presented by

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Pr. Daniel ASIEDU (Univ. Ghana)
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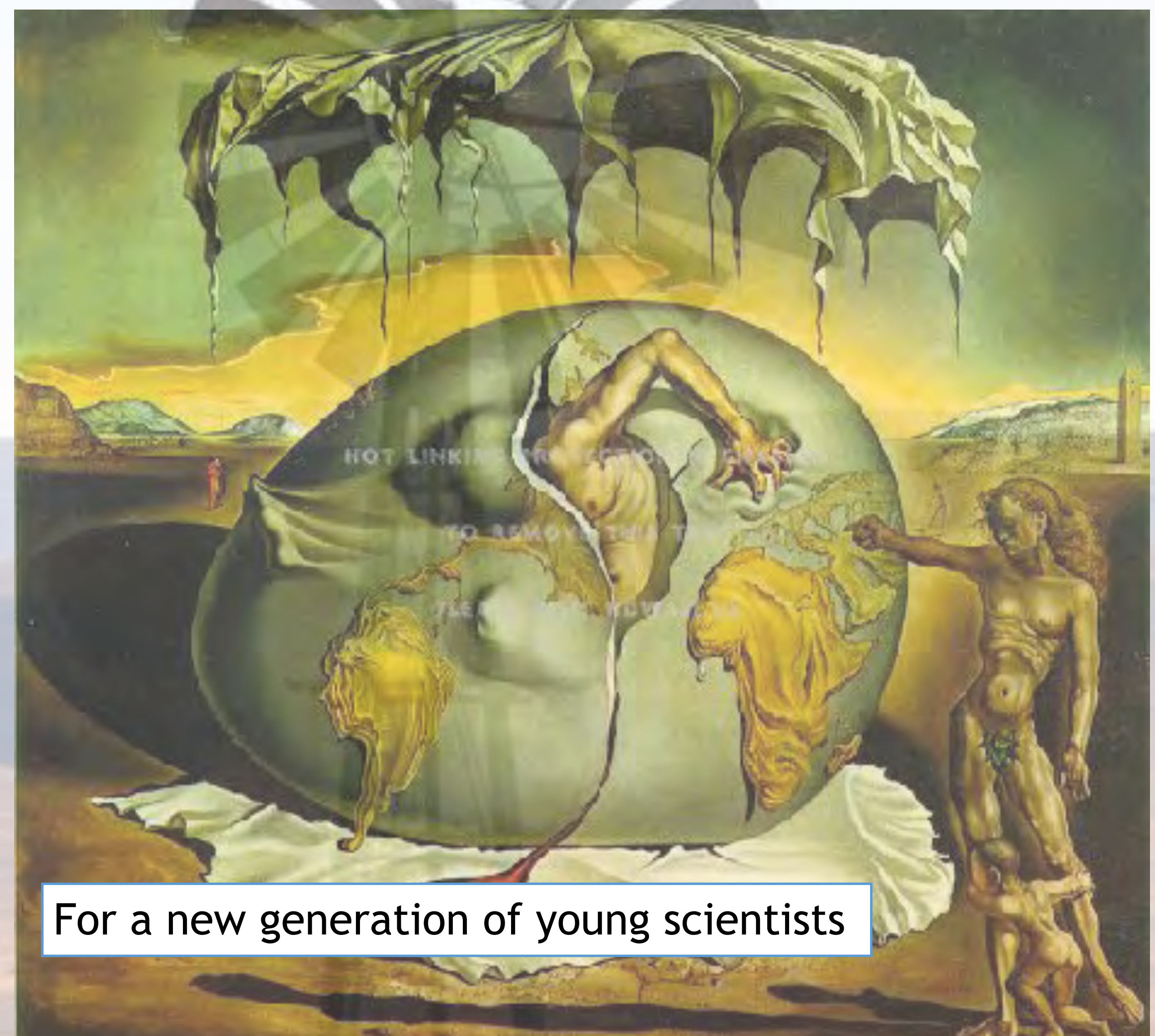
EOL international School

Master international class

Field Trip

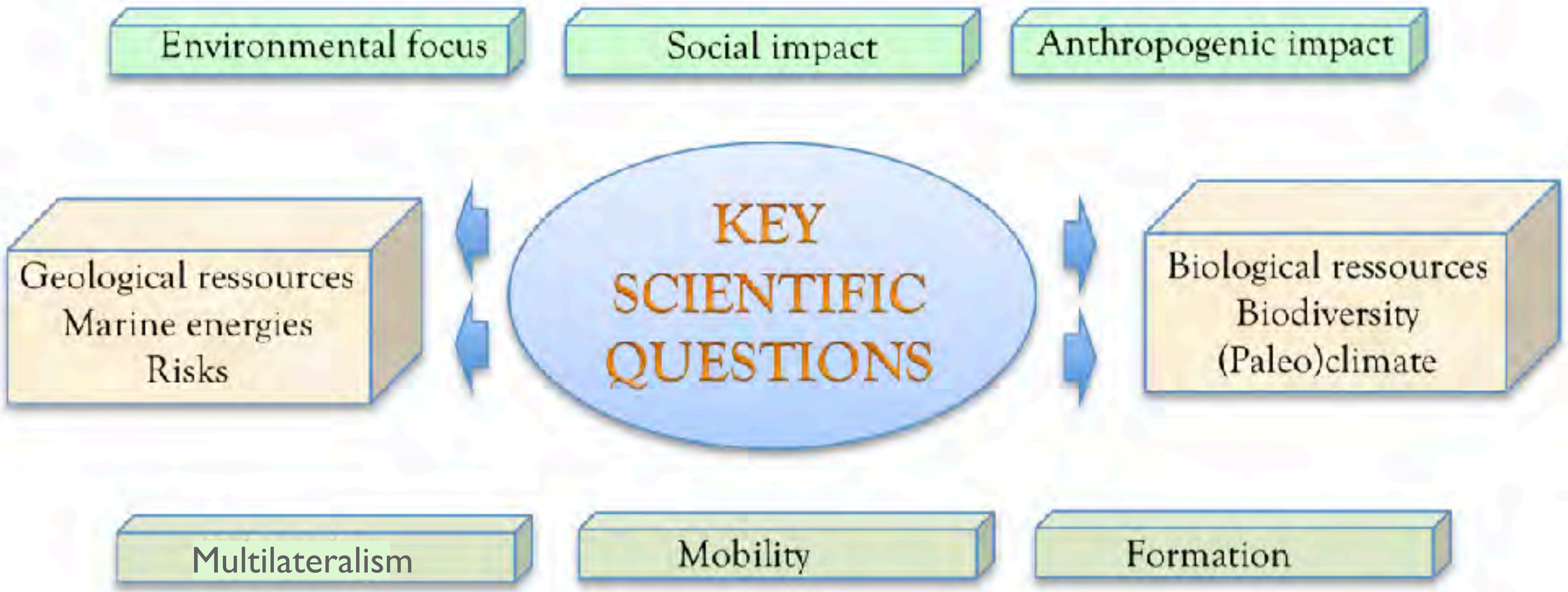


For a new generation of young scientists

Seismic Practicing

Floating university

EOL international School



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Field Trip

Seismic Practicing

Floating university

EOL international School - 2022

Master International school program (5 days)
Epistemology and scientific methodology
Geophysics tools
Plate tectonics
Continental Passive Margins and Basins, Sedimentology, seismic and sequence stratigraphy, sea level evolution

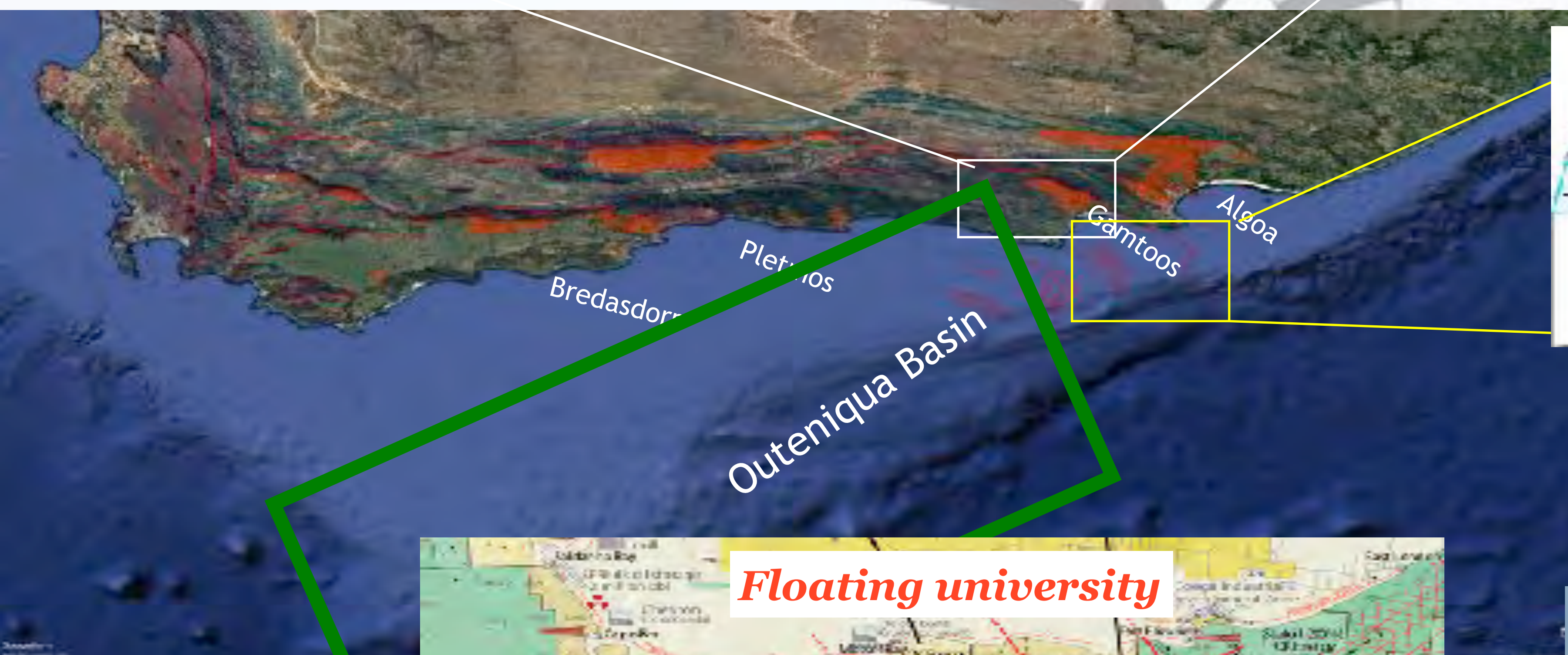
Seismic interpretation, drill hole and modelling
MT & CSEM processing and modelling of land and marine data.
Data processing and simple modelling execution for terrestrial and marine applications

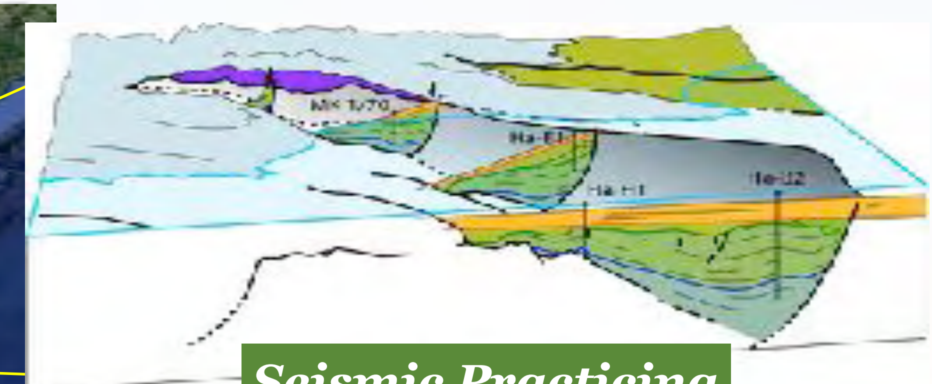
Field training: (5days)
The Gamtoos Basin - Continental-Ocean Connexion
- MT and CSEM for aquifers

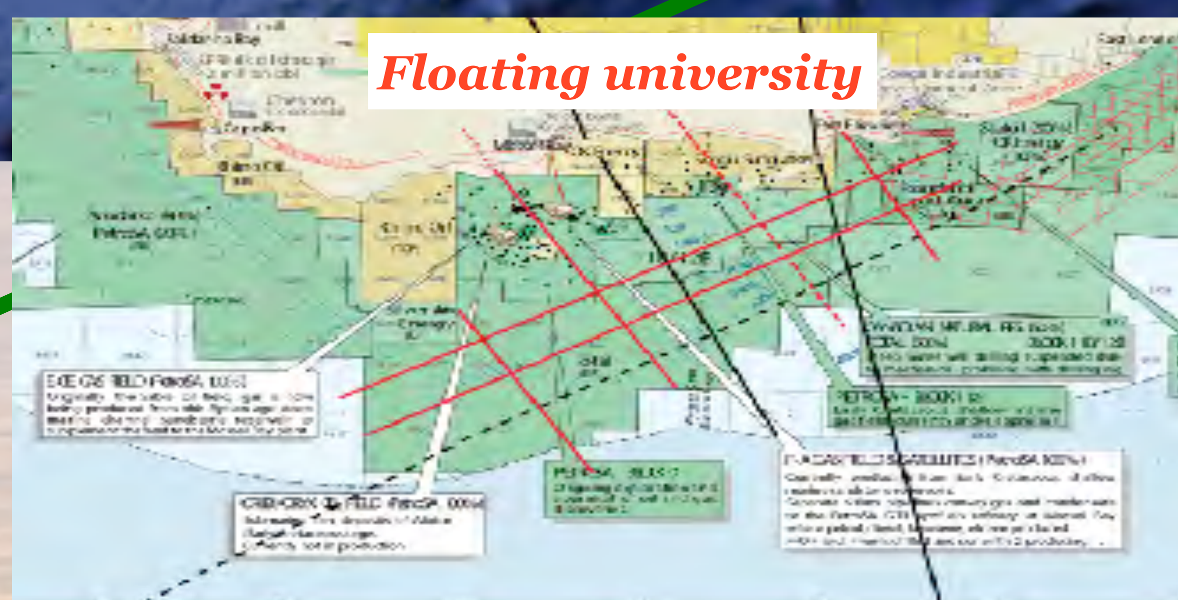
Marine experiment (3days)
Ocean-continental connexion (messinian crisis)

…in natural setting

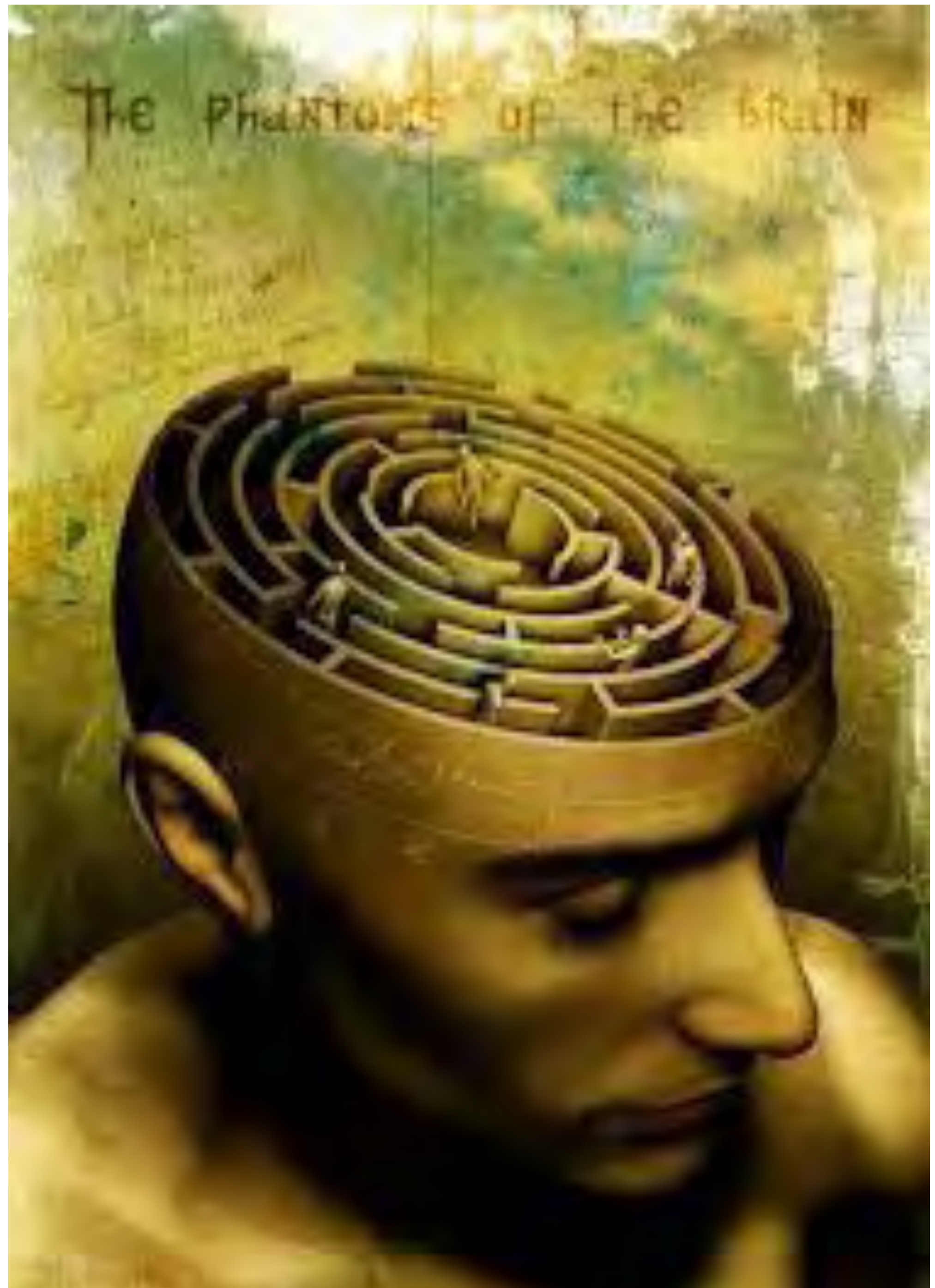
EOL international School - 2022







Your Brain is lying to you…



Daniel Aslanian
aslanian@ifremer.fr

… and you are his accomplice

My questions

What is a scientist for society?
Is it only about finding solutions to specific problems, or rather about finding another way of thinking about the everyday issues that occupy society??

Why do not some of my colleagues see the evidence I beleive I see?
What is true? Why don't we see the same picture? How many truths, that is how many good ways are there to describe a reality?

How does he integrate the information and which ones?
How should I interpret a question, a set of information, and why?

How my brain is working?
Where does it lie? Why is he dependent on models? What makes me blind?

Mieux vaut une vision floue que des hallucinations précises...
It is better to have a blurred vision than precise hallucinations

The difficulty to share observation: what animal do you see?

There are two animals in that picture: 40% of people see the duck, 40% the rabbit, and only 20% both of them,
But the main problem is after seeing one animal, our brain is impacted and it is difficult to see the other one (an therefore to share our « truth » of the picture)

Cognitive Blindness?...
...or Cognitive Avarice?

Jacques is looking to Ann. Ann is looking to Georges.
Jacques is married, but Georges is not married.

Is there a married person who is looking at an unmarried person?

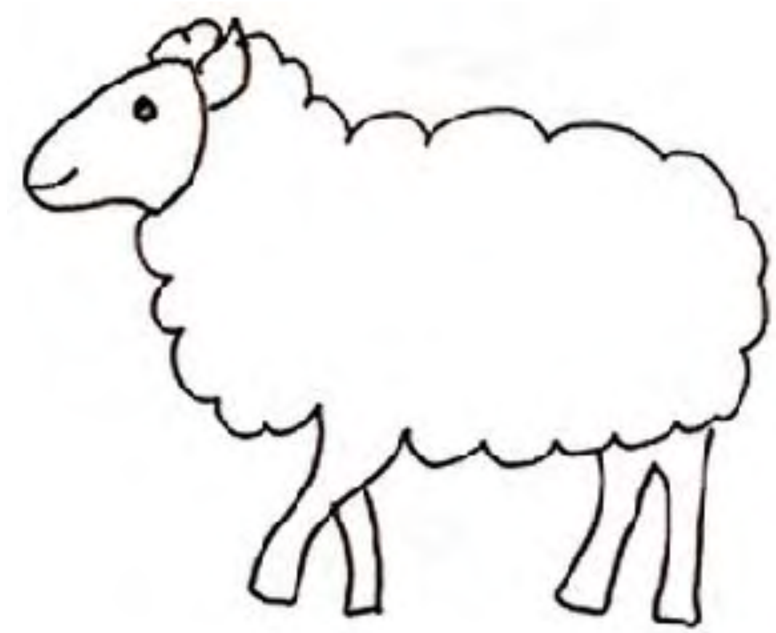
A/ Yes.
B/ No .
C/ we cannot answer the question.

Stanovich, Keith E. (2009). "The cognitive miser: ways to avoid thinking »
In « *What Intelligence Tests miss* »

Observer's point of view respect to the object

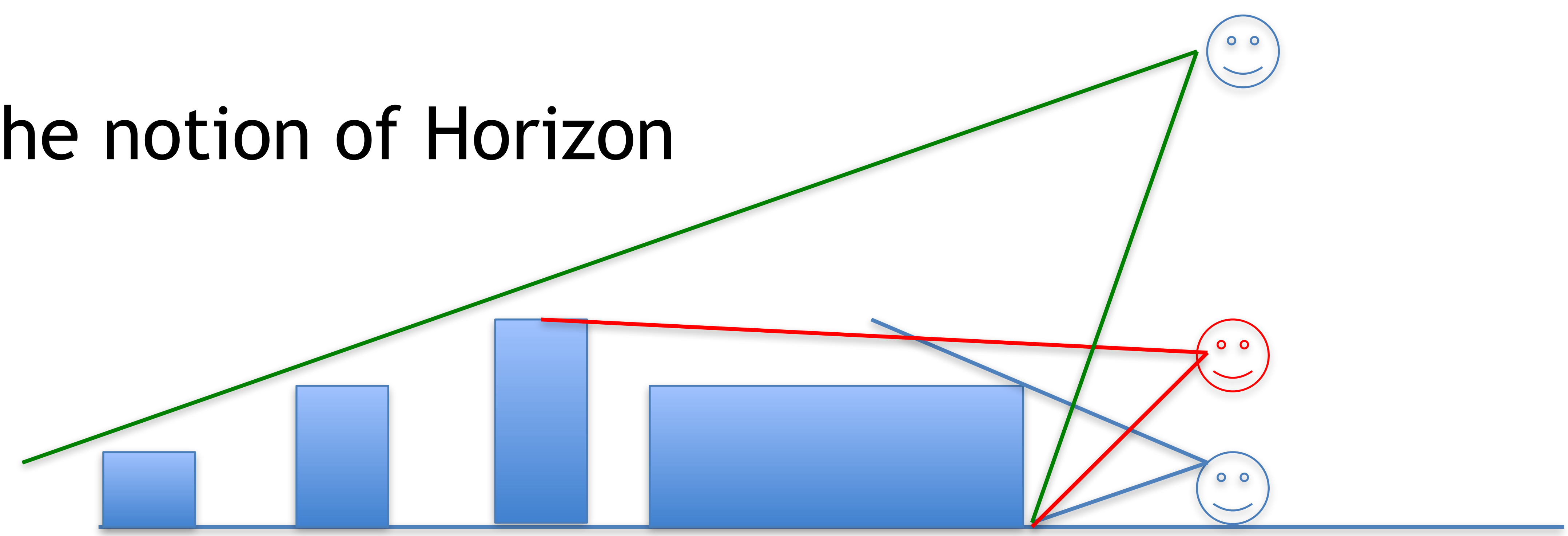
three-quarter side

In profile



DIFFERENT INFORMATION

…the notion of Horizon



THE SIMPLE EXPOSITION BIAS

- Two groups were splited in order to analyse the guilt of an accused
- Both groups have a different list of informations, but a part of these lists is common.
- To the first group, they gave **false** information constituting aggravating circumstances
- To the second group, they gave **false** information constituting mitigating circumstances
- The false informations are in red, and the two groups know, but they go where the false information lead them

Even informations that we know to be wrong have an impact on our brain and our analysis

(Daniel T. Gilbert, R.W. Tafaroidi & P. S. Malone: You can't not believe everything you rea
Journal of Personnality and Social Psychology, 1993)

Two fondamental keys in Science

The Falsification Principle (Karl Popper):

A hypothesis, proposition, or theory is "scientific" only if it is falsifiable.

Scientist must strive to question, for falsification, hypotheses instead of proving them.
The more they resist, the more they become reliable.
Therefore a model should not became dogmatic.

Paradigm (Thomas Kuhn)

Thomas Khun (*the structure of scientific revolution*) shown that scientists work within conceptual paradigms that strongly influence the way in which they see data (**model dependent**).

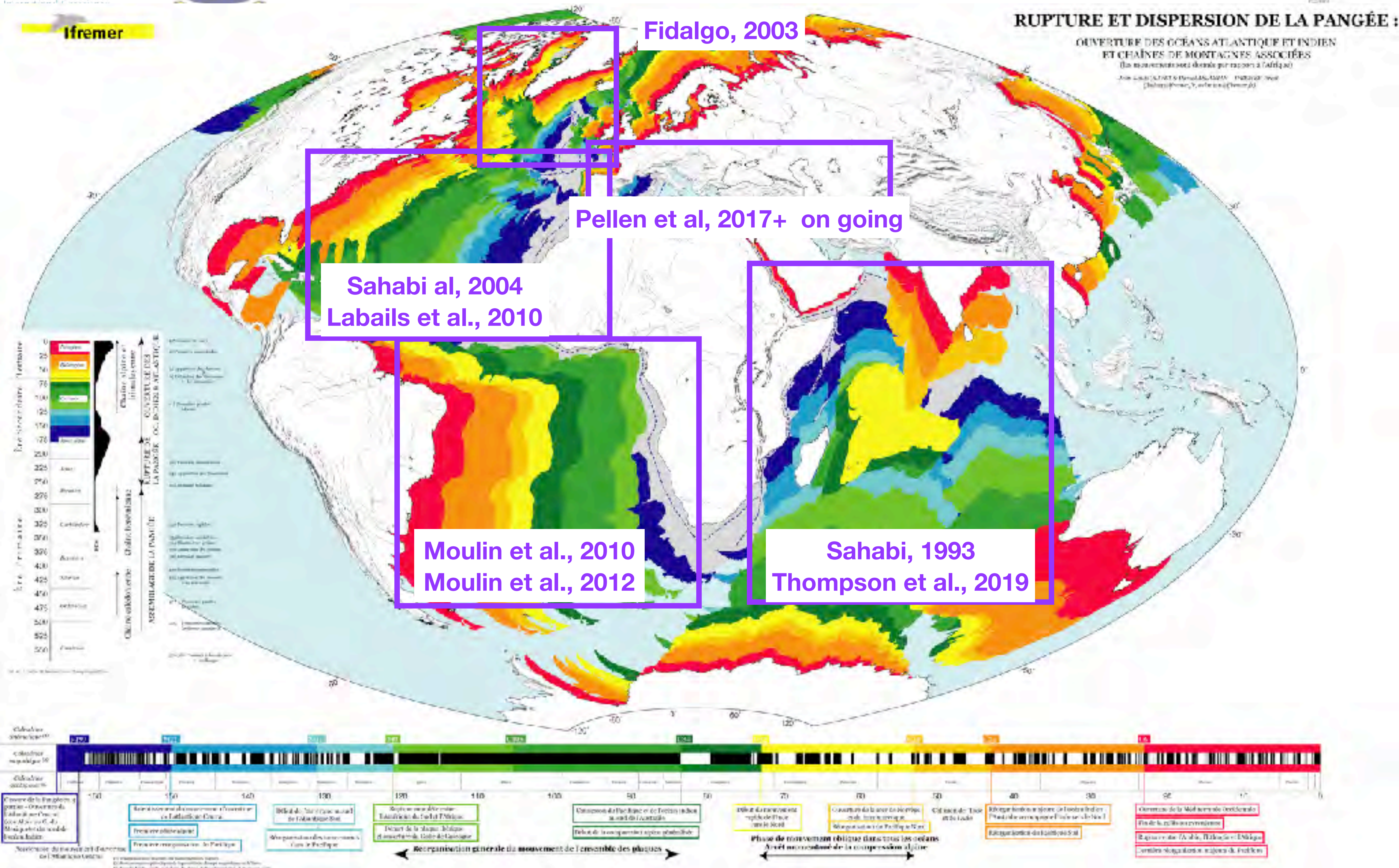
Scientists will work in **closed-system** and go to great length to defend their paradigm against falsification, by the addition of ad hoc hypotheses to existing theories.

