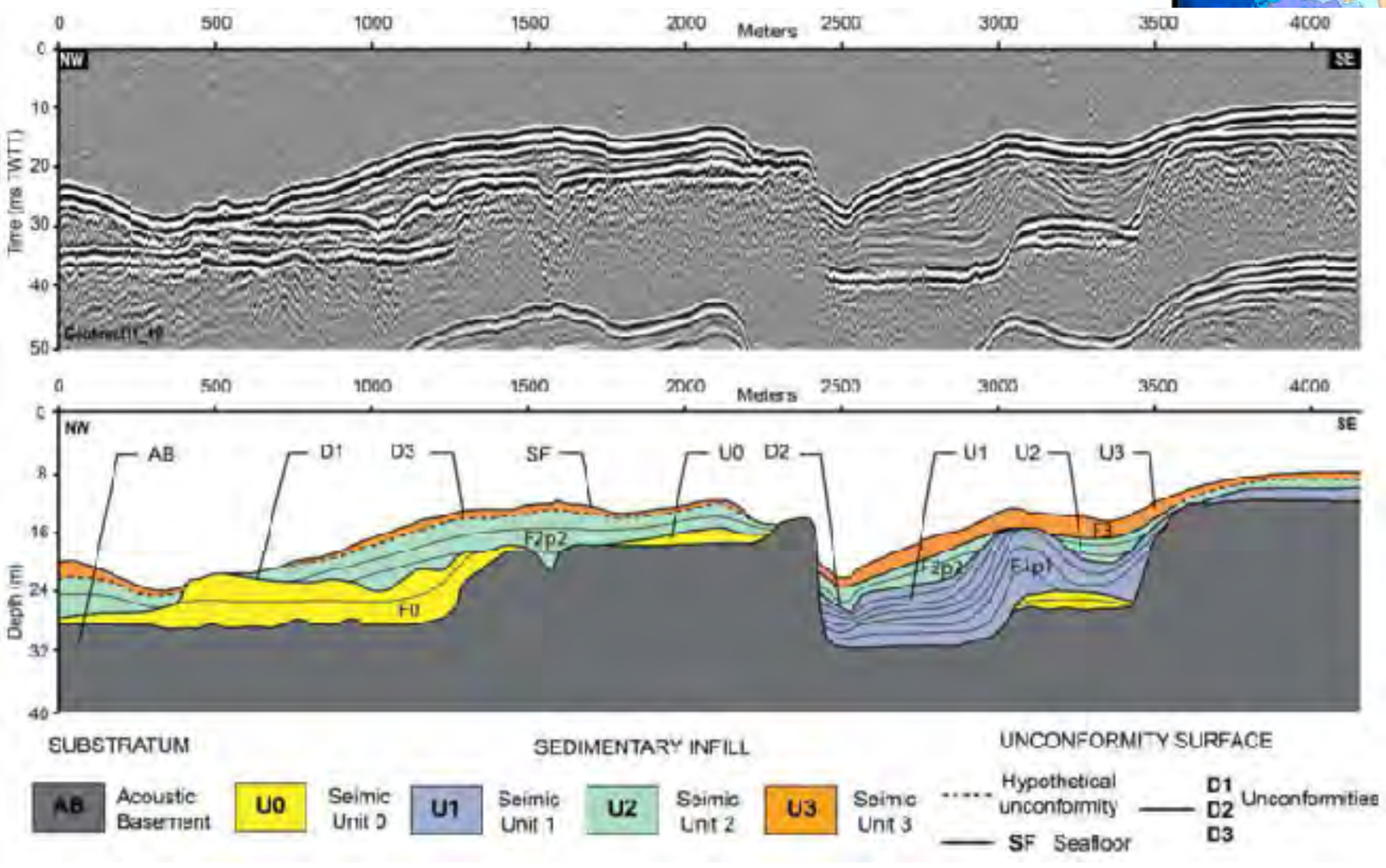


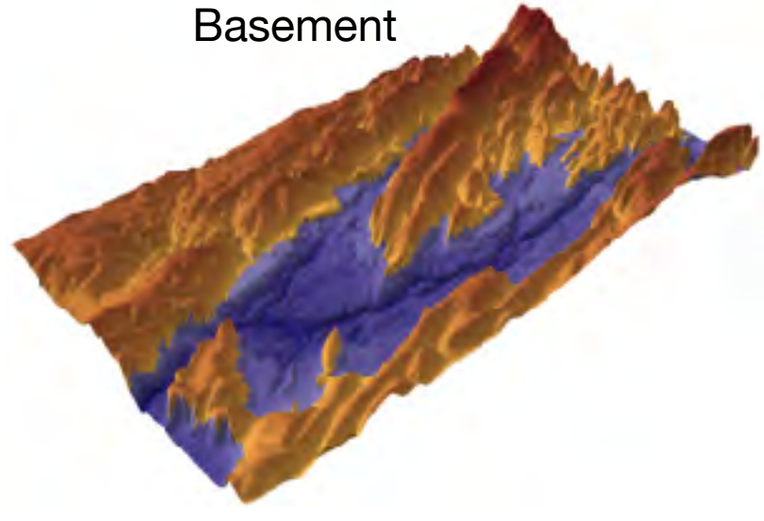


Seismic interpretation :

- highlighted transgressive deposits
- Allowed to individualise 4 units (U0-U3)

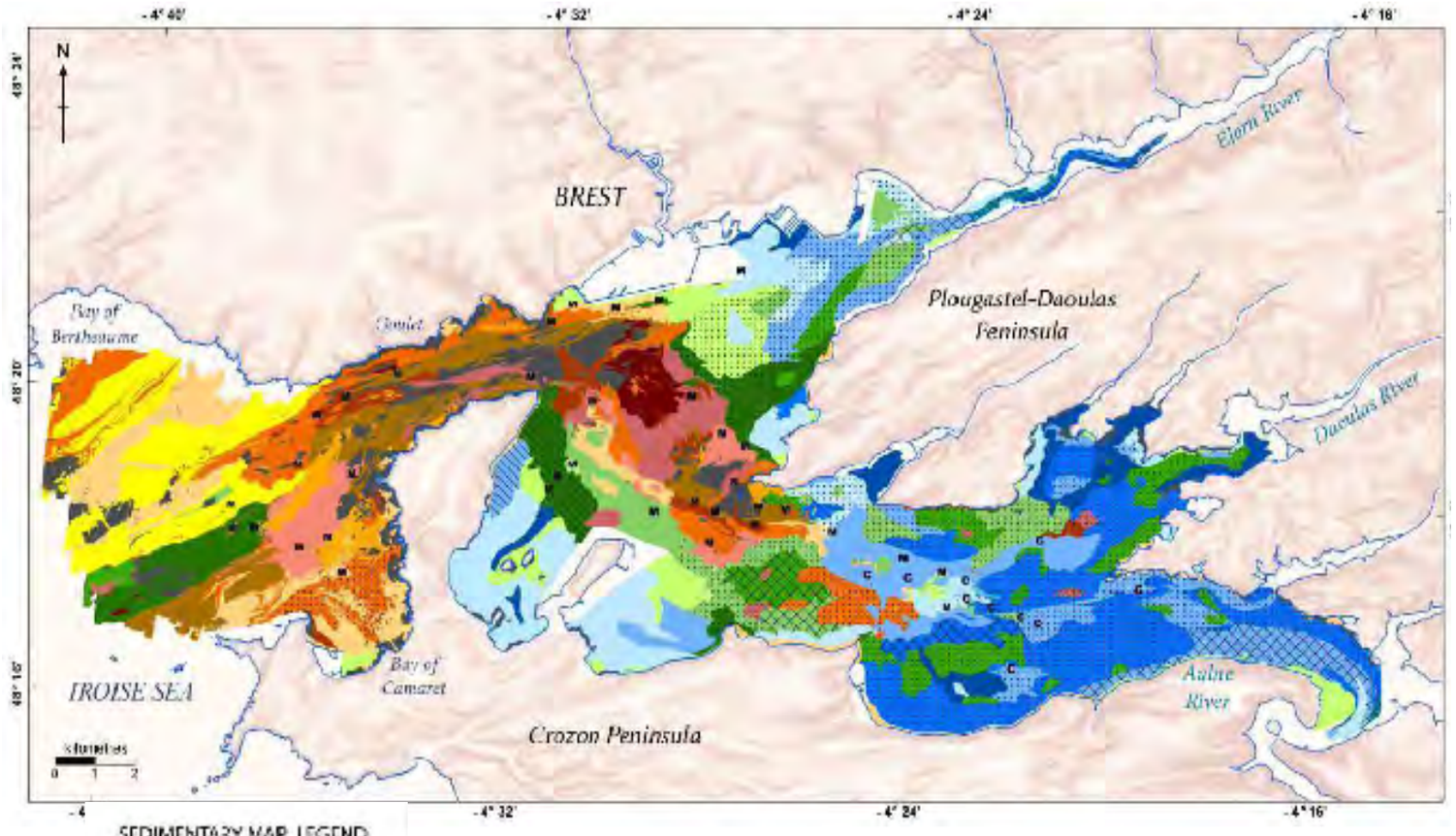






Seismic line in the Aulne estuary. The vertical scale is in two way travel time (ms TWTT) for the seismic line and in meters for the interpretation (Grégoire, 2016).

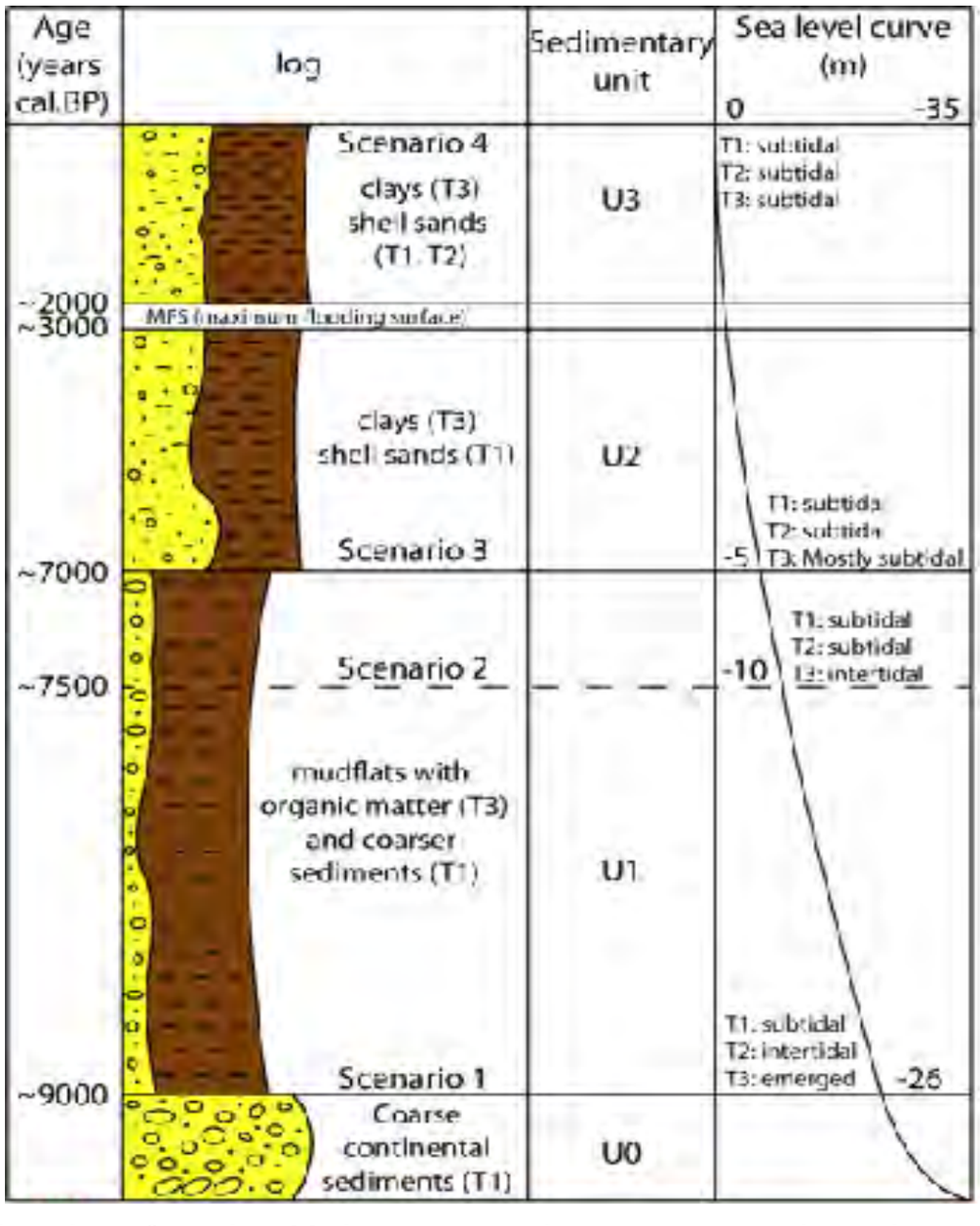
Present-day lithological map of the Bay of Brest + cores locations



Grégoire et al., 2017

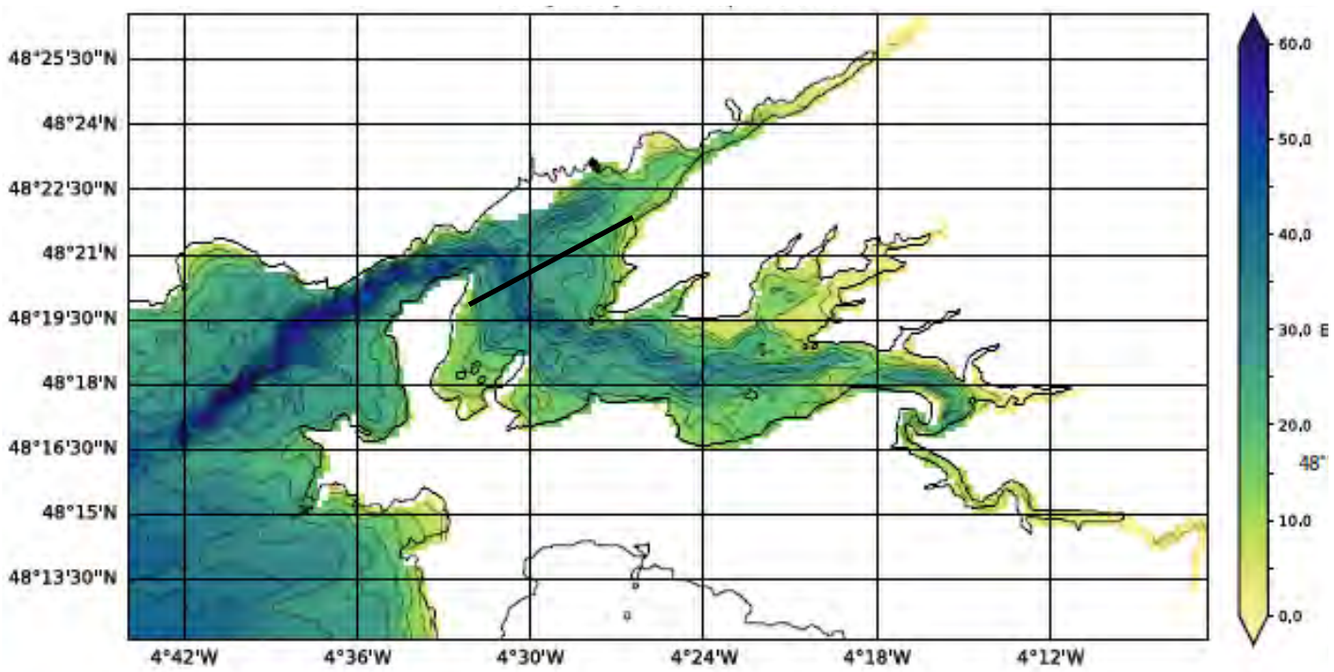
U0 (LST)	> 10 000 ~9 000
U1 (TST1)	~9 000 7 000
U2 (TST2)	6 800 ~3 000
U3 (HST)	~2 000 Aujourd'hui

Cores analyses allow:
- to date those units
- ascribe some lithologies at some points to each of those units

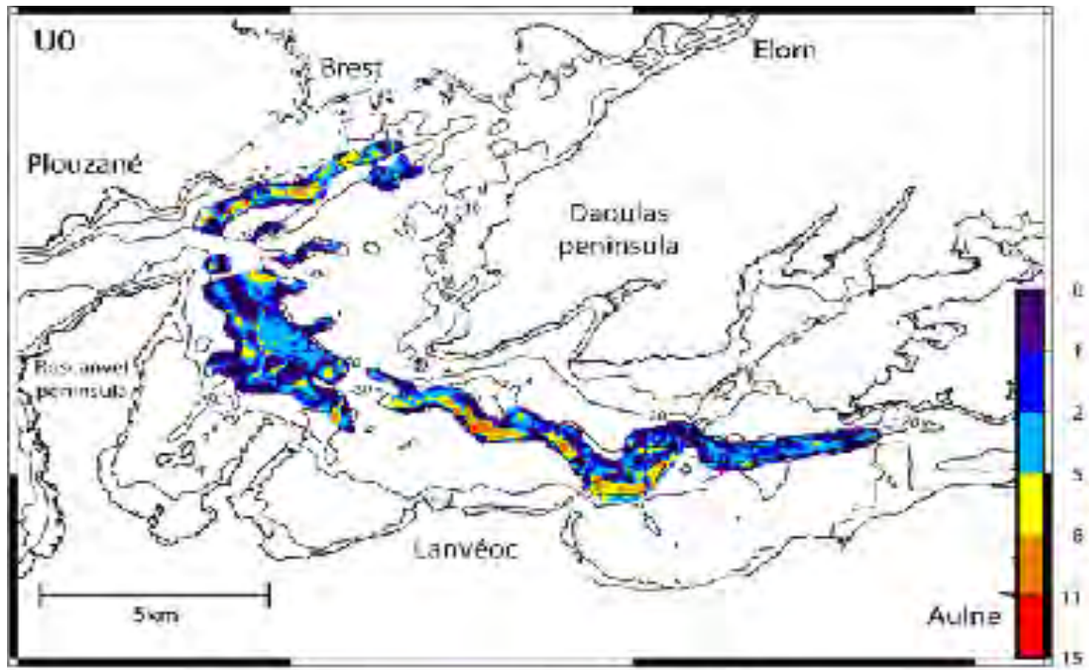


Stratigraphic log for the Holocene sediment record in the Bay of Brest (Olivier et al., in review)

9000 ans cal. BP, Top of U0



Bathymetry at the top of U0 (m)

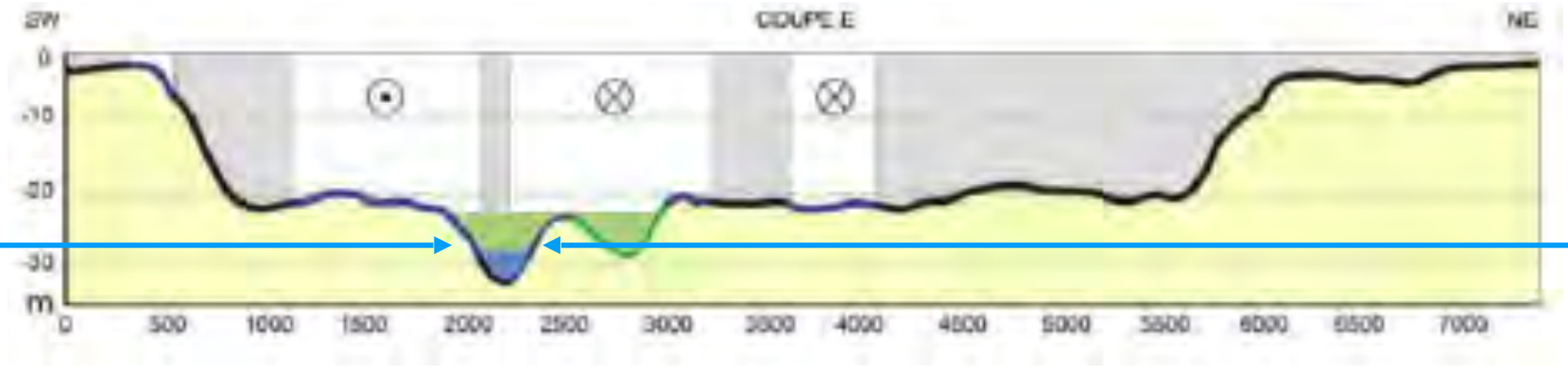


U0 thickness (m)

Intertidal area

Subtidal area

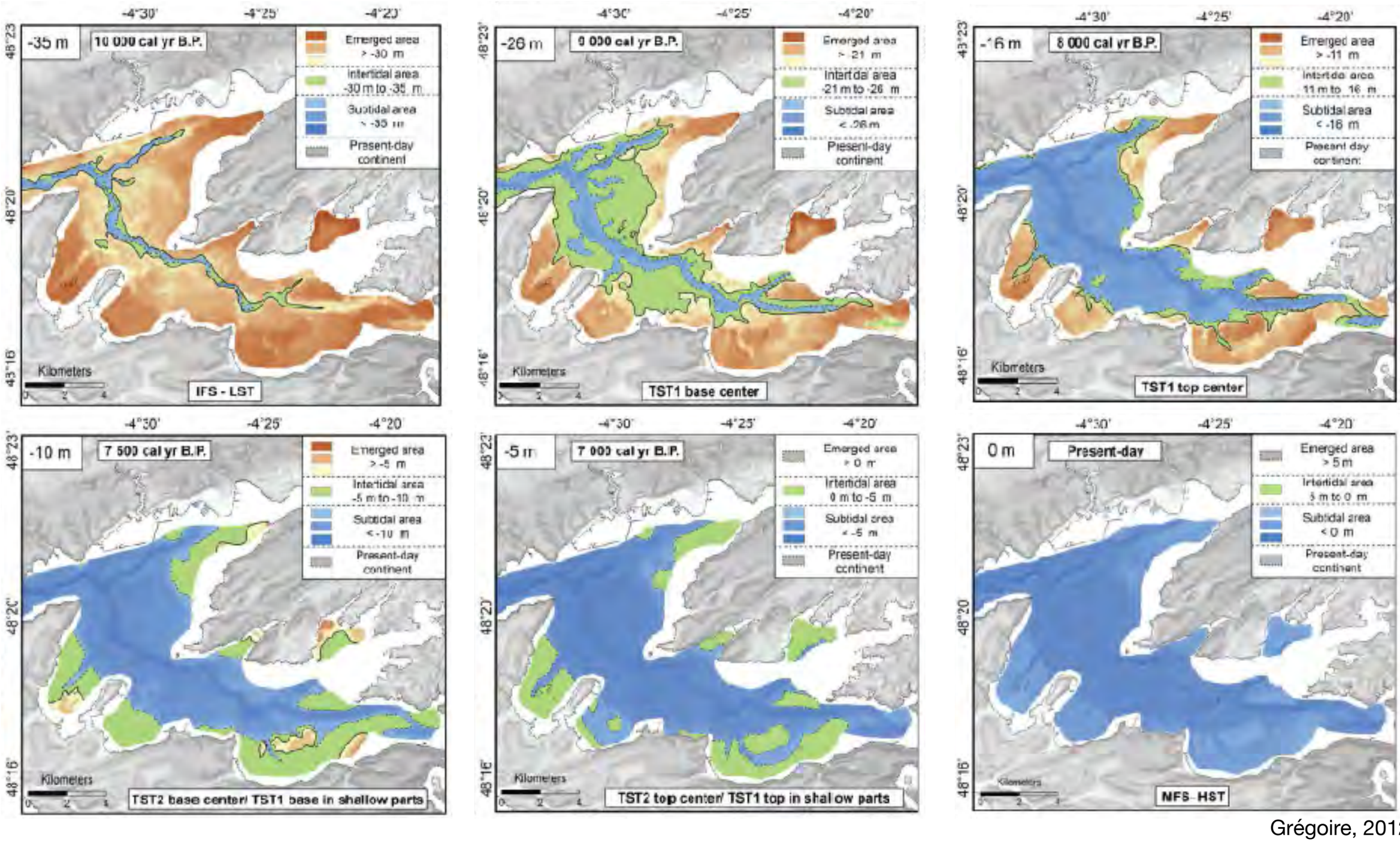
Depth**: -26 m (+/- 4 m)** relative to present-day sea-level