Our Brain is lying to us

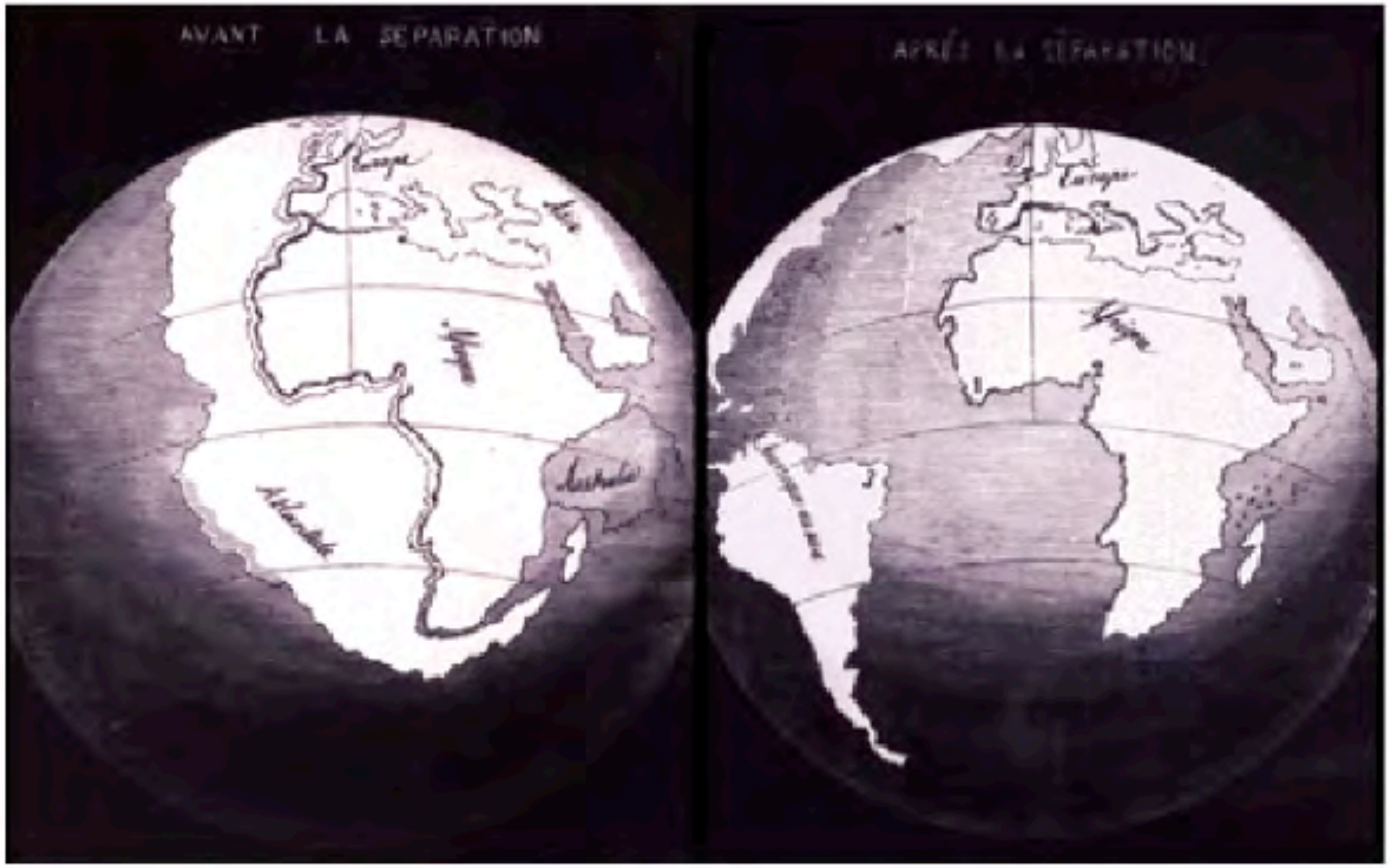
… we must preserve the realms of all possibles
… we must be open-mind as much as possible
… we must never reject an hypothesis because of beliefs

Plate tectonic

THE KINEMATIC EVOLUTION SINCE 200MA



…WHAT ENGINE? WHICH PROCESSES?

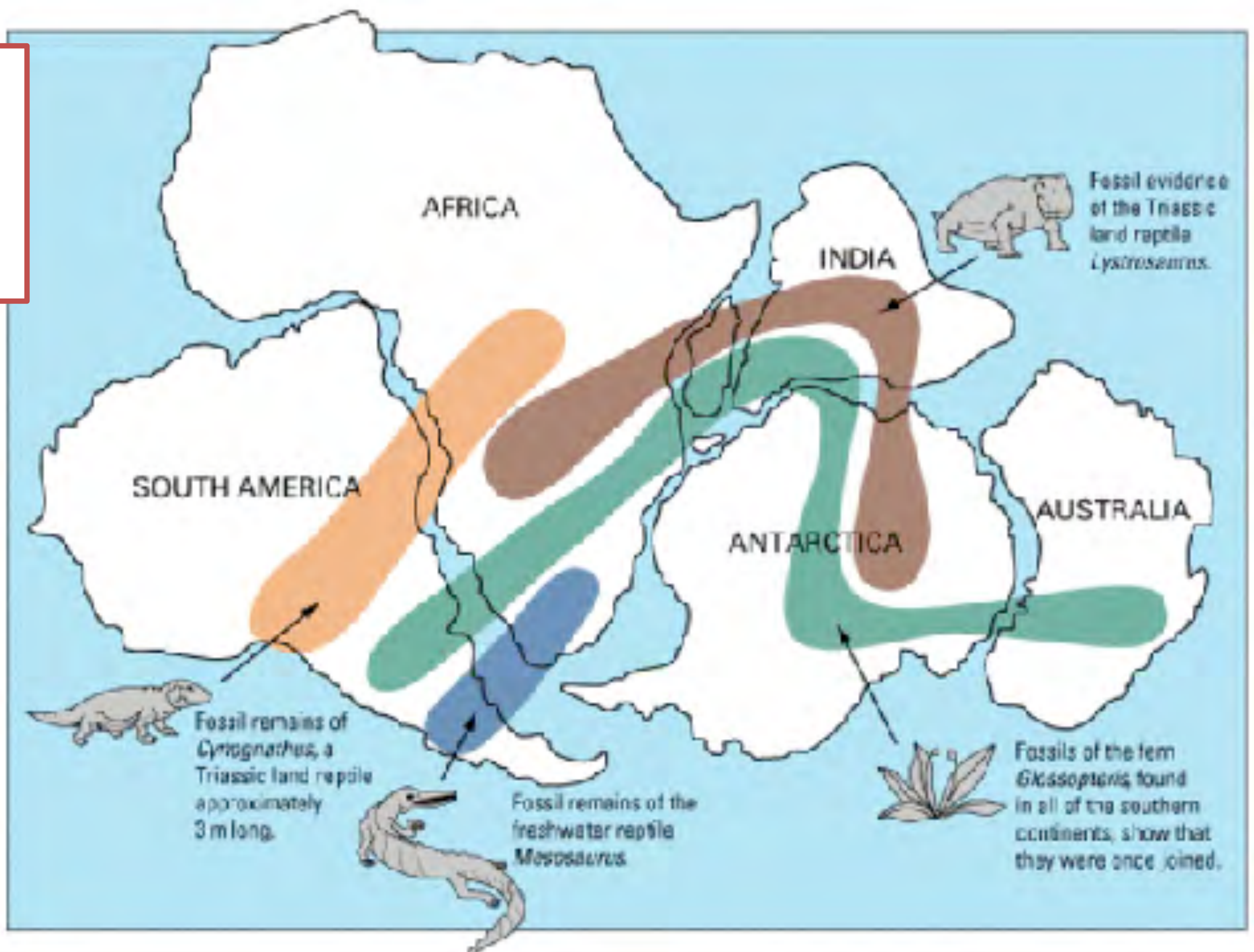


In 1858, Antonio Snider-Pellegrini (geographer) (
Reproductions of the originals maps courtesy of University of California, Berkely) in This Dynamic Earth: the story of the Plate Tectonics (USGS)

Port Elizabeth 16-20 July 2018

Plate tectonic is in fact an old story
It started by the description of continental drift

In 1912, Alfred Lothar Wegener



INTRODUCTION

Evolution of Plate tectonic studies in the Indian Ocean: hypothesis and conce

Main idea:	1. Land bridge connecting all continents hypothesis 2. The Contraction hypothesis 3. The earthquakes and floods Responsible continent Seperation hypothesis	1.The Continental drift hypothesis 2. The pole fleeing forces hypothesis 3. The tidal forces hypothesis	Absentism Debate on initial Gondwana Configuration and fragmentation (Weneger and du Toit	1. Seafloor spreading And Mantle convection hypothesis
Area	Global	Global		Global
Problem to resolve	1. Problem of explaining how same fossils are found on different continents	1. Problem of explaining the continental drift hypothesis		
Reference	1. De Acosta, (1590) 2. De Beaumont, (1852) 3. Ortelius, (1596)	Wegener (1924, 1929)		

Author Holmes

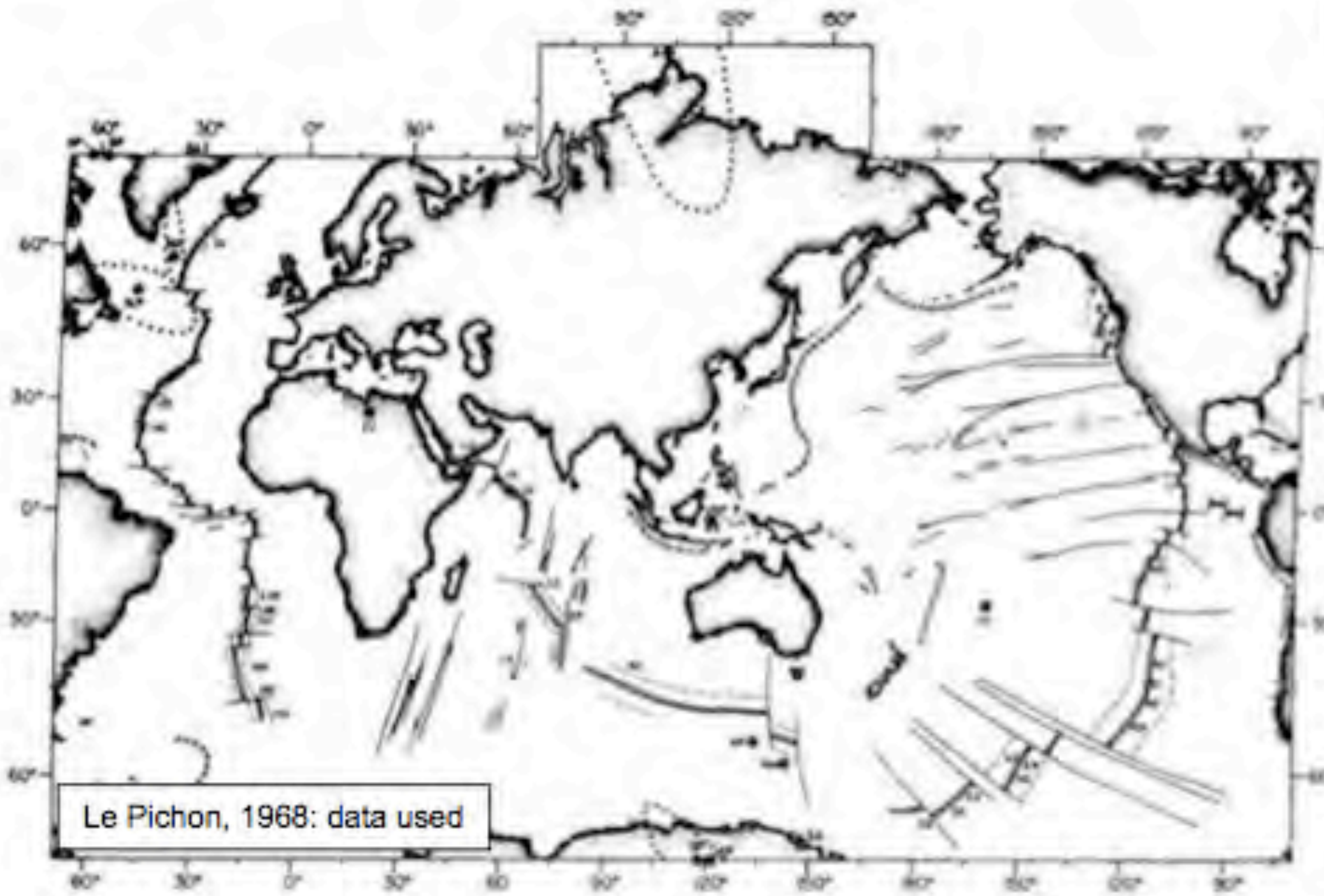
Hess, (1962)

R. Deitz

Before Wegener — 1920's — 1930's — 1940's — 1950's

Some history…

- By late 60's, most concepts are in place: oceanic spreading, magnetic anomalies, transform faults, subduction.
- 1967: **McKenzie and Parker** (Nature) propose the hypothesis of rigid plates, substantiated by the fact that a rotation pole fit to the San Andreas fault predicts observed earthquake slip vectors in Alaska, Kouriles, and Japan.
- 1968: **Jason Morgan** proposes proposes an angular rotation for the Atlantic based on transform faults and magnetic anomalies and a 5-plate model, but not fully quantified.
- 1968: **Xavier Le Pichon** proposes the first global model and fully quantified, with 6 plates (based on anomaly 5, ~10 My).



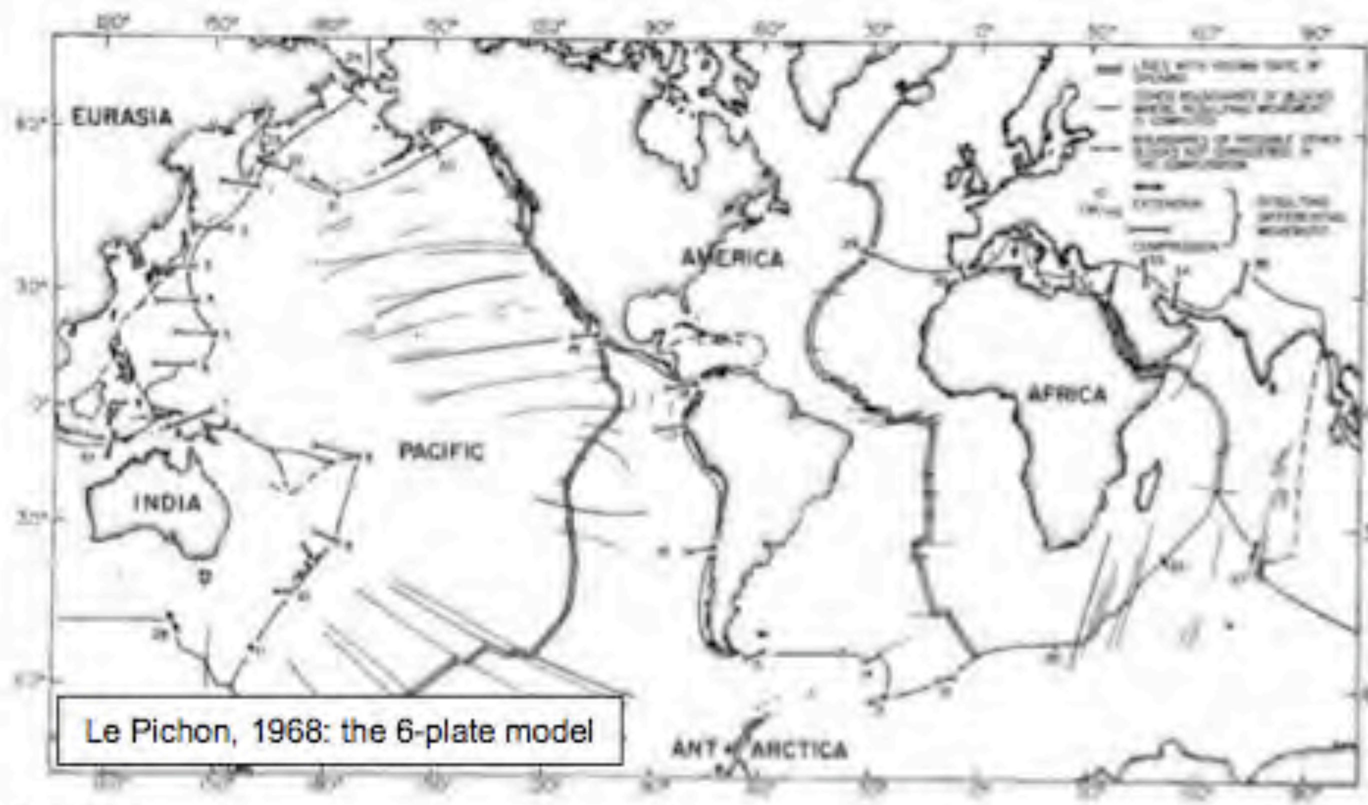


Figure 9-6
The locations of the boundaries of the six blocks used in the computations. The numbers next to the vectors of differential movement refer to Table 9-5. Note that the boundaries where the rate of shortening exceeds about 2 cm/yr account for most of the world earthquake activity.

Plate Kinematic reconstuction

1. Why ?

Obtain a paleo-geographic map

Describe and constrain the movements between the plates (relative movement)

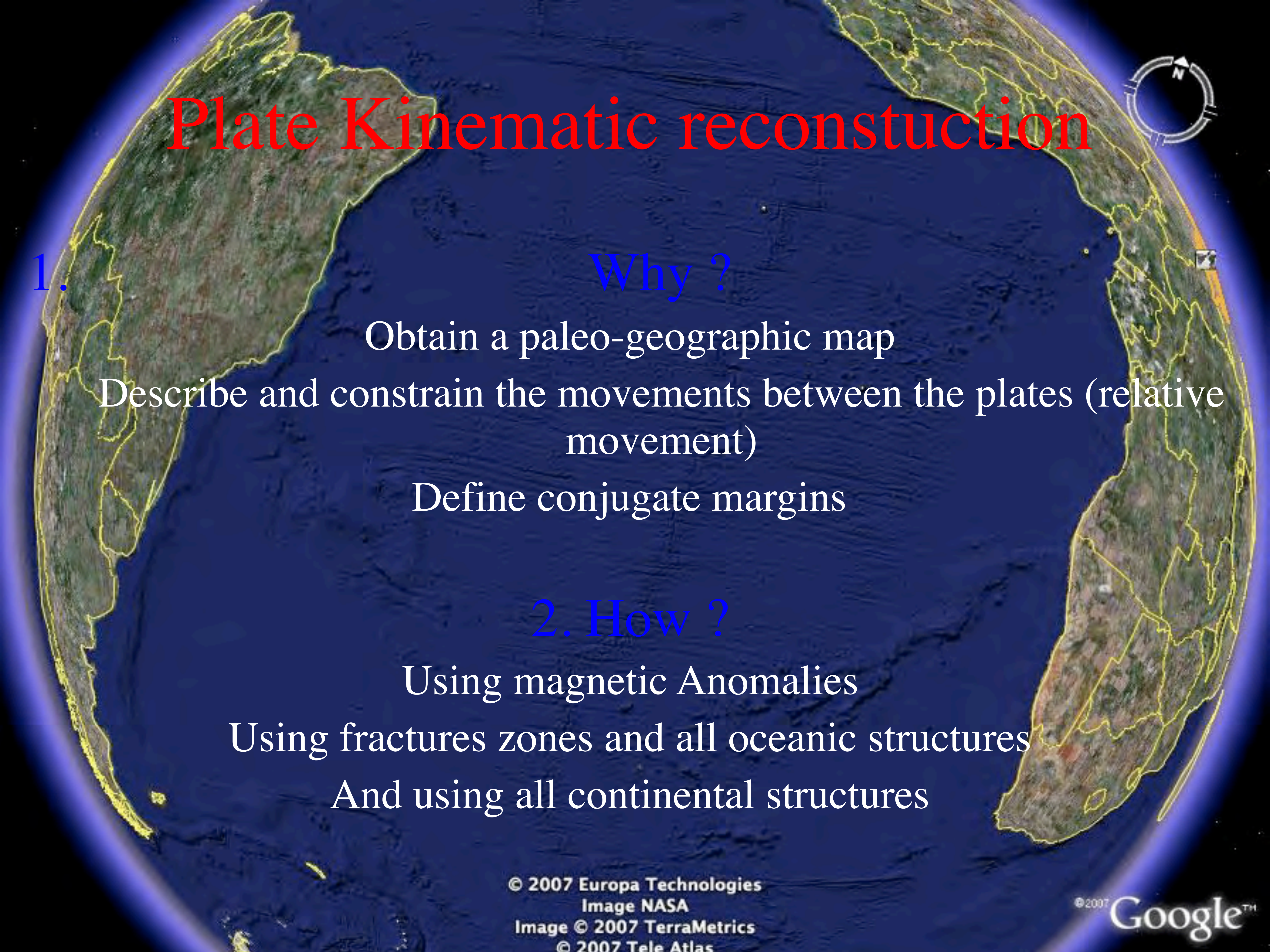
Define conjugate margins

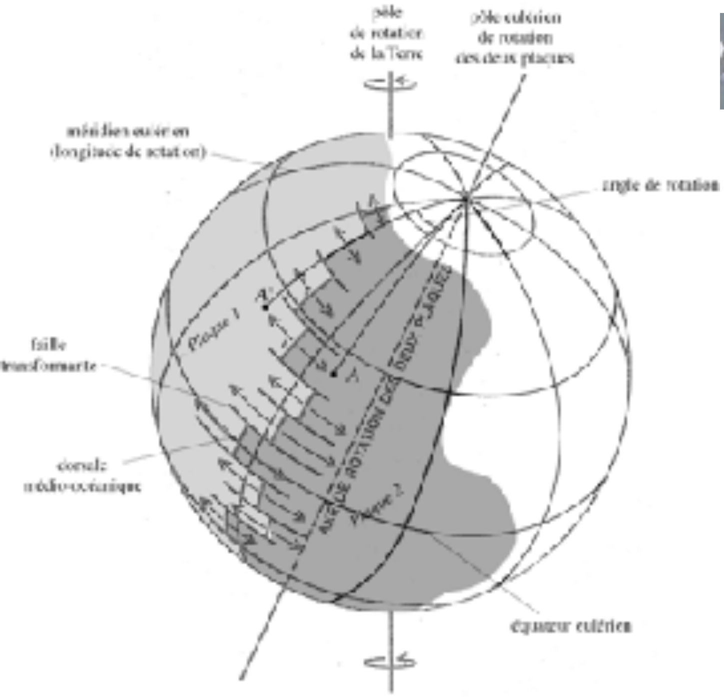
2. How ?

Using magnetic Anomalies

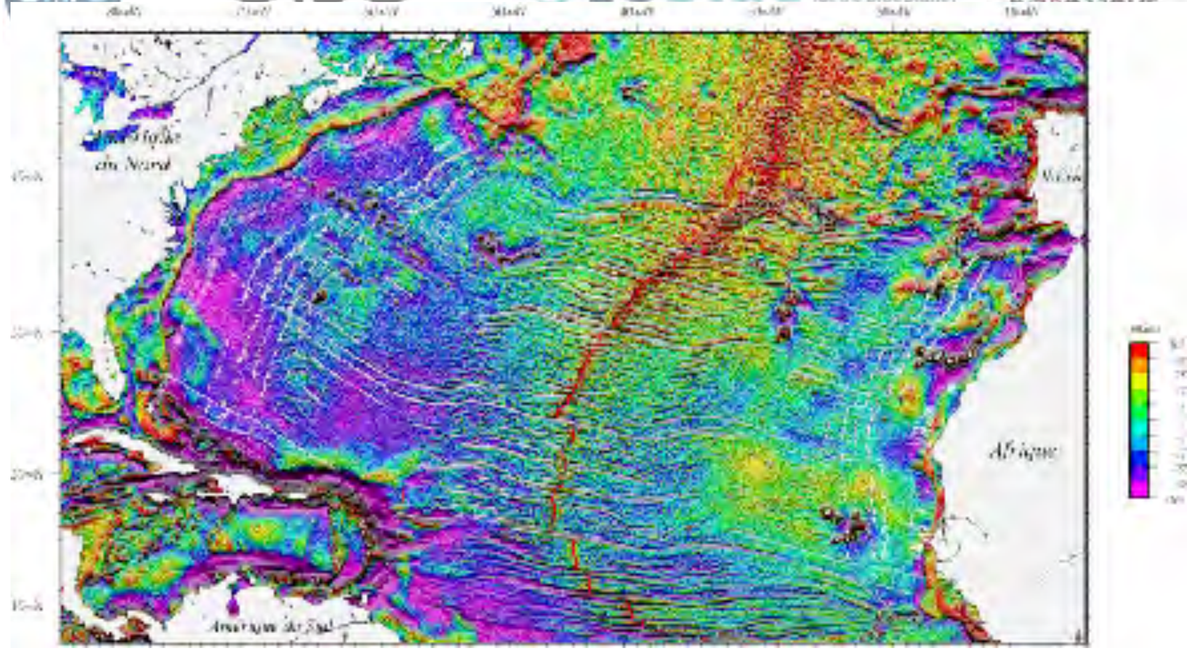
Using fractures zones and all oceanic structures

And using all continental structures





Kinematic Reconstructions

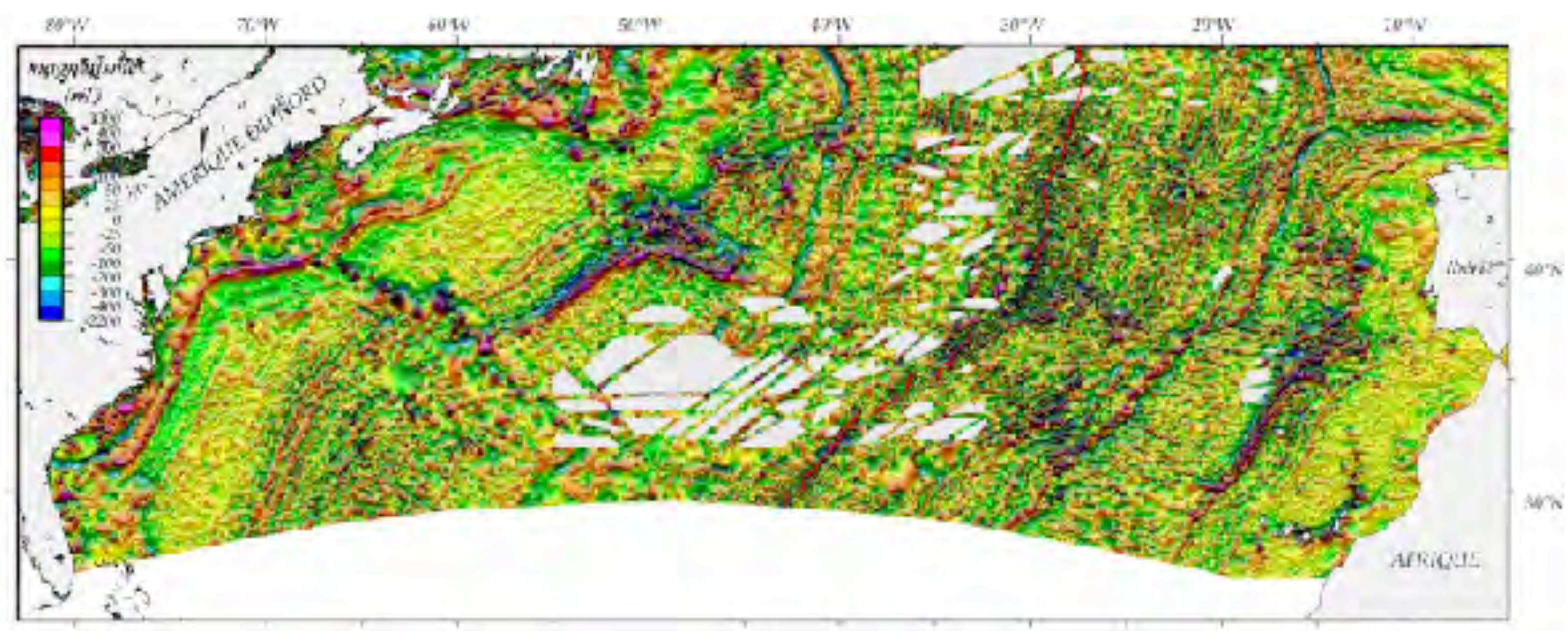


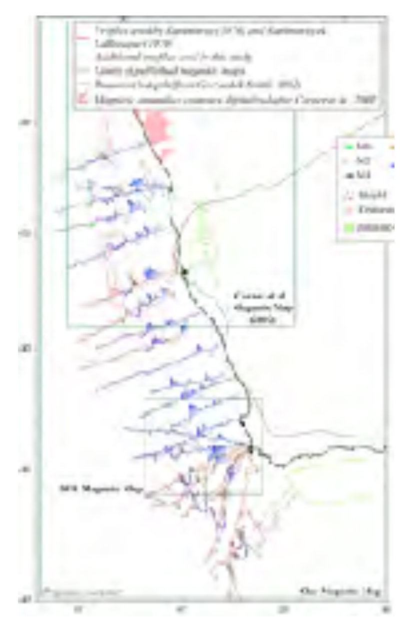
Different Approaches

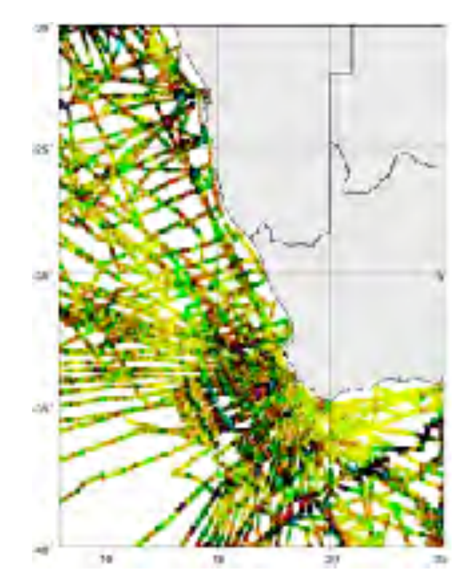
Fracture Zones (relative motions)