Coastline **Coastline**

Impacts of the transgression

- on the **coast line** (submersion of the almost entire Bay of Brest initially emerged)



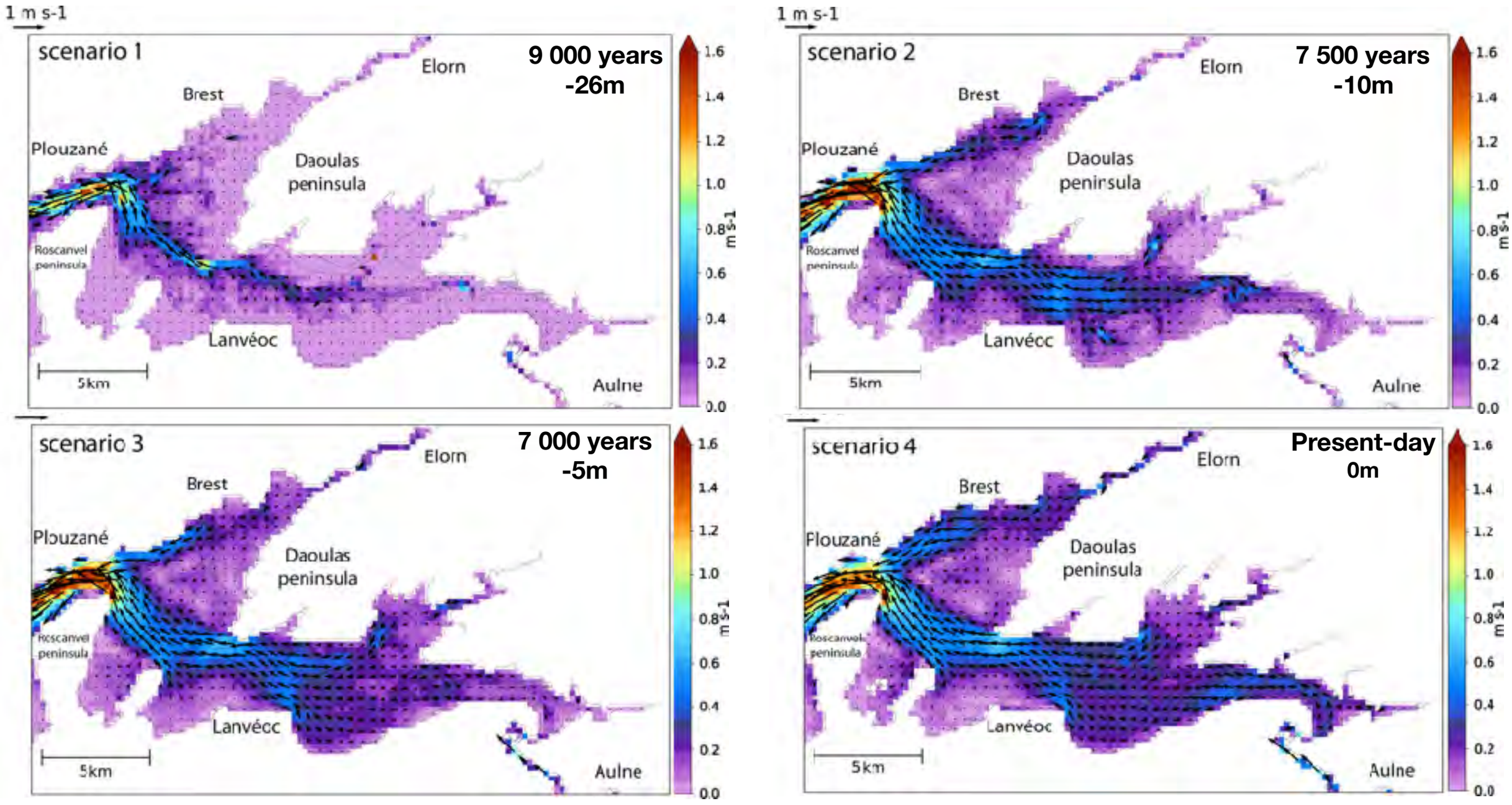
Grégoire, 2012

Impacts of the transgression

- on the coast line (submersion of the almost entire Bay of Brest initially emerged)
- on the landscape (morphology of the sea-floor)
- on the **hydrodynamics**

Hydrodynamics modeling – Mars3D@ifremer

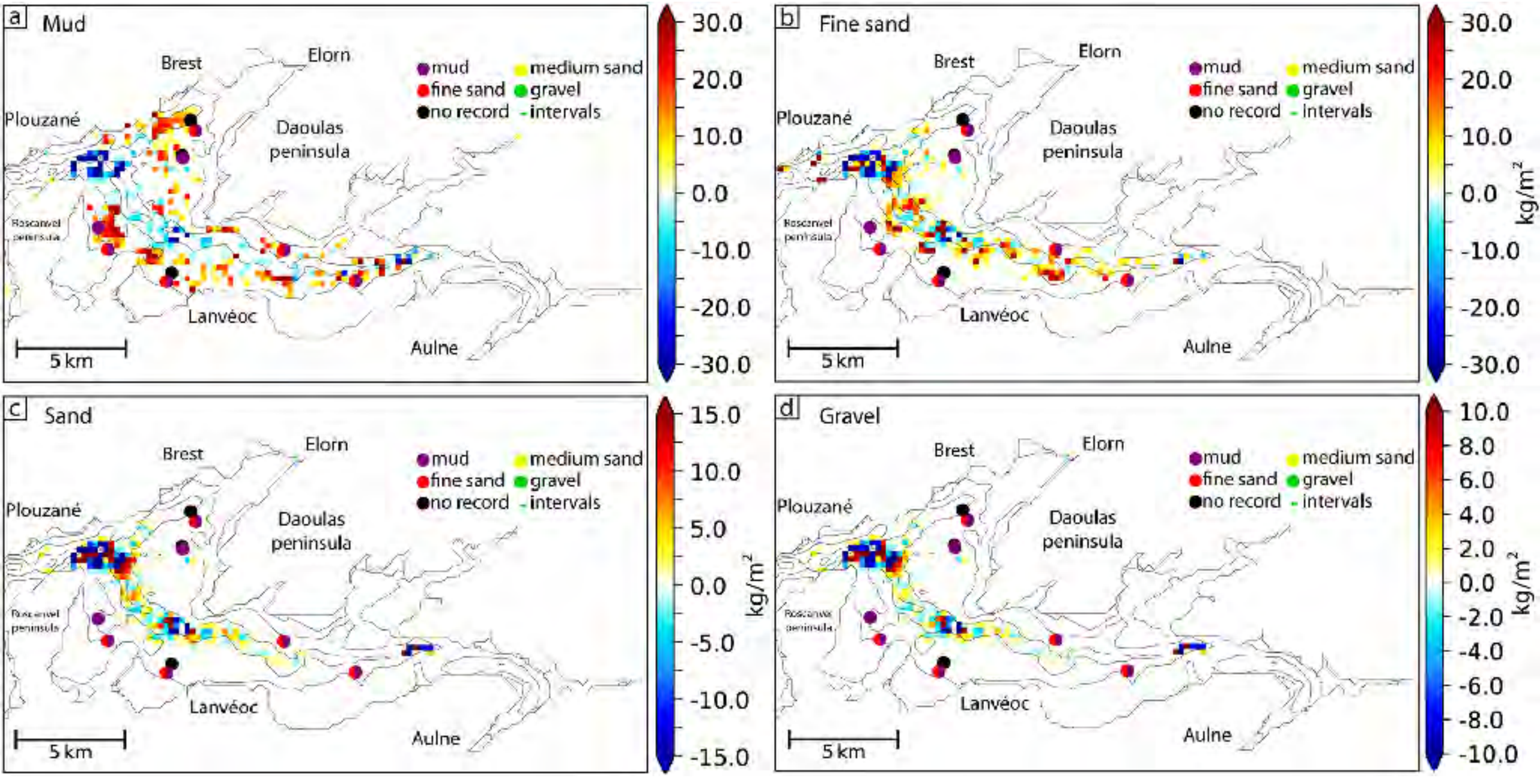
We use paleobathymetric maps reconstructed at the top of each stratigraphic unit as input parameter in the numerical model



Mean velocity and direction of tidal currents during a flood of spring tide (Olivier et al., in review).

Impacts of the transgression

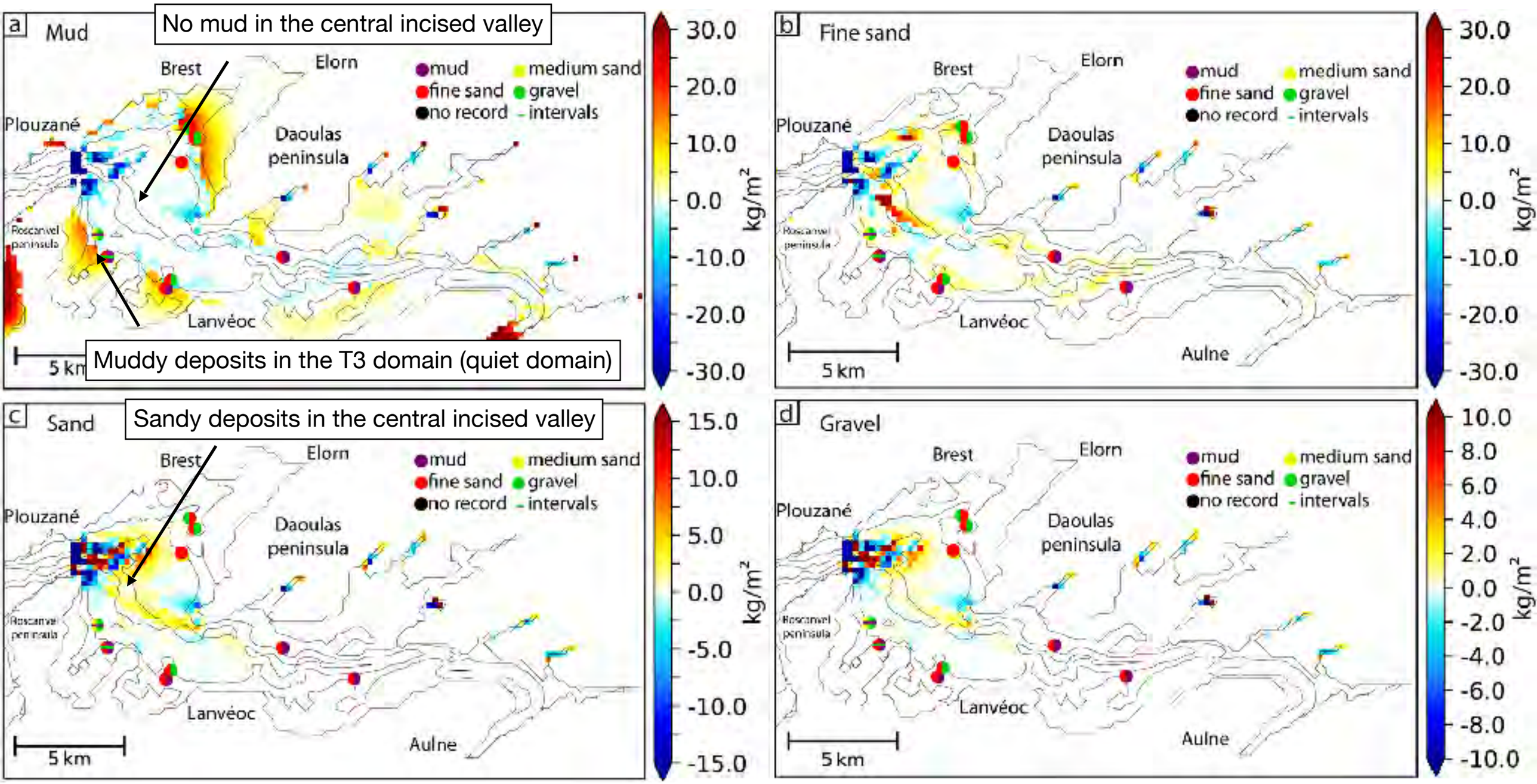
- on the coast line (submersion of the almost entireBay of Brest initially emerged)
- on the landscape (morphology of the sea-floor)
- on the hydrodynamics
- on the **sediment lithologic distribution**



Volume and repartition of sediment preserved for each main lithology (mud, fine sand, sand and gravel) after 1 year simulation for U0 environmental conditions

Impacts of the transgression

- on the coast line (submersion of the almost entireBay of Brest initially emerged)
- on the landscape (morphology of the sea-floor)
- on the hydrodynamics
- on the **sediment lithologic distribution**



Volume and repartition of sediment preserved for each main lithology (mud, fine sand, sand and gravel) after 1 year simulation for U3 environmental conditions

Geology of South AFrica

AEON

AFRICA EARTH OBSERVATORY NETWORK

EARTH STEWARDSHIP THROUGH SCIENCE

Bastien LINOL, Africa Earth Observatory Network – Earth Stewardship Science Research Institute, NMU, Port Elizabeth. Bastien.aeon@gmail.com

NELSON MANDELA UNIVERSITY

(T)(C)RACKING THE SHALE-GAS DEBATE

Baseline data and citizen science @KarooCommons.za

TRANSDISCIPLINARY DATA

Present status > Future risks > Proposed solutions

CHALLENGES FOR THE EASTERN CAPE

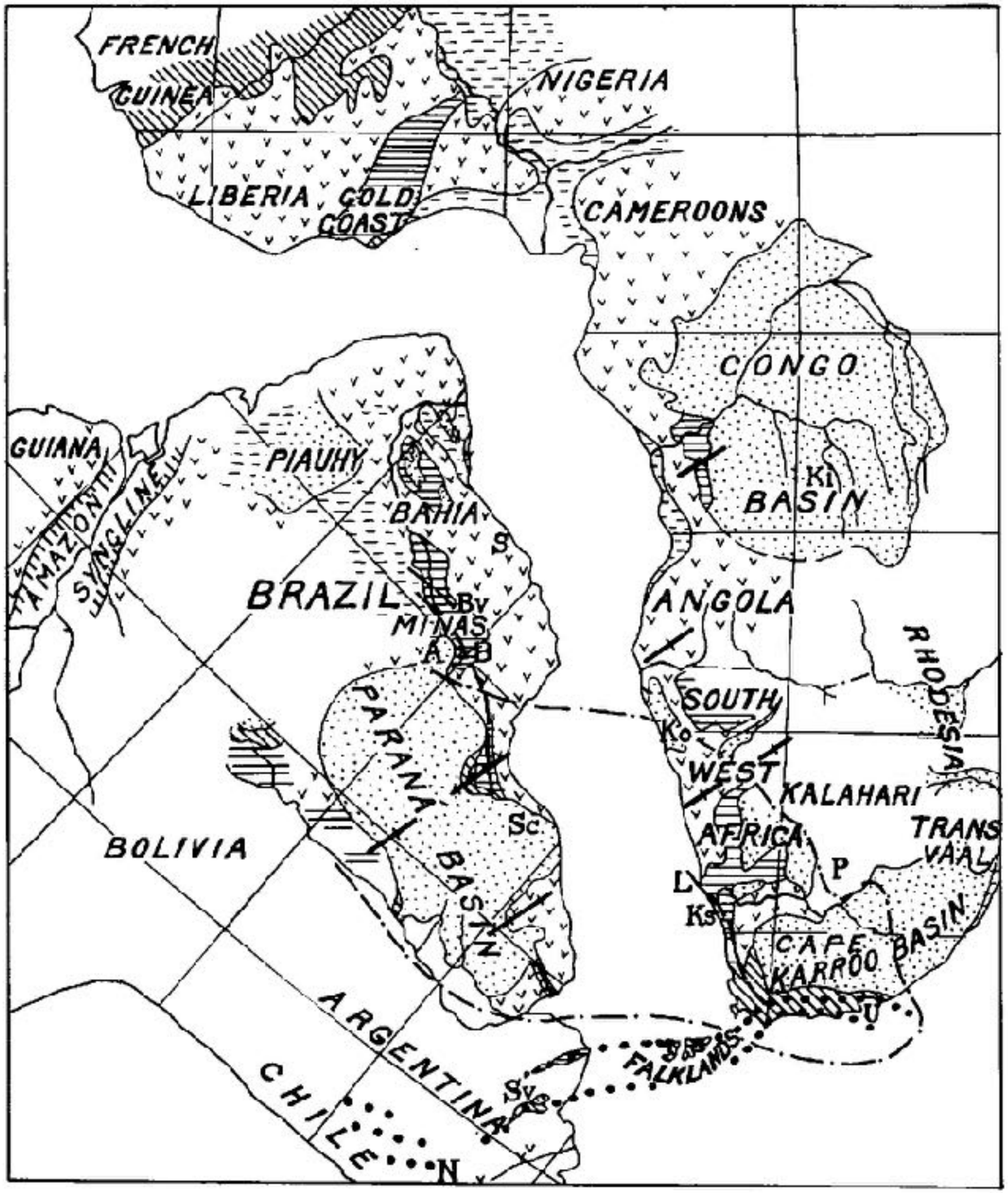
Black Shale at surface

Black Shale at surface

AEON BASELINE DATA

NELSON MANDELA UNIVERSITY

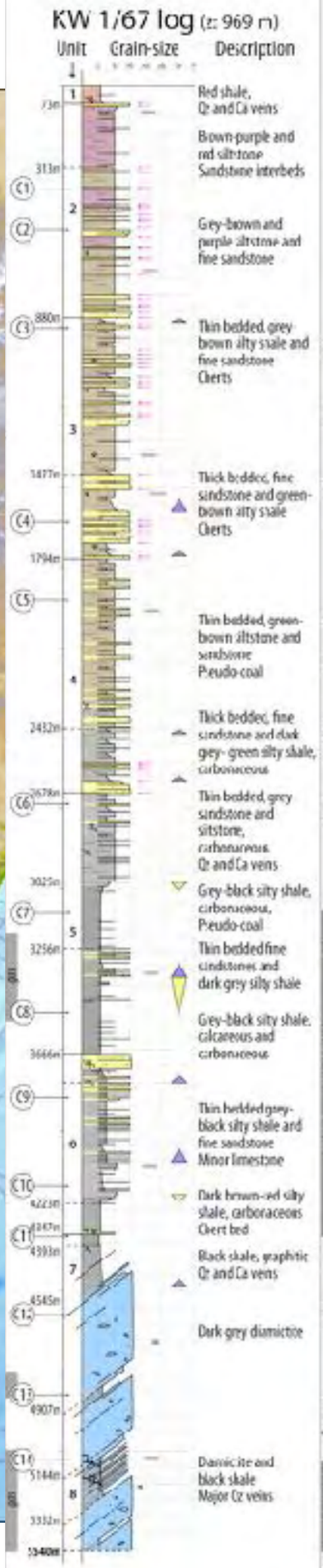
First detailed correlations between Africa and South America by A. du Toit, 1937 (*Our Wandering Continents*)



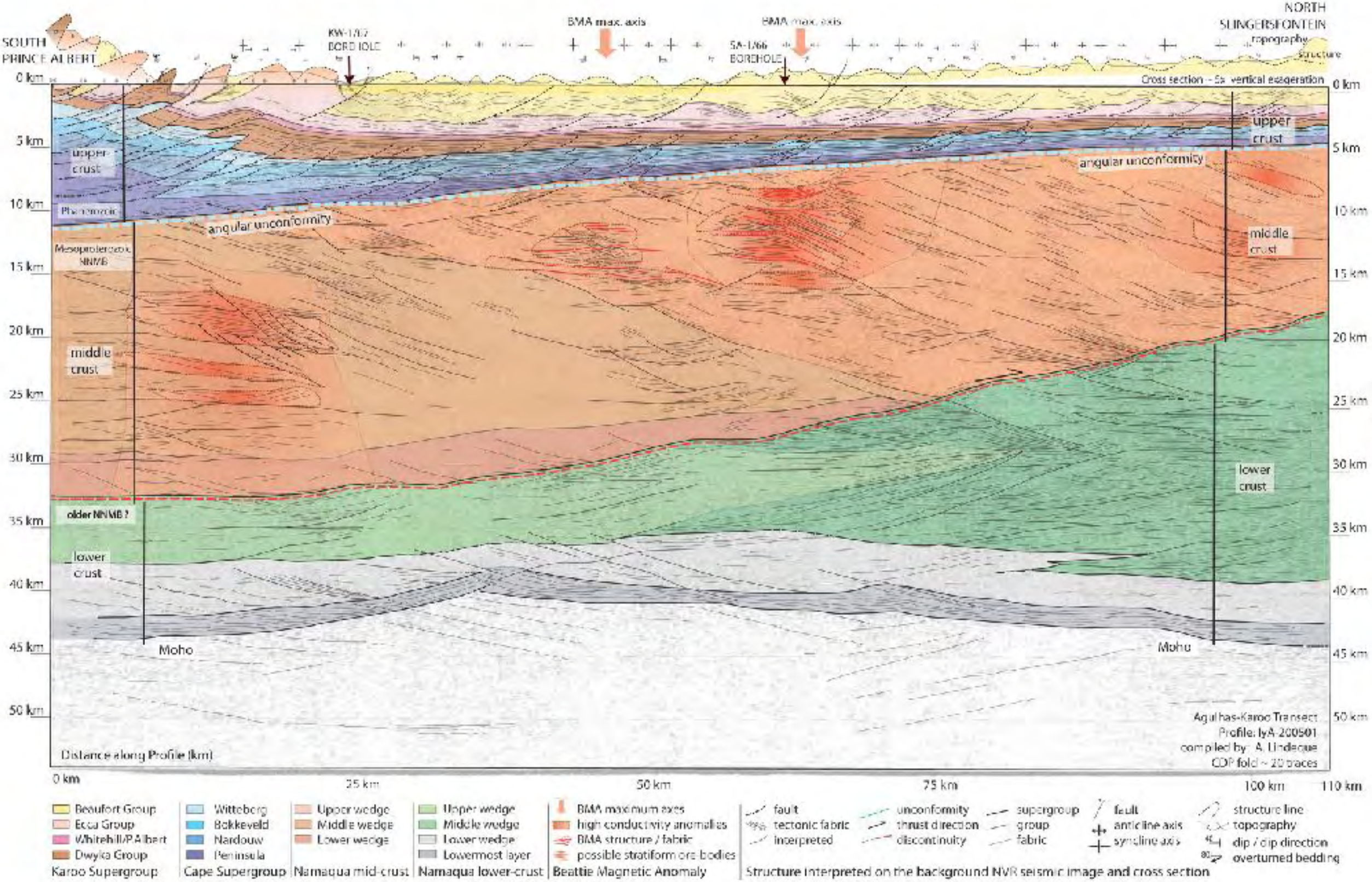
seismic and well data of **SOUTH AFRICA**

lyA-200501

KW 1/67



lyA-200501 Tectonic model of the crust, Moho and Beattie Magnetic Anomaly in the southern Karoo Basin , South Africa



Cenozoic

Mesozoic

Paleozoic

Proterozoic

Quaternary

Uitenhage, Sandveld, Algoa, Bredasdorp and Kalahari Groups

Beaufort Group

Ecca Group

Dwyka Group

Karoo Supergroup

Witteberg Group

Bokkeveld Group

Table Mountain Group

Cape Supergroup

Nama Group

Neoproterozoic Sequences

Namaqualand Basement

Karoo Dolerite Suite (183-182 Ma)

Cape Granite Suite (550-510 Ma)