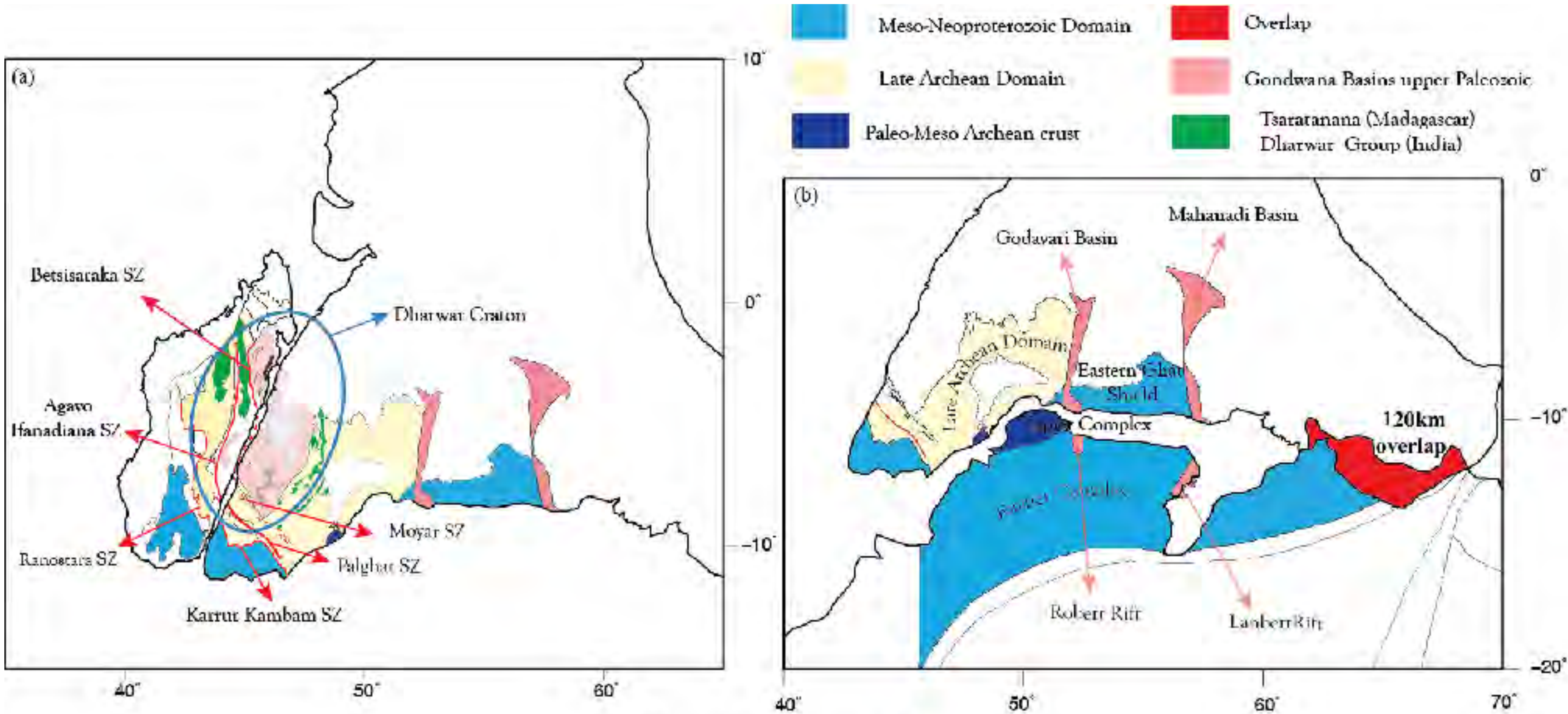
Magnetic Anomalies (< 200Ma)

Homologue Structures



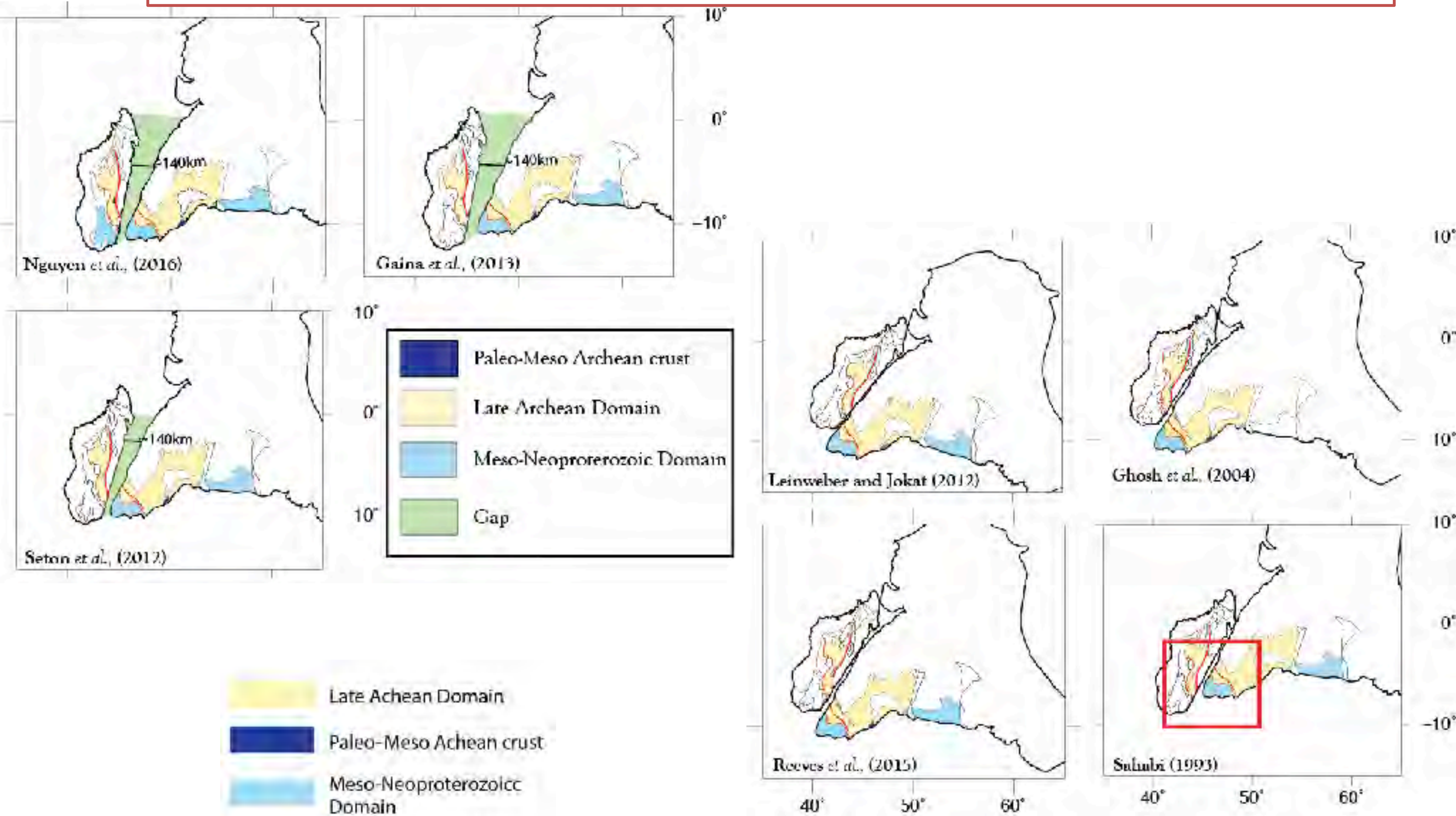






Conjugated continental structures on today's separate plates give strong constraints for the initial adjustment of the puzzle

Need to compare published reconstruction models at the same scale, same limits, and with global and regional views (holistic approach)



Thompson et al., ESR in review

ELSEVIER

Computers & Geosciences 31 (2005) 437–452

COMPUTERS & GEOSCIENCES

www.elsevier.com/locate/cageo

PLACA: a white box for plate reconstruction and best-fit pole determination ☆

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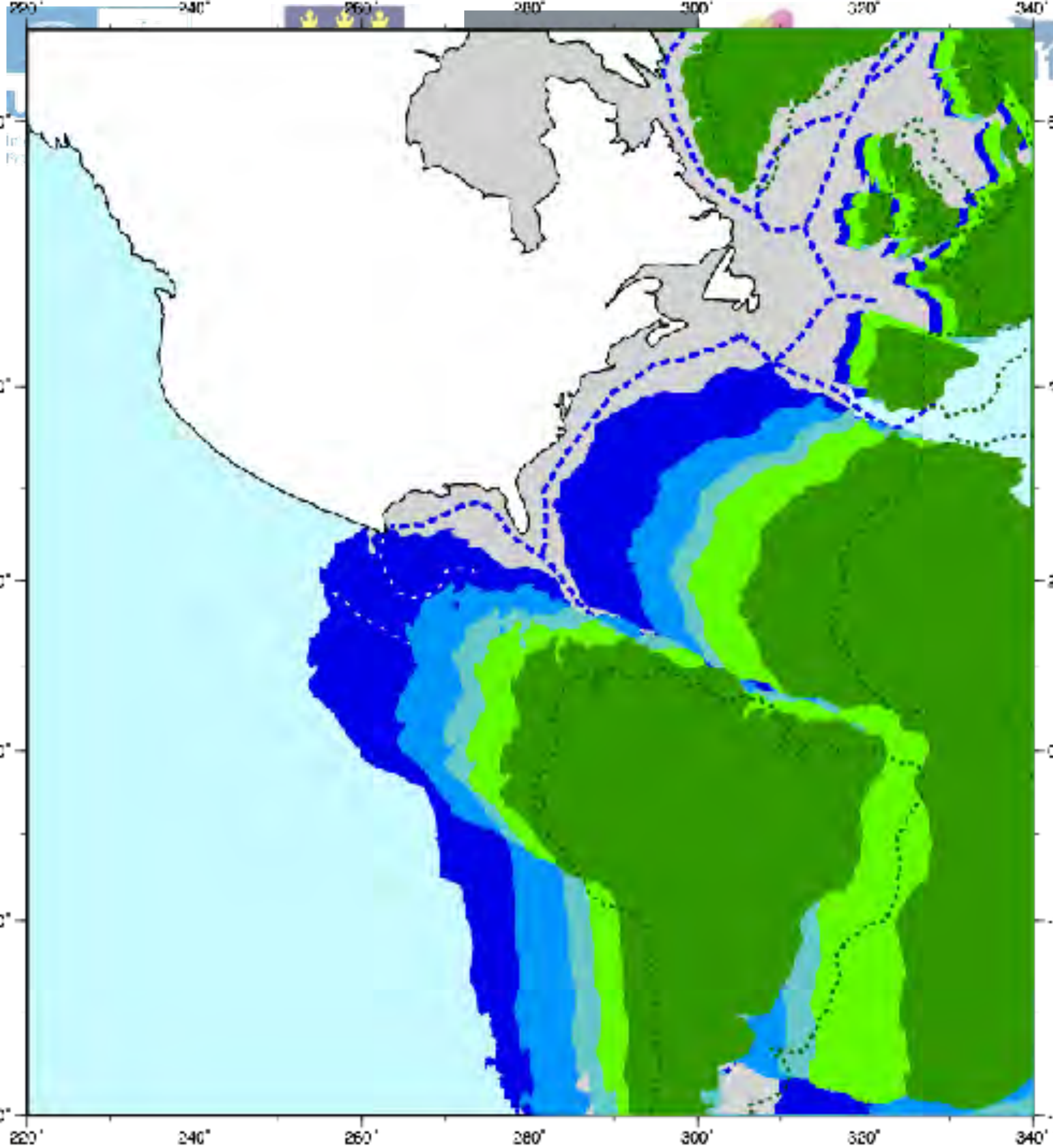
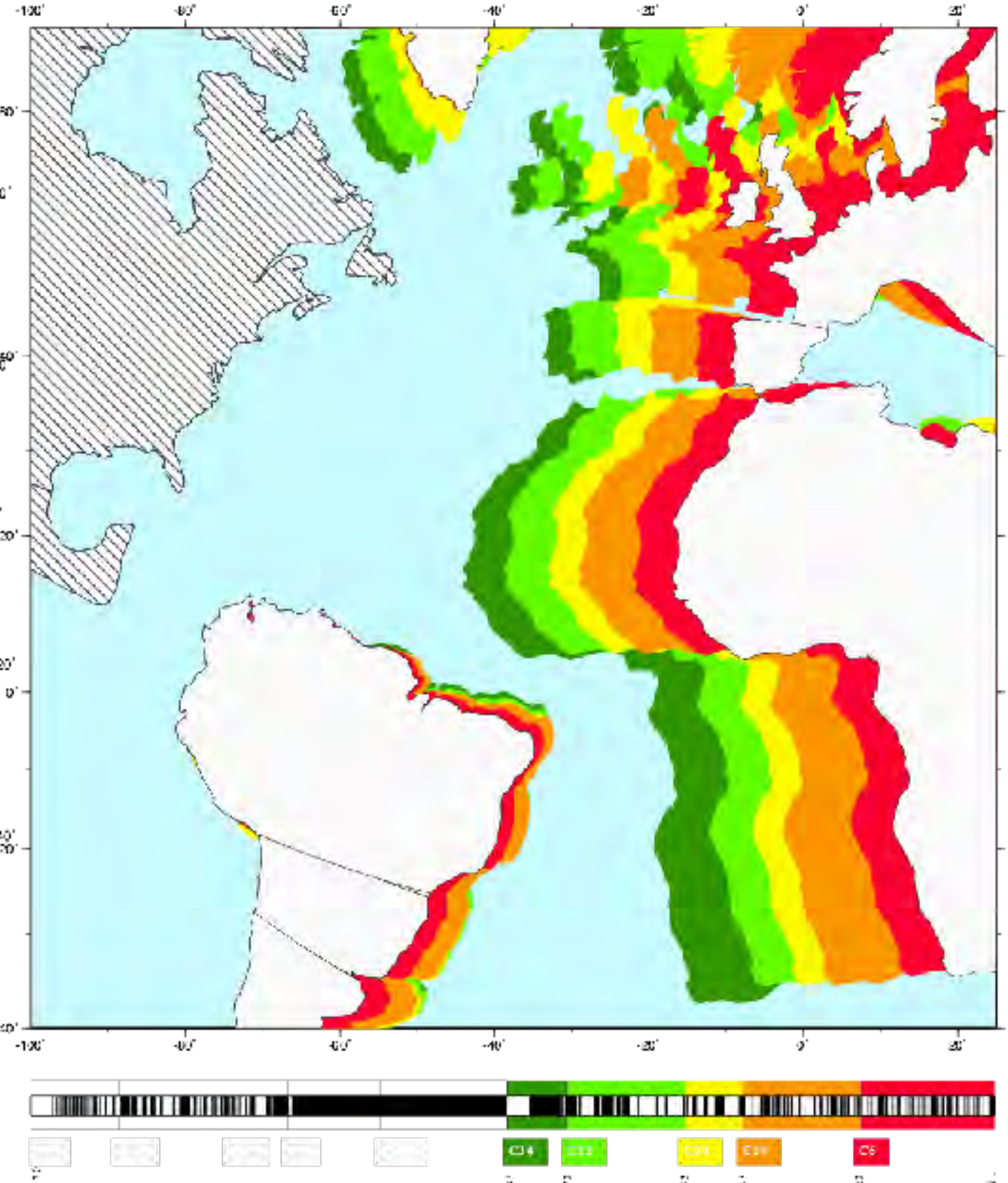
Received 16 June 2003; received in revised form 1 August 2004; accepted 1 September 2004

free access on server at:
http://www.ifremer.fr/drogm/Logiciel/index.htm
or
http://www.gplates.org/

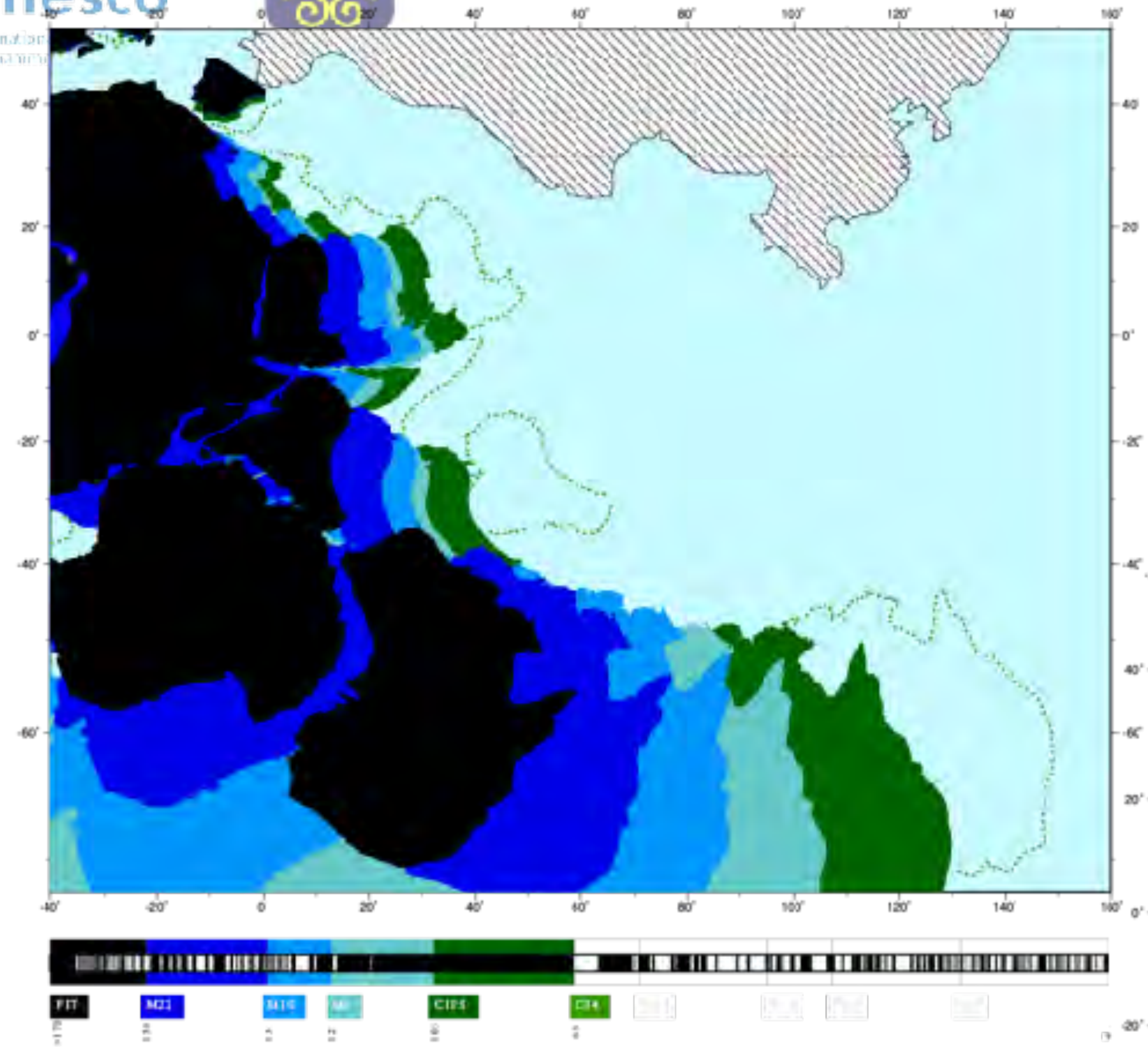
KINEMATIC REVOLUTION





Jean-Louis OLIVET et Daniel ASLANIAN - IFREMER-Brest (jolivet@ifremer.fr; aslanian@ifremer.fr)

KINEMATIC REVOLUTION



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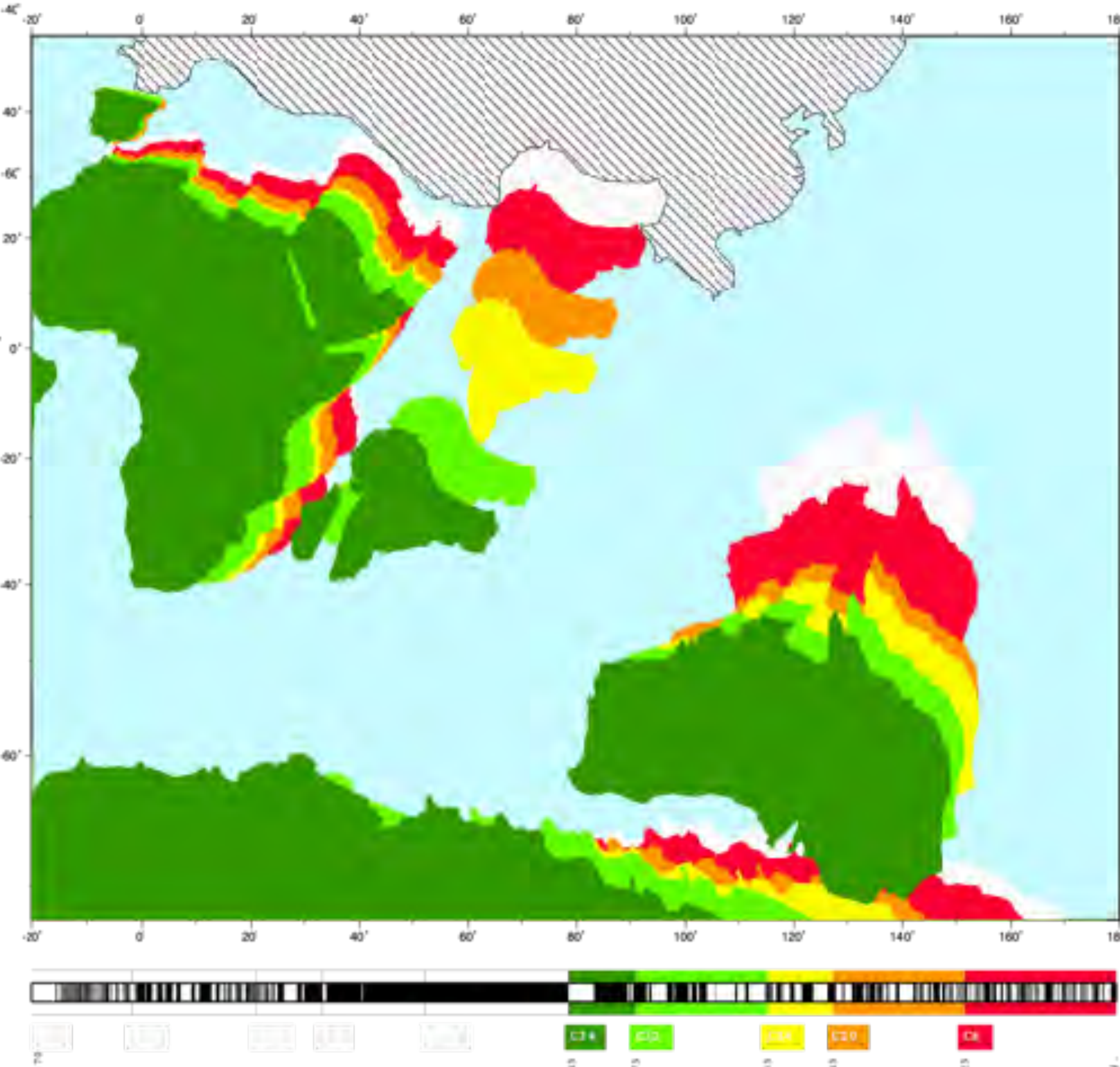
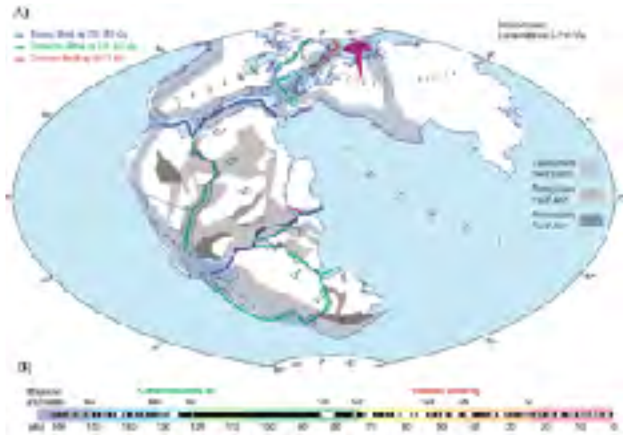
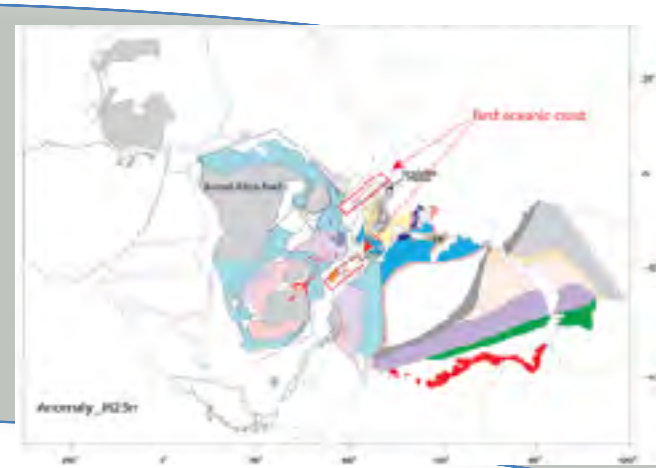


THE KINEMATIC EVOLUTION SINCE 200MA : CYCLIC PHASES?

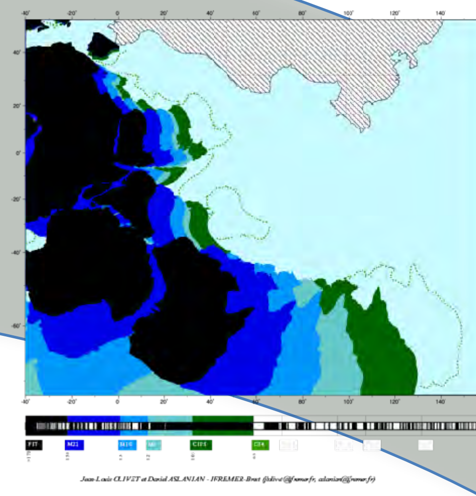
Sinemurian-Pliensbachian (195-185Ma)



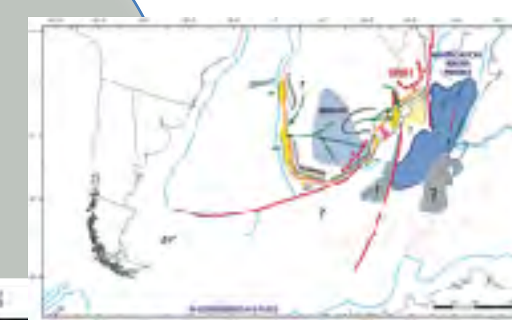
Oxfordian- Kimmeridgian (165-155 Ma)



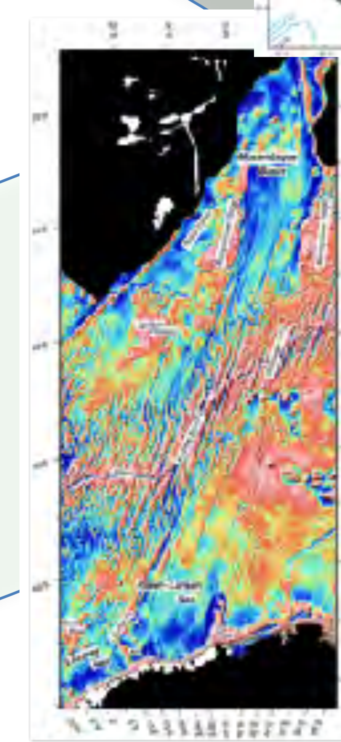
Hauterivian-Barremian phase (135-125Ma)



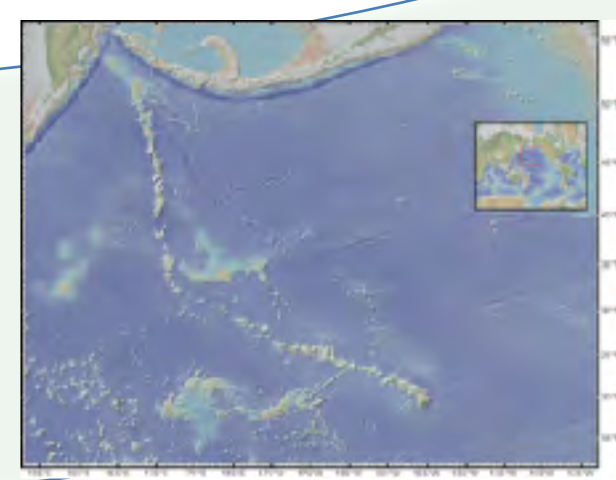
Albian—Turonian (105-95Ma)



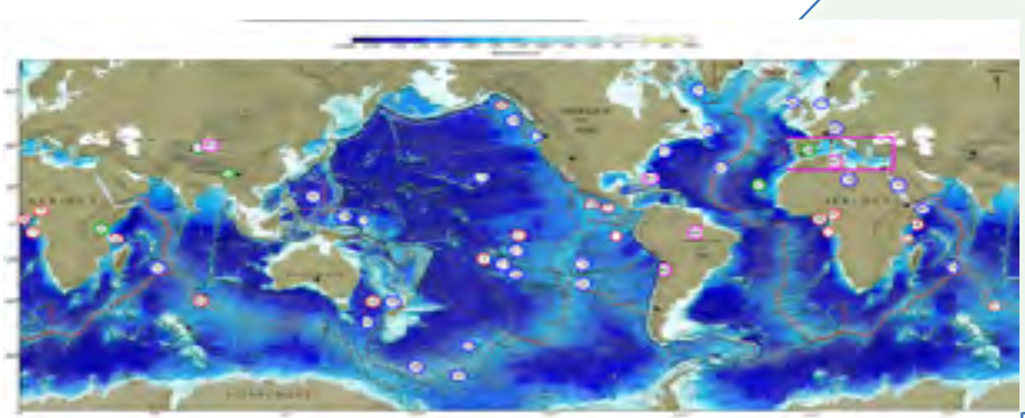
Campanian – KT (75-65 Ma)