Reverse Fault

Normal Fault

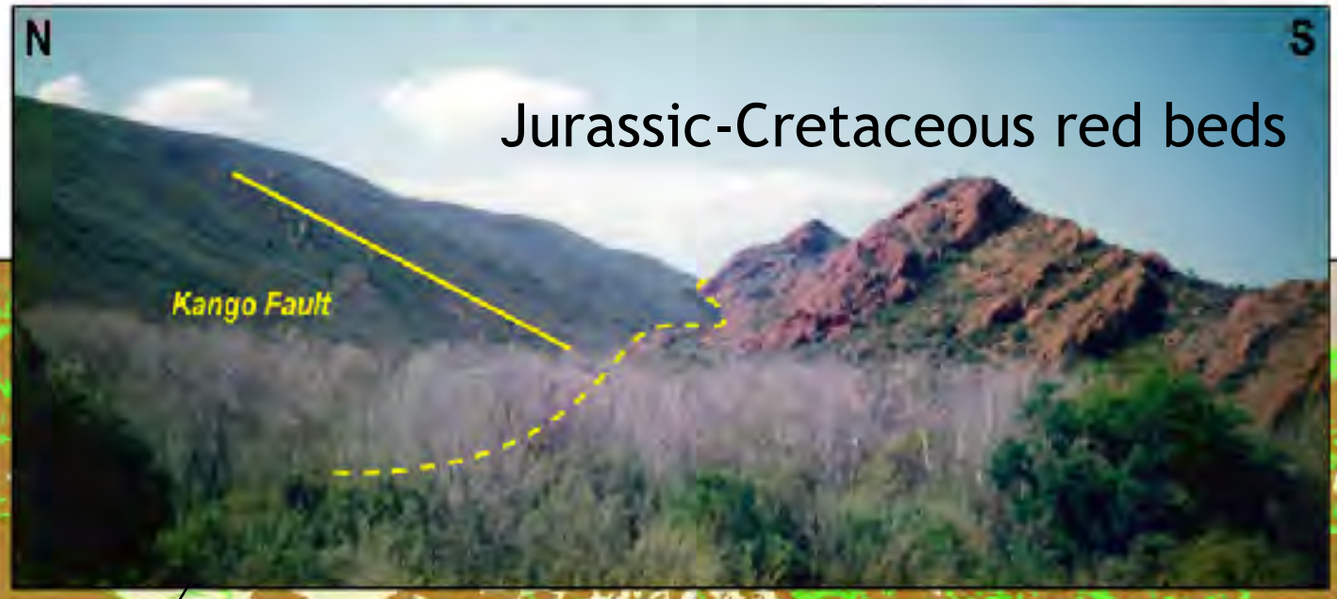
Undifferentiated Fault

Early F_1 Folding

Later F_2 Folding with plunge direction

Anticline

Syncline



N

Cape Agulhas

Bredasdorp Basin

Pletmos Basin

Southern Outeniqua Basin

Gamtoos Basin

Algoa Basin

0 100 km

AEON Indian Ocean Research Program

Project 1: Mesozoic-Cenozoic evolution of the southern coast of AFRICA

A history of transtentional rifting, subsidence and global sea-level changes

KAROO BASIN

Cango

Baviaanskloof

Gamtoos

Falkland Fracture Zone

Agulhas – Falkland Fracture Zone

Pletmos

Bredasdorp

Jurassic-Cretaceous sediments

Goals:

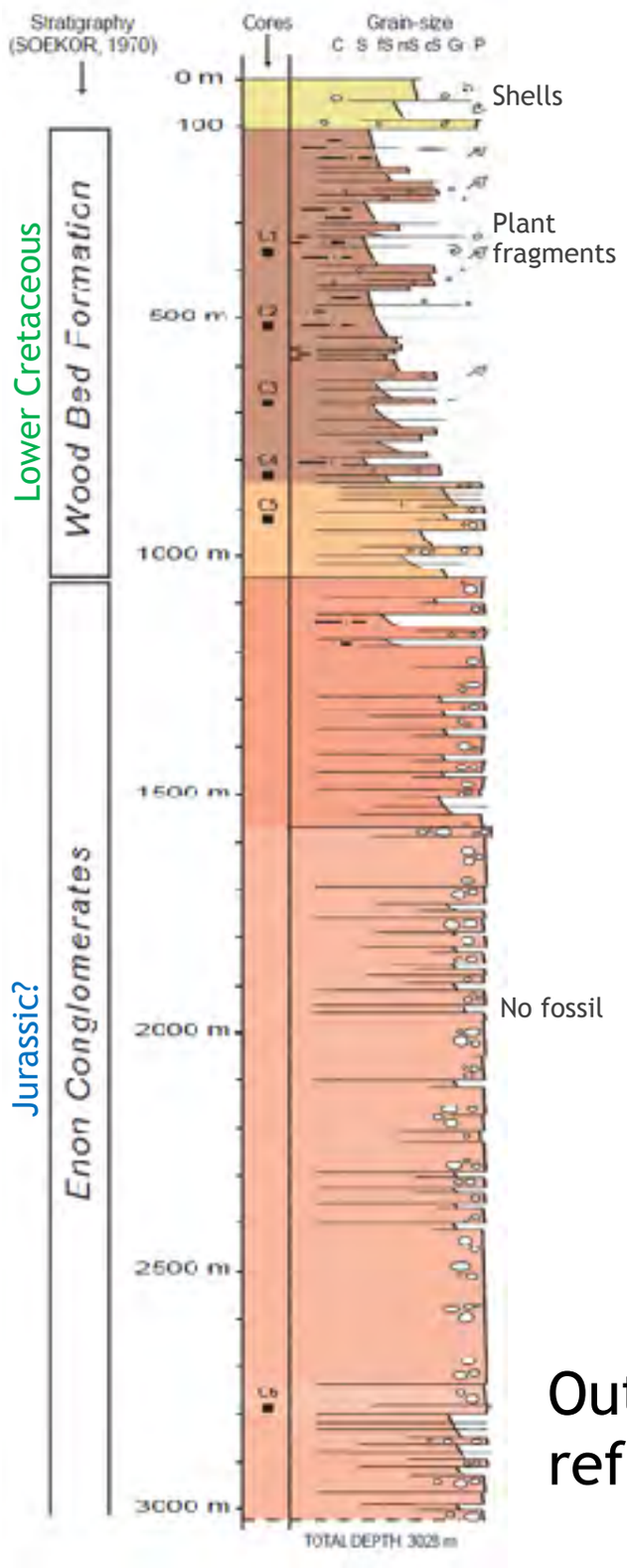
1. Excellent natural laboratory
   - first phase of formation of a passive margin
   - buffer zone between Indian (155 Ma) and South Atlantic (135 Ma) openings
2. Earth – Ocean Links (EOL)
   - geological field mapping
   - sedimentology
   - seismic
3. Regional vs global process
   - subsidence basin analysis & global sea-level
   - paleogeography & paleotopography
   - plate tectonic reconstruction
4. Integration in wider projects
   - itinerant school
   - international conference
   - wide-angle seismic survey
   - petroleum exploration

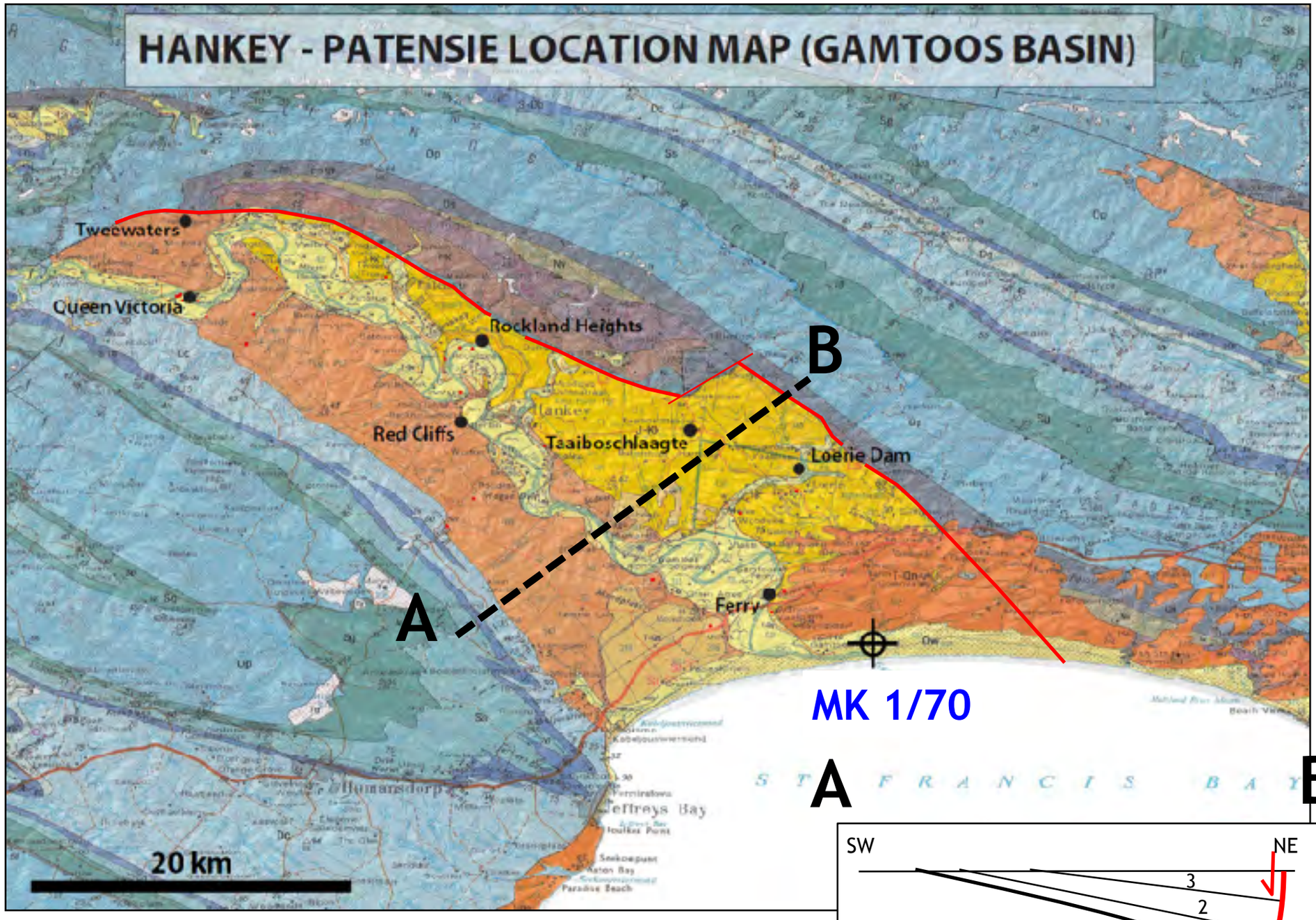
N

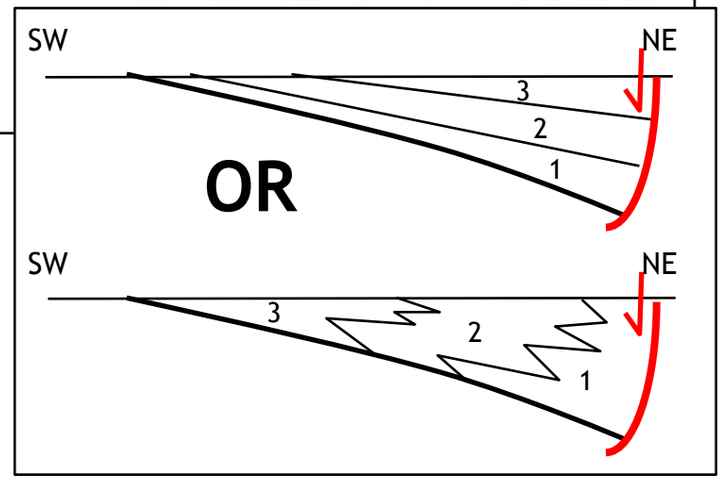
200 km

THE GAMTOOS BASIN (ONSHORE)

MK 1/70 well-log





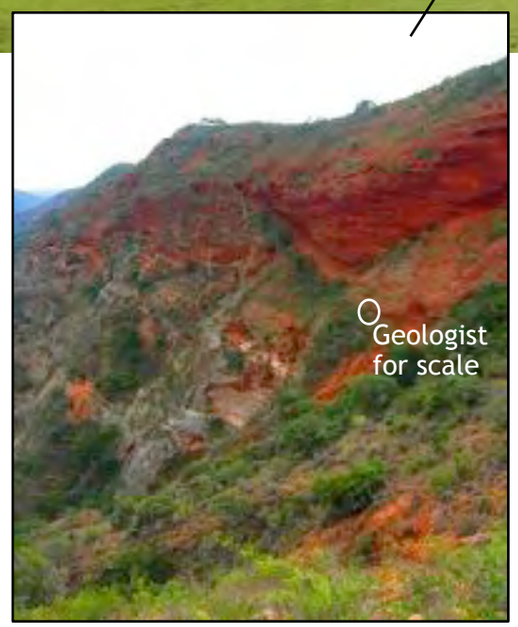


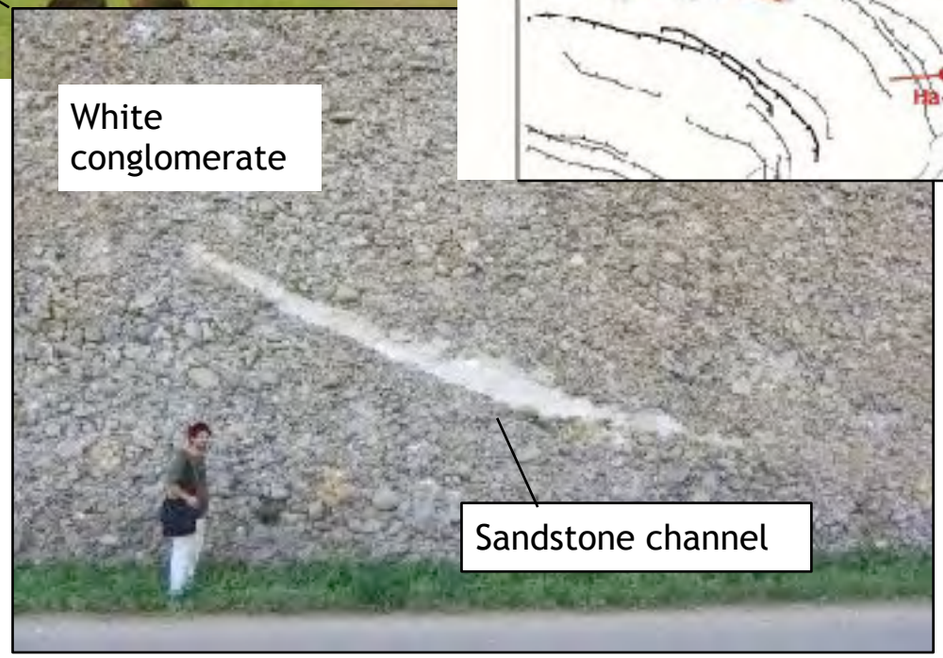
Outcropping sedimentary rock sequences reflect:

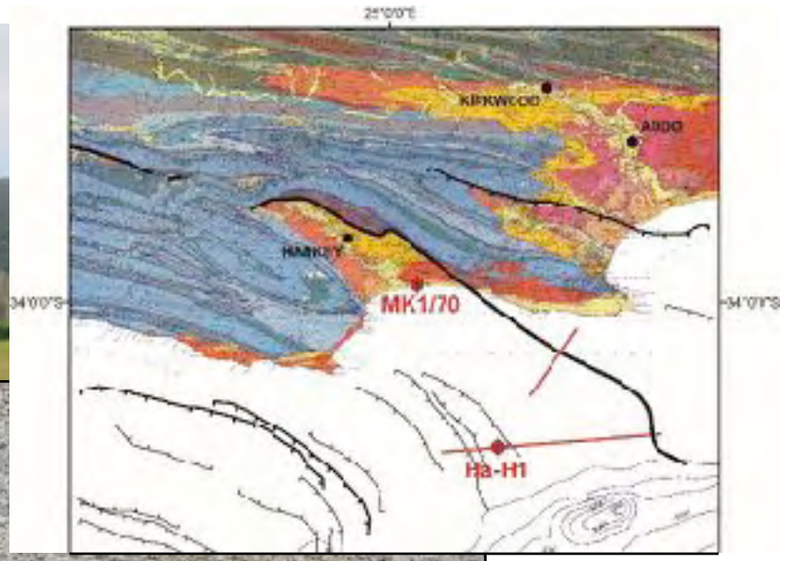
- vertical changes? (stratigraphic)

OR - lateral facies variations?

Enon Formation ONE SINGLE SEQUENCE OR MULTIPLE SEQUENCES OF CONGLOMERATE?



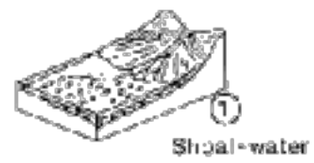




Fan delta

But which type?

HJULSTRÖM



Red Cliffs

Backhousehoek

Sub horizontal, bedded, red and white conglomerate and sandstone

1 km

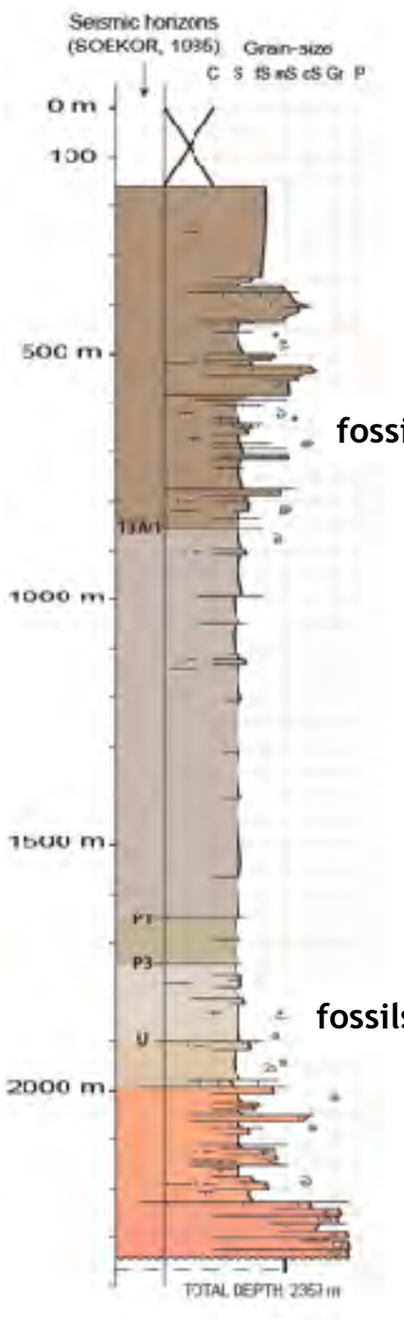
THE GAMTOOS BASIN (OFFSHORE)

Biostratigraphy and seismic interpretations are robust?

Hauterivian- Late Cenozoic
S > A (Progradation)

Kimmeridgian-Valanginian
A = S
(Aggradation)

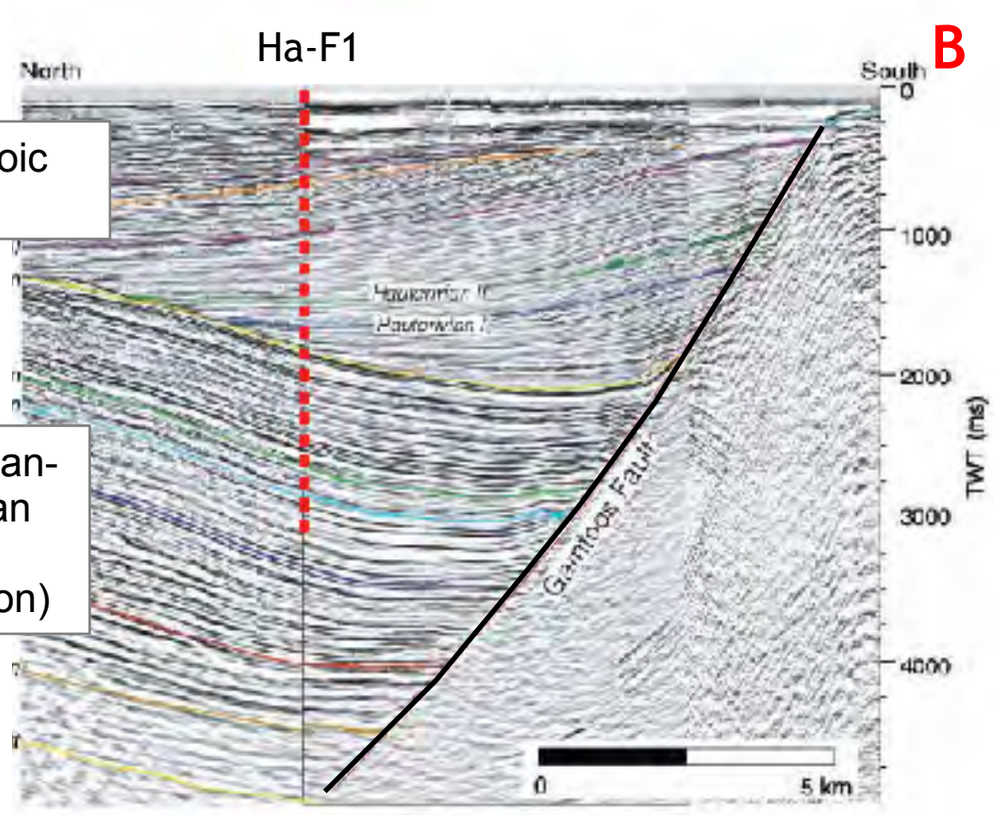
Ha-H1



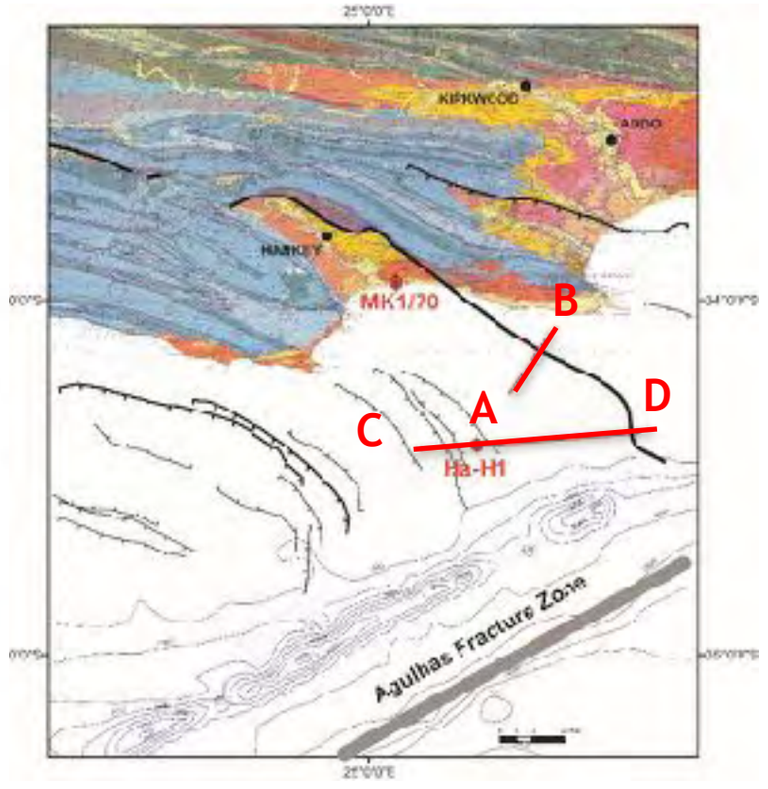
fossils

fossils

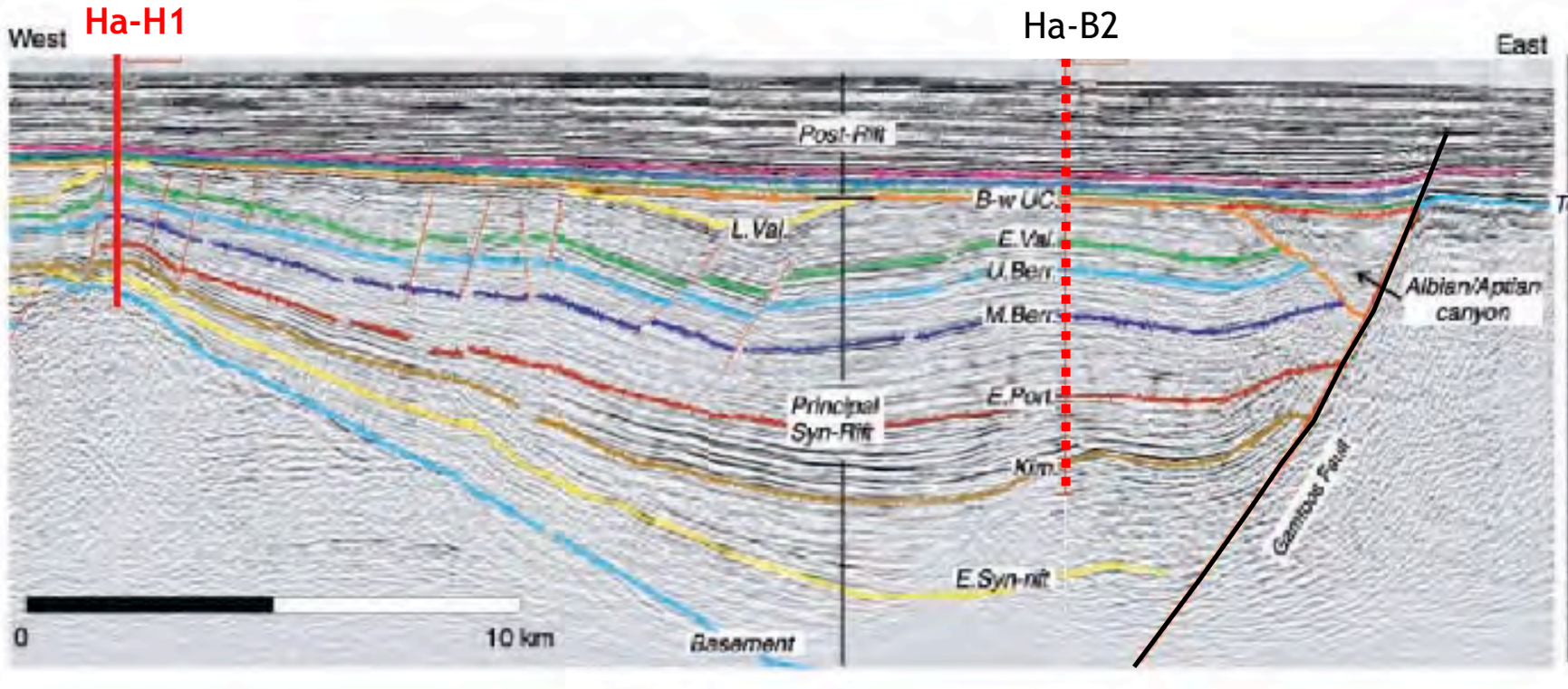
A



B



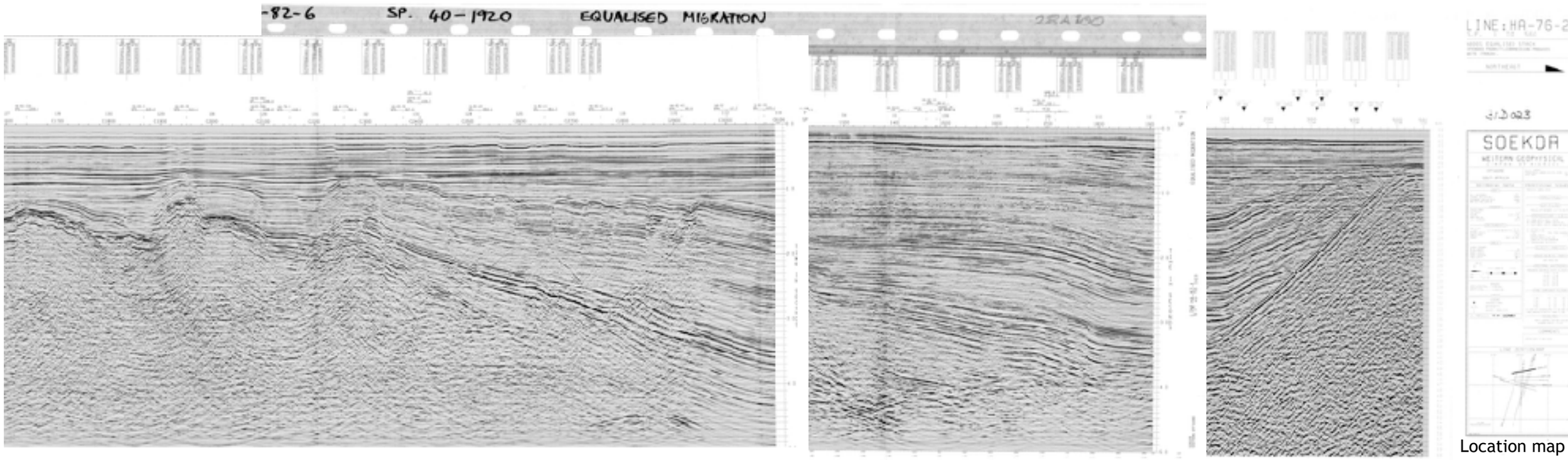
C



D

Paton & Underhill (2004)

Seismic reflection profiles interpretation

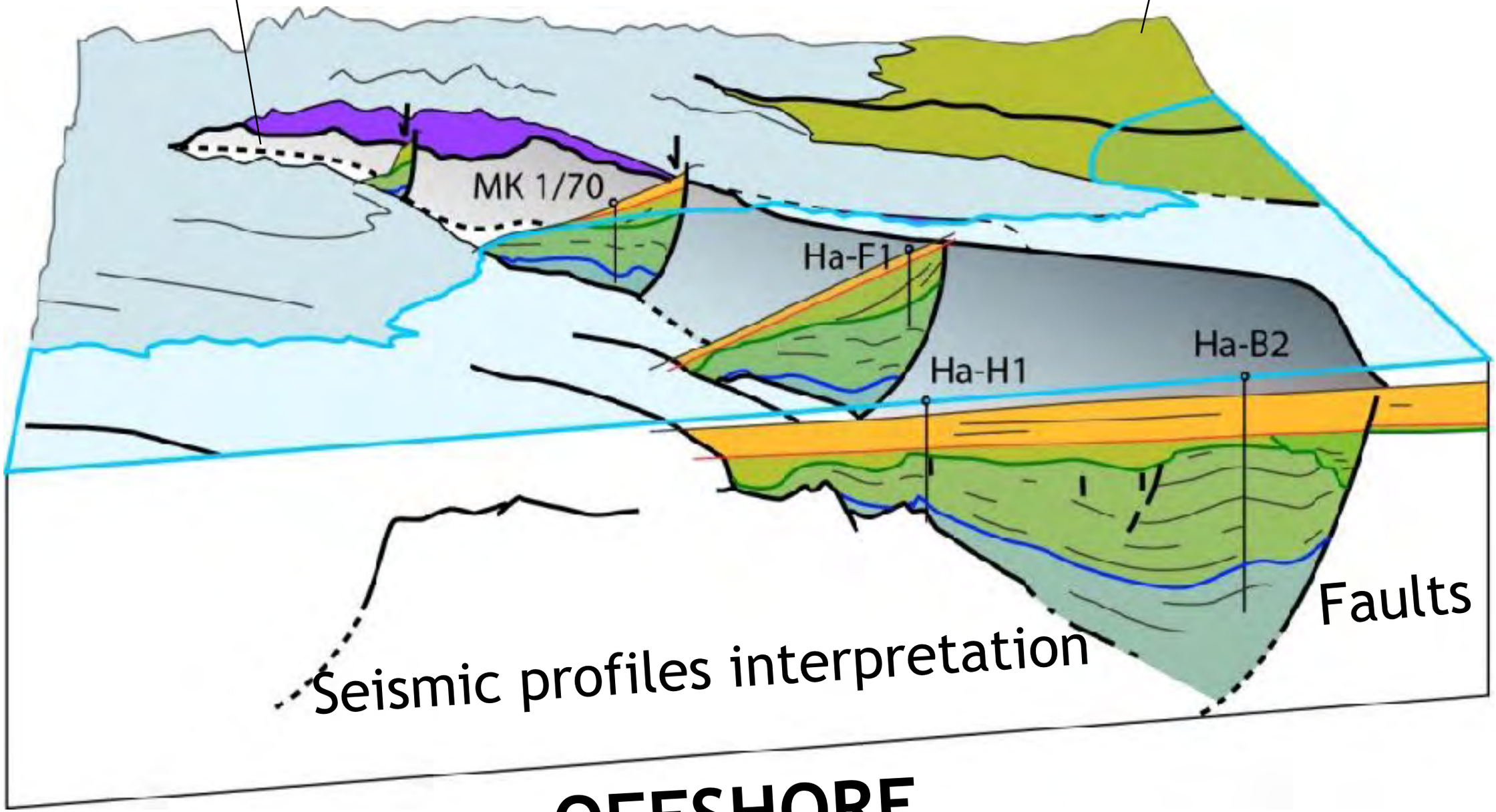


An integrated Model

ONSHORE

Sedimentological cross-sections

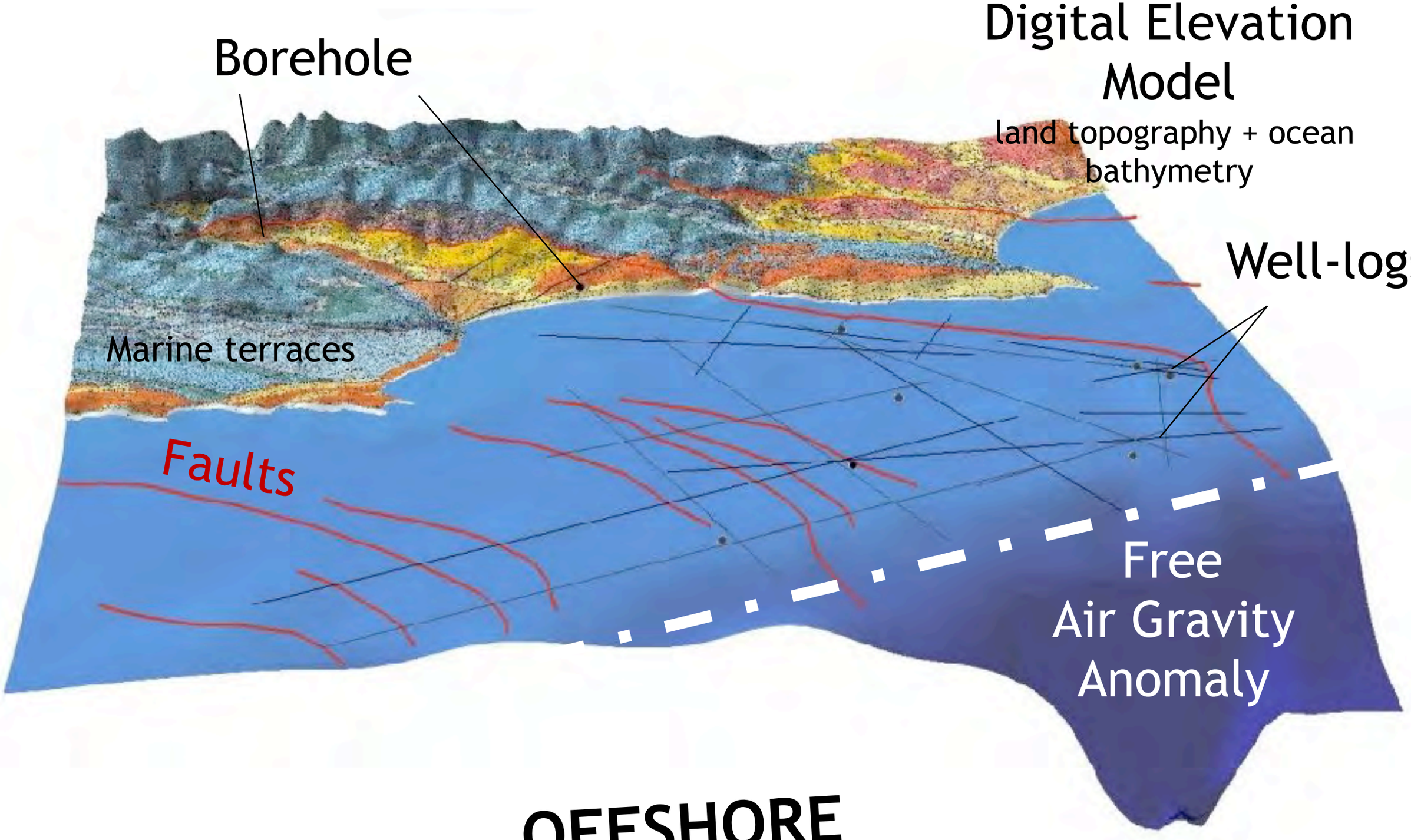
Geological map



OFFSHORE

An integrated Model

ONSHORE



OFFSHORE

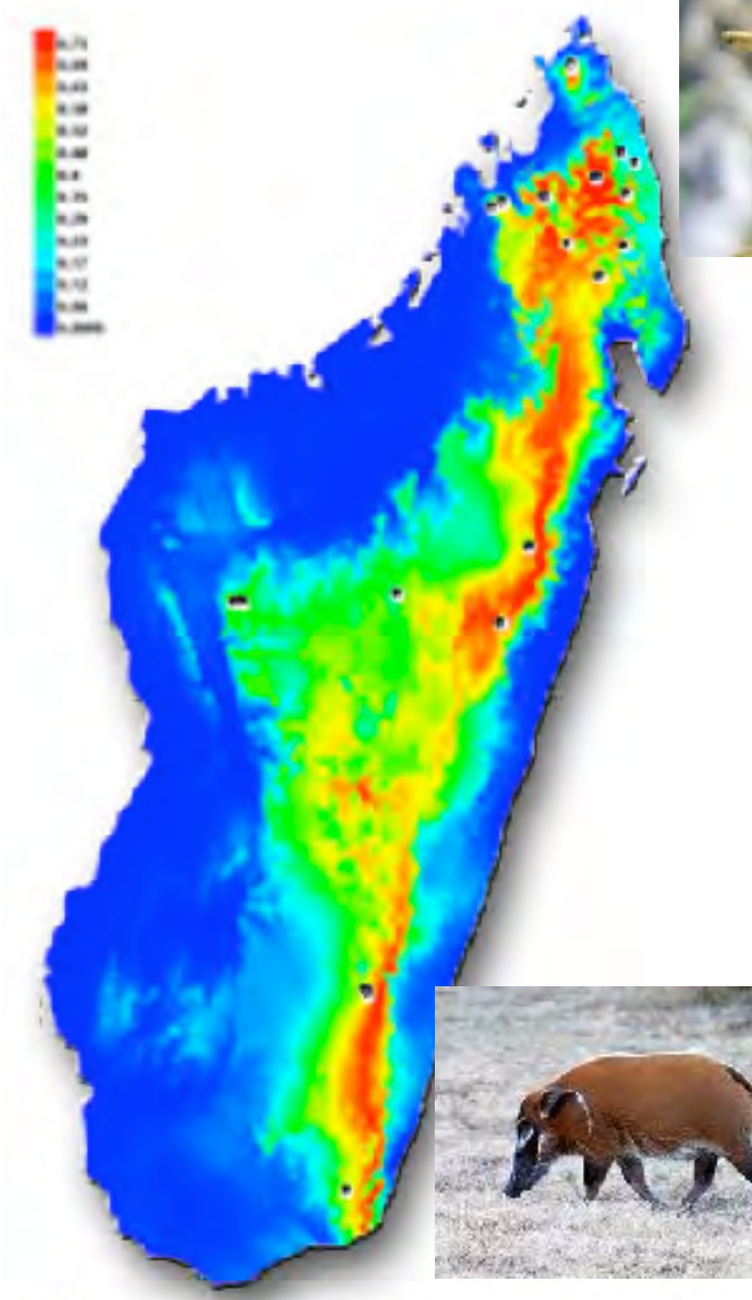
Examples of a holistic approach…

unesco
International Geoscience Programme

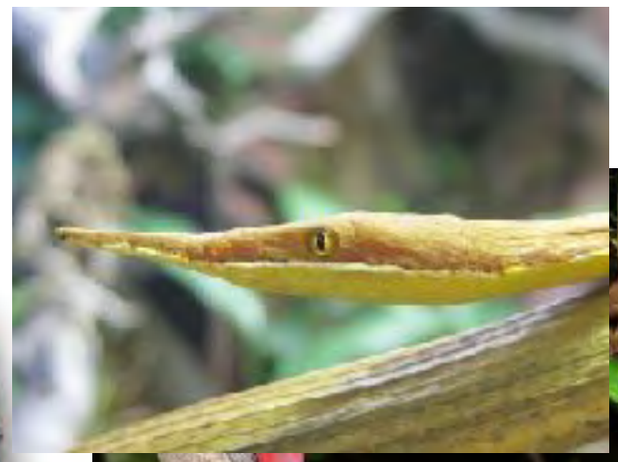
NELSON MANDELA UNIVERSITY

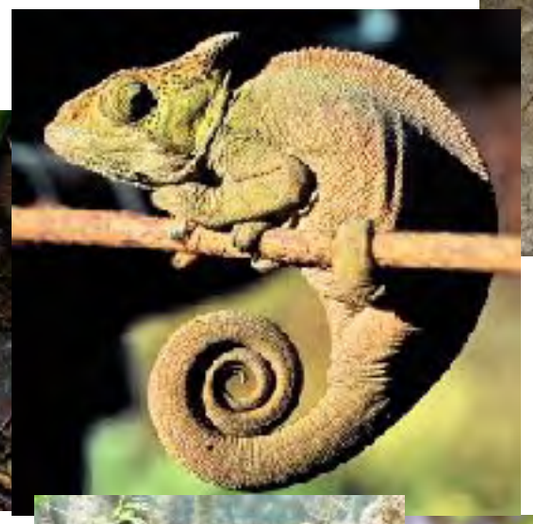
Madagascar

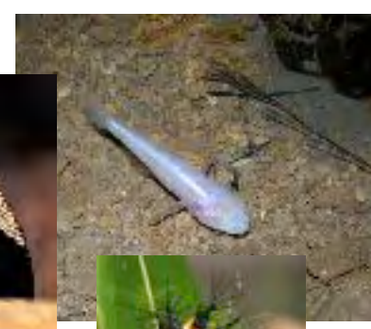
Approximately 80% of all animal and plant species and plants found in Madagascar are endemic

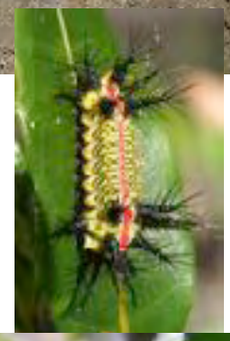


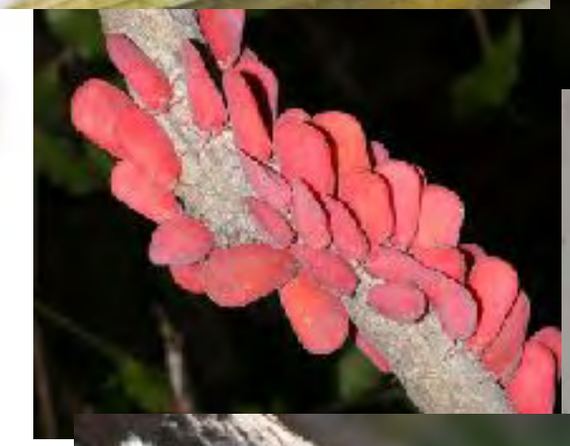
Modélisation de la distribution des espèces
(CBC Biodiversity Informatics Facility)

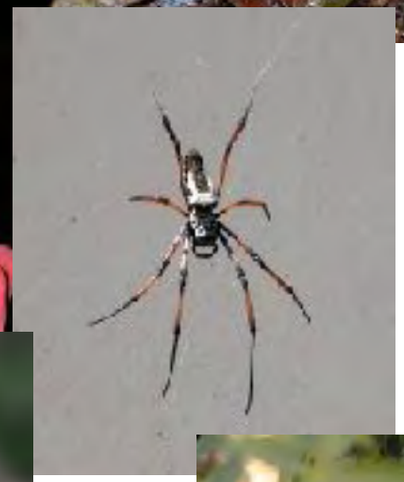


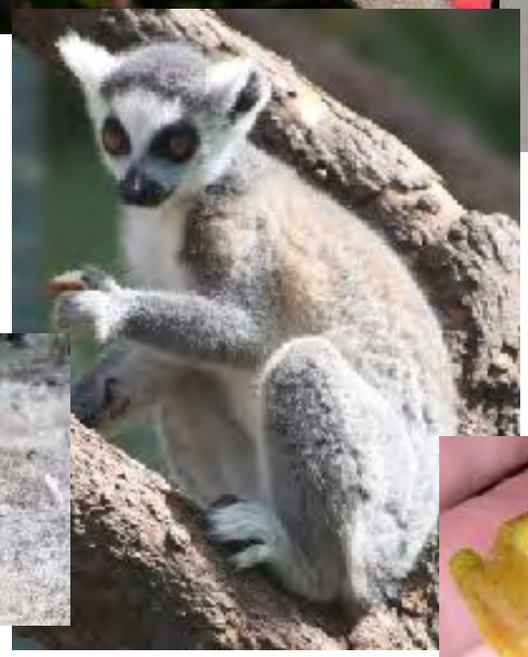













~400km

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DOI: 10.1111/jbi.13659

Journal of Biogeography

WILEY

CORRESPONDENCE

Mammals and long-distance over-water colonization: The case for rafting dispersal; the case against phantom causeways

JR Ali & M Huber *Nature* **000,** 1-4 (2010) doi:10.1038/nature08706

PALEONTOLOGY

Rafting on a wide and wild ocean

During the Oligocene, now-extinct monkeys crossed the treacherous ocean from Africa to South America

By **Marc Godinot**

Scientists first met with skepticism the notion that small mammals crossed large oceanic barriers to populate faraway lands. However, progress in phylogenetics during the 1980s forced researchers to admit that the excellent North American fossil record showed no relatives of South American caviomorph rodents or platyrrhine (New World) monkeys, and that their closest relatives lived on the Afro-Arabian landmass during the Eocene epoch (56 to 34 million years ago). Therefore, to reach South America, these animals would have had to cross the South Atlantic Ocean—which probably was more than 1500 to 2000 km wide during this period. On page 194 of this issue, Seiffert *et al.* (*1*) report on fossils, from Santa Rosa in Amazonian Perú, that provide evidence of a third mammalian lineage of African origin that briefly appeared in South America in the early Oligocene (35 to 32 million years ago): a now-extinct parapithecid anthropoid monkey (genus *Ucayalipithecus*).

Rafting route

A *Ucayalipithecus* monkey or its ancestor sailed from West Africa to South America on the south equatorial paleocurrent (SEC). Recent data (*11*) suggest that teiid lizards crossed over from South America on the north equatorial countercurrent (NECC), eventually arriving in Eocene Europe. Continental positions are from the Oligocene.