Lutetian-Oligocen Phase (45 -35Ma)



Late Miocene — Messinian (15-5Ma)



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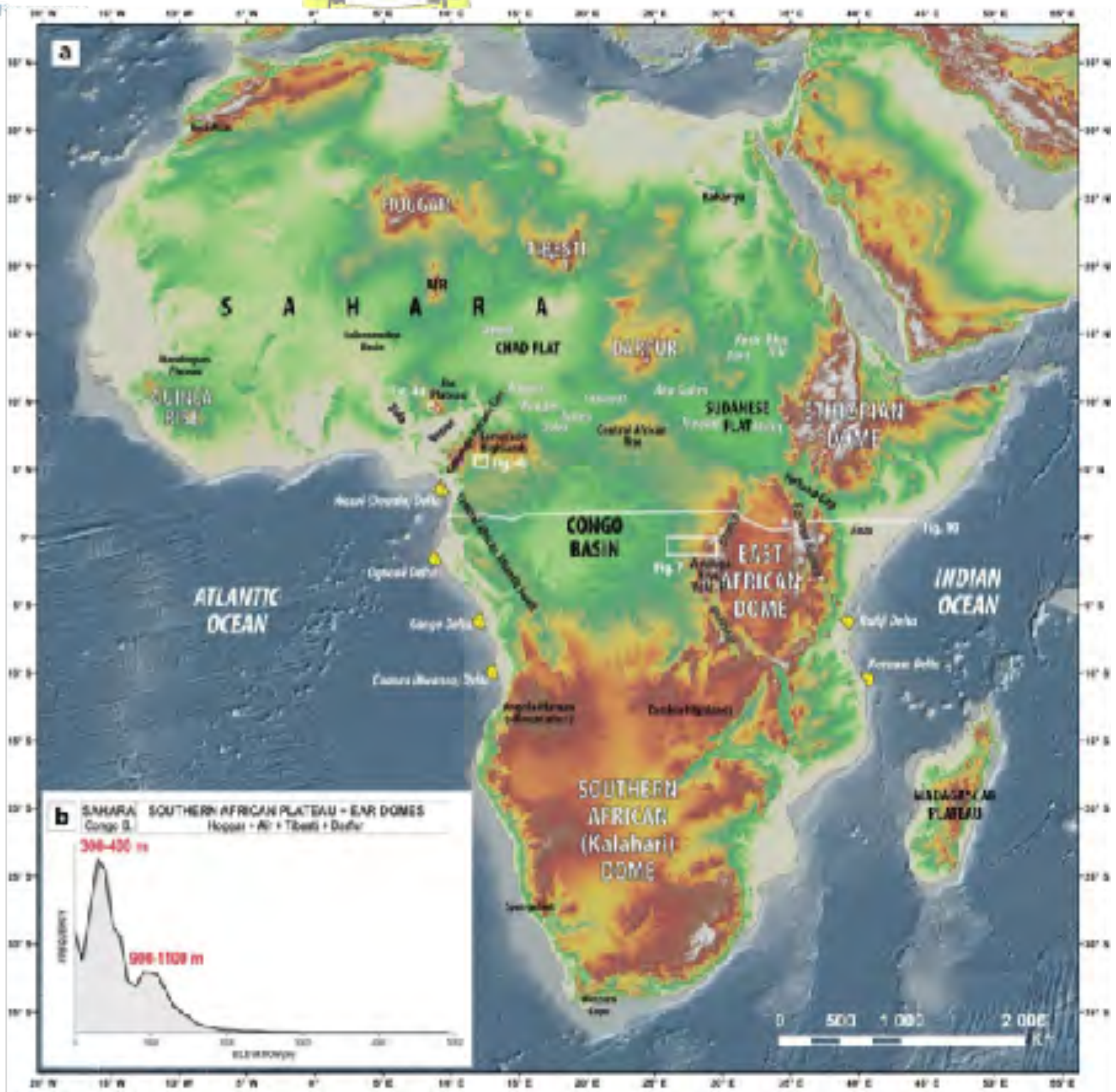


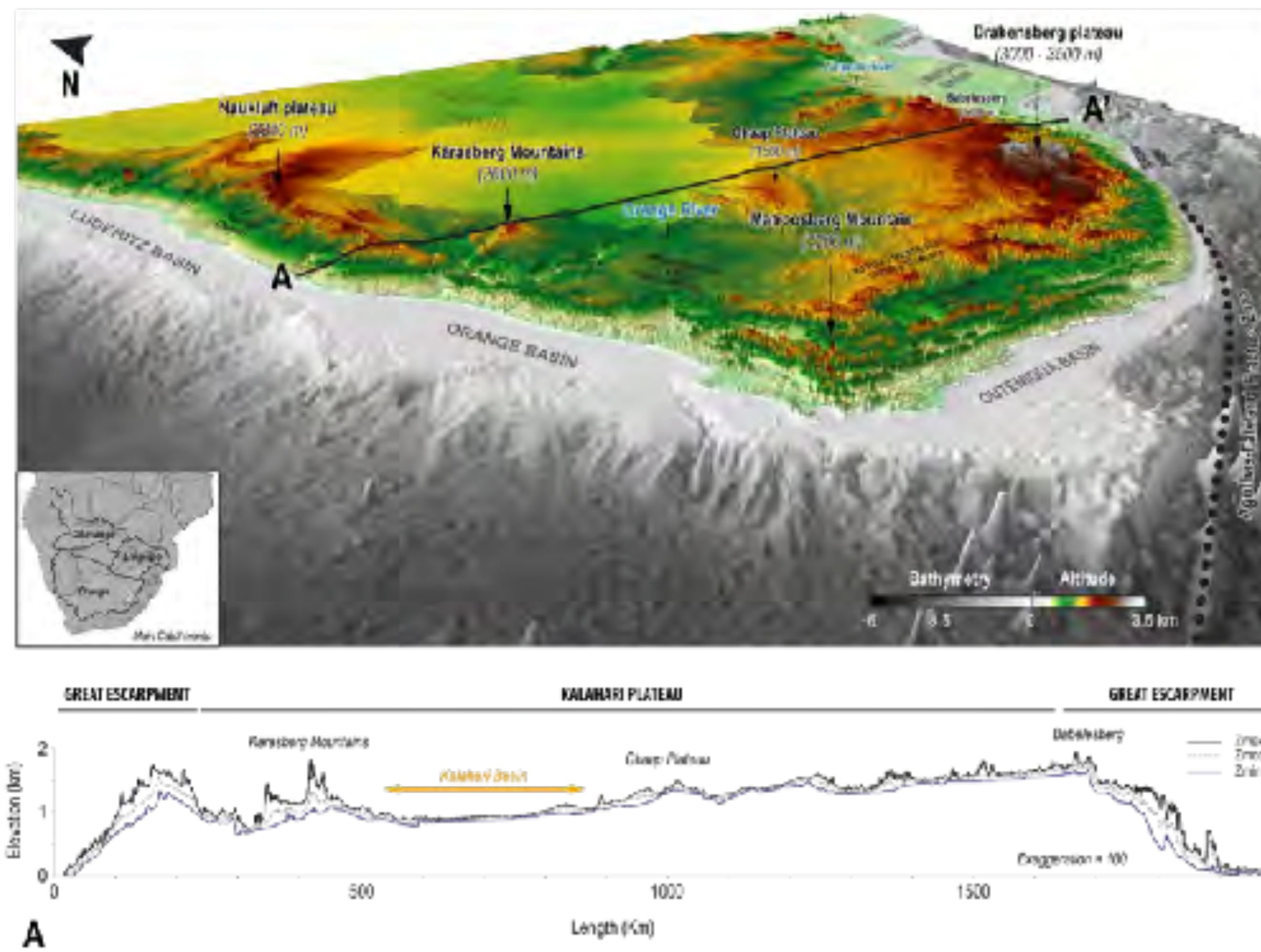


Figure 5.2 : Vue oblique (vers le nord-est) et en coupe (ouest-est) du relief Sud-Africain. Le modèle numérique de terrain est extrait des données GEBCO 2014 (1' d'arc). *(Oblique view (toward the N-E) and topographic profile (W-E) of the southern African relief. Digital elevation model extract from GEBCO 2014 (1' d'arc)).*

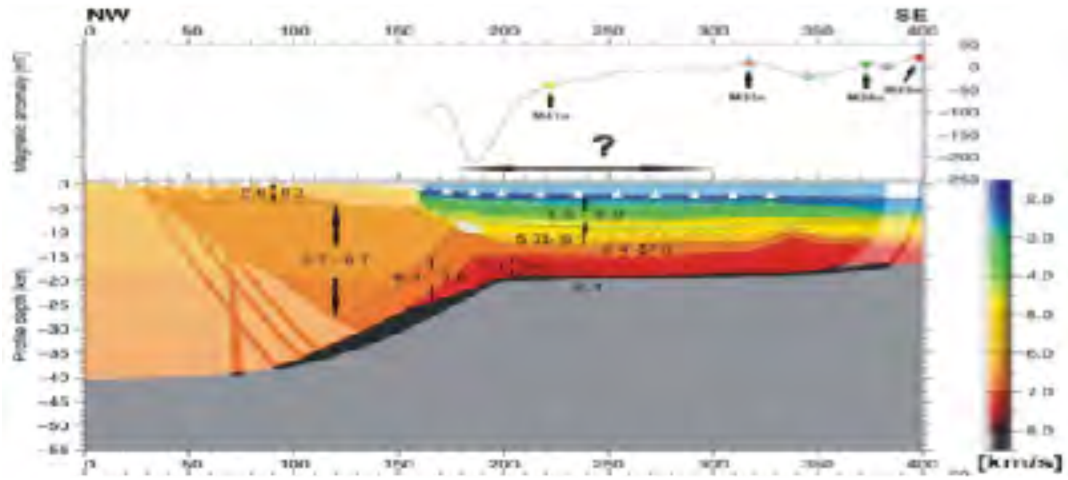
160

G. Baby, 2017)

In West-Indian Ocean… Magmatism

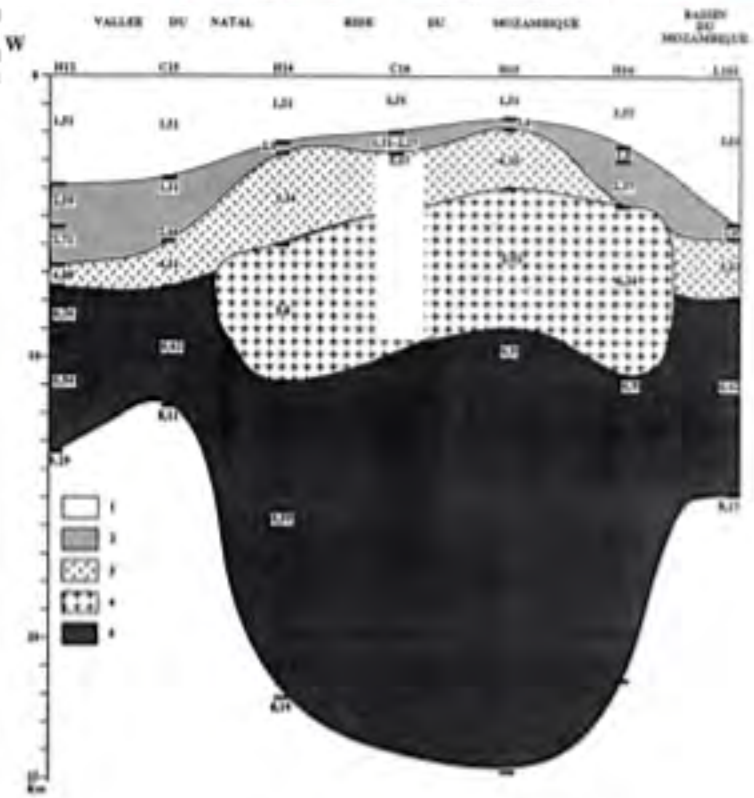
Limpopo Basin (185Ma? - 155Ma?)

Oceanic crust? SDR ?
Trapp Karoo
Intruded Cont. Crust?



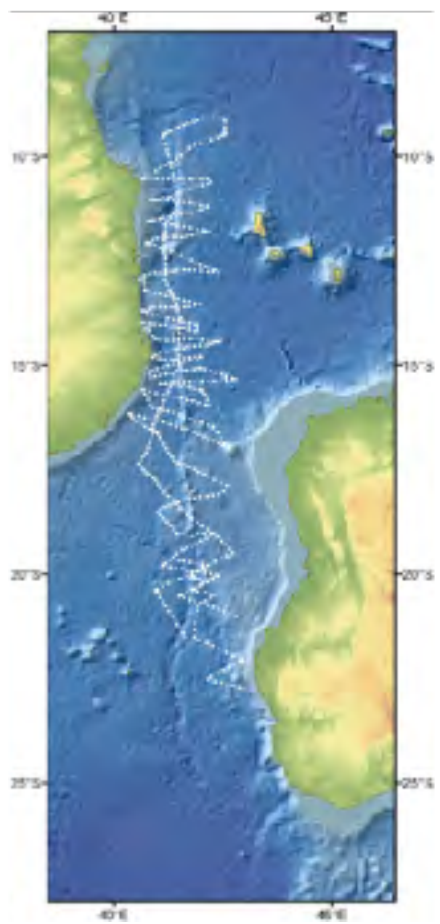
MozambicaineMargin (155Ma?)

SDR?



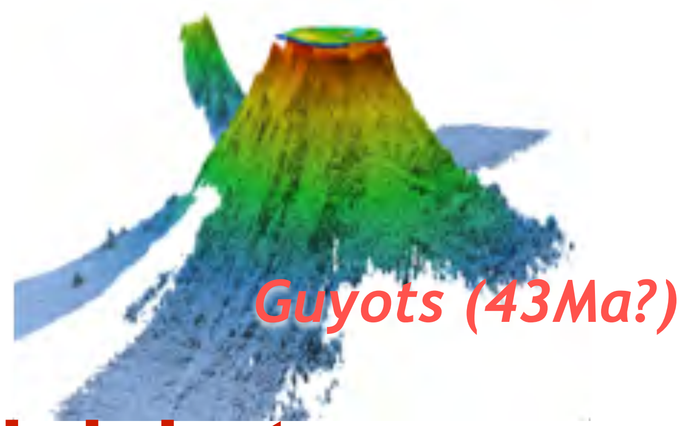
Aseismic ridges(155Ma?)

Courtesy of Maryline Moulin



Comores volcanism

Age and origin?



Guyots (43Ma?)

Turonien Trapps (95Ma)

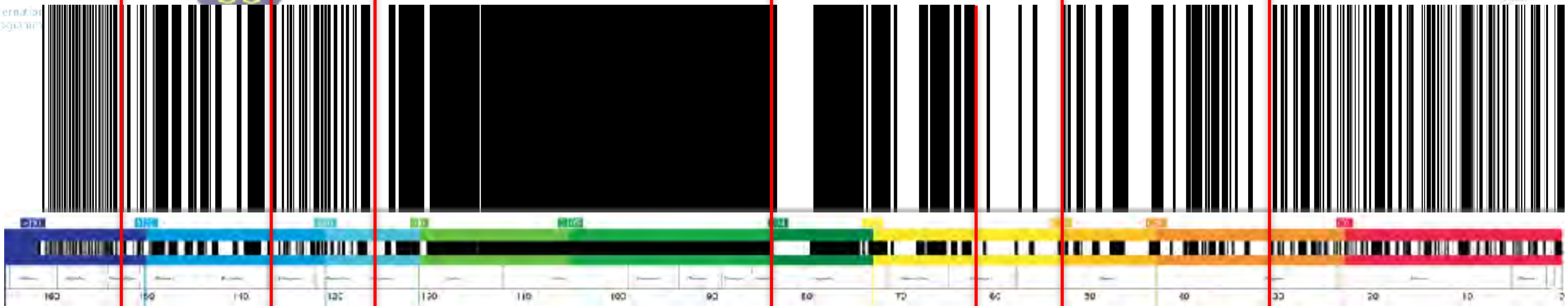
Extension, Origin?

Davie Ridge (112Ma?)

Nature and Origine?

There is a link between Plate tectonic and Magmatic events ?

Magnetic reversals



Pangea Break-up

Indian Ocean

First Global Reorganization

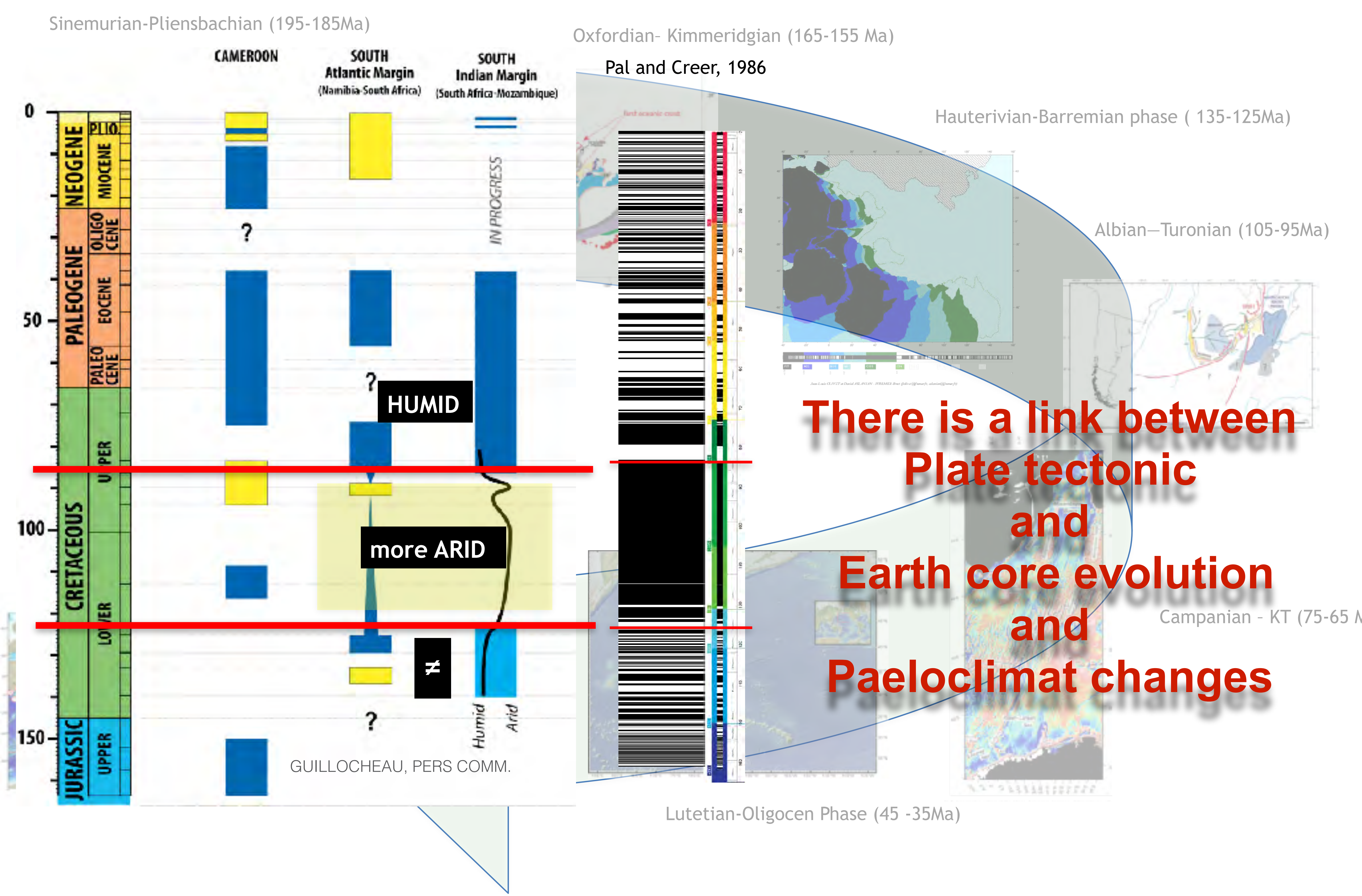
Stop of the alpine compression

Change in FZ

Second Global Reorganization

There is a link between
Plate tectonic
and
Earth core evolution

The cyclicities coincidence



There is a link between Plate tectonic and Earth core evolution and Paeloclimat changes

CONSEQUENCES ON THE ENGINE?

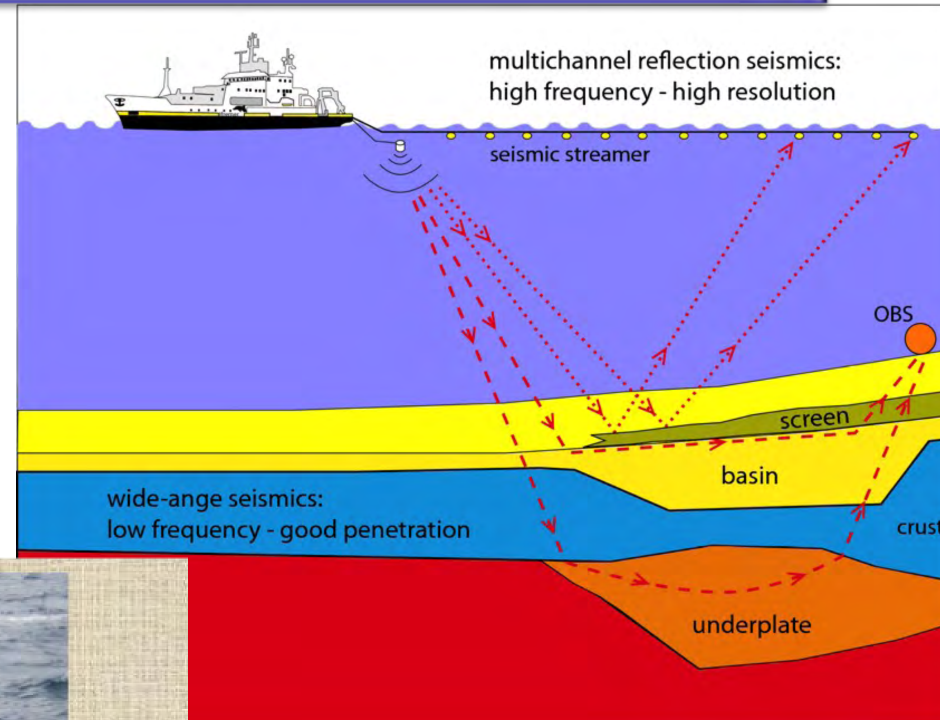
SUBDUCTION PULLING?
MID-OCEANIC RIDGE PUSH?
CONVECTION

The coincidence between the magnetic inversions, related to the convection in the core, and the large kinematic phases suggests a much deeper relation

Geophysic Tools - I

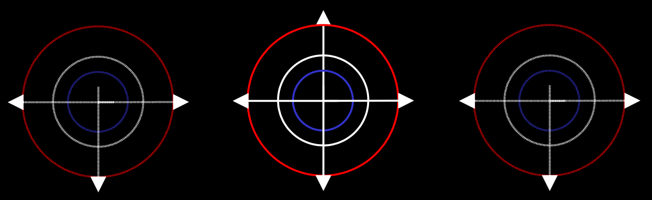
Combined Wide-angle+Streamer Seismics

- Imaging below screen (basalt, salt)
- True geometry at depth
- True interval velocity (P and S)
- Lithology / crustal nature

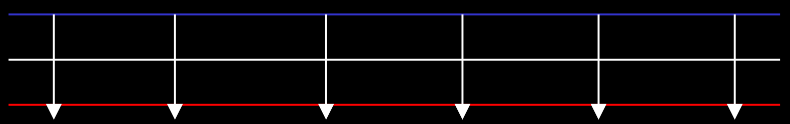


Huygens' Principle

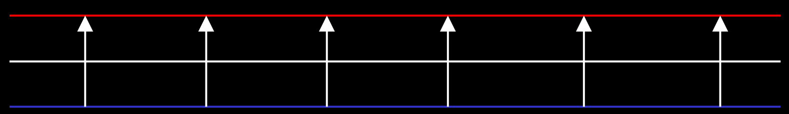
➢Acoustic Source propagation:
-> Ignite 1 isotropic source at the surface



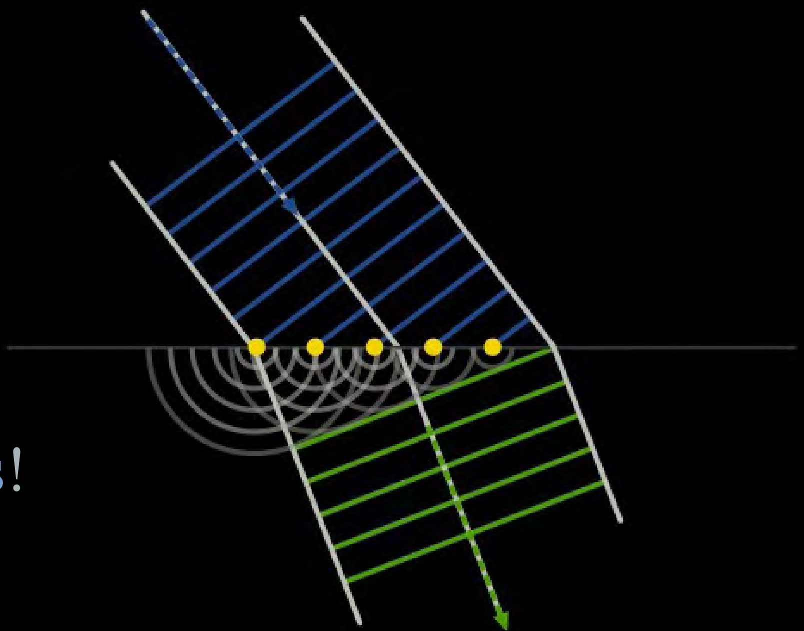
➢Plane-Wave propagation:
-> Ignite ∞ sources at the surface



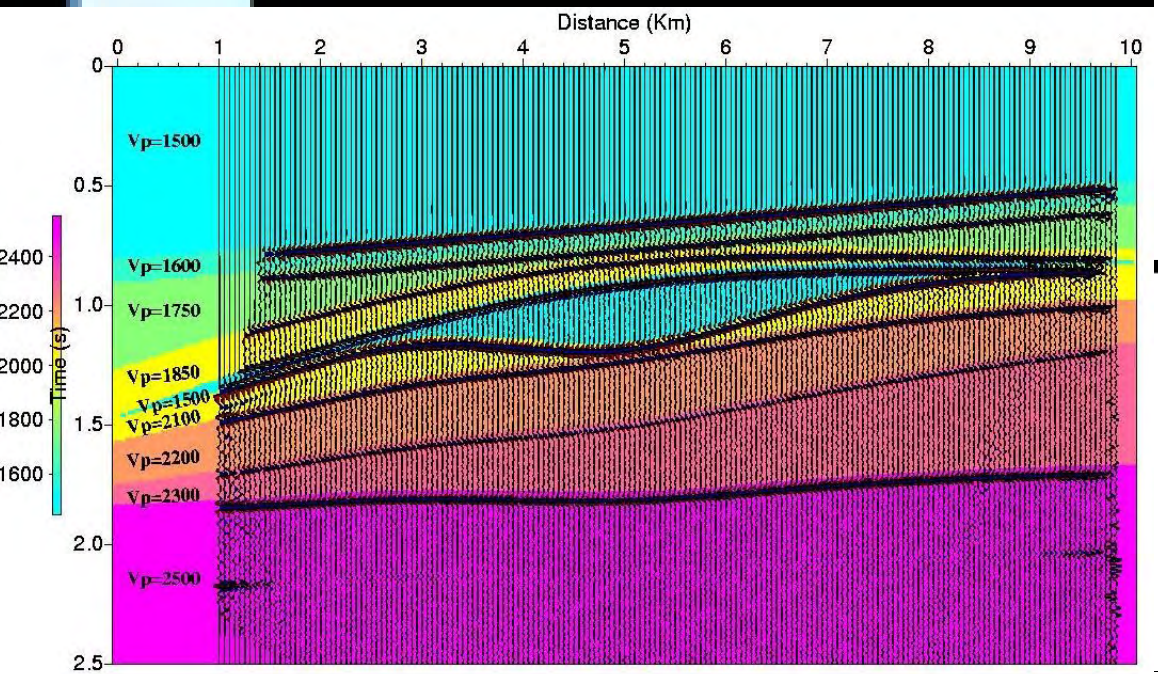
➢Exploding Reflector propagation:
-> Ignite ∞ sources at the reflector

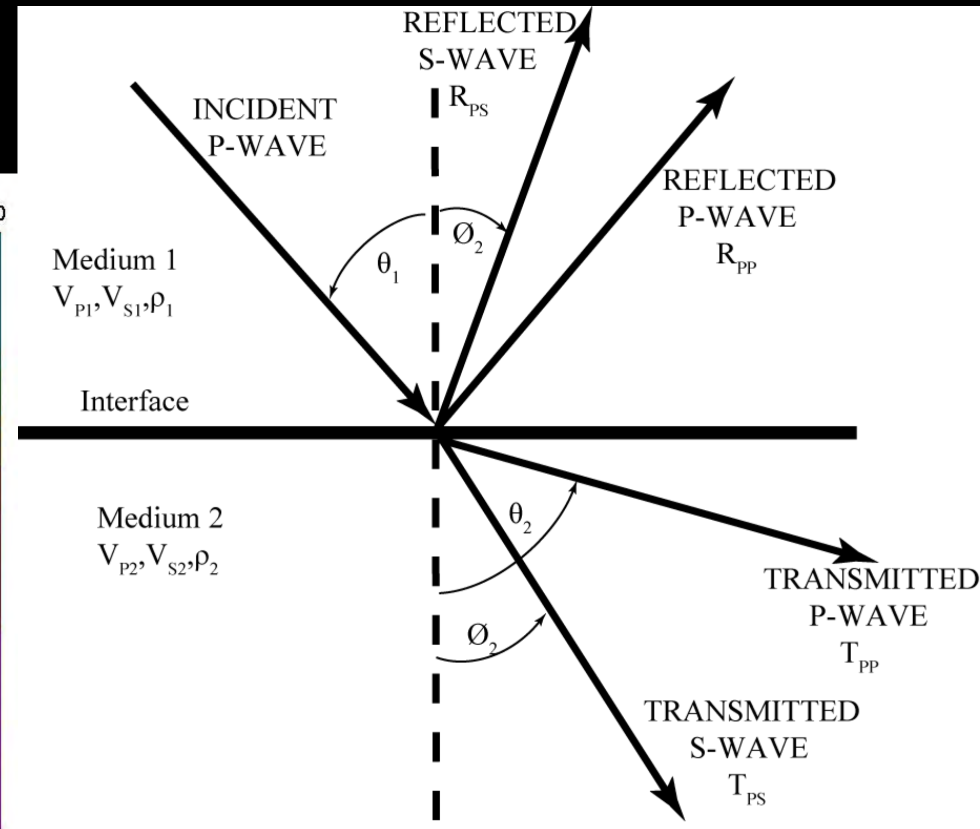


The elastic problem is linear
-> solution (multiple sources) =
SUM [solution (single source)]
The secondary source principle
(Huygens–Fresnel) gives the
equivalence between the three models!