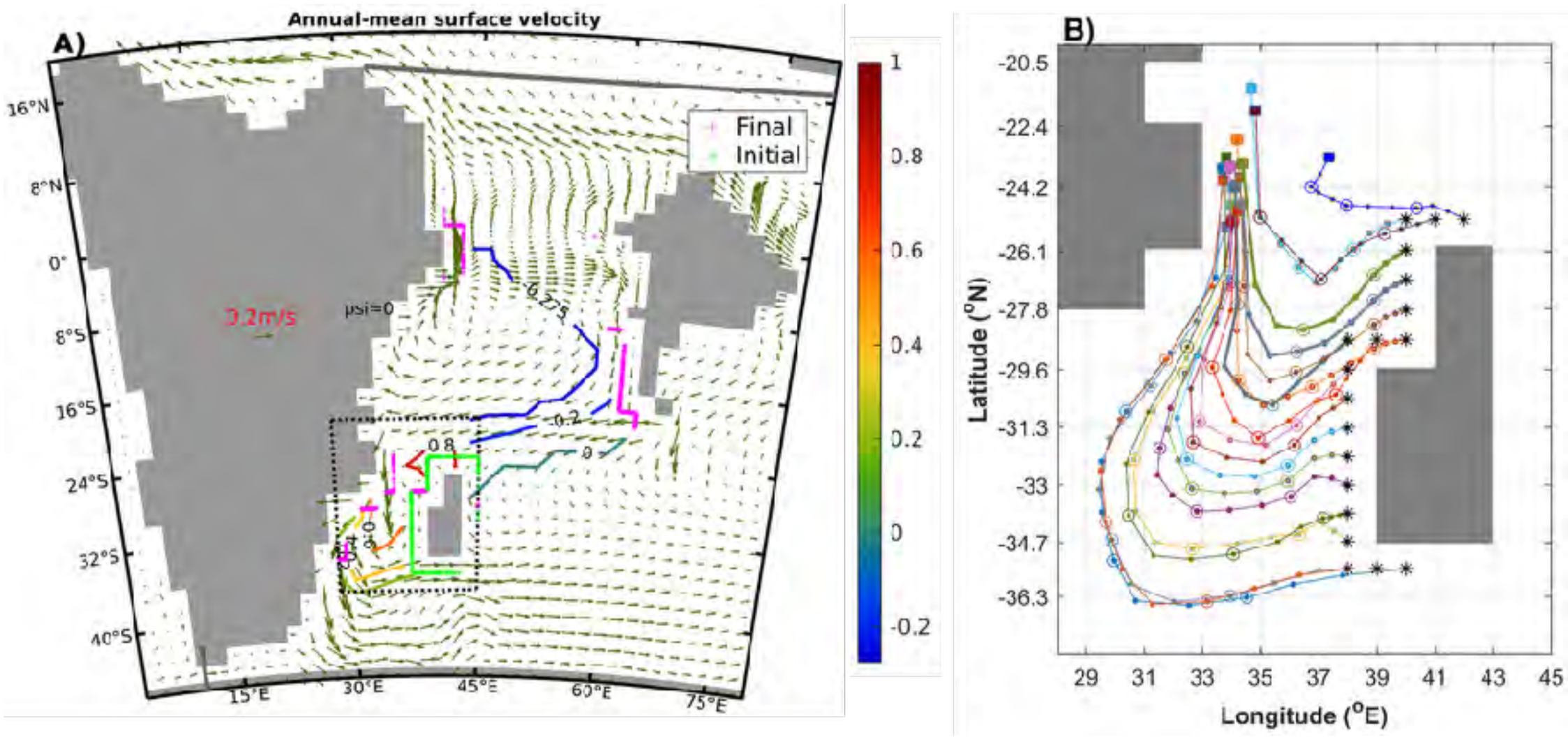
Methodology

- **Paleo-océanography**

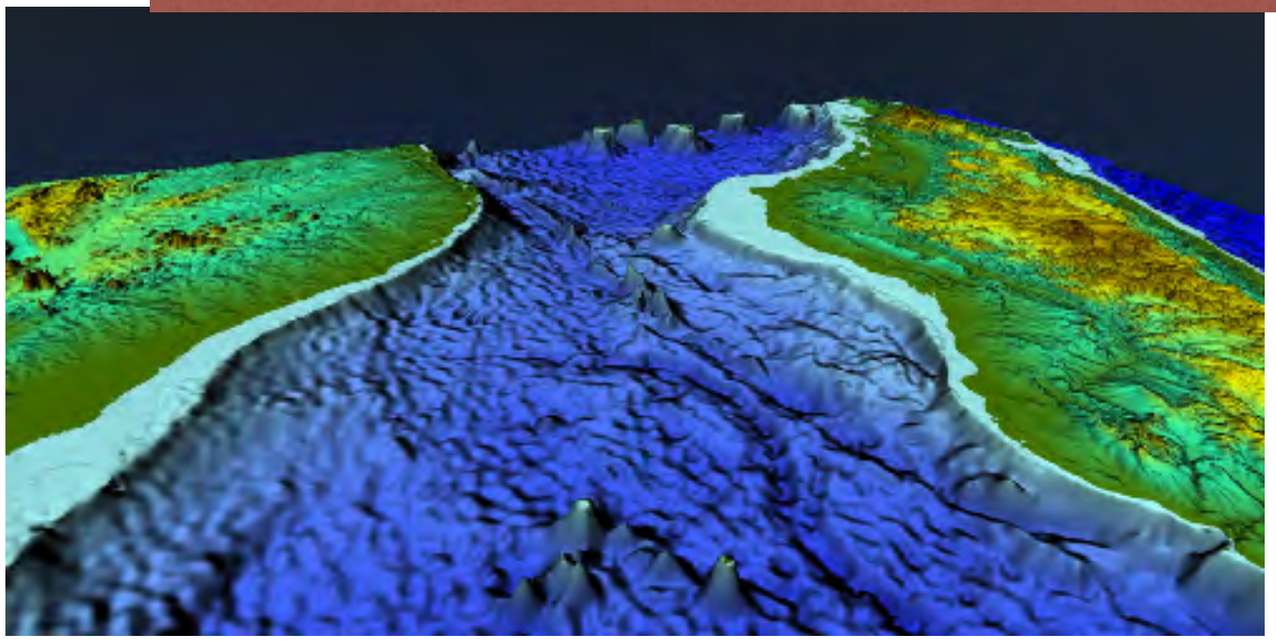
  COC project (coll. LGO - LOPS) : Post-doc Yurui ZHANG

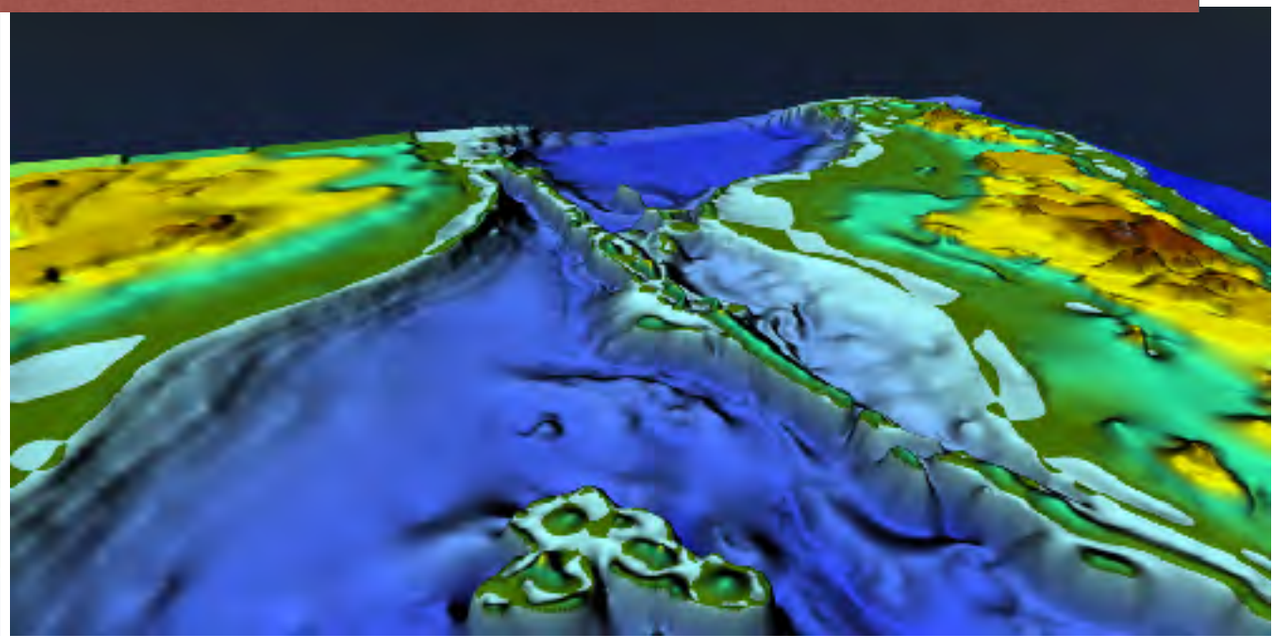
- **Geodynamique - Geobiologie:**

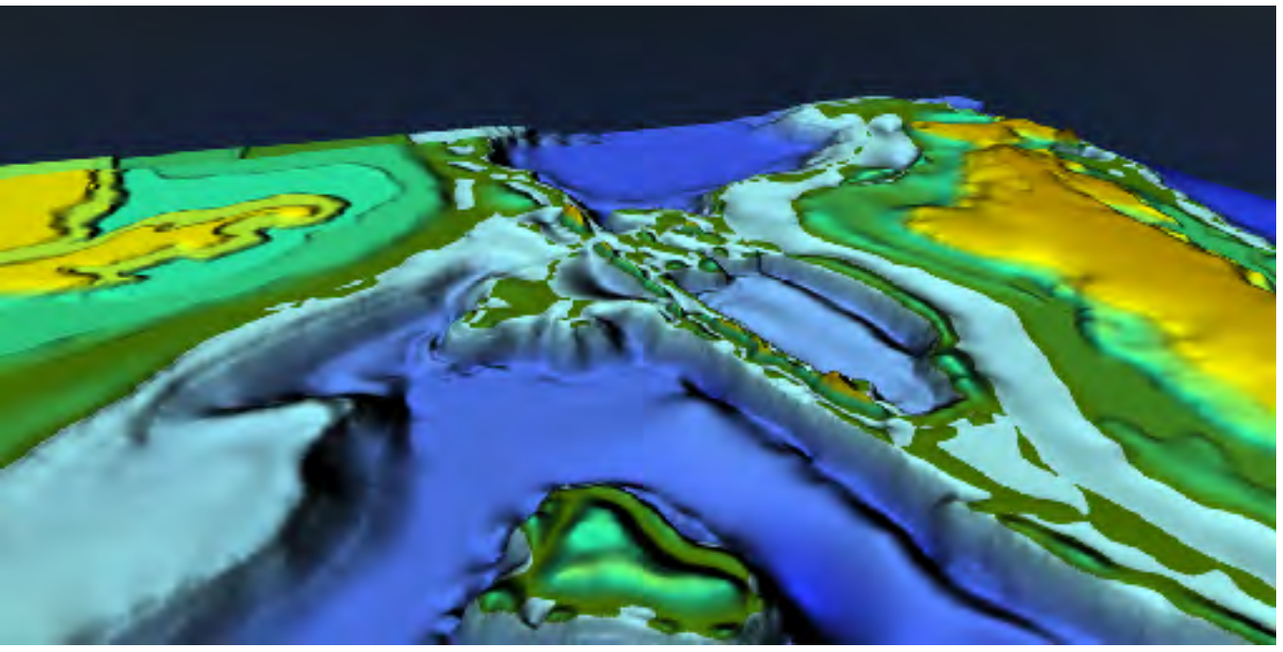
  Post-doc Romain Pellen (coll. Nelson Mandela Univ - LGO)

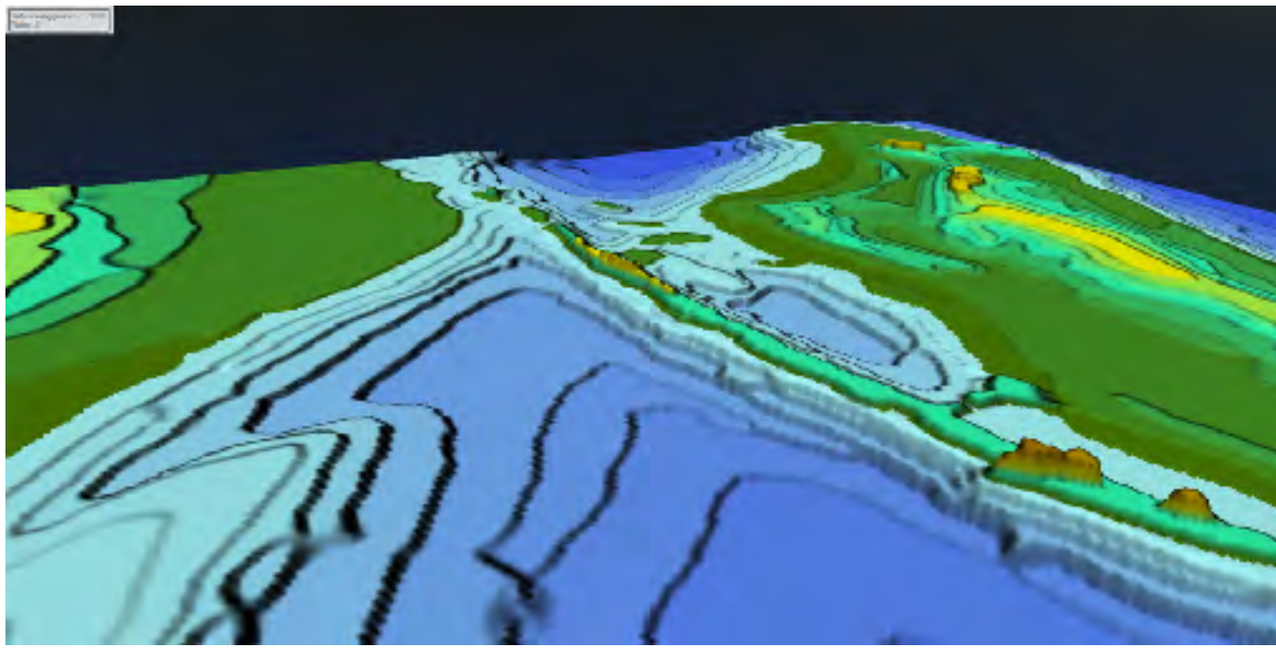


Paelogeography at different ages reconstructed by geological evidences







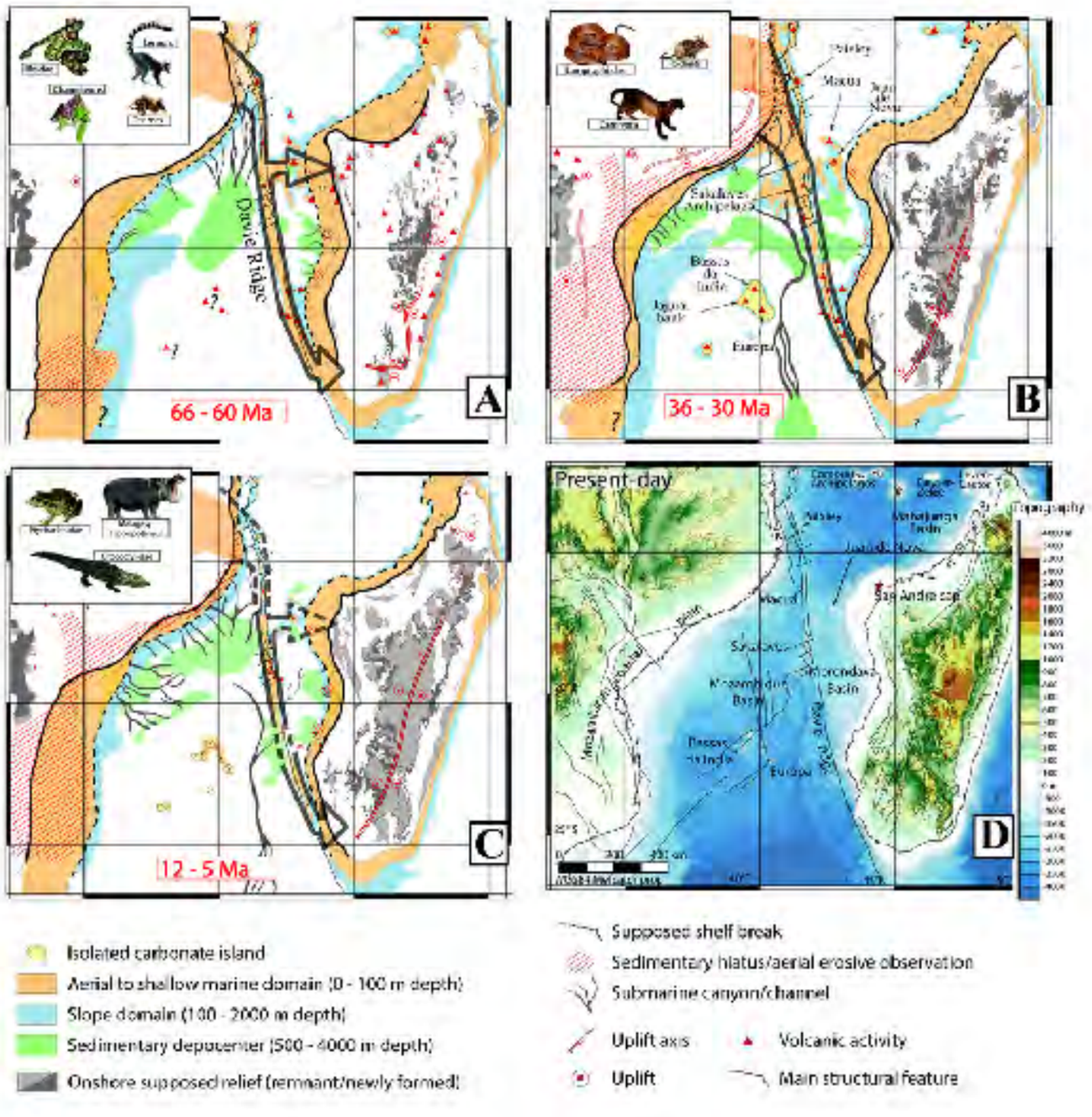


SYNTHESIS

Journal of Biogeography | WILEY

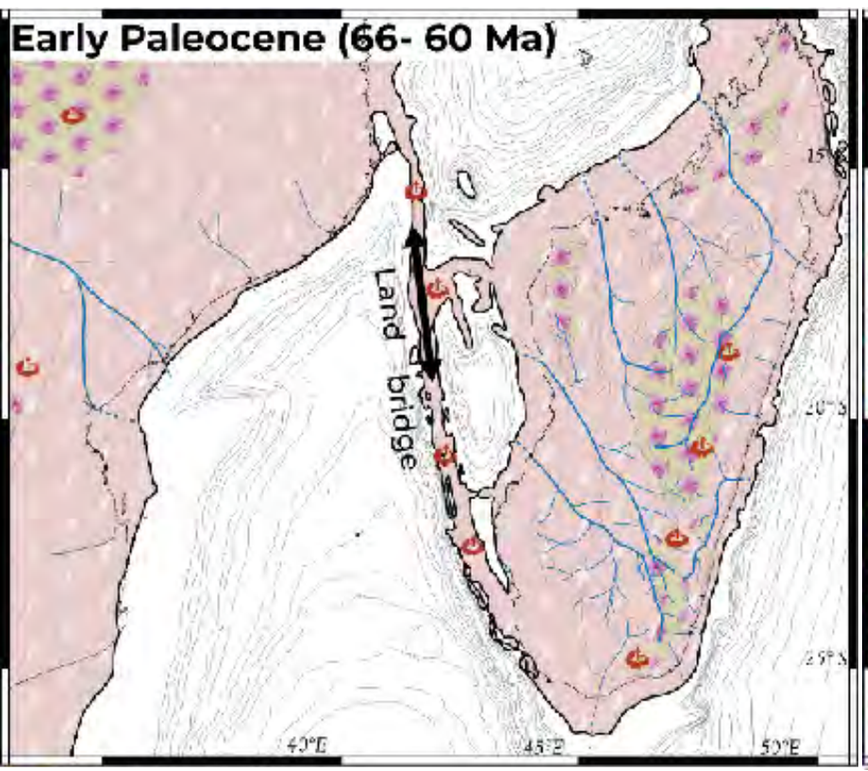
Biogeographic mechanisms involved in the colonization of Madagascar by African vertebrates: Rifting, rafting and runways

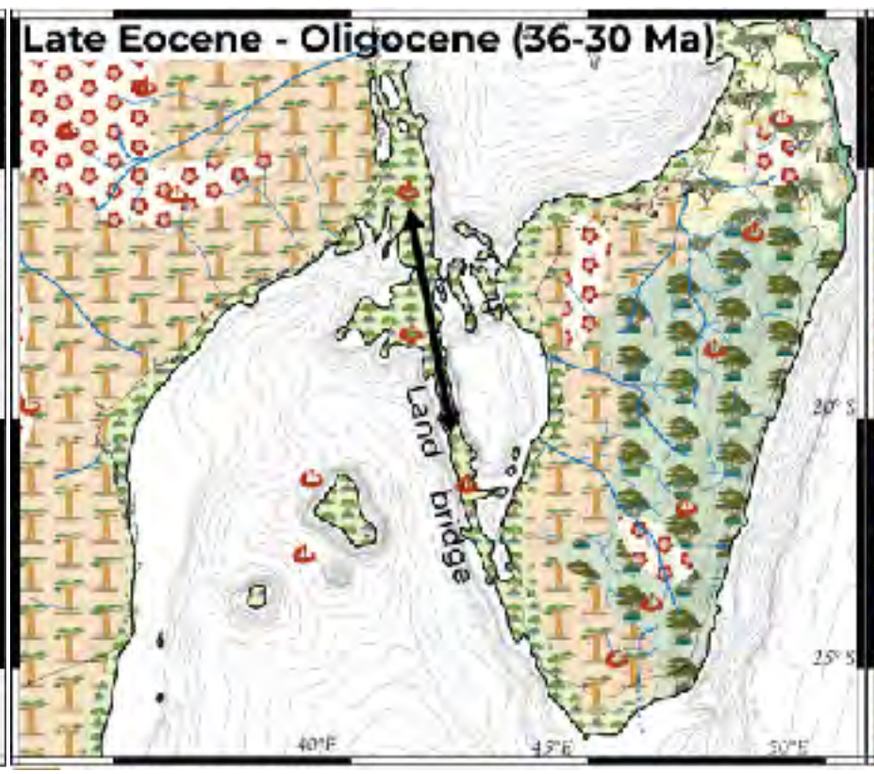
Judith C. Masters[1,2] | Fabien Génin[3] | Yurui Zhang[4] | Romain Pellen[3] | Thierry Huck[4] | Paul P. A. Mazza[5] | Marina Rabineau[6] | Moctar Doucouré[3] | Daniel Aslanian[7]

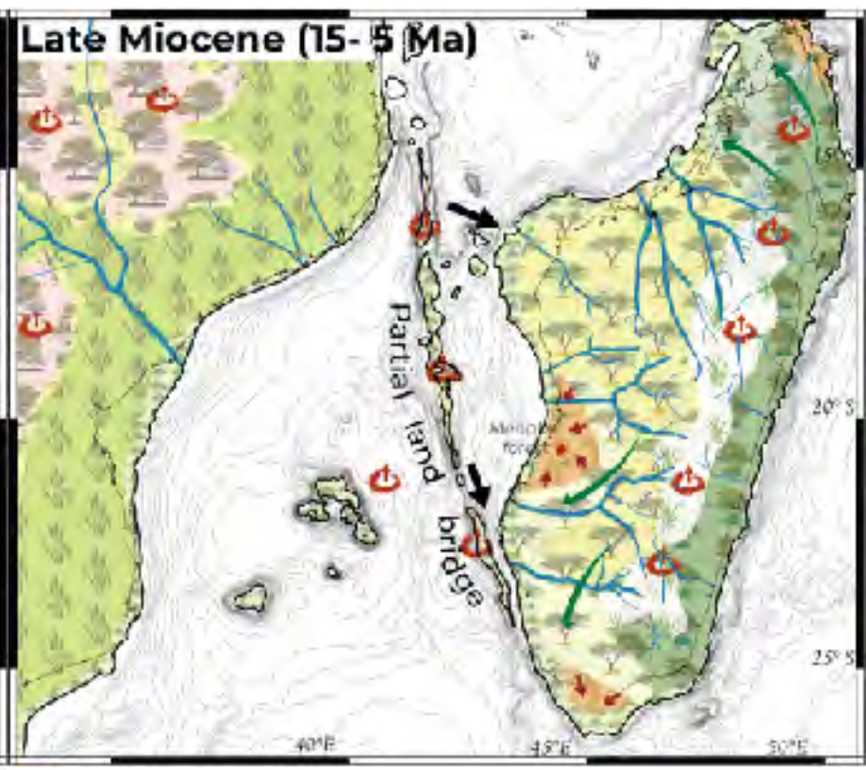


Et aussi :
Masters, et al. The Cenozoic Biogeography of Madagascar: A View from the Land Bridges,
in **The new natural history of Madagascar**. Princeton, *Princeton University Press*, Goodman, S. M. (ed.) including 553 figures and 243 tables, 279 contributions from 539 contributors (in press - scheduled for spring 2022).

Co-evolution : Genin et al, In prep.







- Malagasy Proteaceae thicket
- African Fabaceae woodland
- Afromontane fynbos
- Mimosoid wooded grassland *(Fabaceae grassland)*
- Altitude thicket & Sclerophyllous forest *(Palm forest/Erica thicket)*
- Afromontane Podocarpus forest & grassland
- Dry deciduous forest *(Erica thicket/Euphorbia thicket)*
- Xerophytic ticket *(Erica thicket/Euphorbia thicket,*
- Moist evergreen forest *(Erica thicket/Euphorbia thicket)*
- Mangrove and coastal thicket
- Riverine woodland
- Relief uplift trend
- Faunal and floral migration
- Floral migration
- Floral restriction

- 1 / Integrated Coastal Zone Management (ICZM) : Why and How to define it?
  - From ICZM to Adaptation

- 2 / Integrated Water Resource Management (IWRM) – how to study it?
  - Caste Study IWM : White Volta Basin Case – Ghana : The CPWF & TAI Projects (IWMI, WRC, CIRAD, Bioversity International , …)
  - From modelling (MAS) to serious game

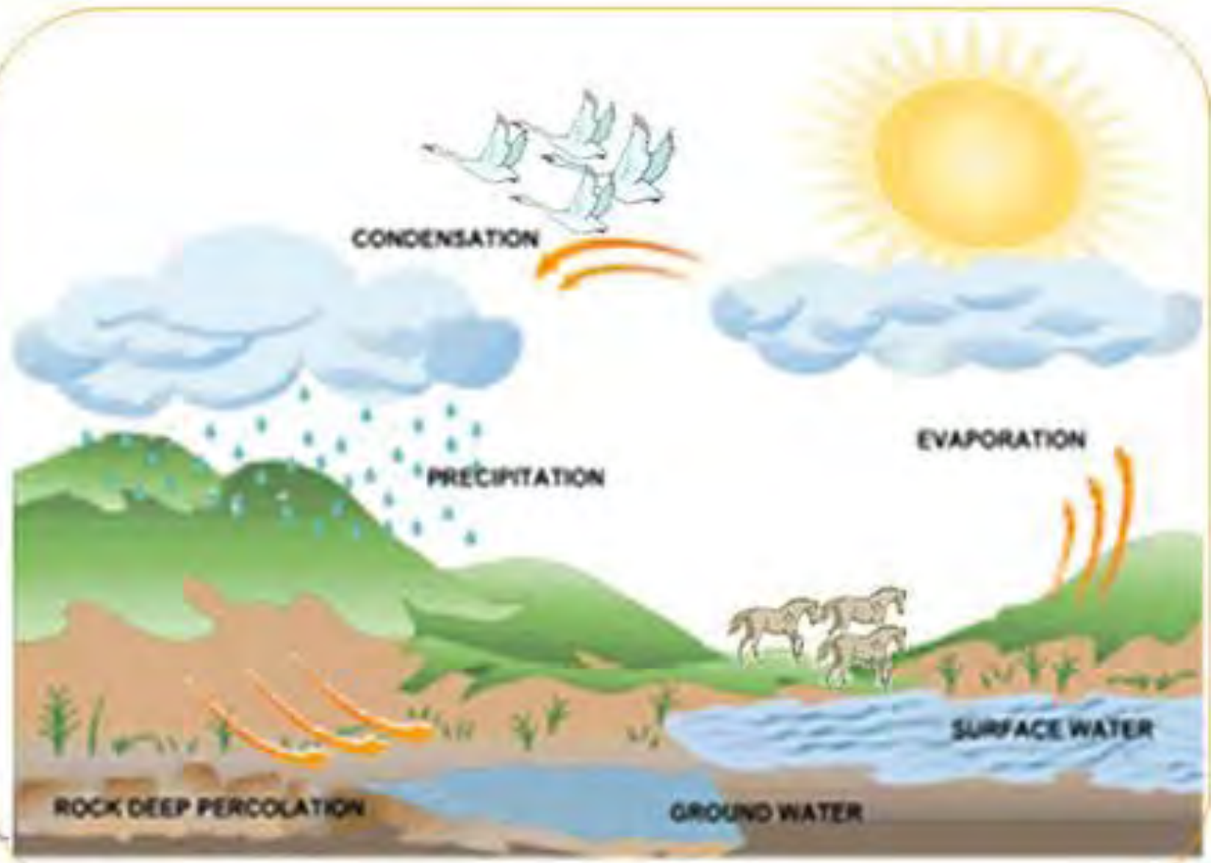
- 3 / Practice : « Citizen Science » -How to involve the stakeholders?
  - Fish Banks : Playing as an individual agent fisherman (Meadows/ Forrester)
  - building a collective cognitive map with Stakeholders (ARDI Method)
  - From ARDI to Role Playing games

Martine Antona
- Cirad -

Social Dynamics

Bio-physical Dynamics

Stakeholders' interactions and point of view



Interactions among stakeholders having different weights & representations of their common environment.

Source : Green CIRAD

Coastal zones through a social science lens

All photos from Therville _ MAGIC Project

- **Coastal Zone are areas, shaped by humans and societies, but also by what is called « non-human » in social sciences**
- **Coastal zones are exposed to risks**
- **Responses to these risks involve various scales of action and representation and raise the question of the time to act.**

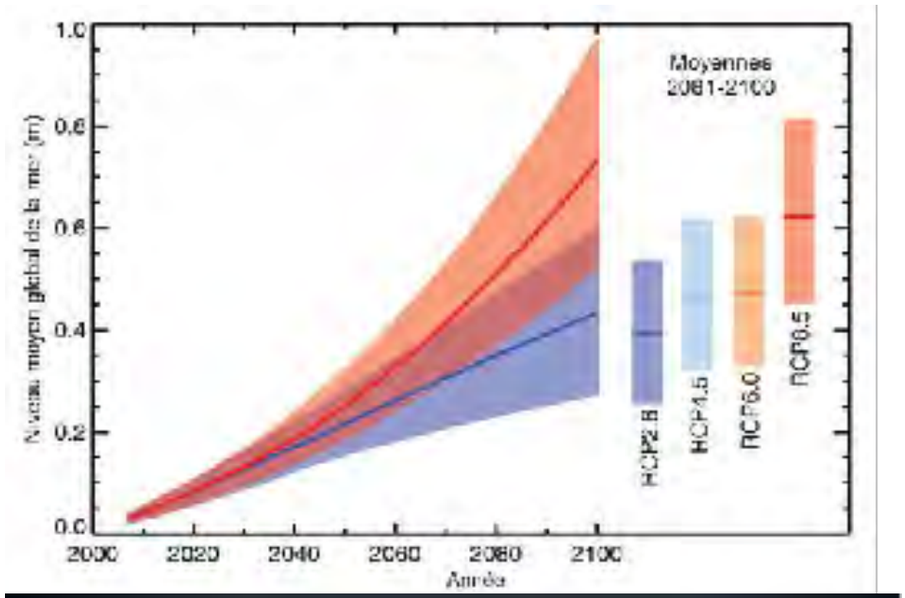
Coastal zones = areas shaped by humans & by « non –Humans » and not fixed

- Place of activities/attractivity & natural and social impacts issues (pollution, infrastructure development, conflicts, overexploitation, …)
- Place of living / demography (20% of World pop < 30km, 50% < 100km) & urbanisation issues (2 of 3 biggest megalopolises)
- Coastal natural changes and responses to human activity

  Interactions with natural changes ?
  Interdependences with non human (salt landscape; wildlife landscape, …)

  Long term issues
  cf. Climate Change and ocean as carbon sink (25%) depending on the development of the coastal zones

Coastal zones are exposed to risks



- Diversity of risks : floods, storms, sea rising linked to GES (1,1 m 2100 +3 °)
  (reasons : water temperature; hydrology changes)
- Inequality in Exposure to risks & in effects according to type of coast (sandy, deltas) and to occupation
- Risks are difficult to predict and anticipate
- How to evaluate the risks and damages effects? Only ex-post? Society's demands to Science:

→*Maps and indicators of vulnerability to risks ?*
→ *Decision support for action ?*
→ *example of the City of Saint Louis Senegal…*

Coastal zones : how societies' respond to risks

- When uncertainty on risks, Decision-making is hard
  - psychology and biases (denial…)
  - Problem to evaluate damages (economical damages vs damages on natural and cultural heritage- less easy to evaluate, to consider)
  - Acceptable responses and controversies

- Responses : risk reduction vs adaptation (reducing risk impacts)?
  3 responses and scientific questions
  - Manage the shoreline, fix it → possible?
  - Protect it with structures (dykes, groynes, windwall…) →What effects ? Here- elsewhere ? Now- Later?
  - Relocate habitats → possible ? Desirable for society? Constraints (land occupation)

- Issue of time for action : while delaying, do we win time to act?
  - *Degrading response (various forms)*
  - *Not solving but transferring problem?*

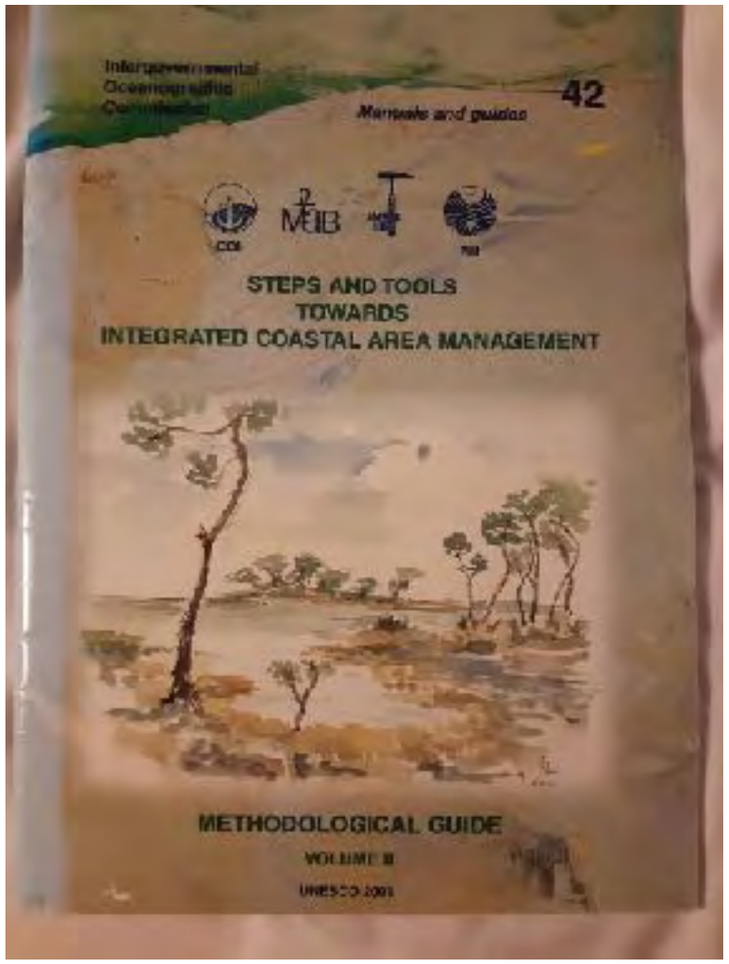
How to figure out Integrated Coastal Zone Management (ICZM)?

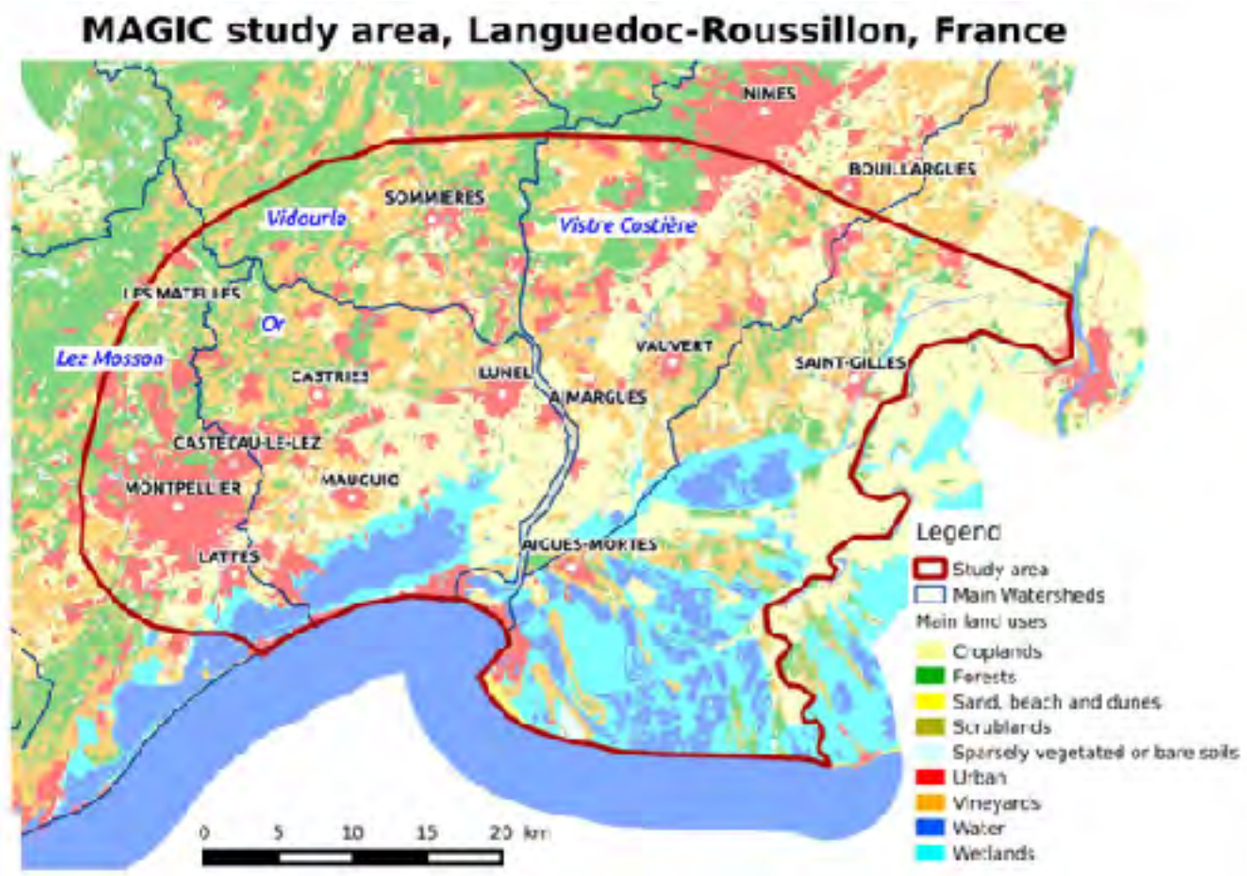
- « Context matters » → No « one fits all » model of Coastal zone
- What did we learned → Feedbacks from pilot projects /practices
- Social stakes / Science needed ? → sharing representation

What did we learned ?

Focus on feedbacks from pilot projects/ policies/ case

UNESCO-COI Guide/from pilot projets
MAGIC project
(Belmont Forum 2016)

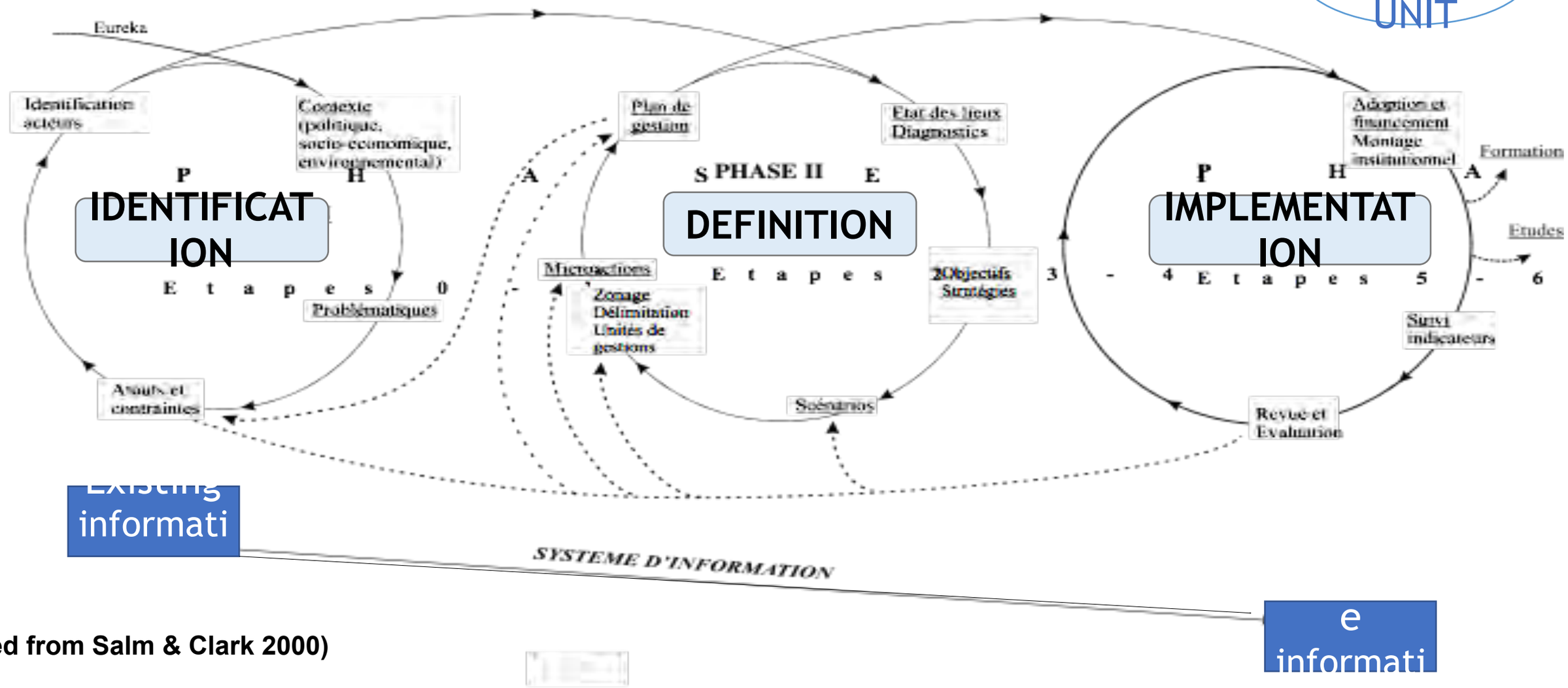




COI Unesco Guide 2001 : ICZM Planning Process

Pionne rGroup

MANAGE MENT UNIT

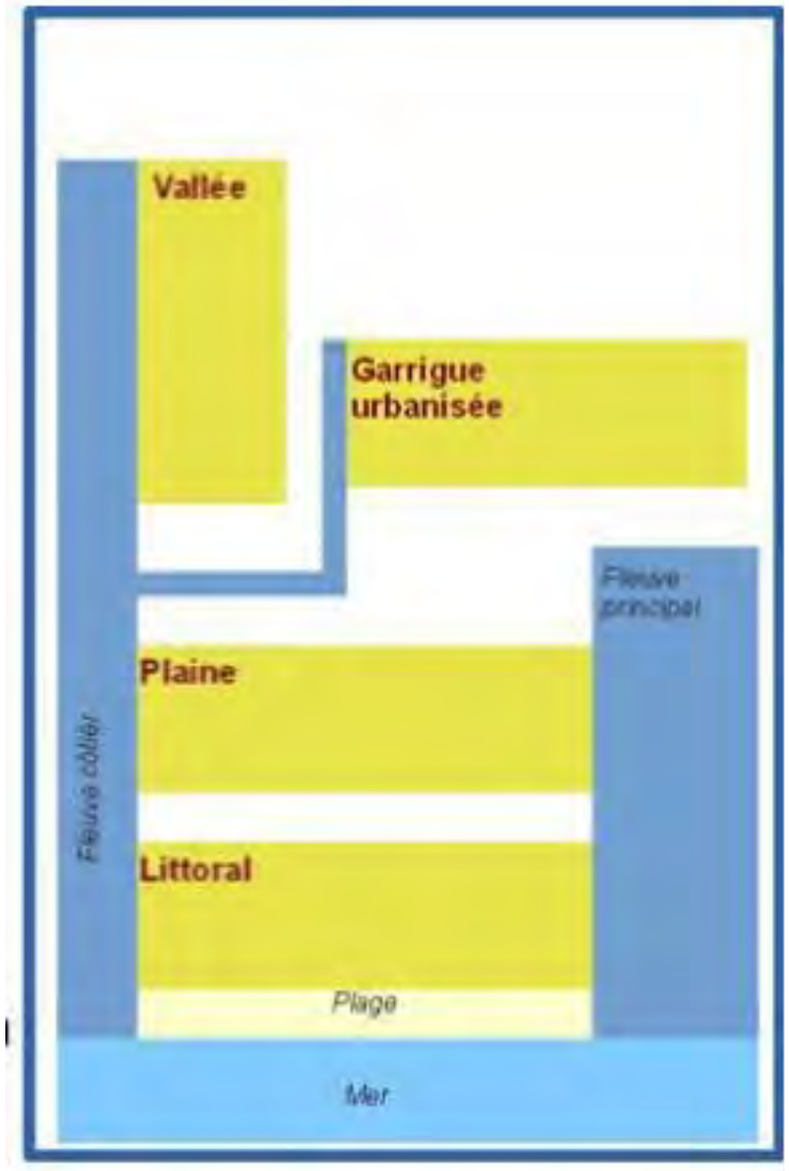


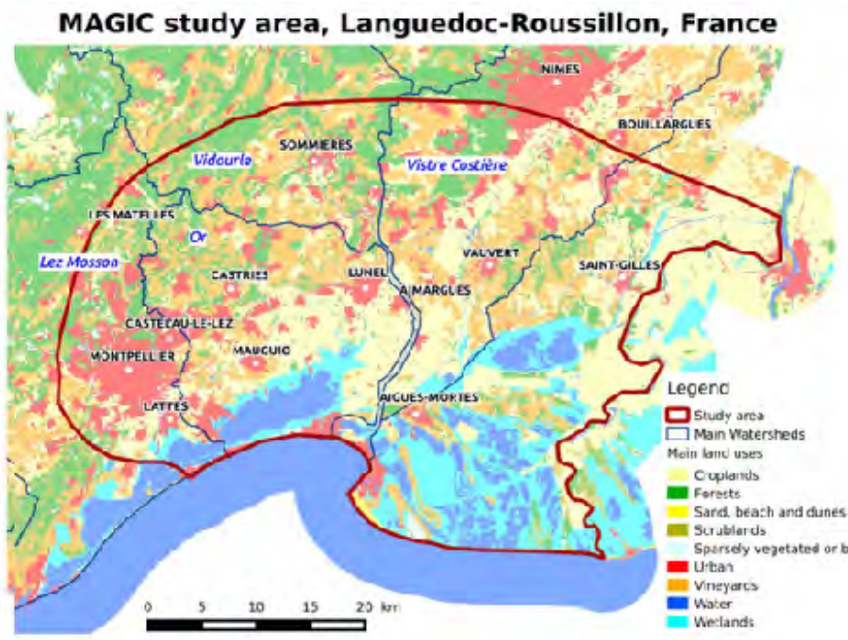
Existing informati

SYSTEME D'INFORMATION

e informati

Adapted from Salm & Clark 2000)





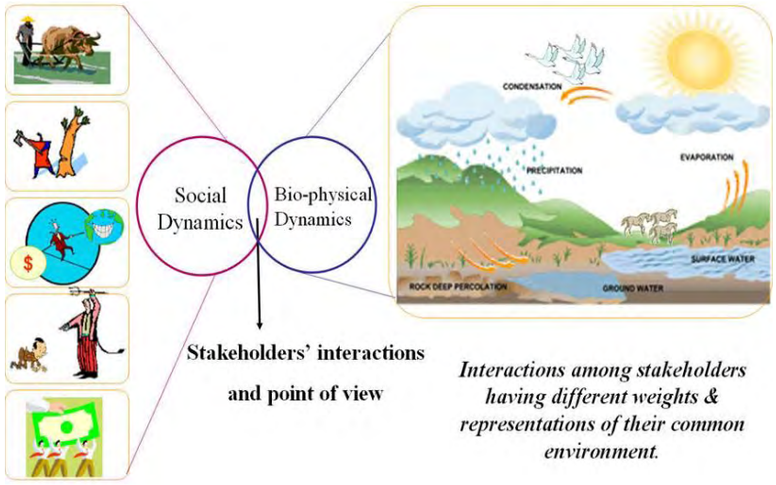
Bonte et al. REC 2009 .Analyzing coastal coupled infrastructure systems through multi-scale serious games in Languedoc, France

MAGIC Project (Belmont Forum)