Seismic Reflection + Transmission

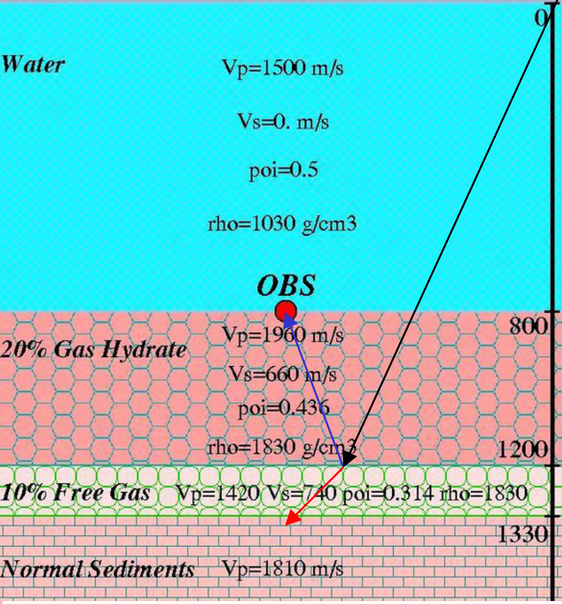


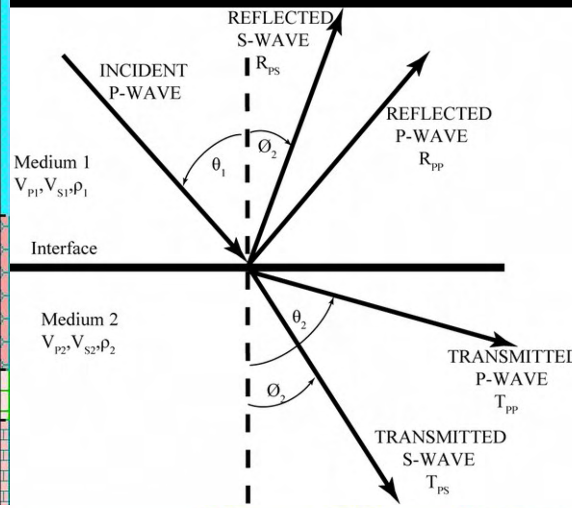


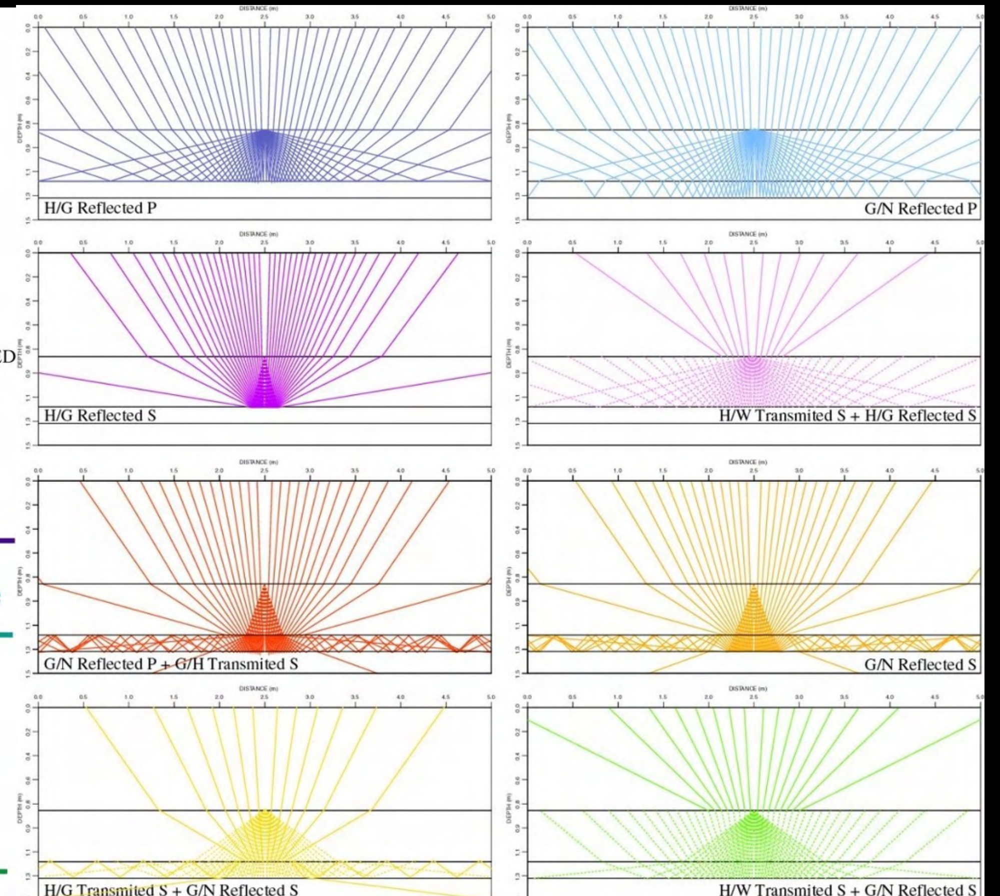
$Vp_1 / \sin(e)$	=	$Vp_1 / \sin(e_1)$	=	$Vp_2 / \sin(e_2)$	=	$Vs_1 / \sin(f_1)$	=	$Vs_2 / \sin(f_2)$
$-\sin(e)\ P$	=	$\sin(e_1)\ P_1$	-	$\sin(e_2)\ P_2$	+	$\cos(f_1)\ S_1$	+	$\cos(f_2)\ S_2$
$\cos(e)\ P$	=	$\cos(e_1)\ P_1$	+	$\cos(e_2)\ P_2$	-	$\sin(f_1)\ S_1$	+	$\sin(f_1)\ S_2$

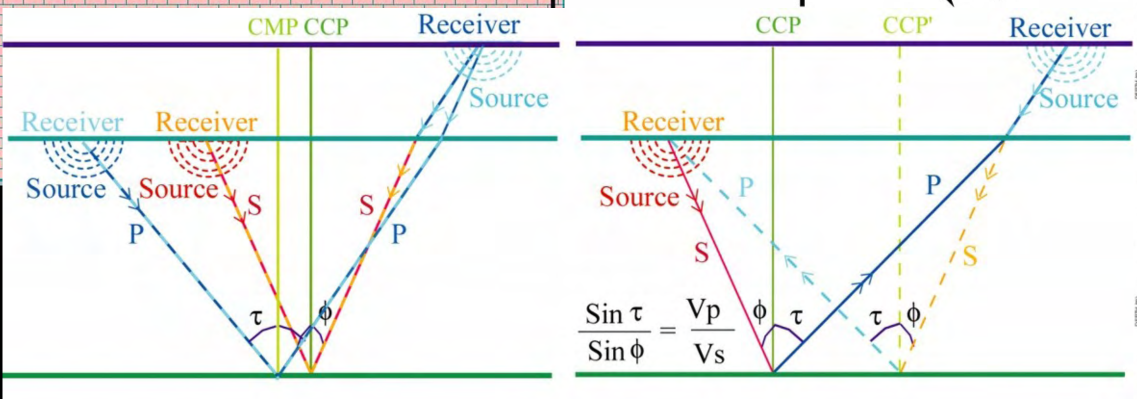
Continuities of displacement and stress and Snell's law at the boundary (Zoeppritz, 1919)

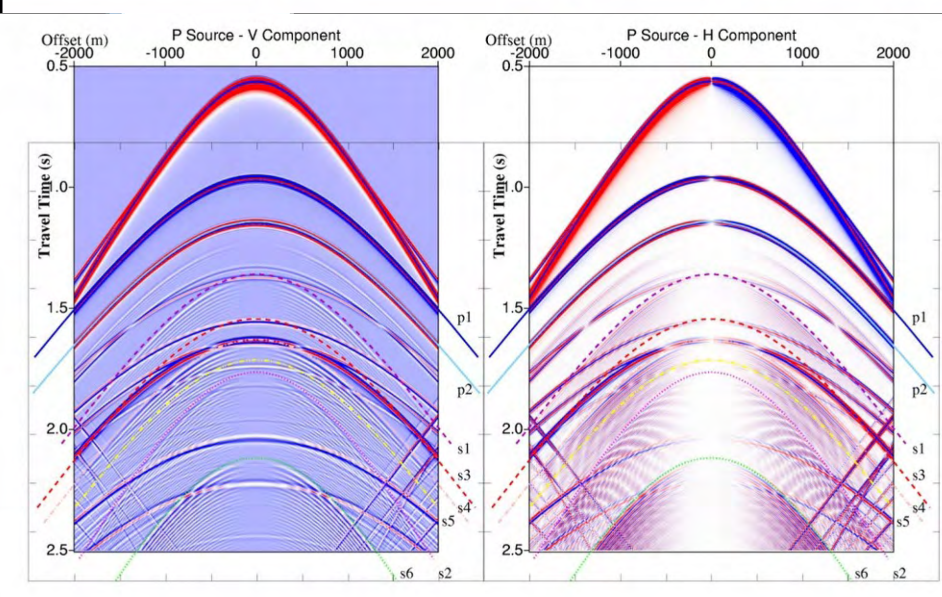
Component Wide-Angle Data (OBS)

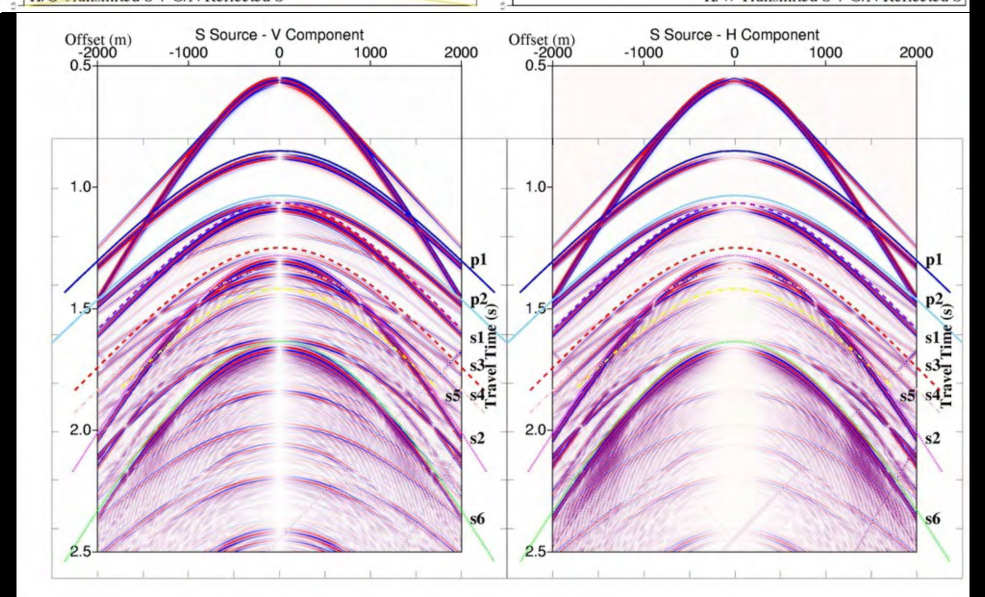




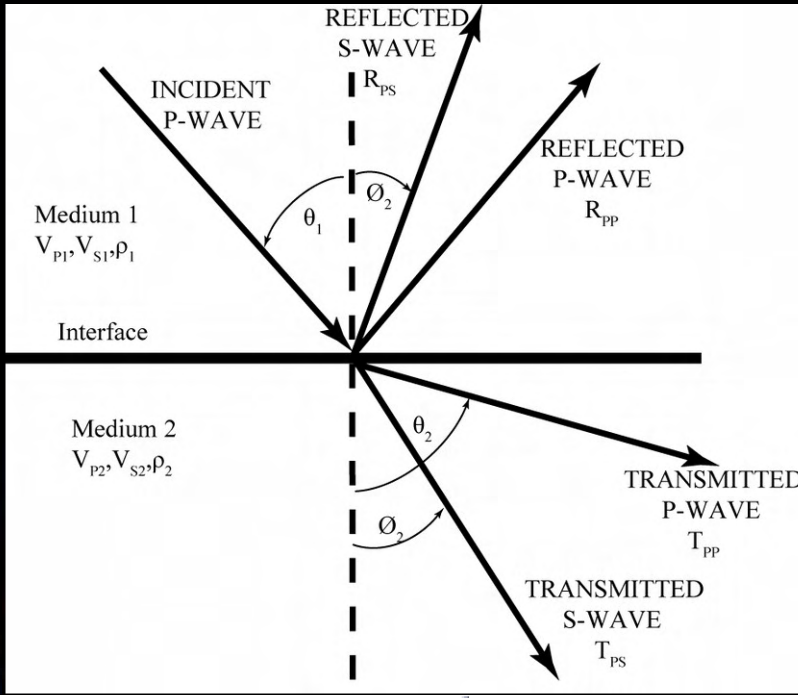


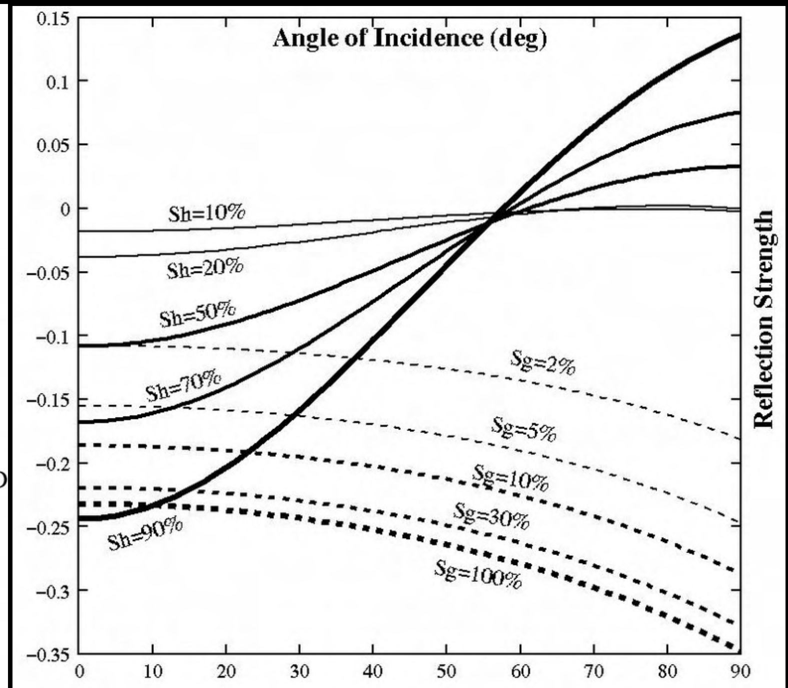


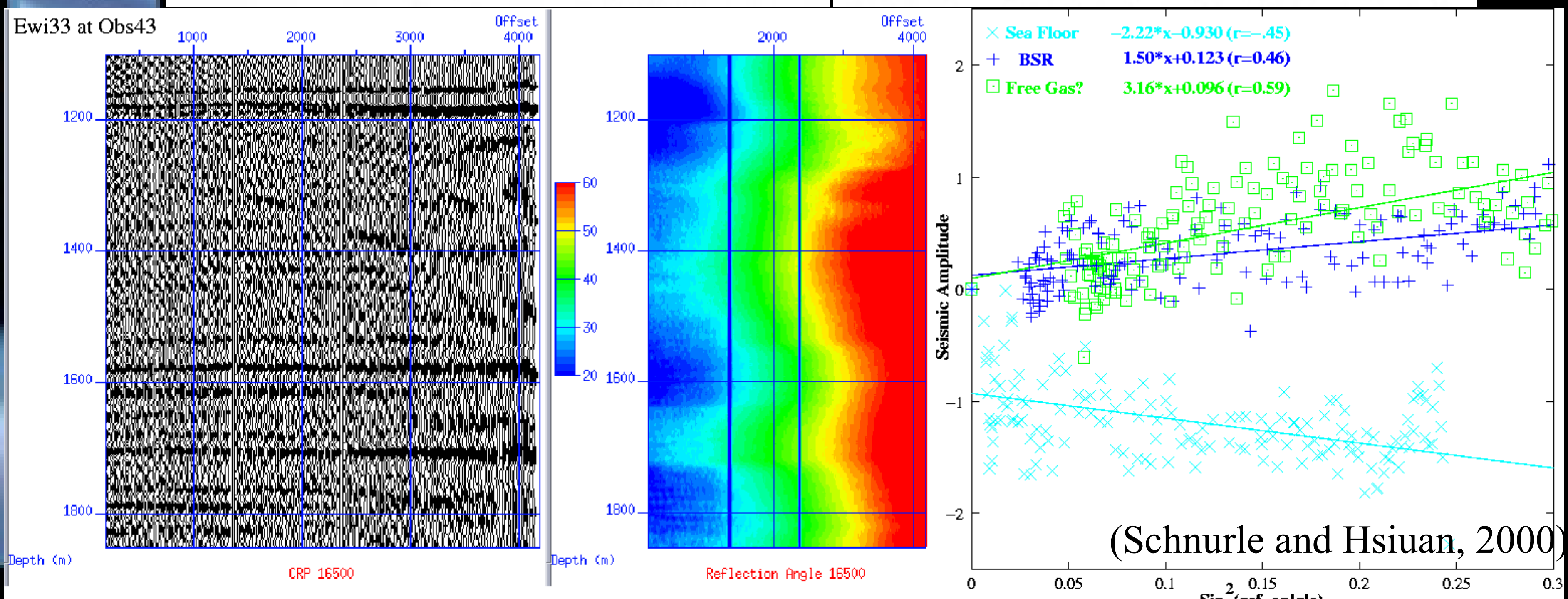




Amplitude versus Angle Reflection Strength

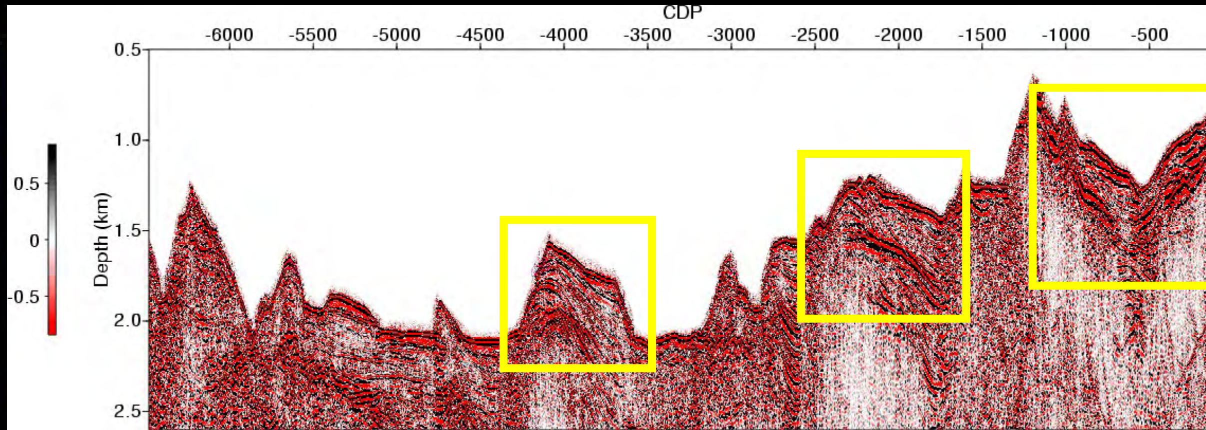


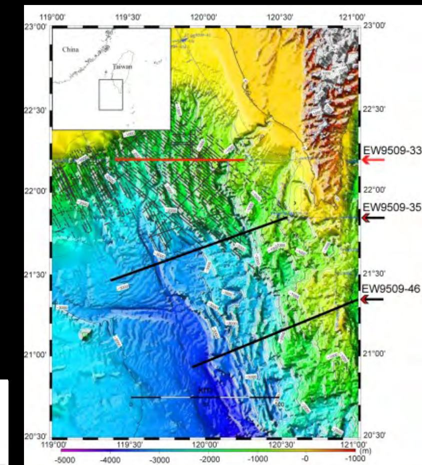


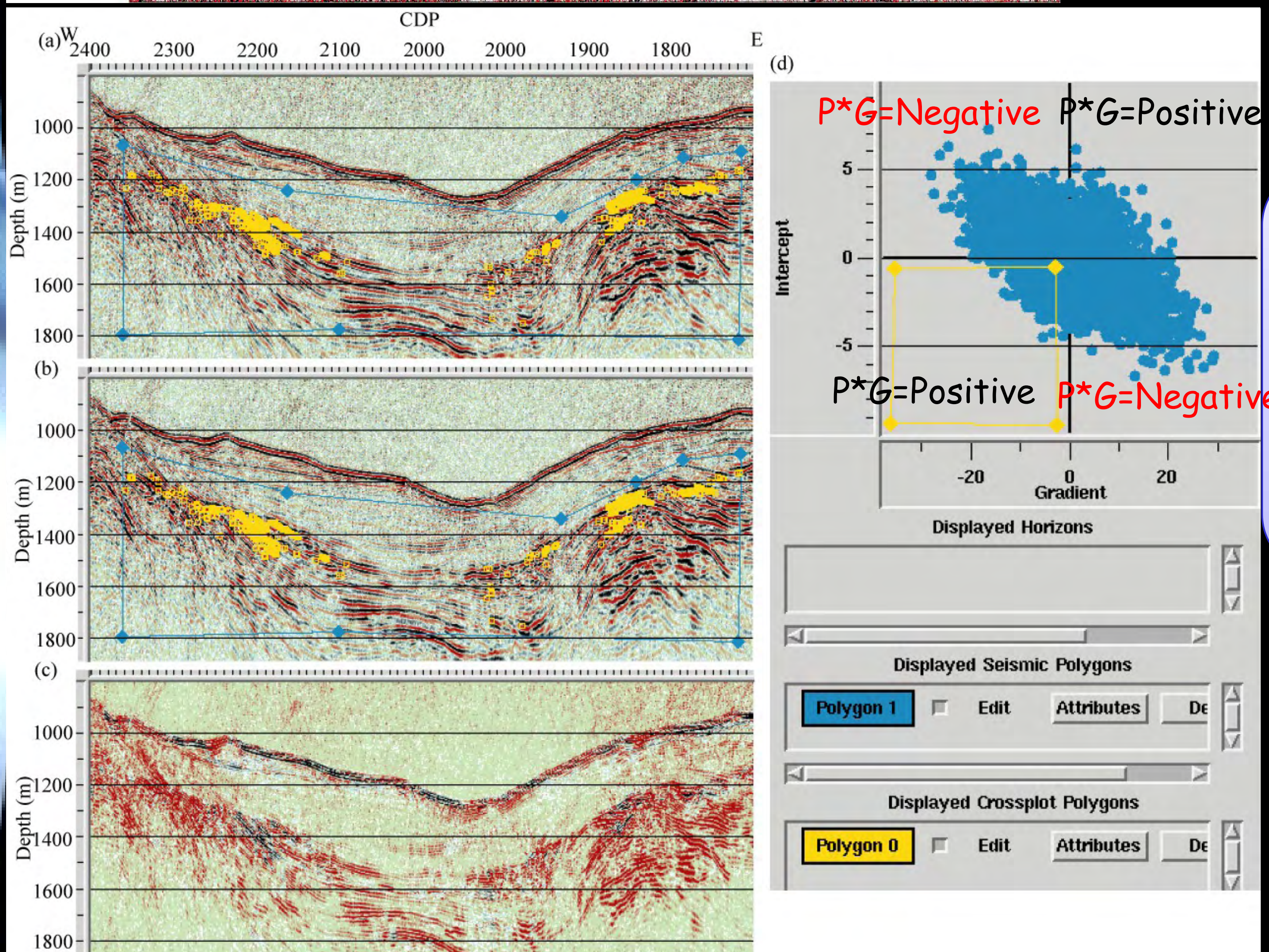


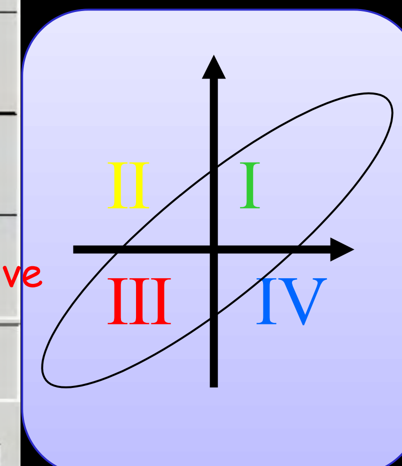
(Schnurle and Hsiuan, 2000)

EW9509-33:


CDP
-6000
-5500
-5000
-4500
-4000
-3500
-3000
-2500
-2000
-1500
-1000
-500
Depth (km)
0.5
1.0
1.5
2.0
2.5
0.5
0
-0.5

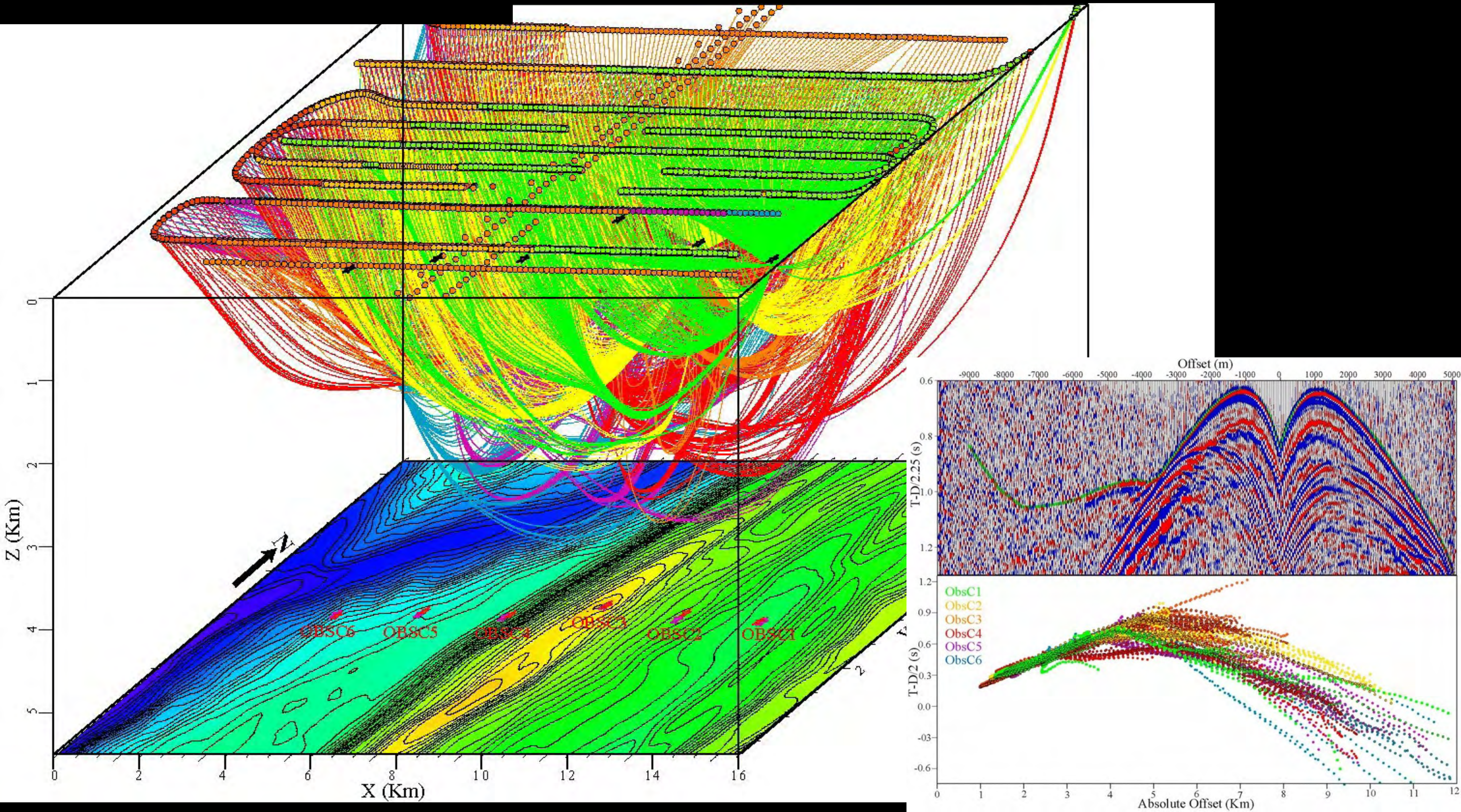

EW9509-33
EW9509-35
EW9509-46
China
Taiwan


CDP
(a)
W
E
2400
2300
2200
2100
2000
2000
1900
1800
Depth (m)
1000
1200
1400
1600
1800
(b)
(c)
(d)
P*G=Negative
P*G=Positive
P*G=Positive
P*G=Negative
Intercept
5
0
-5
-20
0
20
Gradient
Displayed Horizons
Displayed Seismic Polygons
Polygon 1
Edit
Attributes
De
Displayed Crossplot Polygons
Polygon 0
Edit
Attributes
De