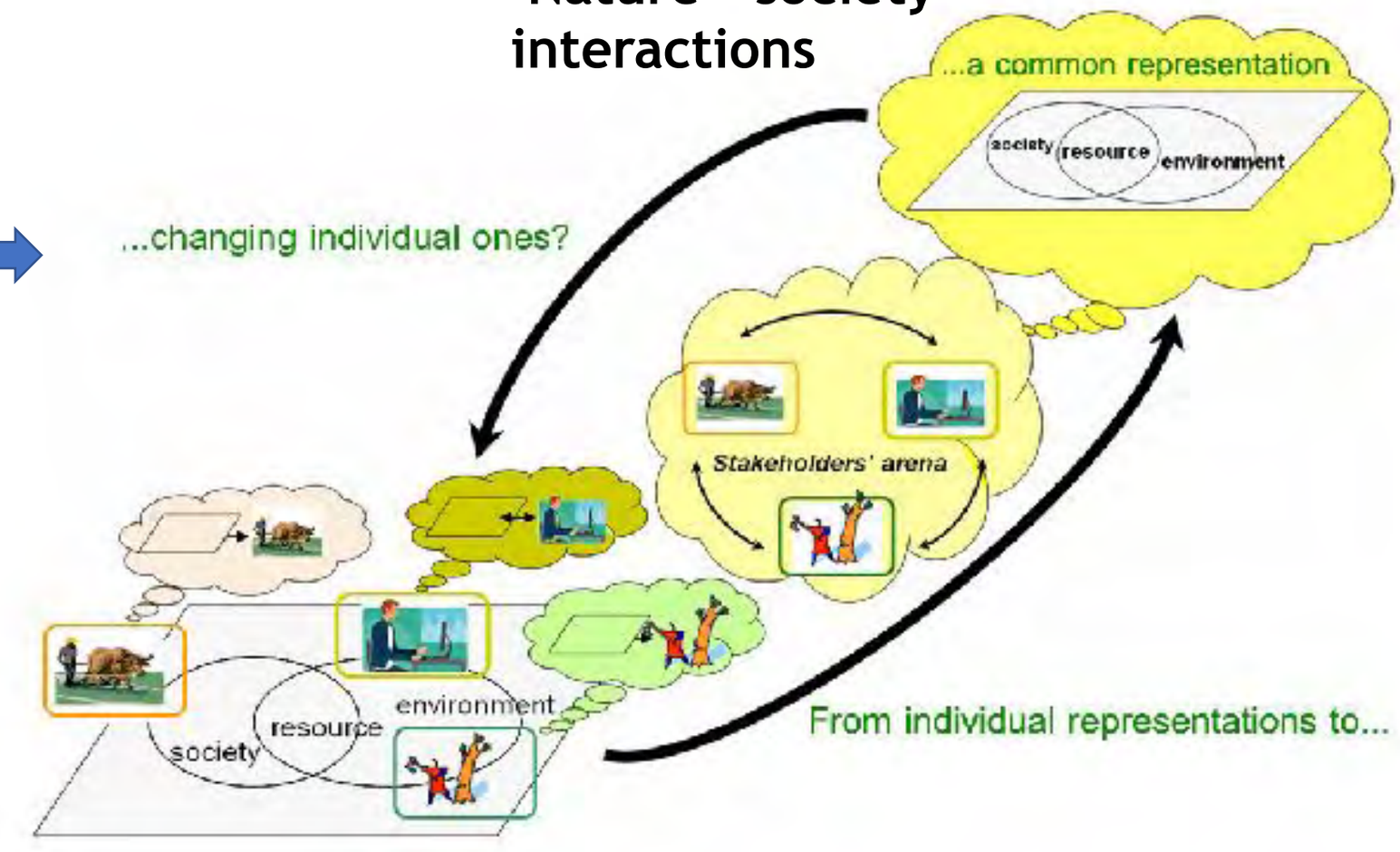
Explore how

- perturbations are perceived, are cumulative
- the adaptation responses are locally defined
- The vulnerability transfer linked to responses and ill-adaptation

Social Stakes and Sciences



Sharing représentations on Nature - society interactions



Integration of challenges in ICZM : Science/ Society issues

- From ICZM to Socio Ecological Systems (Ostrom's Graph)
- From ICZM to adaptation
  - Sustainable Development (Bruntland, 86)
    Van Dijk *et al.*, 2016. Ocean & Coastal Management (tri-national Wadden Sea, NL)
  - Climate Change

    Mahony, C. et al. 2020. Marine Policy (Cork Harbour, Ireland)
  - Cumulative

toward sustainable SES

toward Resilient SES

Issues for SUSTAINABLE DEVT	Methods
SCIENCE Integration of knowledge and information / plurality of issues Concept of coherence / Environmental protection /	System approach, Integrated modeling, Multi-criteria approach ... Question: how to account non-market issues in arbitration
SOCIETY Integration of points of view to collectively define common objectives (compromise) Concept of acceptability Territorial inequalities	Concerted management =Focus on governance arrangements and concern for equity : Question: how to support for changes /how to consider values

	Issues for CLIMATE CHANGE	Methods
SCIENCE	Taking into account uncertainty through the definition of adaptation trajectories	Need for regular, high-resolution information to identify tipping points Question: how to define and support adaptive management
SOCIETY	Long-term integration Consider the diversity of risks Vulnerability transfer linked to responses	Monitoring to facilitate anticipation ; Pooling ; Question how to define adaptive policies for coastal and retro-coastal spatial solidarity

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ICZM

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- Ehler, C. & Douvere, F. 2009. Marine Spatial Planning: A Step-by-Step Approach Toward Ecosystem-based Management, Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides No. 53, ICAM No. 6. UNESCO, Paris

From ICZM to Adaptation

- Van Dijk, J., Broersma, L. & Mehnen, N. 2016. Options for socioeconomic developments in ICZM for the Tri-National Wadden area. Ocean & Coastal Management, **119**: 76-92.
- O'Mahony, C., Gray, S., Gault, J. & Cummins, V. 2020. ICZM as a framework for climate change adaptation action–experience from Cork Harbour, Ireland. Marine Policy **111**: 102223.

MAGIC PROJECT (Belmont Forum, 2016- 2018)

- Bonte et al. Analyzing coastal coupled infrastructure systems through multi-scale serious games in Languedoc, France Regional Environmental Change (2019) 19:1879–1889 ; https://doi.org/10.1007/s10113-019-01523-6
- Therville et al. Challenges for local adaptation when governance scales overlap.Evidence from Languedoc, France Regional Environmental Change (2019) 19:1865–1877; https://doi.org/10.1007/s10113-018-1427-2

2/ Case Study –The Integrated Water Resource Management (IWRM) – how to study it?

- Integrated Water Management in Ghana : Introduction
- From Surveys to *Companion modelling approach* : Muli-agent sysem modelling and « serious game »

Martine ANTONA – CIRAD _ UMR SENS – France
EOL - Ghana

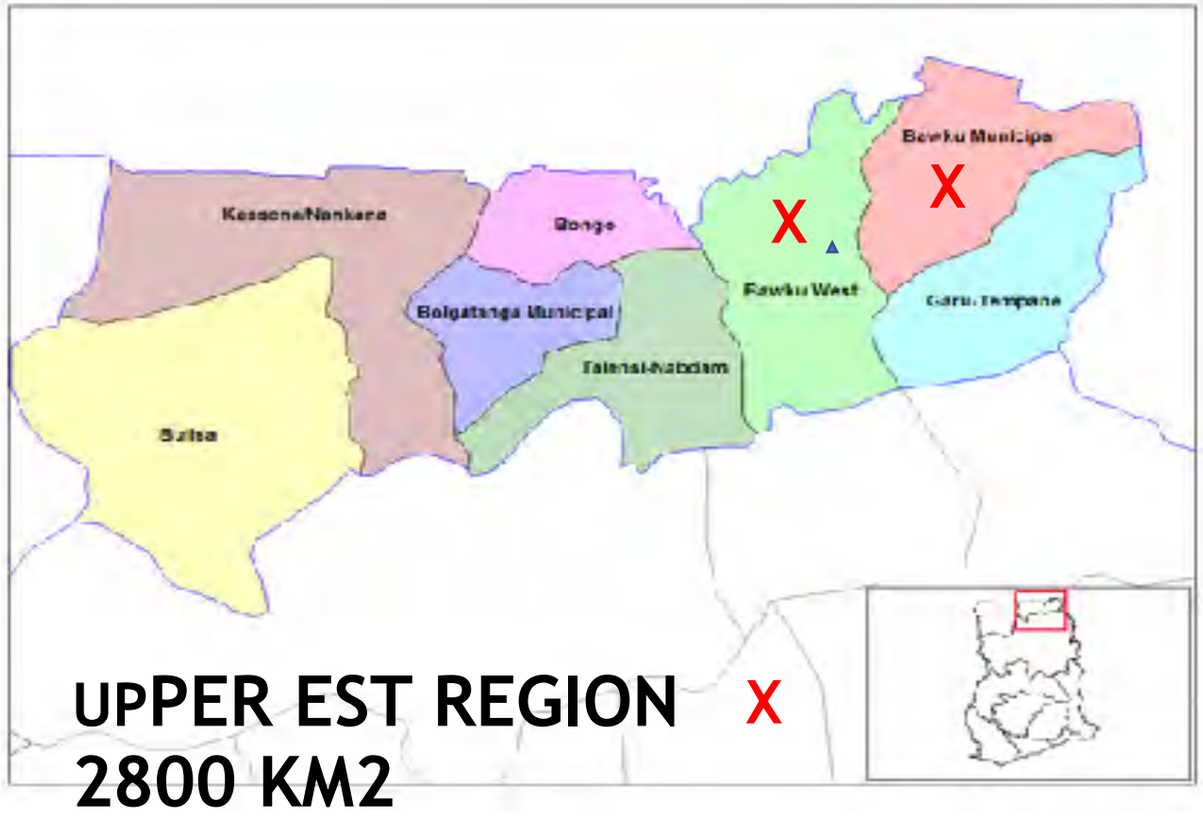
https://www.commod.org/en

21. IWRM – Integrated Water Resource Management in Ghana - Introduction

- 1992: International Water and Environment Conference in Dublin => IWRM principles
- 1996: Ghana - Adoption of the Water Resource Act
  -->creation of the Water Resource Commission (WRC)
  --> operational en 1998
- 2006: creation of the White Volta Basin Board, N°2
  - 3 regions, 29 districts,
  - 20% of the water supply to Lac Volta (-> Accra),
  - Multiple uses: hydroelectricity, irrigation, fisheries..
- 2007: New Water Act Nouvelle loi sur l'eau (Water management, urban water, community sanitation)

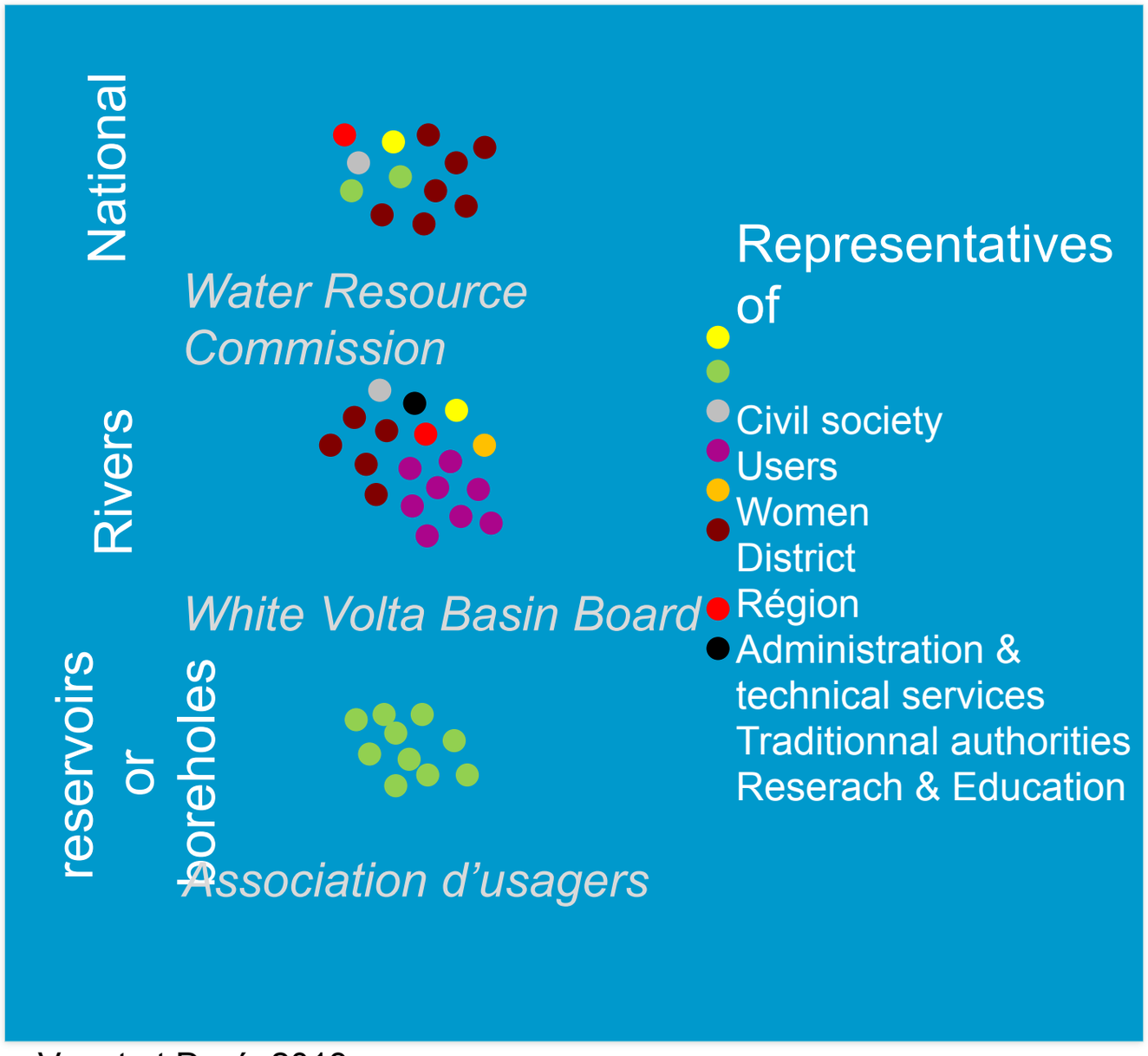
Volta River Basin

- 470 000 km²
- 6 countries: Burkina Faso, Ghana, Togo, Bénin, Niger, Mali



UPPER EST REGION X
2800 KM2

- Recurrent flooding and pb with small reservoirs/dams
- Flooding : September 2007
  - 266 000 people affected in the three regions crossed by the White Volta
  - + 11000 destroyed houses
  - + 12 000 ha of cultivated land devastated in the Upper East region alone
  - non-potable water over a long period
  - Cost: 21 millions US $.
- Issues raised:
  - Lack of coordination for the release flood warning
  - Farming practices which increased the negative effects of this flood



Venot et Daré, 2013

IWRM in Ghana

- Establishment of spaces for multi-stakeholder consultation?
- Few interactions between the different level of action/ management / decision making of the water resource.

22. The White Volta Basin Case: Bawku-Do

- Issue

How to limit the impacts of floods on food security and to foster the dialogue between water mangement actors (Region, District, community)?

- Study on the Case of a Upper Volta Basin :
  - 2 districts : Bawku Principal & Bawku
  - « Bawku – Do » *Meaning « Lots of Water »* = serious Game and Model = Companion modelling …..
  - Projects funded by IWMI (CPWF V2 & TAI projects)
  - Participants
    - 7 Researchers from Ghana, UK & France
    - "Experts" carrying political knowledge on the issues in the area (including WRC) : " the scouts"
    - Senior officials (agriculture, hydrology, environment); Regional council member ; University ; NGO with local and international mandate ;
    - Field Actors with empirical, technical, social and political knowledge :

Team : Pr Arun Aduna (WRC) , Andrew Asaviansa (WRC), Fred Kizito (CGIAR); W. Daré, JP. Venot, C. Le Page, (CIRAD & IRD), & M.Antona (CIRAD) for TAI project

Companion modeling approach

ComMod Companion Modelling

Provides dialogue that supports collective communal management of natural resources (that is hopefully sustainable)-☺

Co-construction of a shared representation of issues at stake (actors, resources, dynamics and relationships)
through local stakeholder consultation –**ARDI-RPG**

Watershed modeling (Biophysical SWAT and MAS Netlogo)

Collective identification of social and ecological dynamics - VALIDATION

The Role Playing Game

ComMod
Companion Modelling

STAGES

1. Starting Process: ComMod training & common redaction of the project
2. Participative operating mode defined with the scouts
3. Individual and collectives surveys + participative mapping + internship for collecting stakes, point of views and their localisation
4. First map and identification of the common stake for the 3 layers of participants

5 communities, Volta River in the middle, rivers and reservoirs

sedimentation of small reservoirs
rivers bank erosion
and flood
→ Where/who is affected

The Role Playing Game

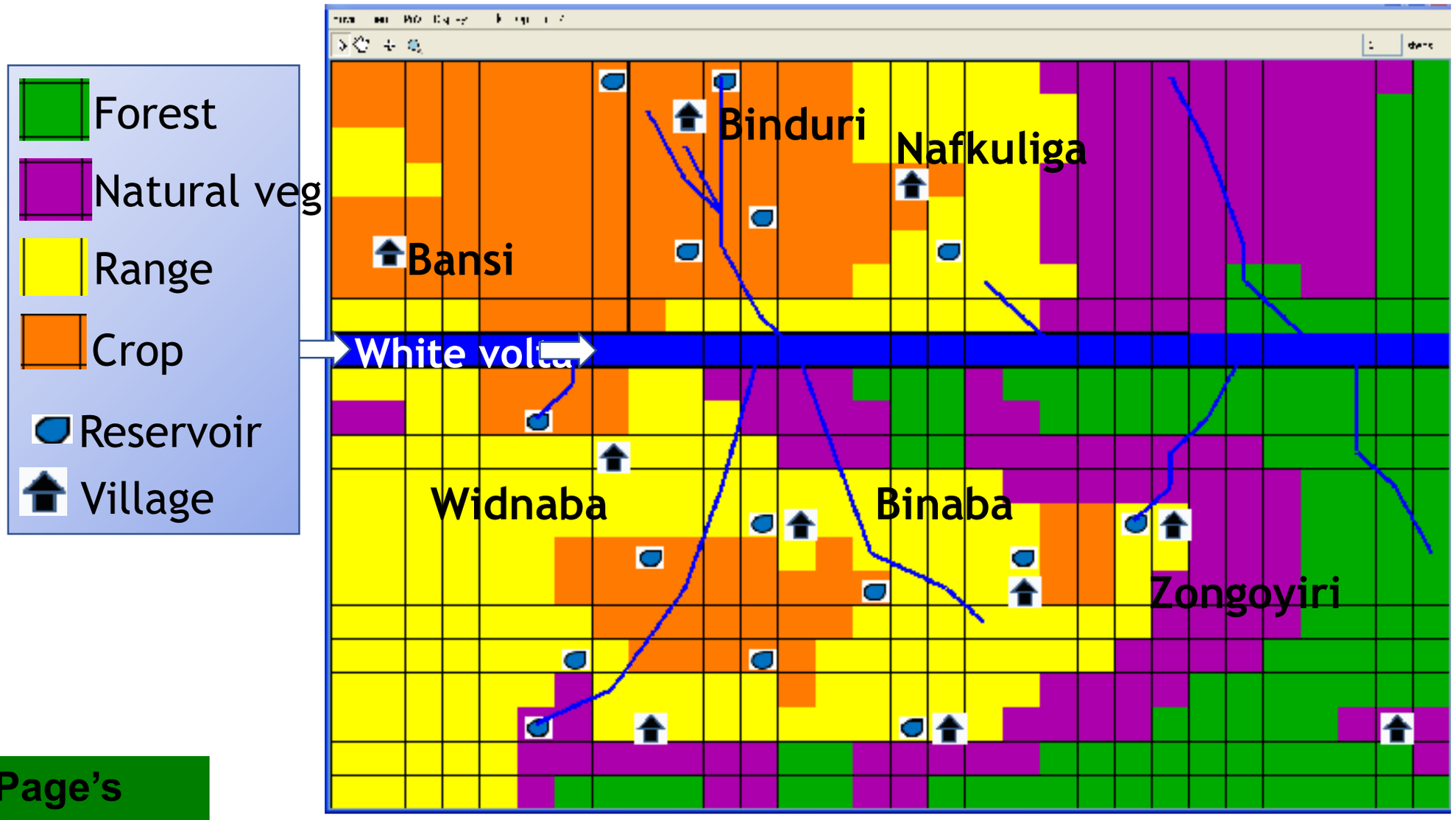
ComMod
Companion Modelling

STAGES

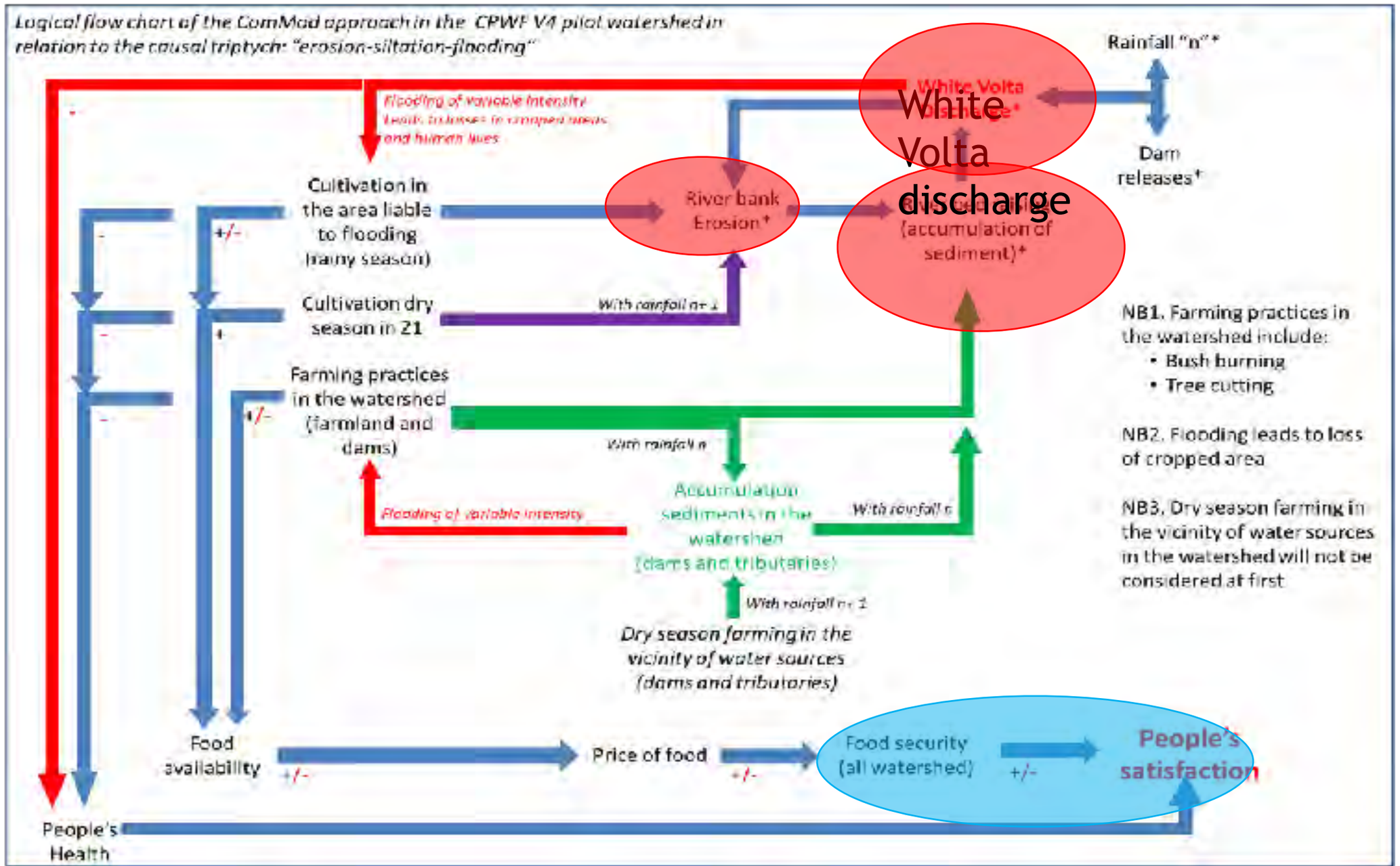
5. First version of the « Role playing game » (RPG)

- Test of the game and modification in a 3 days workshop (1 day /1 layer Community, district, Region)
- Modelling Presentation of a pre - version of MAS simulator associated with the RPG

Modelling : From the model to replay the game (behavior)…to the model to simulate (15 years)



C. Le Page's Modell



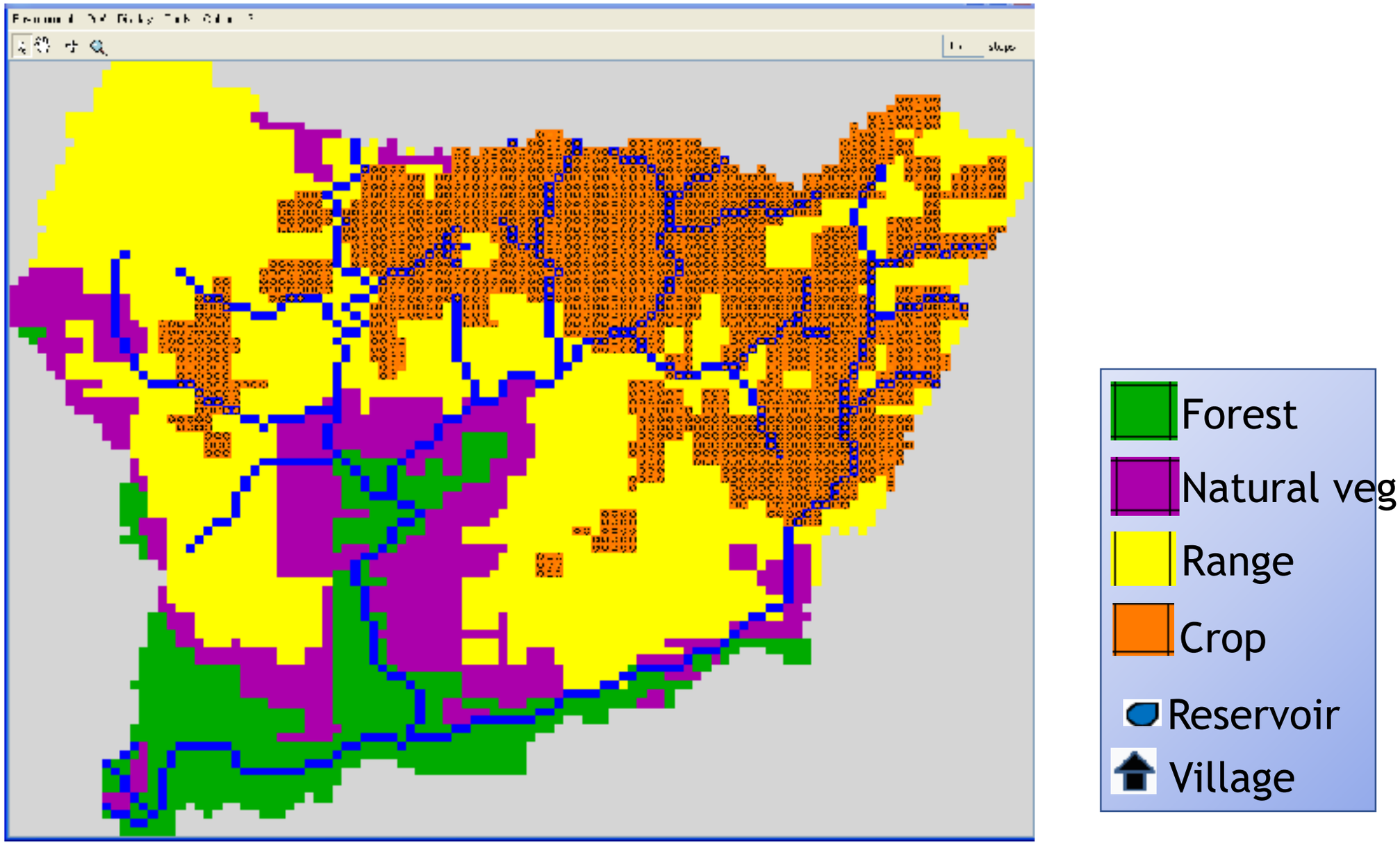
White Volta discharge

F.K.

Biophysical modeling

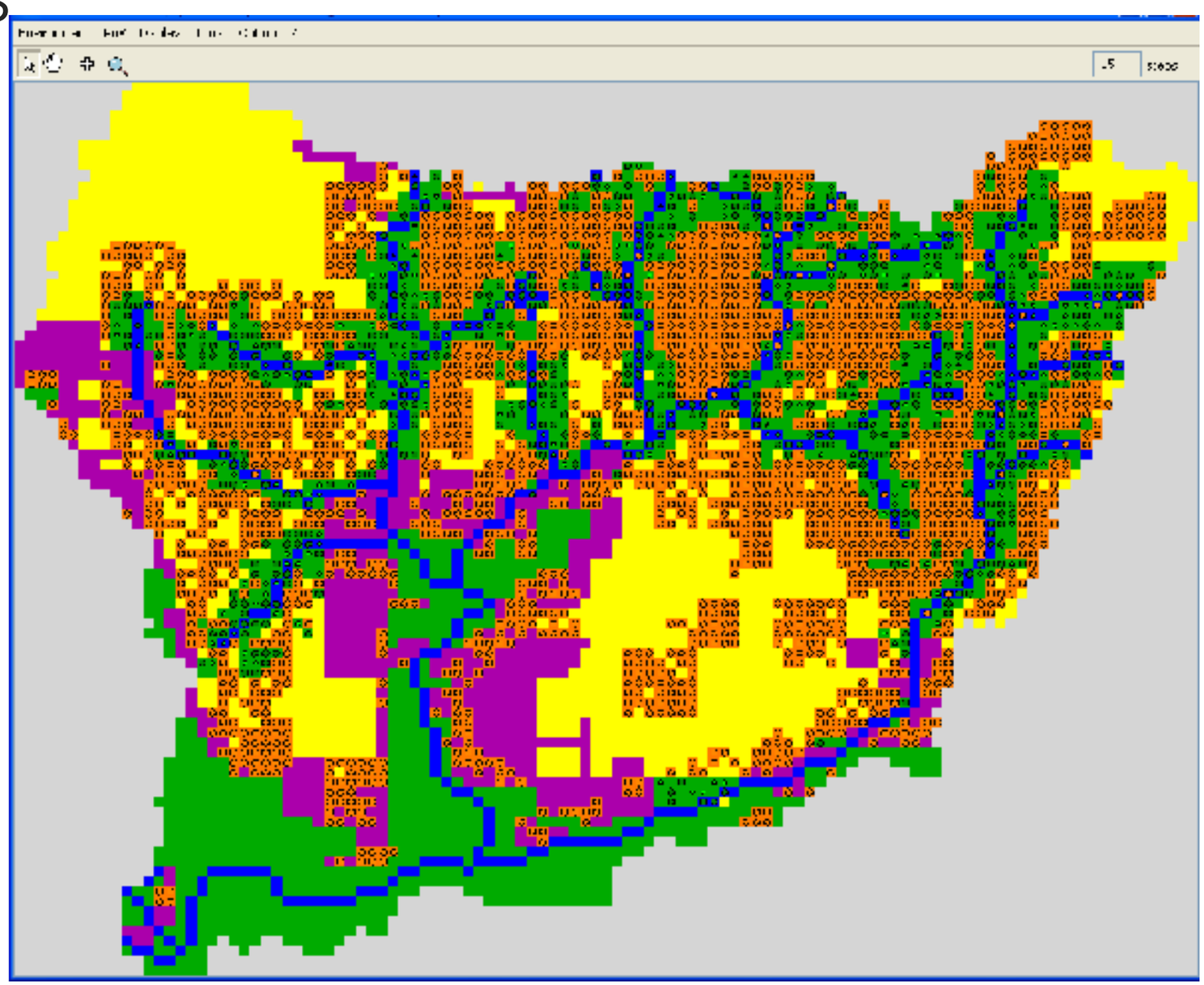
Scenario Assessment

Initial Scenario = « Business as usual »



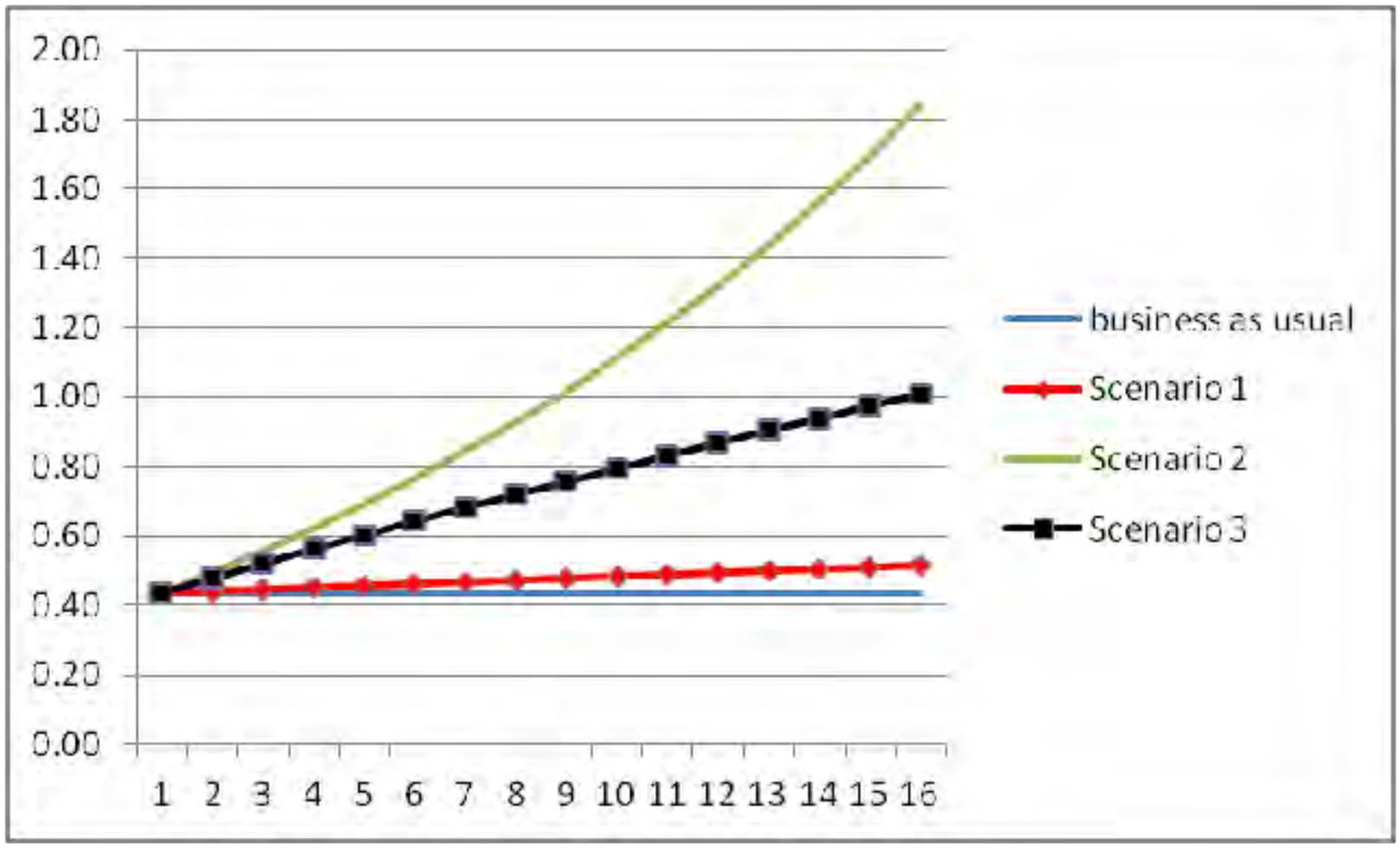
C. Le Page's Model

Scenario 3: Flood & Tree Plantation in buffer strips+ No risk Zones



C. Le Page's model

Environnemental Index – Simulation 15 years



C. Le Page's model

To conclude

- Initially :
  - No common(s) stake(s) at the watershed level
  - No interactions between actors from different levels
- Survey, RPG
  - 2 pbs: Communities reports yearly decrease in water capacity;
  - LT Viability of the water supply system because of sediments (reservoirs pipes feeding downstream irrigation zone).

  ➔Problems affect then formal and informal cropping area and multiple uses of small reservoirs
- Modelling : two objectives for scenarios:
  - Secure water capacity; Secure the functioning of the supply system (pipes)
  - 3 interventions simulated : **buffer strips (sc 3)**/dredging/check dams

To conclude

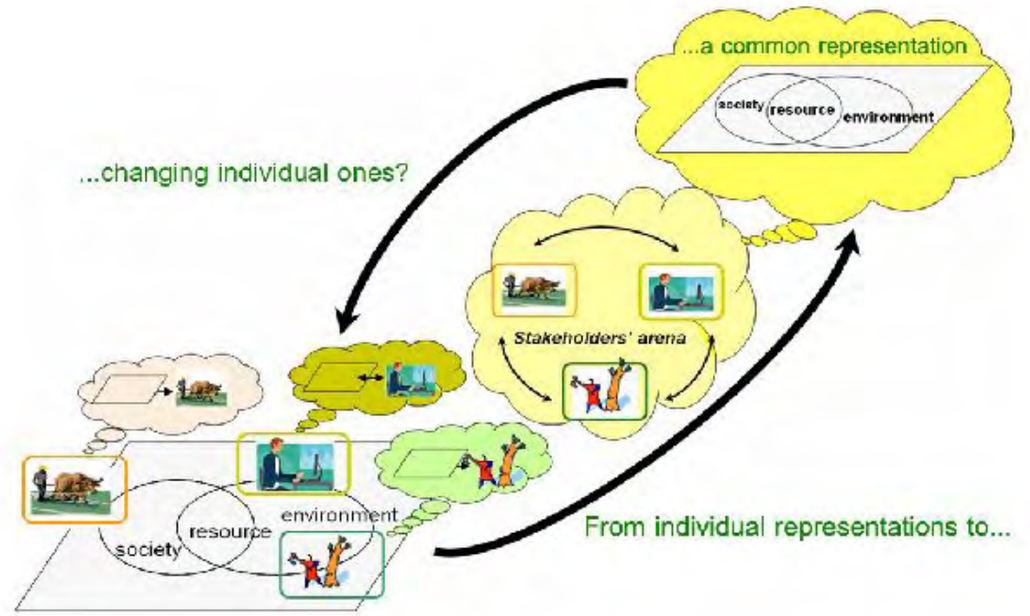
- **Results**
  - Identification and discussion of common stake (bottom up)
  - Oberved changes in capacities to interact, to exchange informations, to listen other constraints or inputs, and to express demand
  - Changes in trust between the parties; commitment in a process of change
  - Start of integration entre between Hydrological model and MAS based on collective RPG
  - balancing rate of return and risks over crop results for each intervention/project and the 3 together ; buffer strips have high rate of return but show higher risks, etc…. Better with the 3 together
  - Other results on critical decision making variables: value of crops (onion, rice…); cost of the interventions (for example no idea of the costs of buffer strips) and willingness to pay of decision makers for the interventions.

- **But how do we know simulated "water fund" activities (ie buffer strips, …) will actually result in the modelled changes?**

  MONITORING to provide evidence of impact on the ground → TAI Projects

Perspectives/outcomes

- creation of a « mini-board » at the request of the White Volta Basin Board officer – at the scale of the studied watershed = **New Stakholder arena**
- This management structure will benefit from the experiment
- Extension to other sites in Ghana with Volta Basin Authority



III/ - Practice : Citizen Science
How to involve the stakeholders?

- What are the « serious games »?
- Playing FishBanks game (Meadows / Forrester)
- ARDI Collective Exercise
- To go further on companion modelling

31. What are the « serious games » ?

- Definition and debates for almost 50 years (Crookall, 2010).
- An application (computerized or not) which combines serious aspects (teaching, learning, communication, marketing, information) and playful aspects (Alvarez, 2007)
- What for ? Pluridisciplinarity (players = scientists)/ Citizen Science (players= SH, scientists for animation)/ Both
- The ComMod collective mainly uses serious games in the form of computer simulations and / or role-playing games. These games represent and simulate the functioning of socio-ecosystems (eg: forest, watershed, livestock, fishery, etc.).
- By being around a game board or in front of a computer, the players interact and seek a solution to the problems of the system they have contributed to figure out (ex: deforestation, poverty, water quality, etc.) ….
- … by learning together, by coordinating. and taking collective decisions.

- https://www.commod.org/en

Playing FishBanks

- One of the first « serious game »
- designed by Pr Forrester & D. Meadows (1972 Report of the club de Rome as a warning)
- You will play the role of a fishing company (resource user)
- You will have too take decisions to exploit, how et where.
- Let's do it !

Let's do it - Steps

Step 1 **. <u>Receive the annual report from the computer</u>.**

Step 2. **Choices**

- **Choice 1 : Number of ships**
  - Participate to auctions or not to buy boats. ***They can fish during this turn***
  -*Or* Buy or sell ships from other teams. ***They can fish during this turn***
- **Choice 2 : Number of fish : Order the construction of new ships.** ***They can fish during the next turn***
- **Choice 3 : Chose the area to fish and record it on the decision sheet (*Deep sea/ coastal Sea/no fishing ie ship stays in the harbour)-***

Step 3**. <u>Place the ships on the game board</u>**
(coastal zone/ Deep sea/ harbour. ***Each choice have a cost. The information is shared with the other companies***

Step 4. **<u>Give the Decision Sheet to the game manager.</u>**

•

To be discussed

- Collectively : Which strategy was the more fruitful? Why (according to you)?
- Individually: Were your decisions based on a long term strategy? Or on what ?
- Individually : Was your strategy successful ? How do you appreciate the success of your strategy ?
- Did you take into account the actions of the other teams and modify your strategy according to it?
- Did you take into account the scientific information that was provided to you (Fish density model, fish effectiveness)
- Did you make observations?
- Was it easy to make decisions ?

ARDI method (Actors *? Resources*, Dynamics , Interactions*)

- A method for analysing an issue / a context
  with the SH (Citizen Science)
  Within scientists (for pluridisciplinarity) (Etienne et al., 2011)
- ARDI Collective time :
  - How to co-construct a cognitive map of the Costal Zone situation (ARDI)
  - The floor is your ! Your example of the Coastal zone issues in Ghana
- Conclusion :
  - How to share and elaborate a conceptual model
  - in order to simulate over time the trajectory of the whole system with Role Playing game and model.

Etienne et al. 2011.

	Starting frem a problem/ an issue	A= Actors (User+ Governance system)	R= Resource (Resource Unit Ressource system)	D= dynamics	I= interactions
Objective	Issue : Searching how to understand or to improve the situation!	Identification of main Features	Characterisation (ex; used, produced, affected, created)	Evolution and factors involved	Synthesis Finalization of the conceptual model
Protocol	Surveys collective workshops Science Literature	Surveys Synthesis workshops Literature	Surveys ; Maps Synthesis workshops Literature	Workshop Focus group on specific questions Secondary data	Data analysis Staff dialogue SH workshops for validation
Main source of information (to be discussed for Coastal Zone)	Mainly based on accumulated Knowledge	Scientific and non scientific knowledge	Scientific and SH knowledge integration	New information to produce	New scientific information to produce / integration of knowledge

ARDI Method : TWO STEPS

- **Step 1: What elements are decisive for managing the issue ?**

  Main features

  - A = identification of actors*
    (Two categories resource use § governance systems)
  - R = Identification of resources *
    two categories (resource unit and resource system)

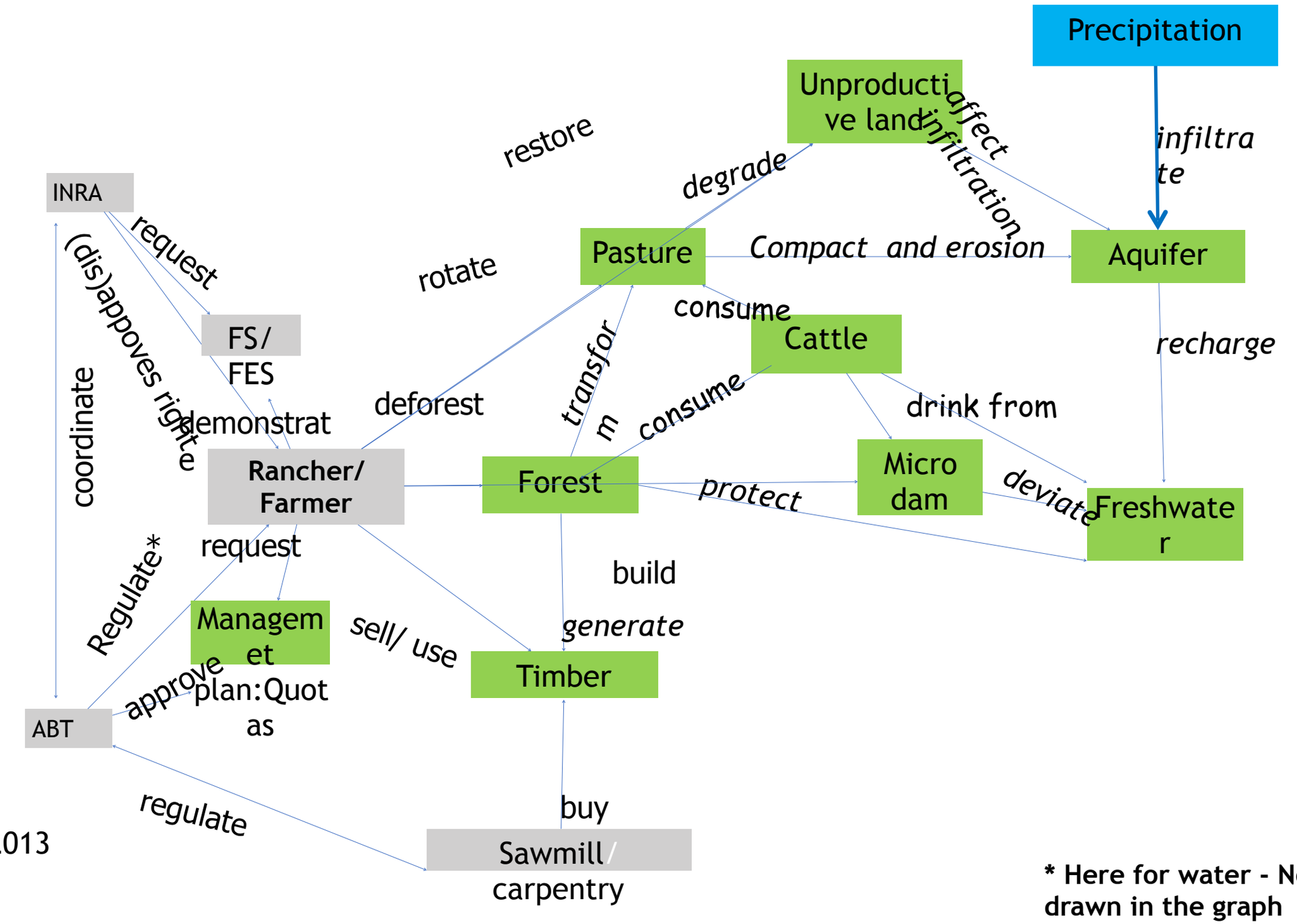
- **Step 2 : how do these elements interact ?**

  Actions = verb of action

  - D= Dynamics - What are the main processes that provoque changes, notably for the issue to tackle , But also for the actors& resources
  - I = Interactions * drawn on the graph : from actors to resources (from actors to actors and from resource to resource- both sides)

* = are represented on the ARDI graph

Exemple : how to understand current practices on agricultural frontier and their implications ?



From Fallot 2013

*** Here for water - Not necessarily drawn in the graph**

The floor is yours ! EOL Ghana Coastal Zone Case Study

- Day 2

= individual identification of ICZM issues (Ghana and/or South Africa)

- 4 identified categories of problems/ issues
  - Issue 1 : Access to beach (sand mining , dumping sites, plastic pollution, effluents, *recreation*) (Abena, X , Y , Kuame, Abigail, Joseph) + Marina
  - Issue 2 : Harmful Fisheries and Species protection (poaching, trailers, informal and formal fisheries, harmful practices ie chemicals…)
    (Thusile, Christian, Danaa, Abigail2, Bless) + Estelle
  - Issue 3: lack of coordination of multiple coastal uses and conflicts (chemical spills, pollutions, petroleum exploration, Mining)
    (Nana Kojo, Florence, Manyano, Yaa, Z0)
  - Issue 4 : Sand dredging, erosion and spatial development (Large scale sand exploitation for infrastructure development ie Harbour or habitats, Tourism development)
    (Ewen, Yaa2, Duna, Z1, Benjamin, Aldric, Alex, Mochcel, Z2)

- Day 5:

= *collective exercise* - How to represent them with ARDI method
= *5 teams for starting with – the shared definition of the issue to tackle*

To go further on Companion modelling and serious games - References

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