II
I
III
IV

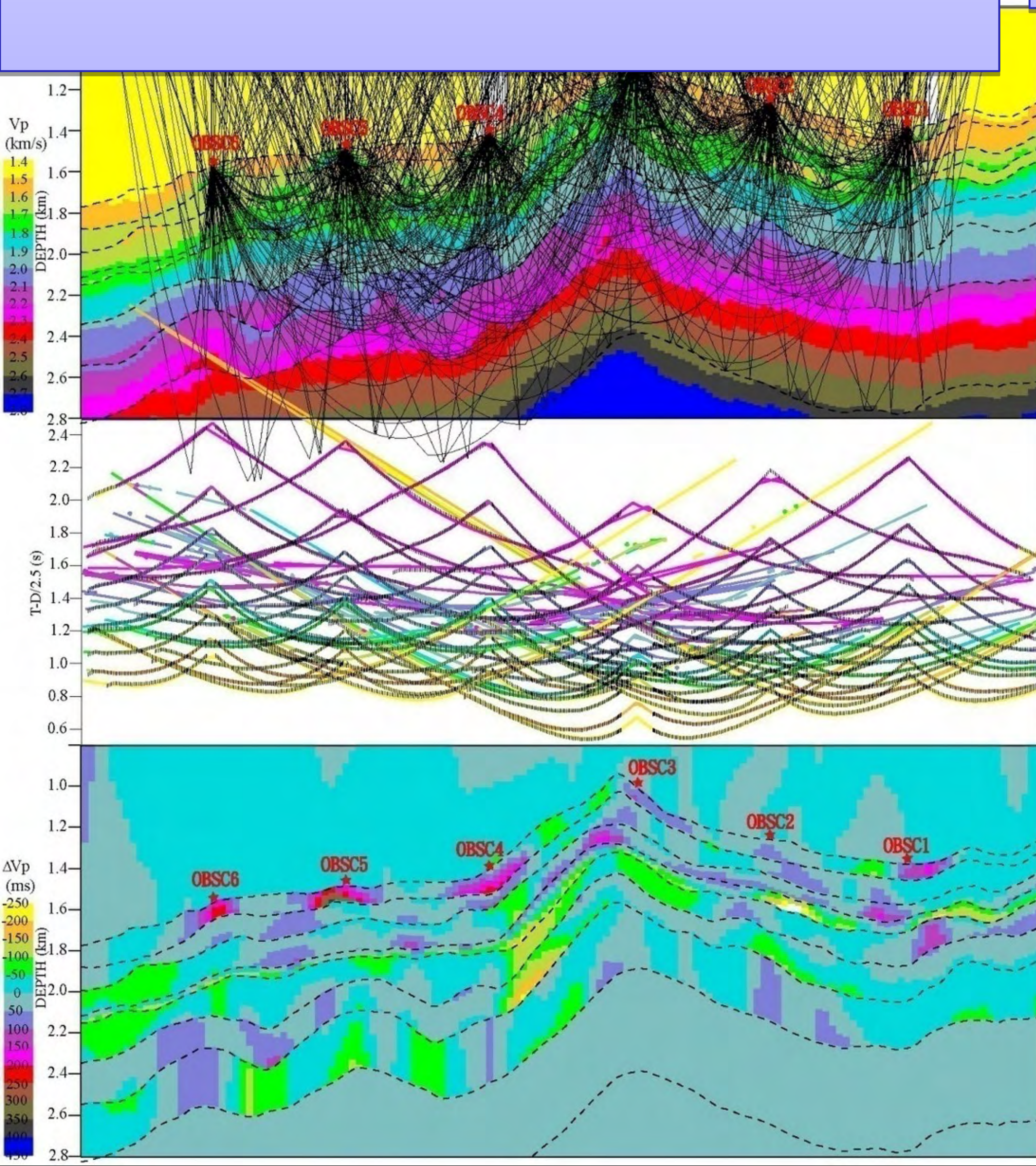
3-D Tomographic First Arrival P-P Inversion

OBS735 Transect C



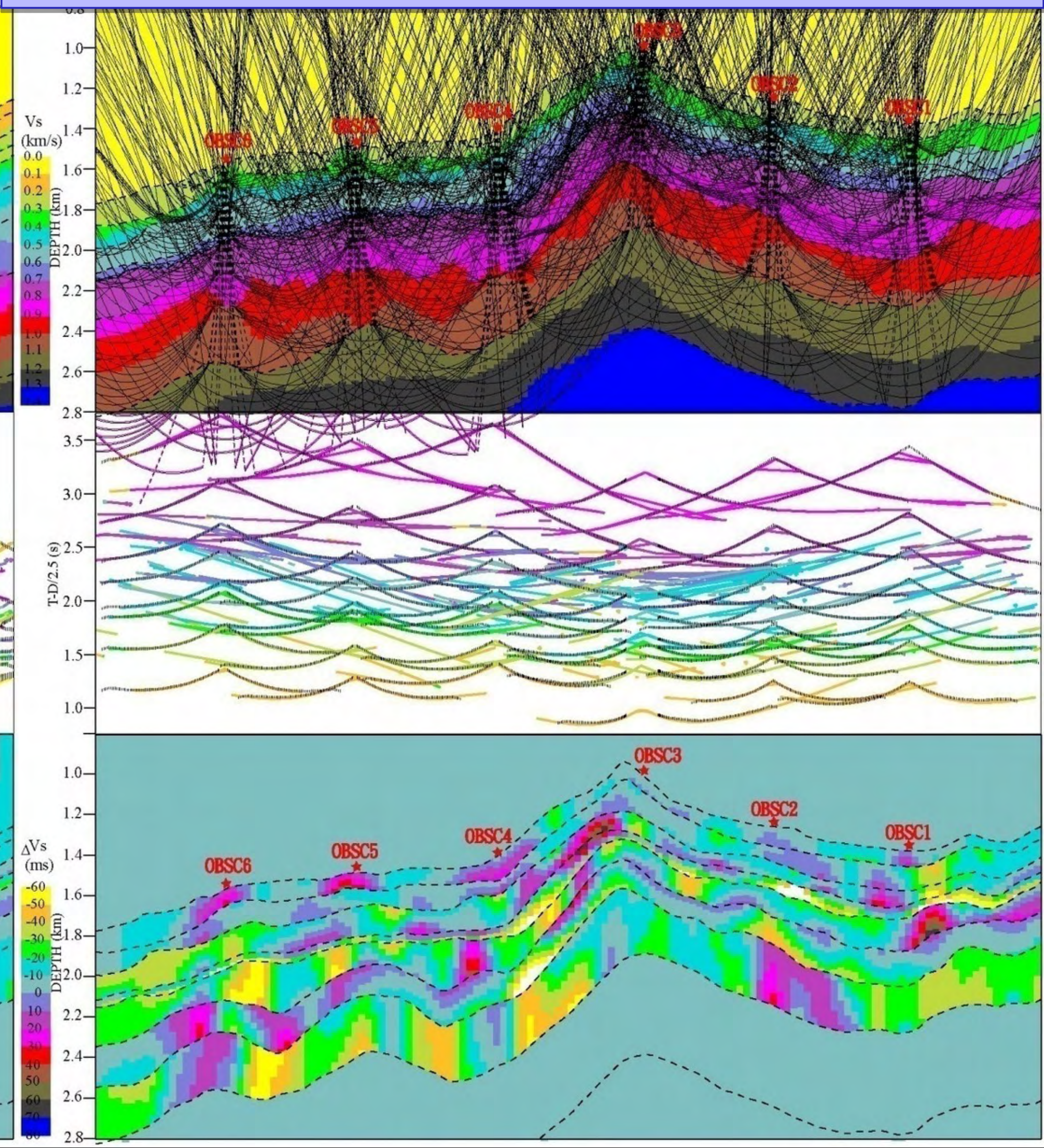
Acoustic Velocities

2-D inversion of the P-P reflected, and refracted acoustic arrival of this OBS transect

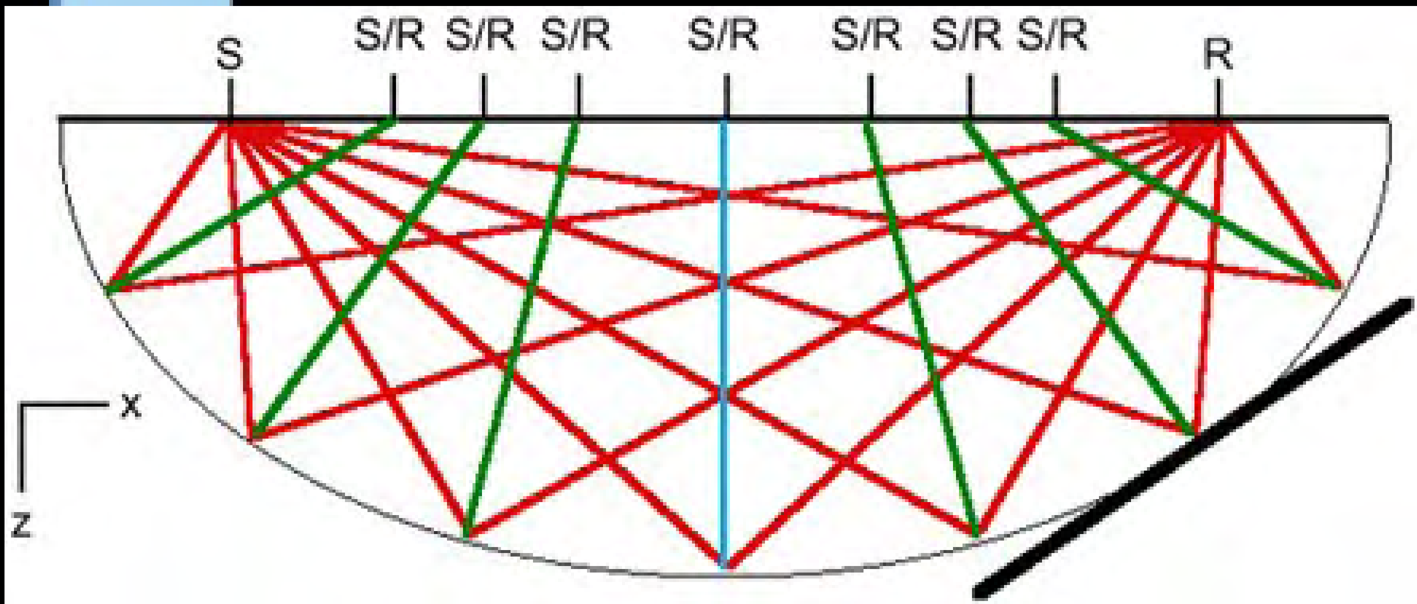


Shear-Wave Velocities

2-D inversion of the P-S reflected, and refracted mode-converted arrival of this OBS transect



NMO-DMO-Migration



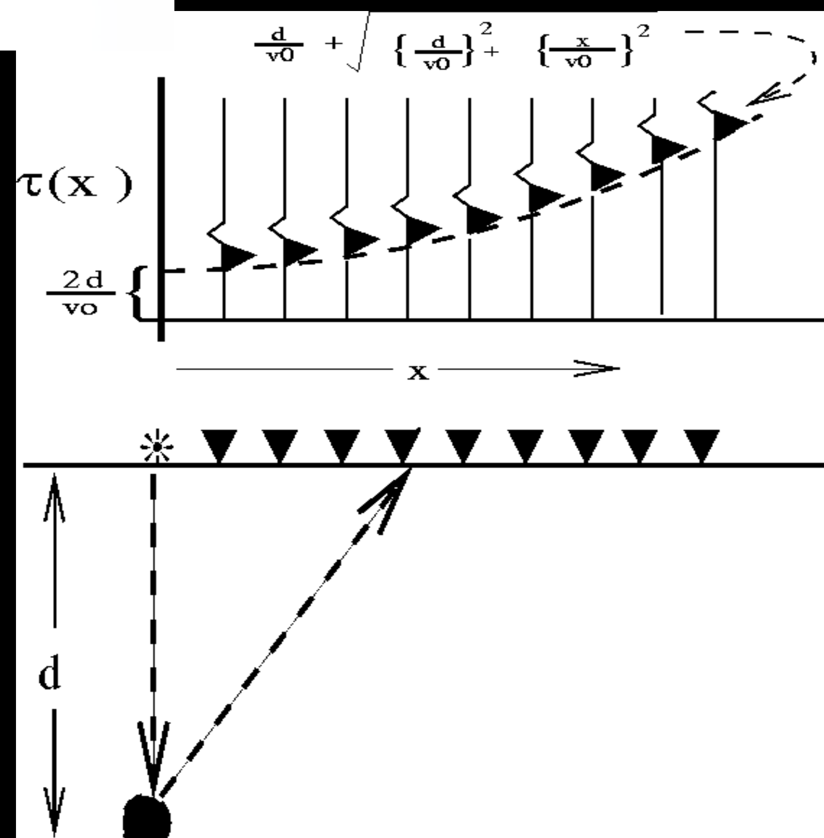
In a flat layered isotropic media, the relationship between the travel time and offset is given by Yilmaz (1987);

$$t^2(x) = to^2 + X^2/V^2;$$

where to is the vertical two-way travel time and V is the P-wave velocity of the medium.

Re-written as the double-square root equation:

$$T = \sqrt{T_M^2 + \frac{(x+h)^2}{v^2}} + \sqrt{T_M^2 + \frac{(x-h)^2}{v^2}}$$



Mathematical Foundations

Symes, W.W., Mathematics of Reflection Seismology, in *Annual report, The Rice Inversion Project*, Rice University, 1995-1998

Linearized Migration Problem:

Given a data set $\{\delta p(xs,xr,tr):0<tr<tmax, (xs,xr) € Xrs\}$, find the loci of high-frequency components in the coefficient perturbations $\delta\sigma/\sigma$, $\delta\rho/\rho$. It is presumed that $\delta p=Lf[\rho,c]\ [\delta\sigma/\sigma,\delta\rho/\rho]$ for suitable smooth reference parameters ρ,c.

The migration problem is expressed as pseudo-differential operators which are **pseudo-local**: they preserve the loci of high frequency components (no singularities in new locations).

A] Integral representation (Kirchhoff):

$L[\delta\sigma/\sigma,\delta\rho/\rho] = \int dx\ R\ (N.\ \nabla_x)^2\ (\delta\sigma/\sigma - \sin^2(\theta/2)\ \delta\rho/\rho]\ \delta(t- ts - tr)$

$L^*\ u(xs,x) = \int dx'r\ R(xs,xr,x)\ (N.\ \nabla_x)^2\ u(x'r, ts(x) + tr(x))\ .\ (-1/ \sin^2(\theta(xs,xr,x)/2))$

Apart from the derivative, each component of the output is a weighted integral over the move-out curves $t = ts(x) + tr(x)$. Since one wants only an "impedance image", i.e. a function of the location rich high-frequency energy, we need only the first part:

$M\ u(xs,x) = \int dx'r\ R(xs,xr,x)\ (N.\ \nabla_x)^2\ u(x'r, ts(x) + tr(x)) \approx \int dx'r\ R(xs,xr,x)\ \partial^2 u/\partial t^2\ (x'r, ts(x) + tr(x))$

which depends mainly on the phase ts(x) + tr(x) and hardly on the amplitude R.

B] Boundary value problem (Reverse-time):

$(1/\rho c^2\ \partial^2/t^2 - \nabla 1/\rho\ \nabla)\ \delta G = 2\ \delta c/c^3\ \partial^2 G/\partial t^2\ ,\ \delta G = 0\ ,\ t << 0$

Suppose v solves: $(1/\rho c^2\ \partial^2/\partial t^2 - \nabla 1/\rho\ \nabla)\ v = F\ ,\ v = 0\ ,\ t >> 0$

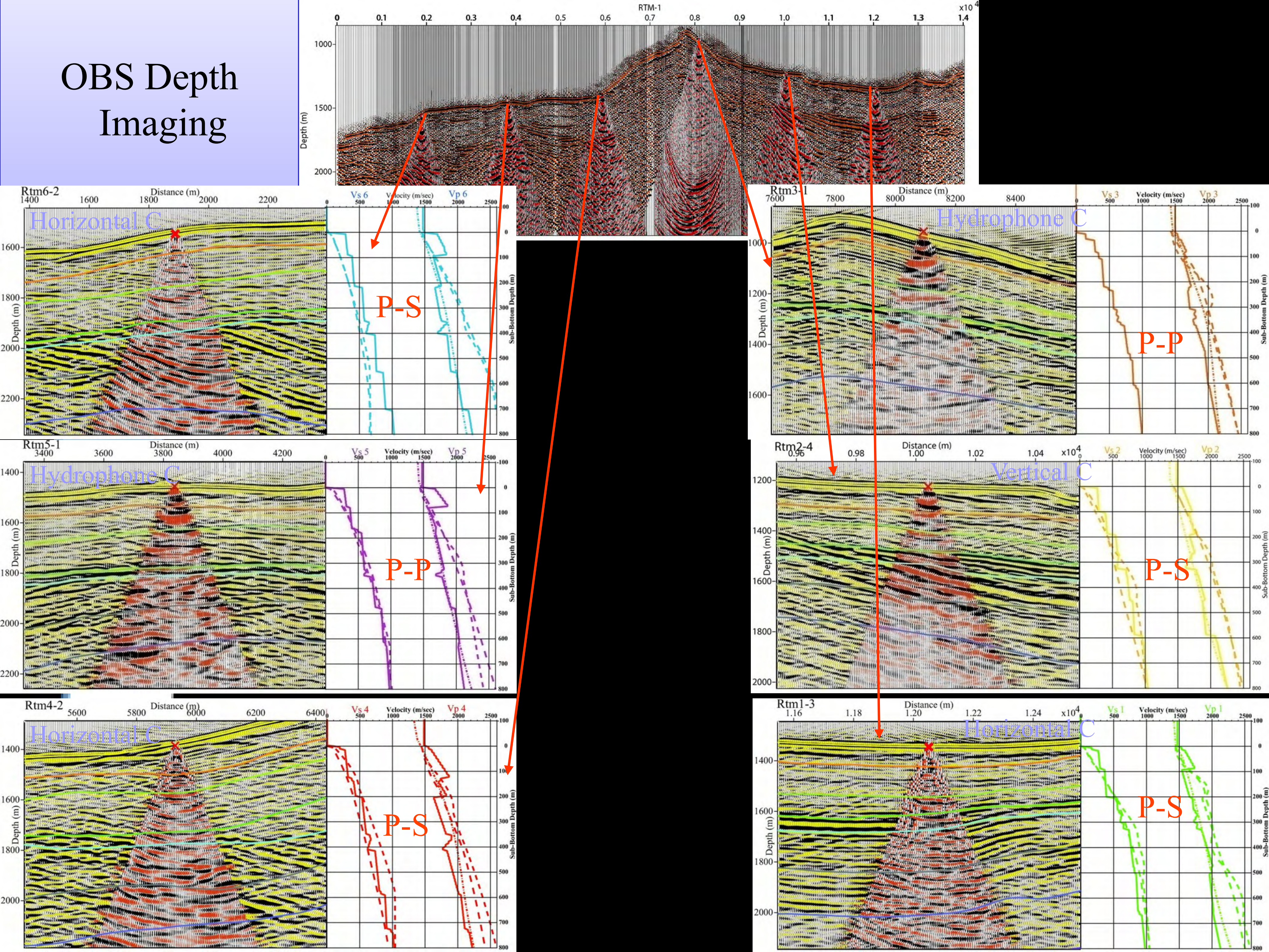
The Green formula gives: $\int dx\ \delta c/c(x)\ \{2/c^2(x) \int dt\ v(x,t)\ \partial^2 G(xs,x,t)/\partial t^2\ \} = \int dx \int dt\ \delta G(xs,x,t)\ F(x,t)$

Therefore, if $F(x,t) = \Sigma xr\ u(x'r,t)\ \delta(x-xr)$ then, $M\ u(xs,x) = 2/c^2(x) \int dt\ v(x,t)\ \partial^2 G(xs,x,t)/\partial t^2\ \}$

That is the adjoint (shot record migration) operator is obtained by "**propagating the data backwards in time**, using the receivers as sources" (i.e. solving the final-value problem given above) and "**cross-correlating the back-propagated field with the second t-derivative of the direct field**". In practice G is often replaced by the leading term in its progressing wave expansion, and often the leading singularity is changed so that $\partial^2 G(xs,x,t)/\partial t^2$ is a δ-singularity; The M becomes something like: $M\ u(xs,x) \approx v\ (x, t(xs,x))$.

The final section is obtained by stacking over shots: $\Sigma\ M\ u(xs,x)$

OBS Depth Imaging



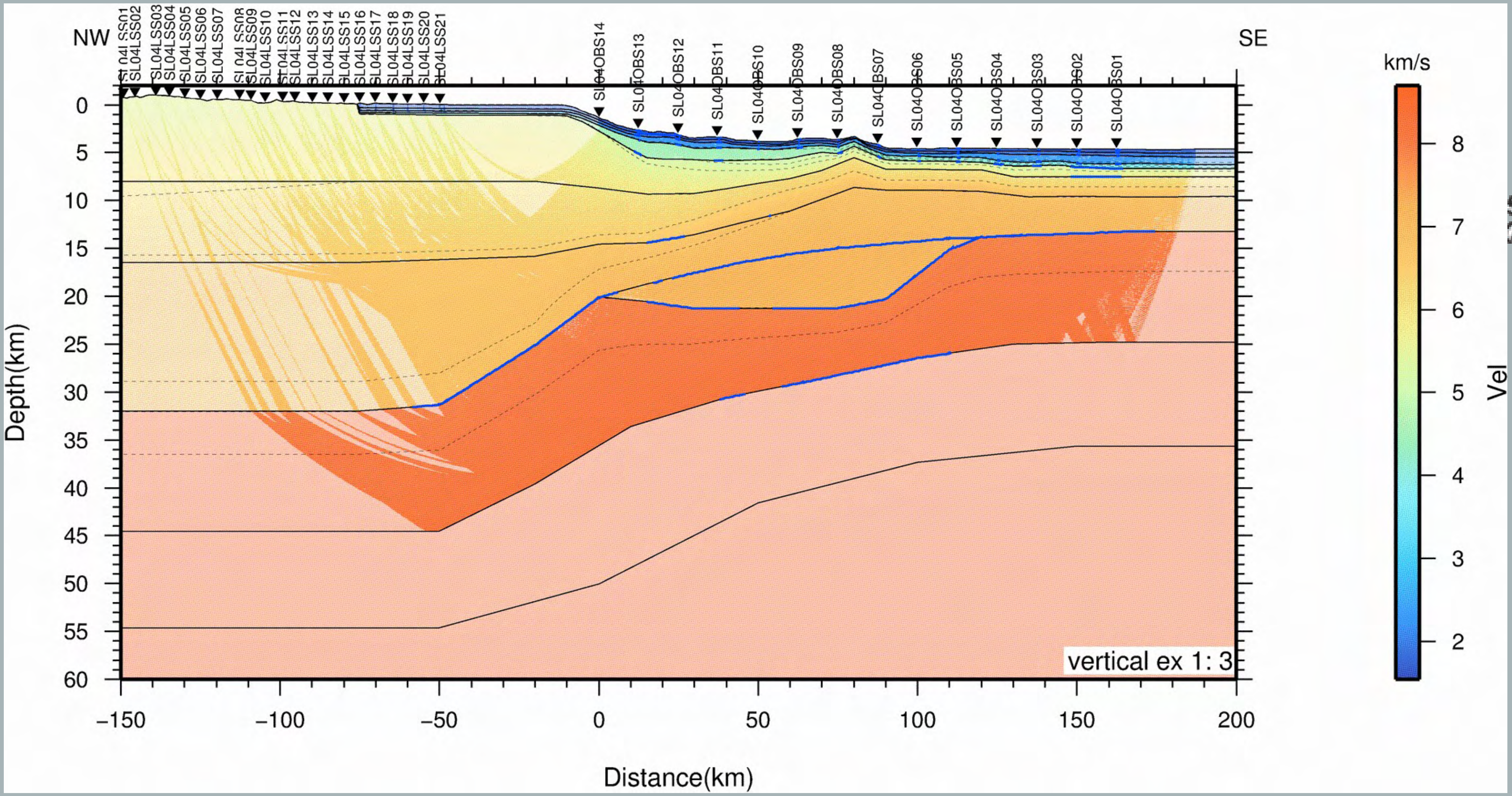
Geophysic Tools -II

Wide-Angle and Multi-Channel Seismic Experiment in the Jequitinhonha-Camamu-Jacuipe-Alagoas-Sergipe Basins (NE Brazil)

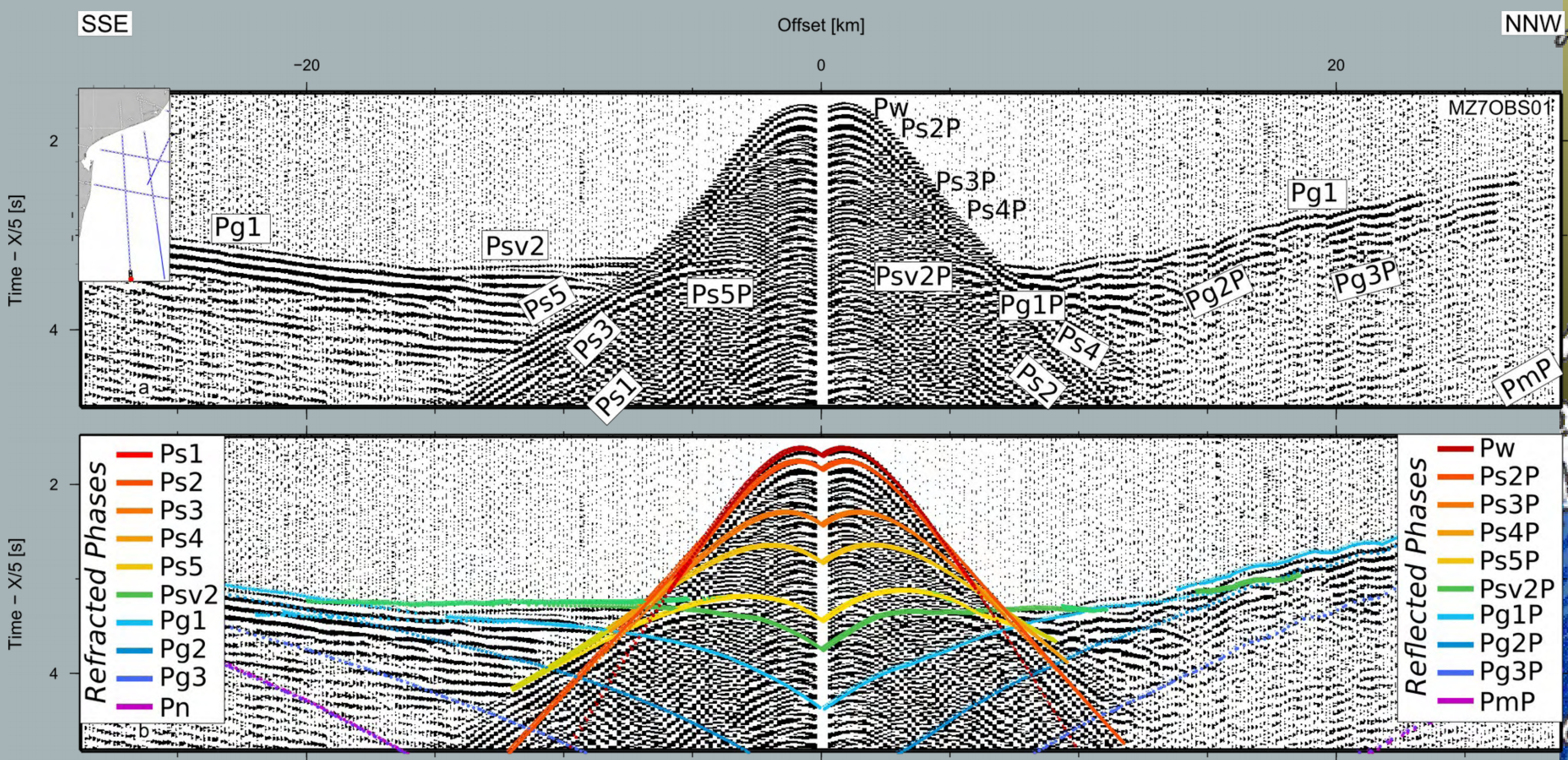
Daniel Aslanian (1)
Mikael Evain (1)
Philippe Schnurle (1)
Afonso Loureiro (3)
Frauke Klingelhoefer (1)
Marina Rabineau (4)
Massinissa Benabdellouahed (1)
Maryline Moulin (1)
Alexandra Afilhado (2)
Flora Gallais (1)
Joao-Marcelo Pinheiro (1)
Nuno Dias (2)
Agnès Baltzer (5)

& the Salsa Team of Petrobras, managed by José Antonio Cupertino.

The main outcome : Vp earth model



OBS Record



OBS/LSS records reach up to 700 km offset and up to 70 km depth

-> deep seismic imaging;

OBS are 1 hydrophone and 1 3-compoenent geophone

-> Both Vp and Vs of the earth imaged.

Layer based with Vp nodes earth model

One can distinguish 3 "primary" steps (in loops if necessary):

1) Vertical (zero offset) travel-time velocity model where the interfaces are constrained by MCS+OBS after Normal Move-Out (NMO); The 2 unknown in each interface (roof and base velocity) are fully constrained where both a reflected and refracted event are observed;

2) Depth velocity model consisting of trial and error in a "Pliers and Scissors" fashion;

3) Depth migration of MCS (/OBS) data resulting in velocity updates/interfaces re-interpretation;

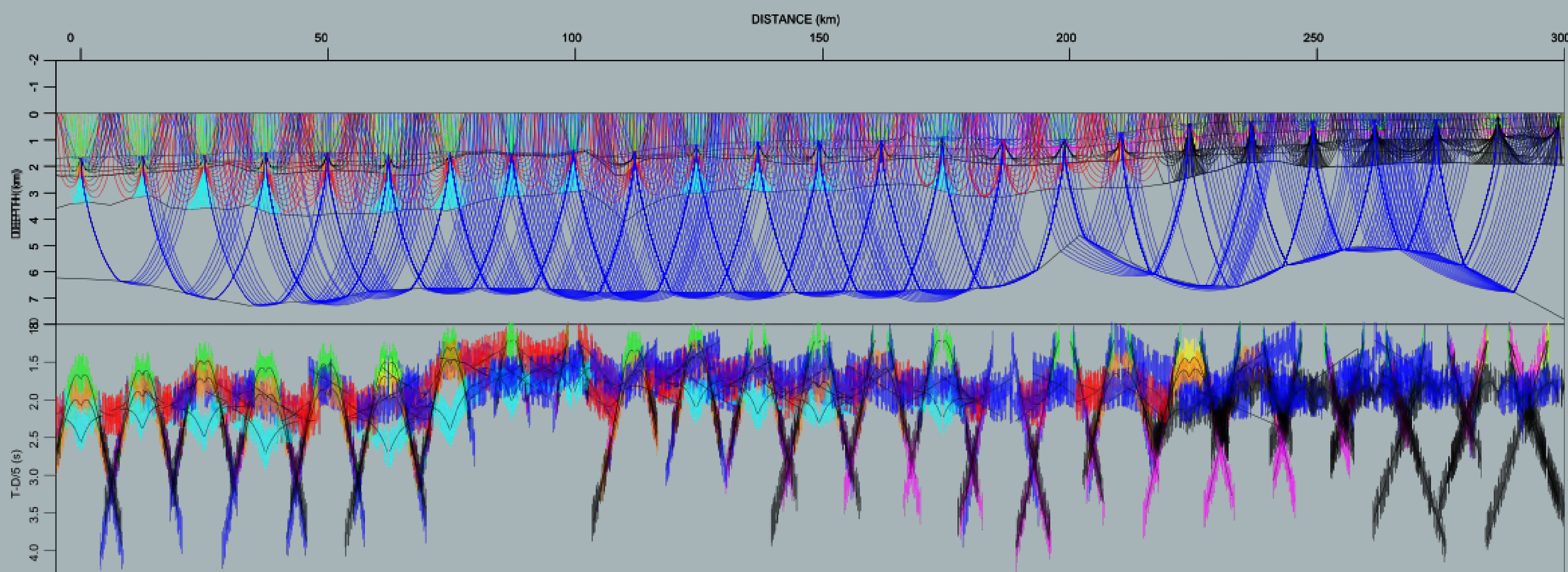
and 3 "secondary" steps (questioning oneself):

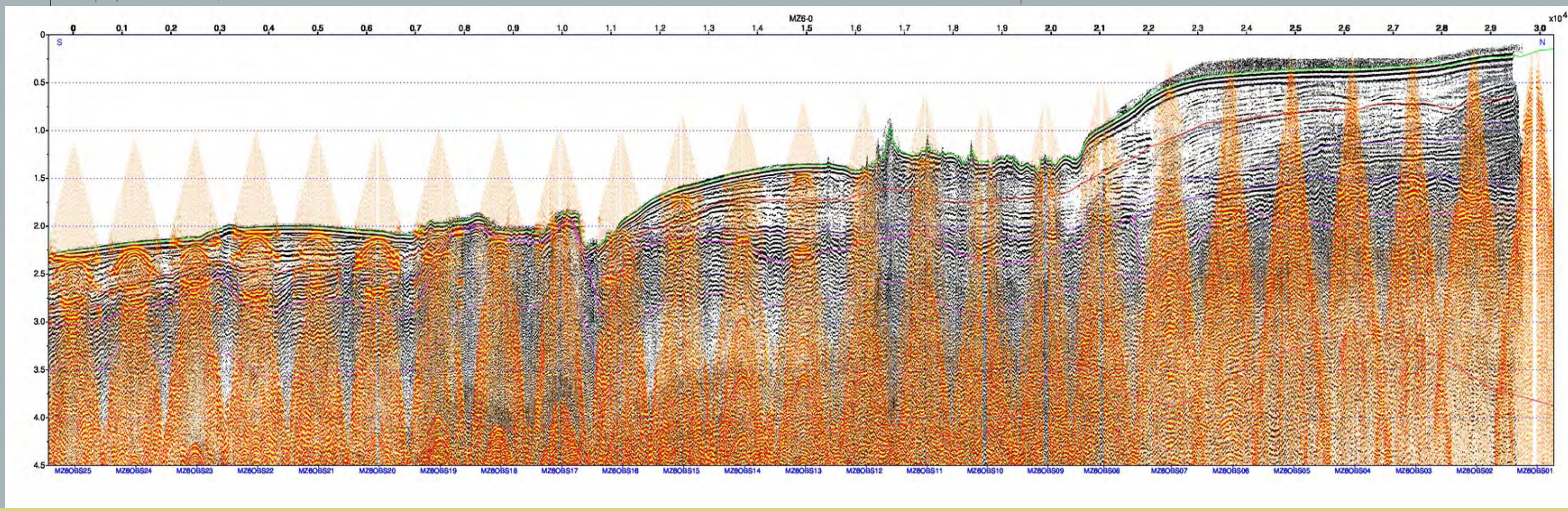
1) Evaluate the precision and resolution of the inversion;

2) Extend the interpretation "regionally" with parallel/neighboring/crossover profiles and compare the arguments for conflicting models;

3) Construct/control the geological evolution scheme (structural, tectonic, petrological, stratigraphic, kinematic...) and compare it with existing models/data (gravi/mag.)..

1) Vertical (zero offset) travel-time model

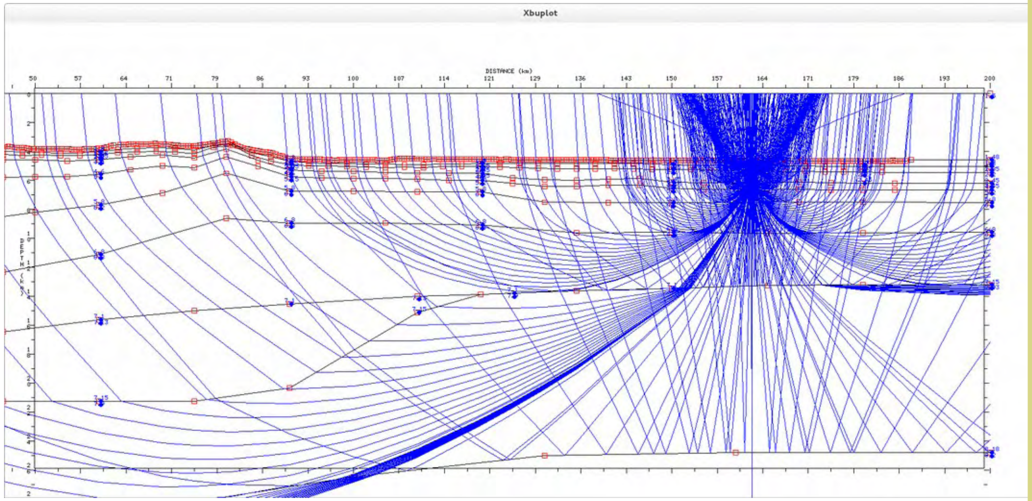




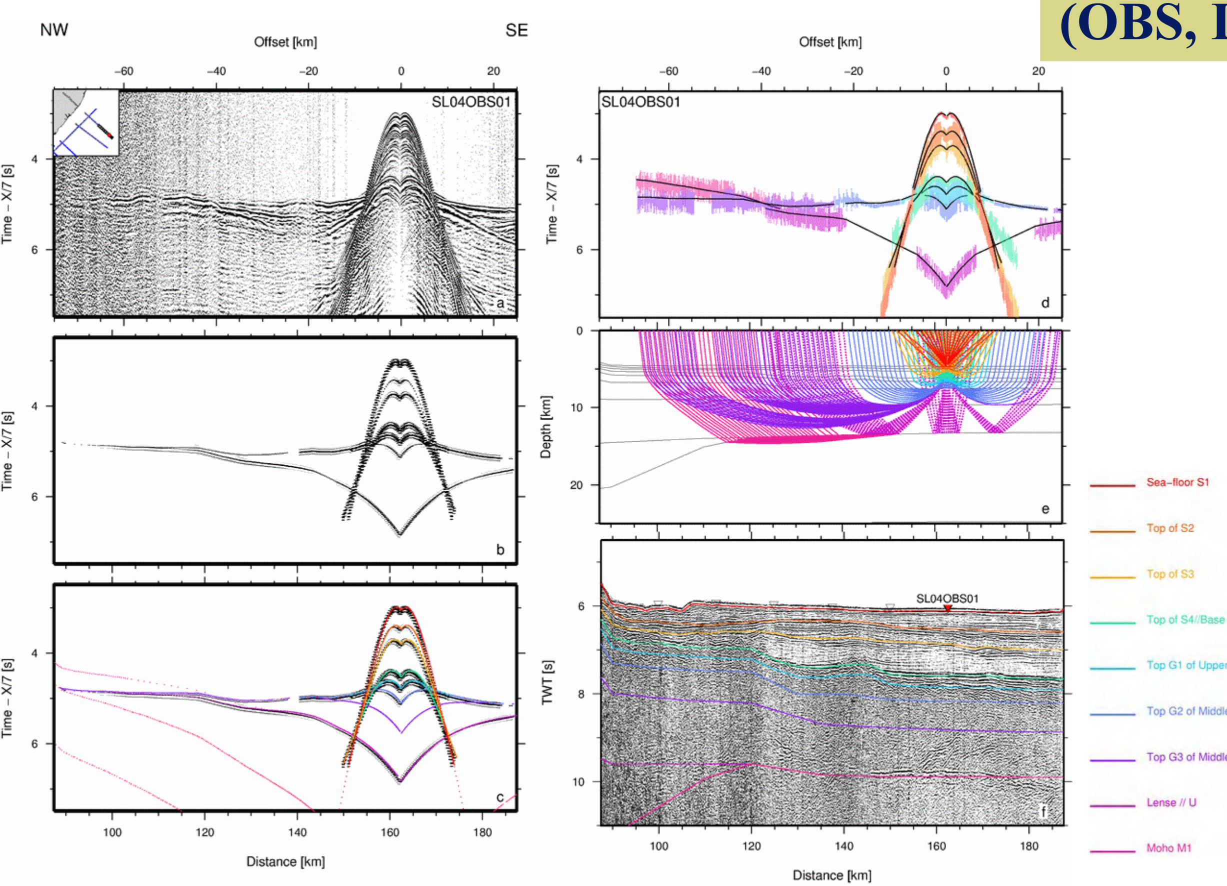
Interfaces are constrained by MCS+OBS after Normal Move-Out (NMO);

roof and base velocity are fully constrained where both a reflected and refracted event are observed

2) Depth velocity model



- Construct a layer-based (structural) velocity model consiting of interface nodes and top and bottom interval velocity nodes;
- Tool capable to compute travel-time and amplitude (synthetics) of primary/multiples - P/PS waves;
- Minimise the travel-time/amplitude missfit between forward modeled and recorded data (OBS, LSS, MCS).



OBS/LSS records reach 400 km offset and 70 km depth (SL07)

-> deep seismic imaging;

Interfaces must be consistant with MCS seismic image/interpretation -> high spacial resolution.

Sedimentary Bassin SL11OBS13

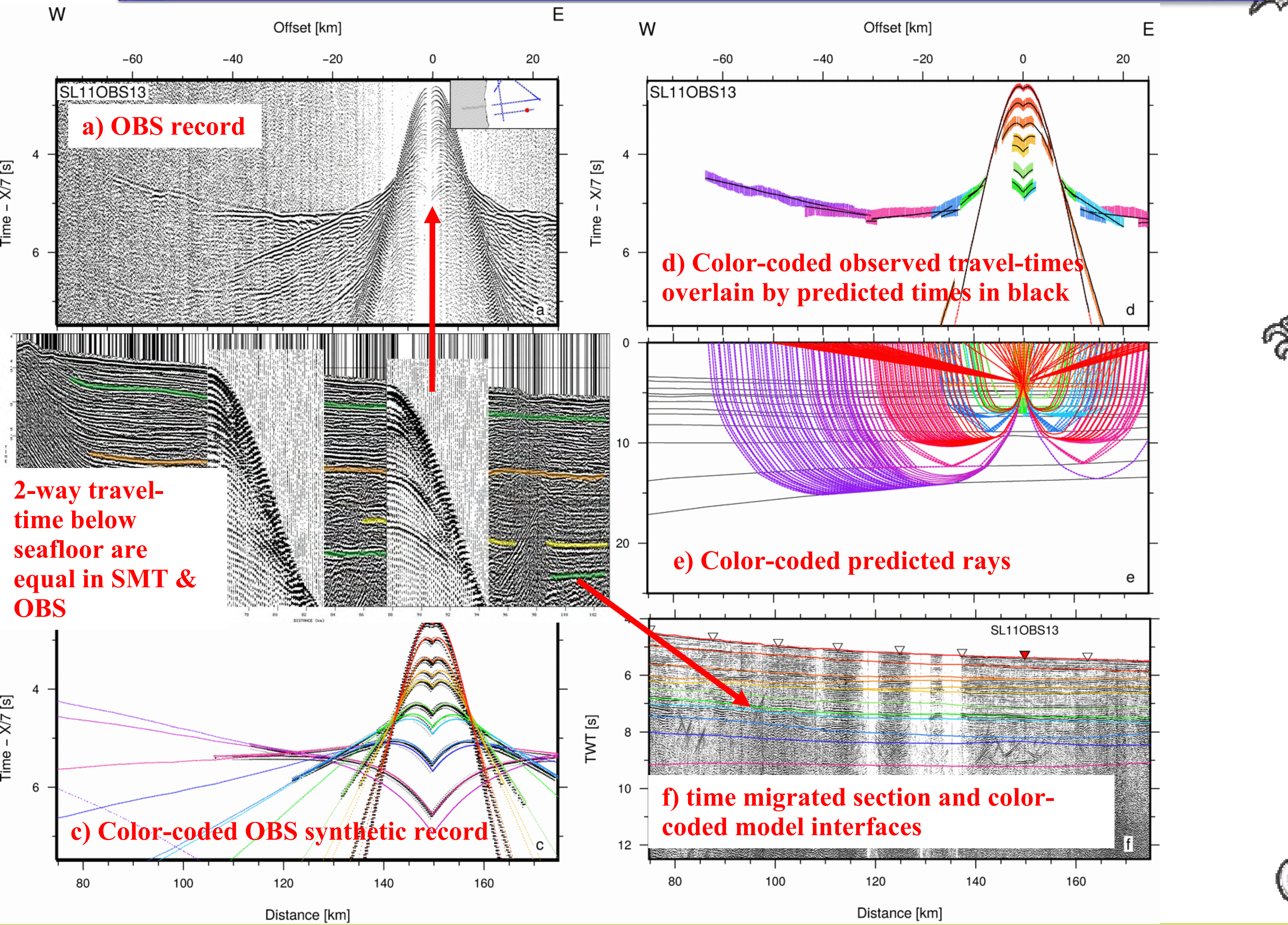
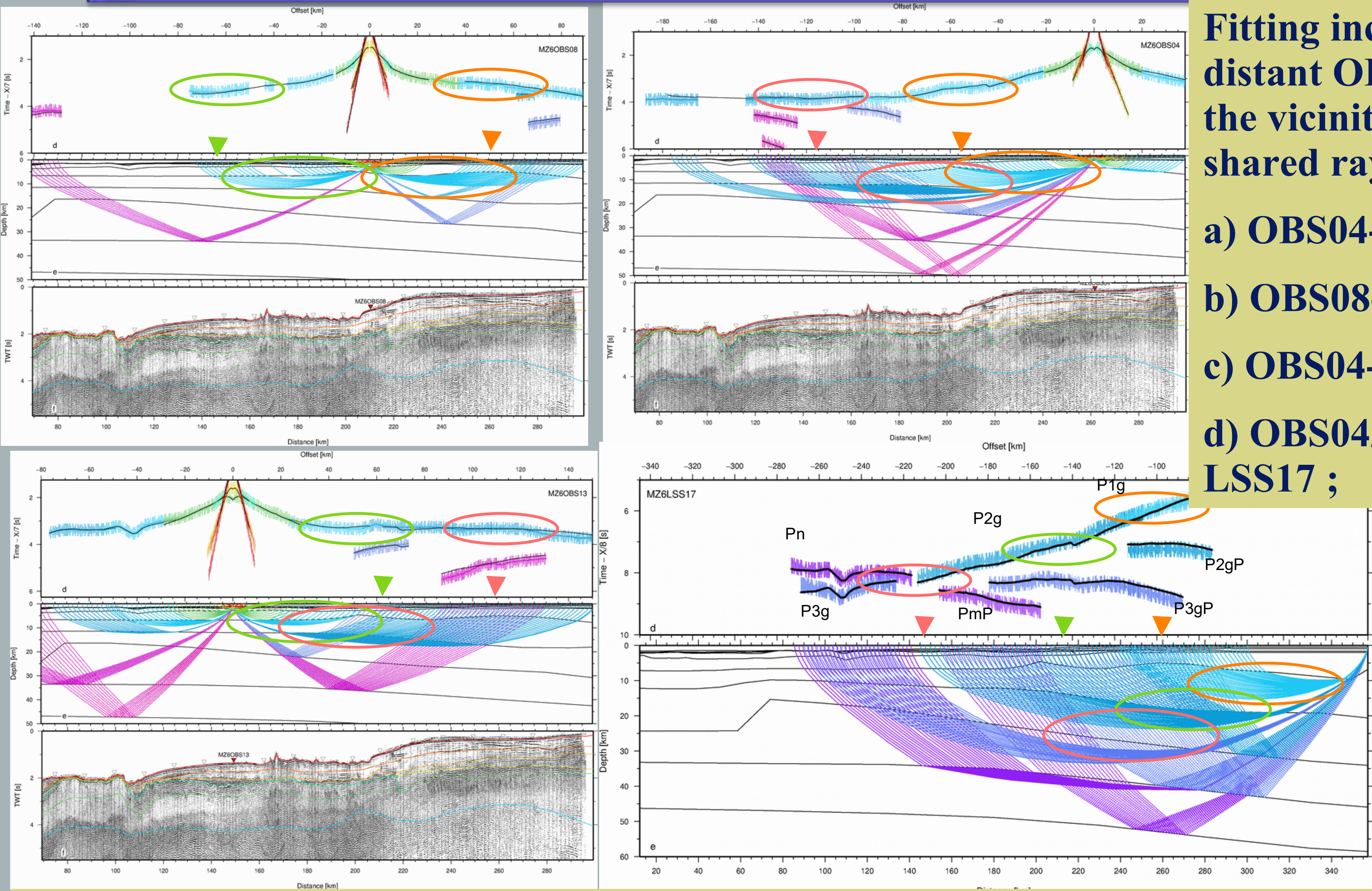


Figure IV.13 - SL11OBS13 on profile SL11 - west direction to the left and east to the right. a) Seismic record; b) Synthetic; c) Color coded synthetic; d) Color-coded observed travel-times overlain by predicted times in black; e) Seismic rays; f) SALSA11 time migrated section and color-coded model interfaces. On a, b, c, and d, travel-time is reduced to a velocity of 7 km/s..

2)Pliers and Scissors trial and error method



Fitting increasingly distant OBSs pairsat the vicinity of a shared ray-path

a) OBS04-OBS08,

b) OBS08-OBS13,

c) OBS04-OBS13,

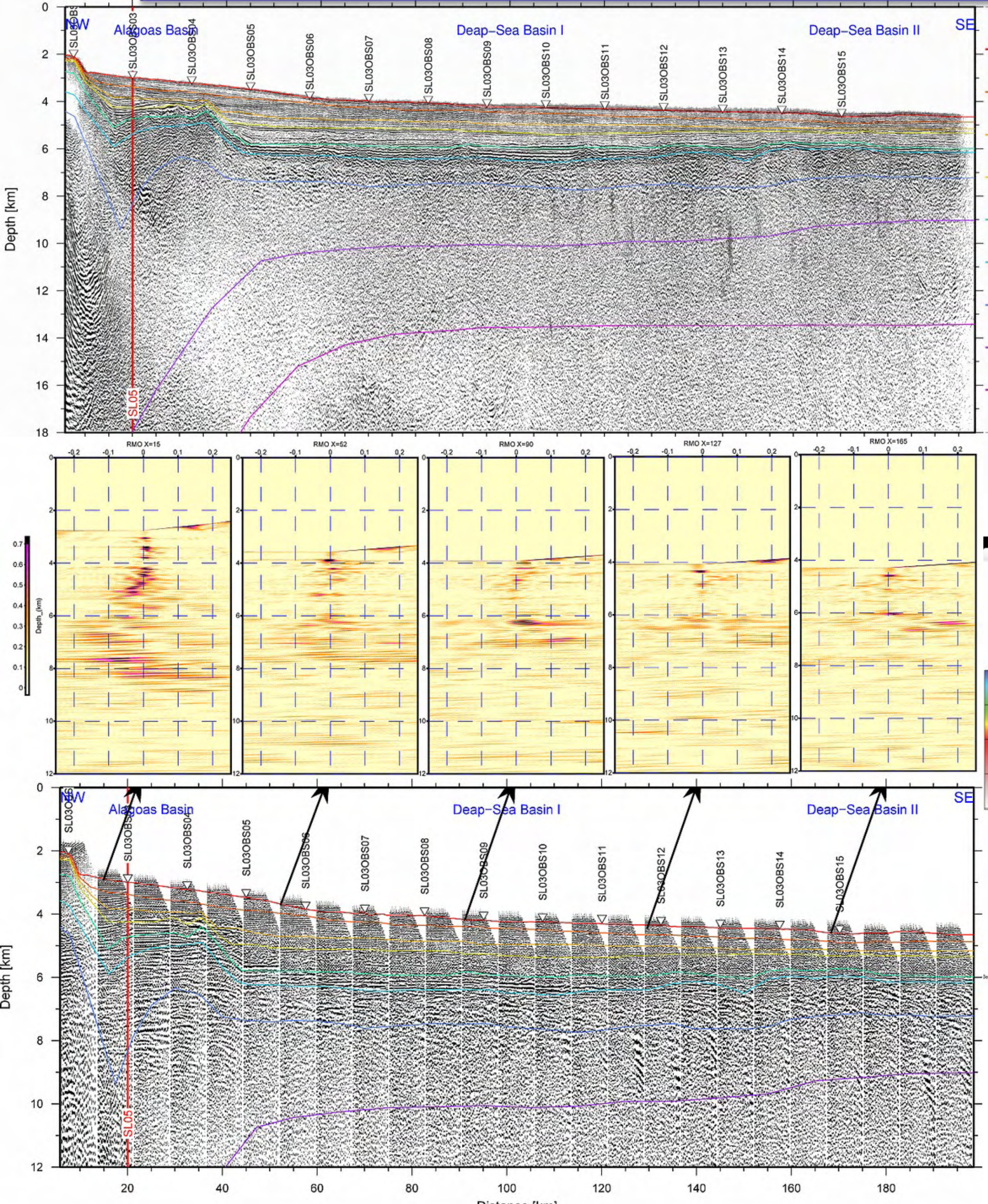
d) OBS04/08/13-LSS17 ;

Trial-error (from top to bottom) adding interface/velocity nodes ; Rule:

- inexact velocity on the receiver side results in a delay of all arrivals (the pliers)

- inexact velocity on the source side results in delays of each arrivals (the scissor)

Multi-channel Seimic Depth-processing



The PSDM processing of the MCS (pre-processed time-) data is undertaken down to 18 km depth using the Seismic Unix package (Stockwell Jr., 1999; Cohen & Stockwell Jr., 2003). The PSDM consists in 2 steps:

- Ray tracing where, the wide-angle velocity model is utilized to compute travel-time tables regularly spaced at 200 m along the profile by paraxial ray tracing on a 50 × 24 m spaced grid, then travel-times in shadow zones are compensated by solving the eikonal equation;
- Common offset Kirchhoff depth migration is performed: migrated traces are outputted as common image gathers (CIG) binned at 25 m with 30 offset-classes between 227 and 4627 m spacing at 150 m.

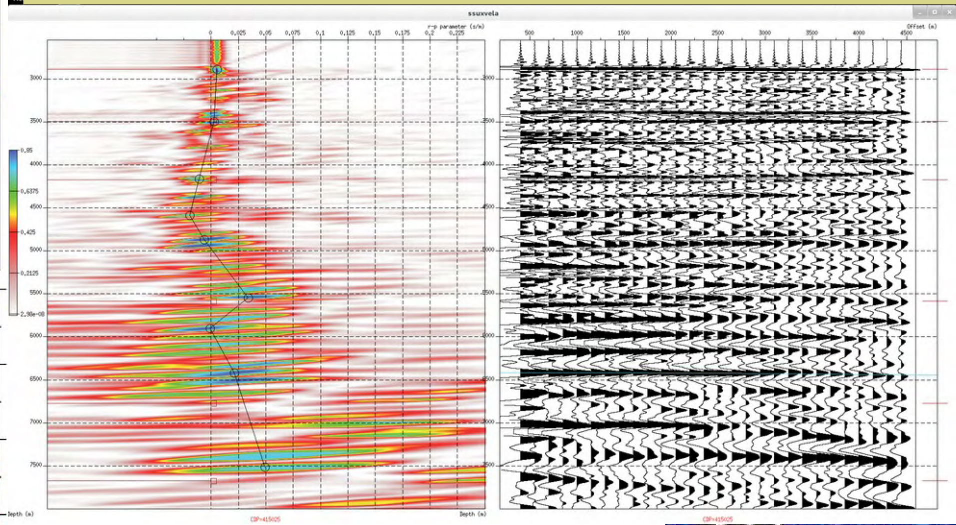


Figure IV.8 a) Pre-stack depth migrated record section of MCS data along SALSA03 profile. Model's interfaces are represented with continuous lines. b) Residual Move-Out analysis at 45 km model distance increment; Model's interfaces are represented with brown square and brown lines. c) Common image gathers extracted every 10 km. Vertical exaggeration is 1:5.

A-priori knowledge harvesting

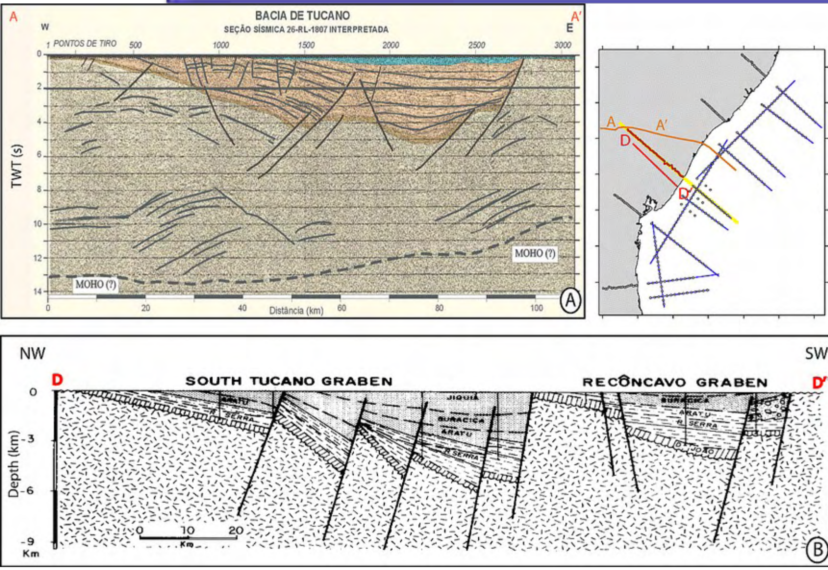


Figure IV.69 - Onshore morphology of the South Tucano and Recôncavo Basins: A- Two-travel time (s) seismic section after Mohriak, 2003; B- Depth seismic section after Milani & Davison, 1988.

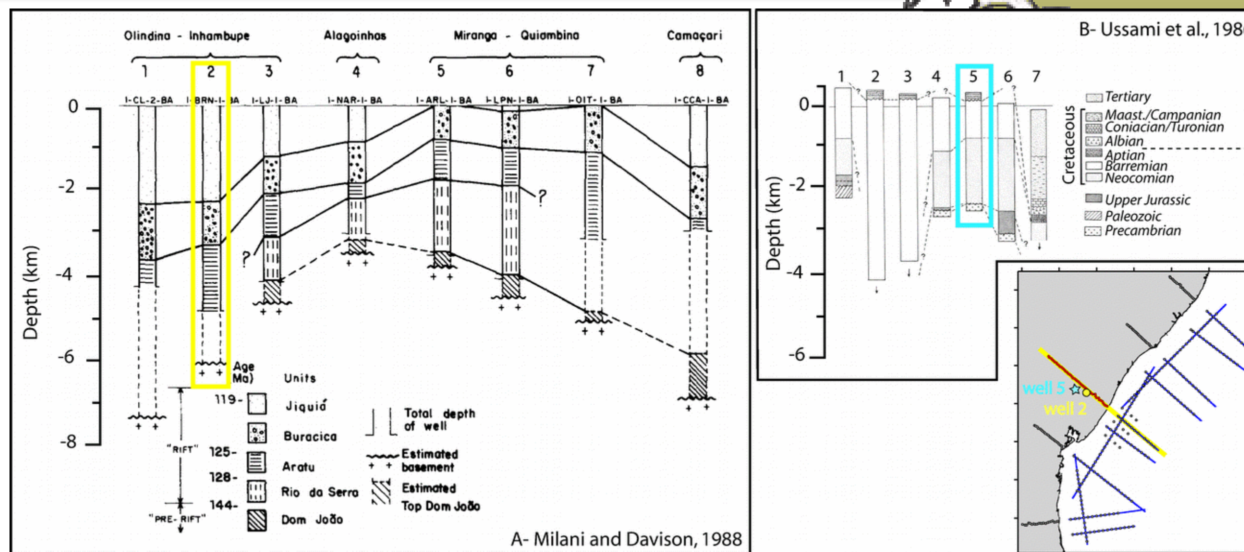


Figure IV.70 - Stratigraphy in the main depocenters of South Tucano and Recôncavo grabens. Location of the wells on Figure IV.68. A- after Milani and Davison, 1988; B- after Ussami et al., 1986. See the position of the two wells used to constrain the thickness of sediments for the forward modeling of the SALSA07 profile. Yellow line corresponds to the SALSA07 profile.

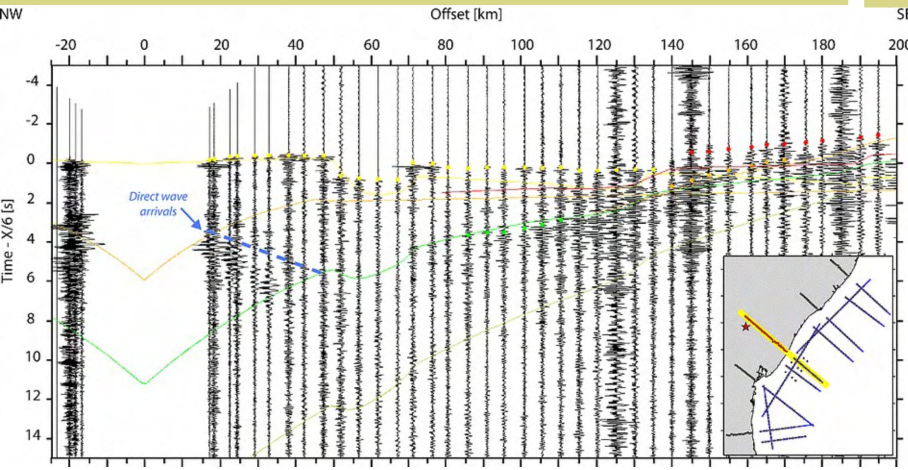


Figure IV.72 - Blast in a quarry detected during the SALSA experiment (blast02 - red star on the map). Yellow picks: refracted Pg1 in the upper continental crust; red picks: refracted Pg2 in the lower continental crust, Orange picks: refracted Pn in the mantle; Green picks: reflected PmP at the Moho.

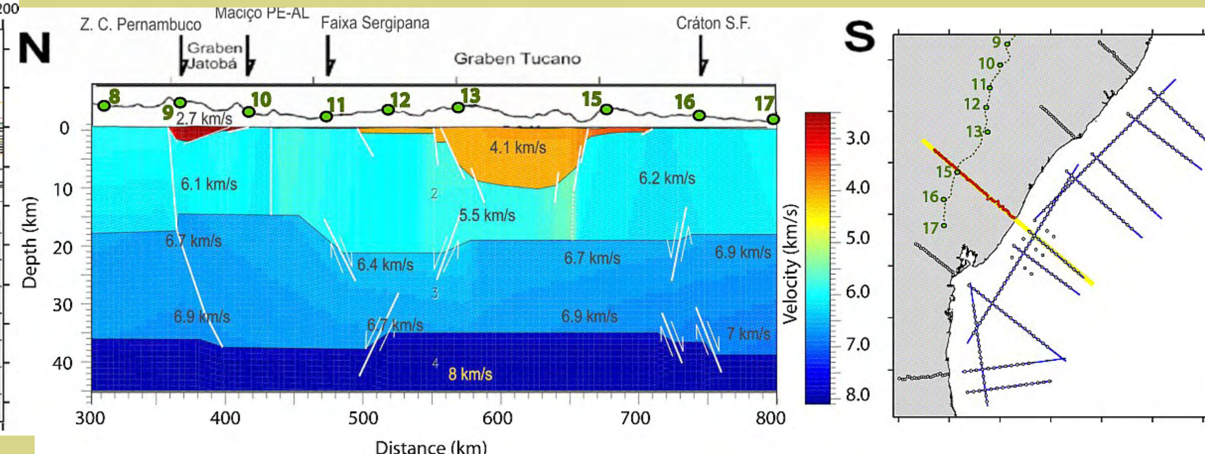


Figure IV.71 - North-south P-wave velocity model imaging the Jatobá and South Tucano grabens. See the position of the refraction seismic (green line) and shots (green dots) on the map.

A-priori knowledge harvesting

SL03-04

SL09-10-11-12

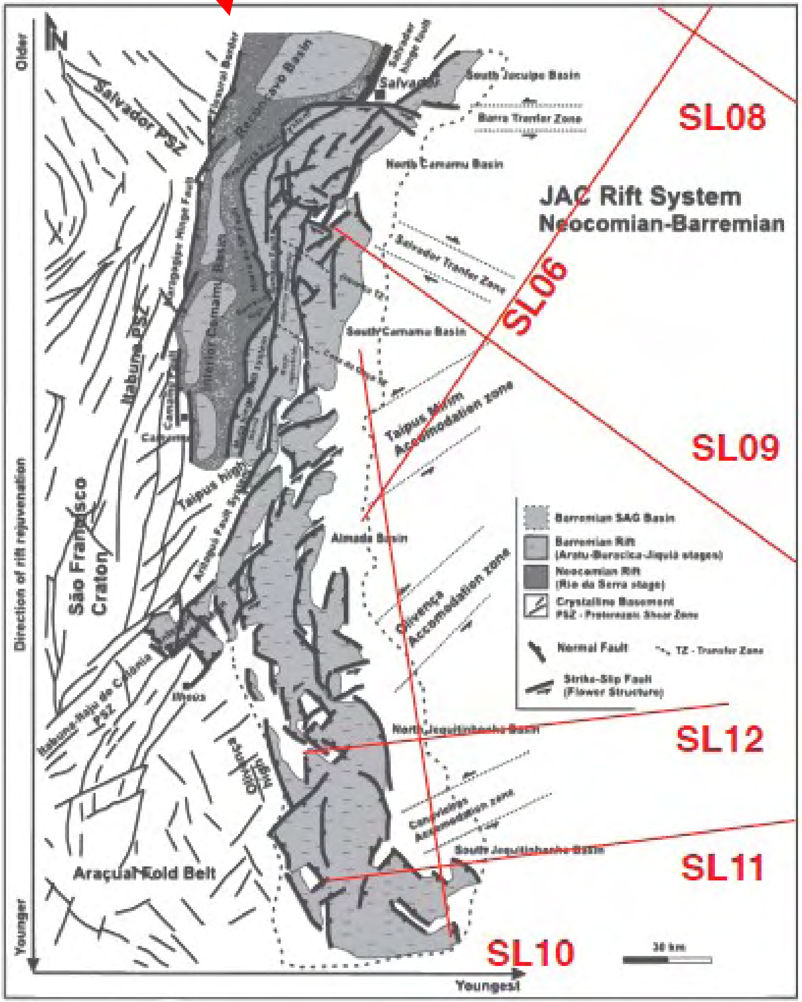


Figure IV.35 - Jequitinhonha-Almada-Camamú rift system architecture and location of SALSA profiles. Adapted from Ferreira et al. [2013].

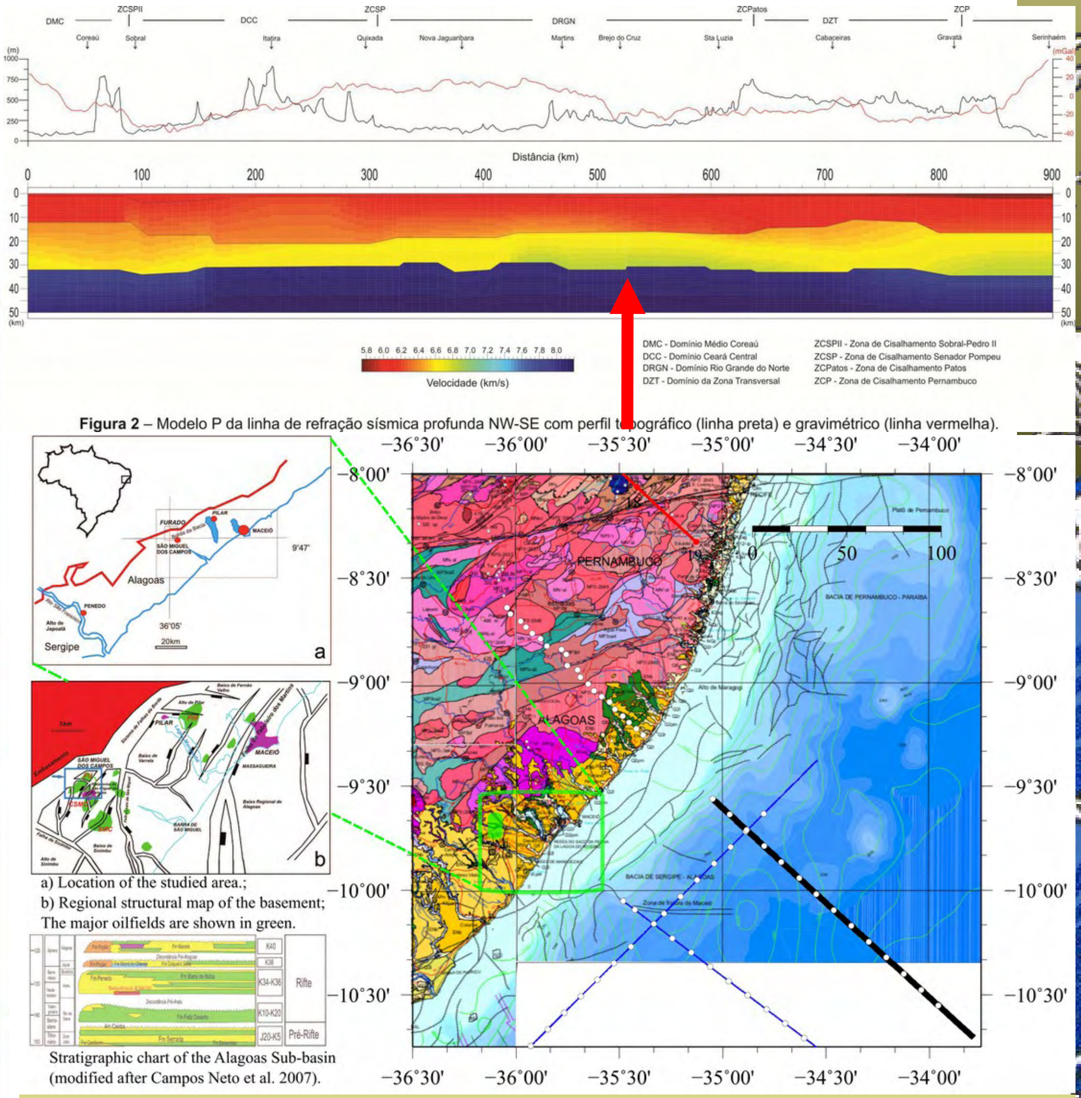


Figure IV.135 - Available gathered onshore information. Alagoas sub-basin structure south of SL04 profile: a) and b) location of the São Miguel - Dos Campos field, and structural map, and c) Stratigraphic chart of the base of the Alagoas Basin (from Borba et al., 2009); d) SL04 location and onland geological map; d) INCT-ET/CNPq on-land wide angle profile (Soares et al. 2010; Tavares et al. 2012; de Lima et al., 2015).

Model Evaluation (Kernel Analysis)

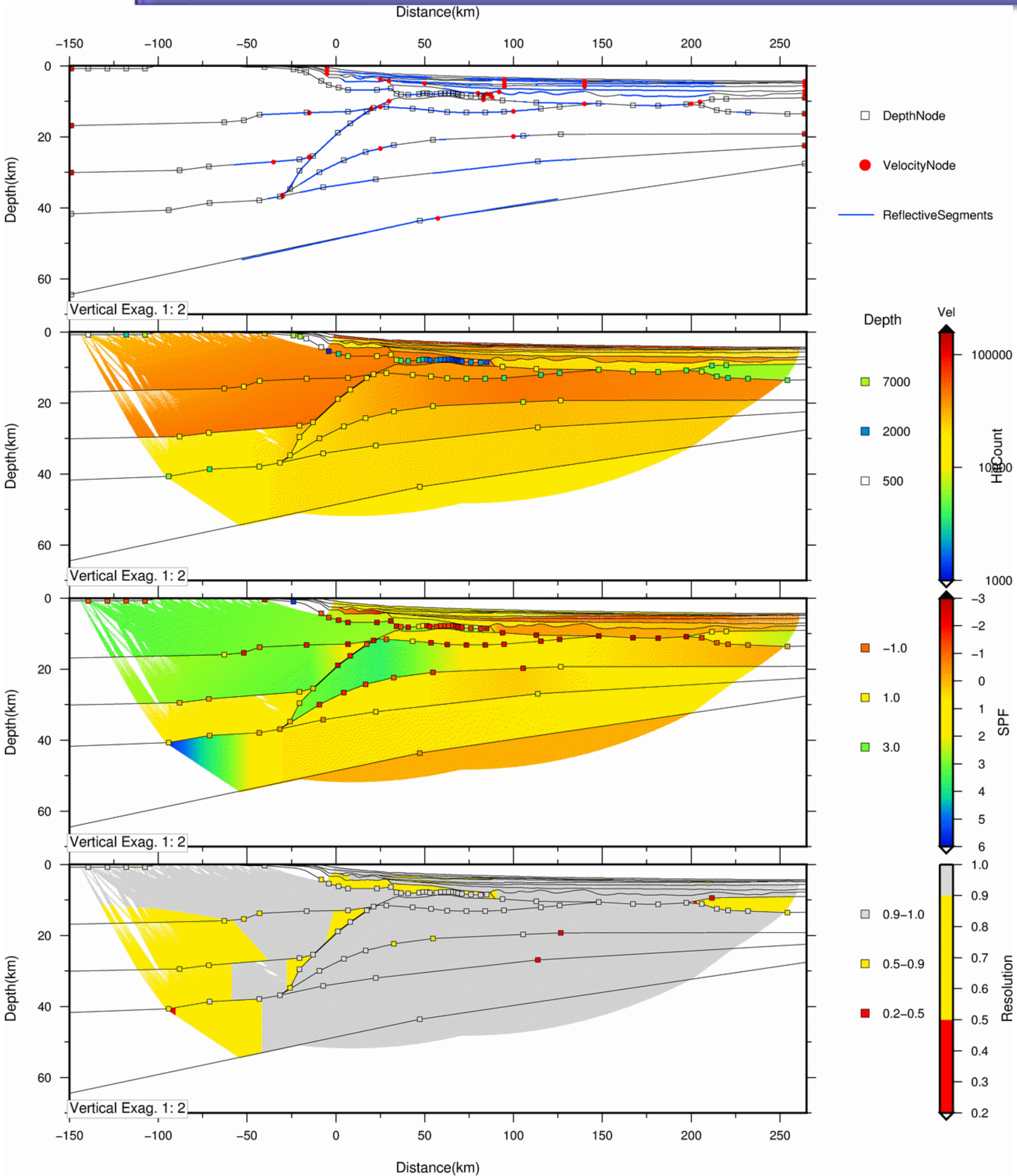


Figure IV.46 - Evaluation of the wide-angle model SL09.

- **a) Model parameterization includes interface depth nodes (squares), top and bottom layer velocity nodes (red circles); interfaces where reflections have been observed on OBS/LSS data are highlighted in blue.**
- **b) Hit-count for velocity (gridded and colored) and depth nodes (colored squares).**
- **c) Smearing from Spread-Point Function (SPF) for velocity (gridded and colored) and depth nodes (colored squares). -> kernel off-diagonal.**

Ex: changing velocity at this node, how much missfit when changing any-other node.

- **d) Resolution of velocity (gridded and colored) and depth nodes (colored squares). Zones that were not imaged are blanked; -> kernel diagonal.**

Ex: how much missfit when changing velocity at this node

Model Uniqueness (Monte-Carlo)

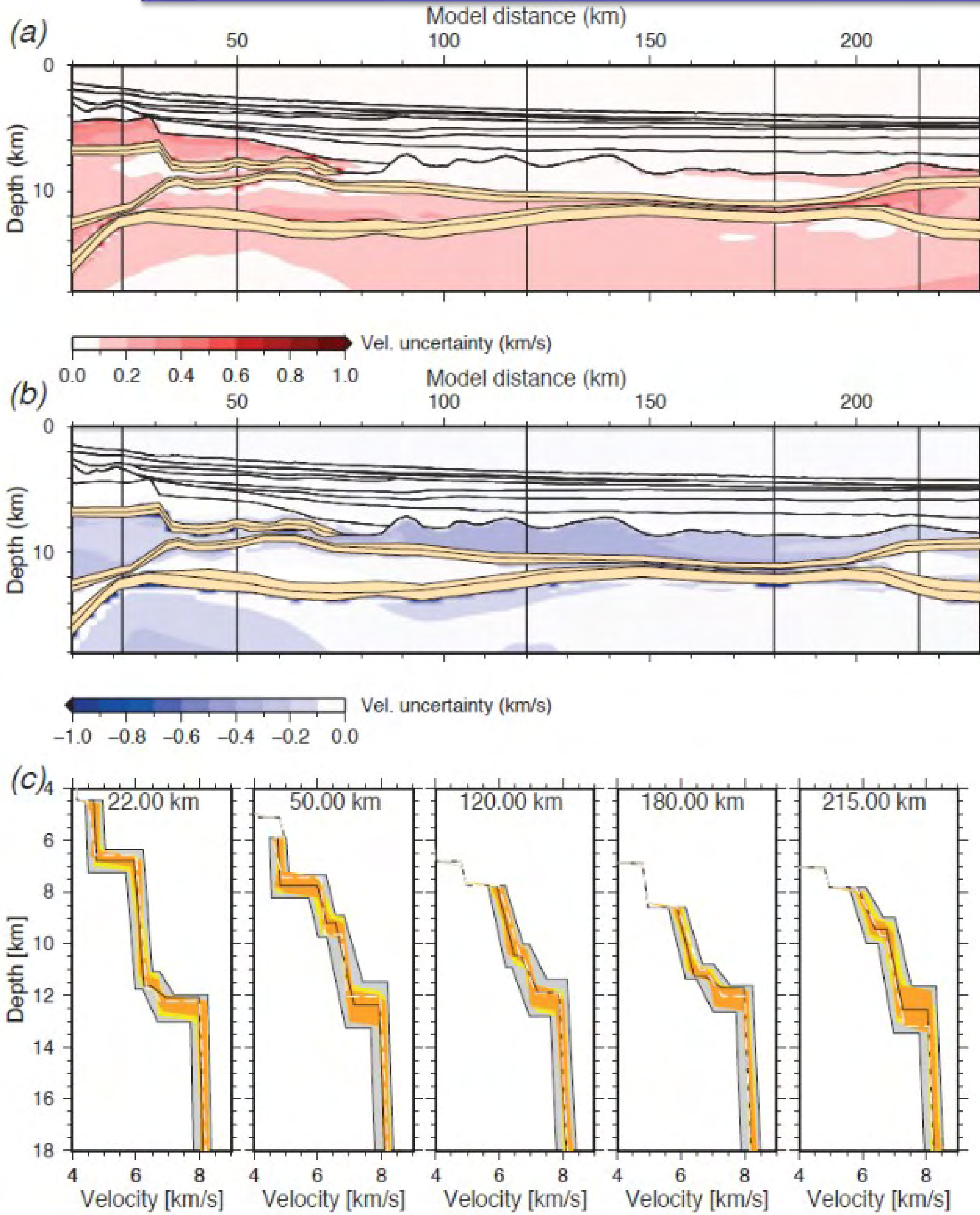
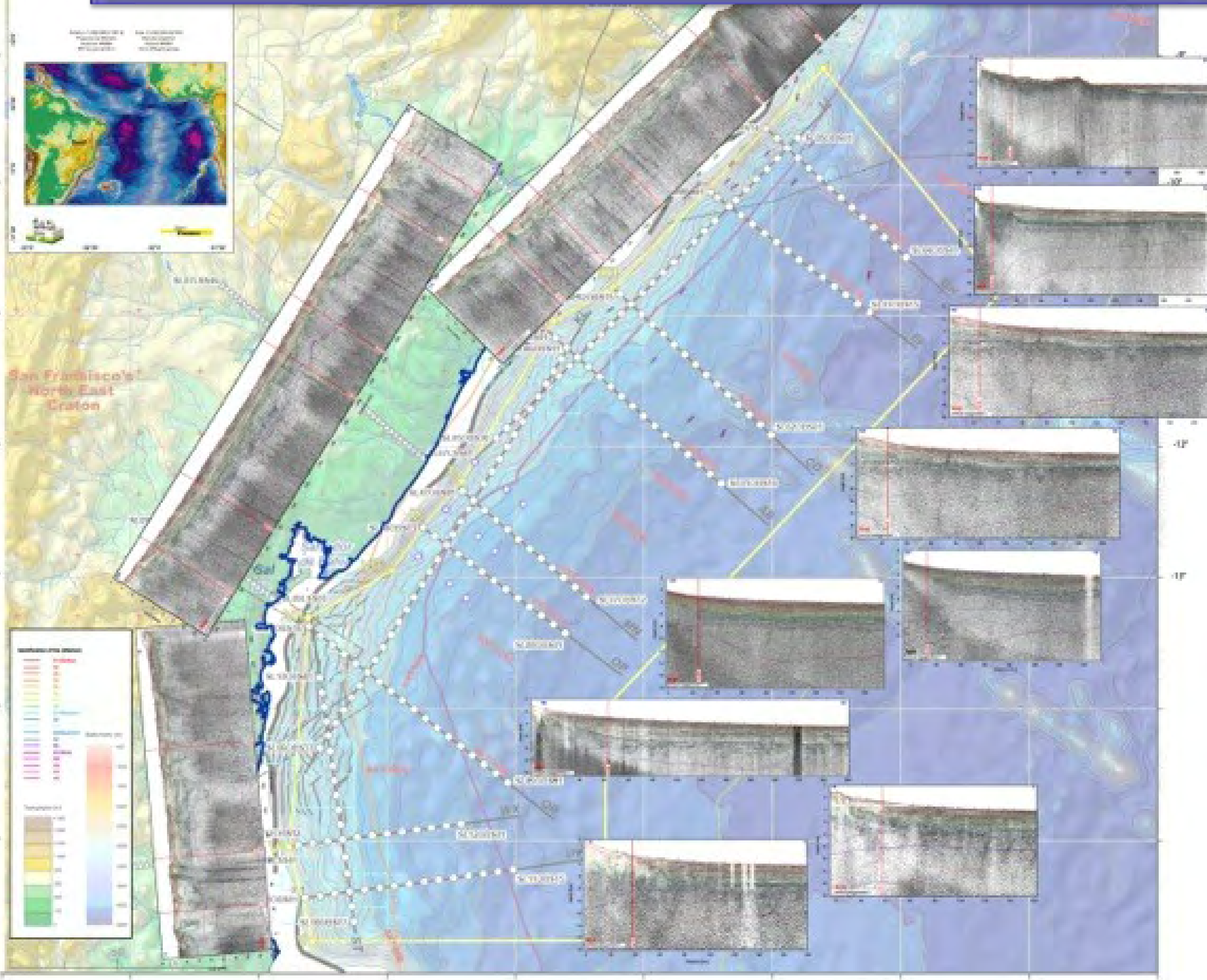


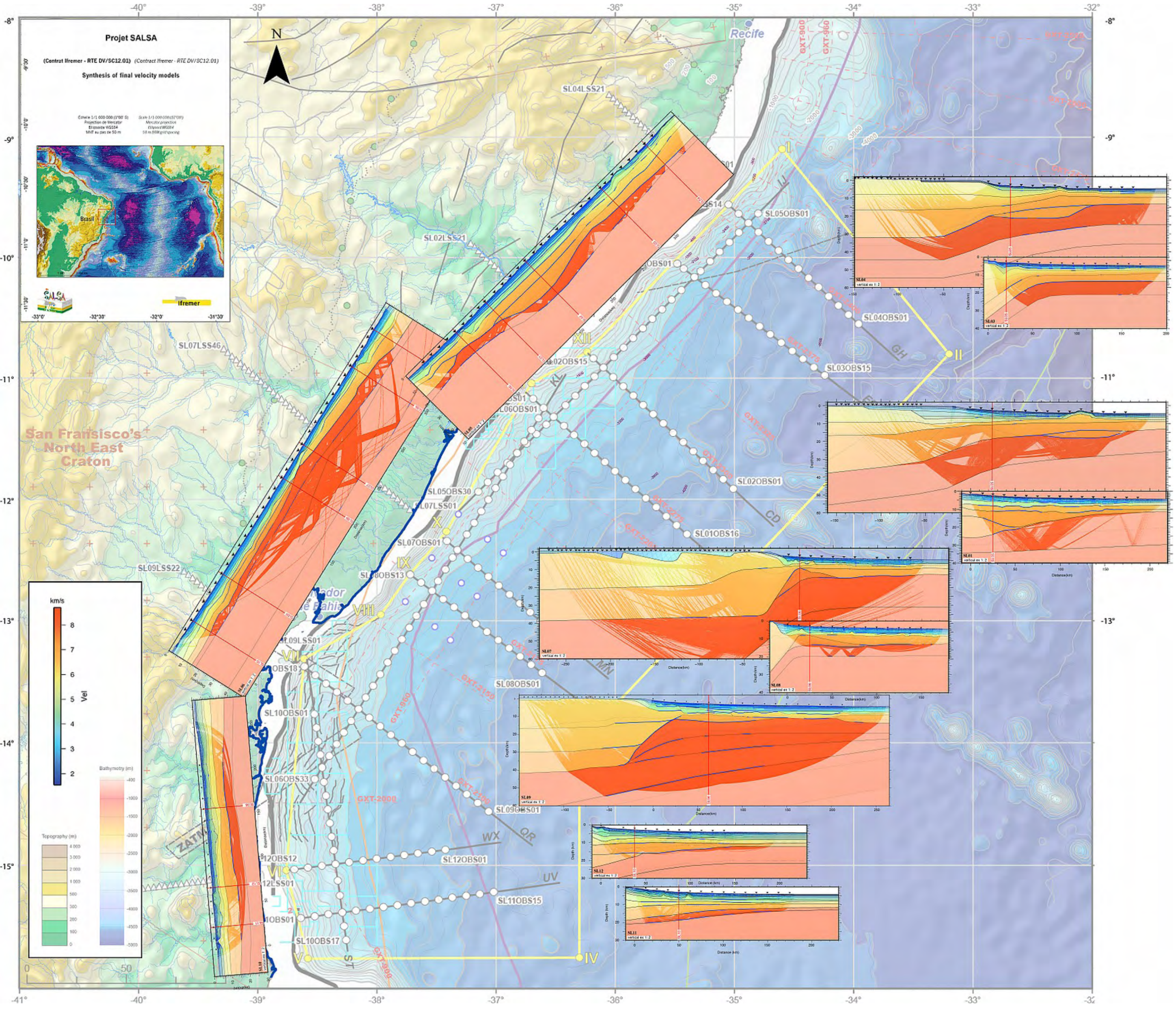
Figure IV.50 Uncertainty estimate according to Loureiro et al., 2016 doi: 10.1016/j.tecto.2016.05.040

- **a) Maximum and b) minimum admissible velocity deviations, built from 13 models within the same quality thresholds as SL09 model. SL09 model's interfaces are indicated by black lines and velocity deviations are coloured according to colour scales. The best random model's interfaces are indicated by dashed lines. Orange regions around interfaces indicate interface depth's fluctuation.**
- **c) Velocity-depth profiles with uncertainty bounds: velocity-depth range of 49968 random models (grey), velocity-depth range of 55 models complying with score of SL09 model (yellow) and velocity-depth range of 13 models complaining with number of rays, chi2 and time root mean-square residual of SL09 model (orange). SL09 model's and best random model's velocity-depth profiles are indicated by continuous black line and dashed white respectively.**

Extend the interpretation « regionally »



Extend the interpretation « regionally »



Construct/control the geological evolution scheme

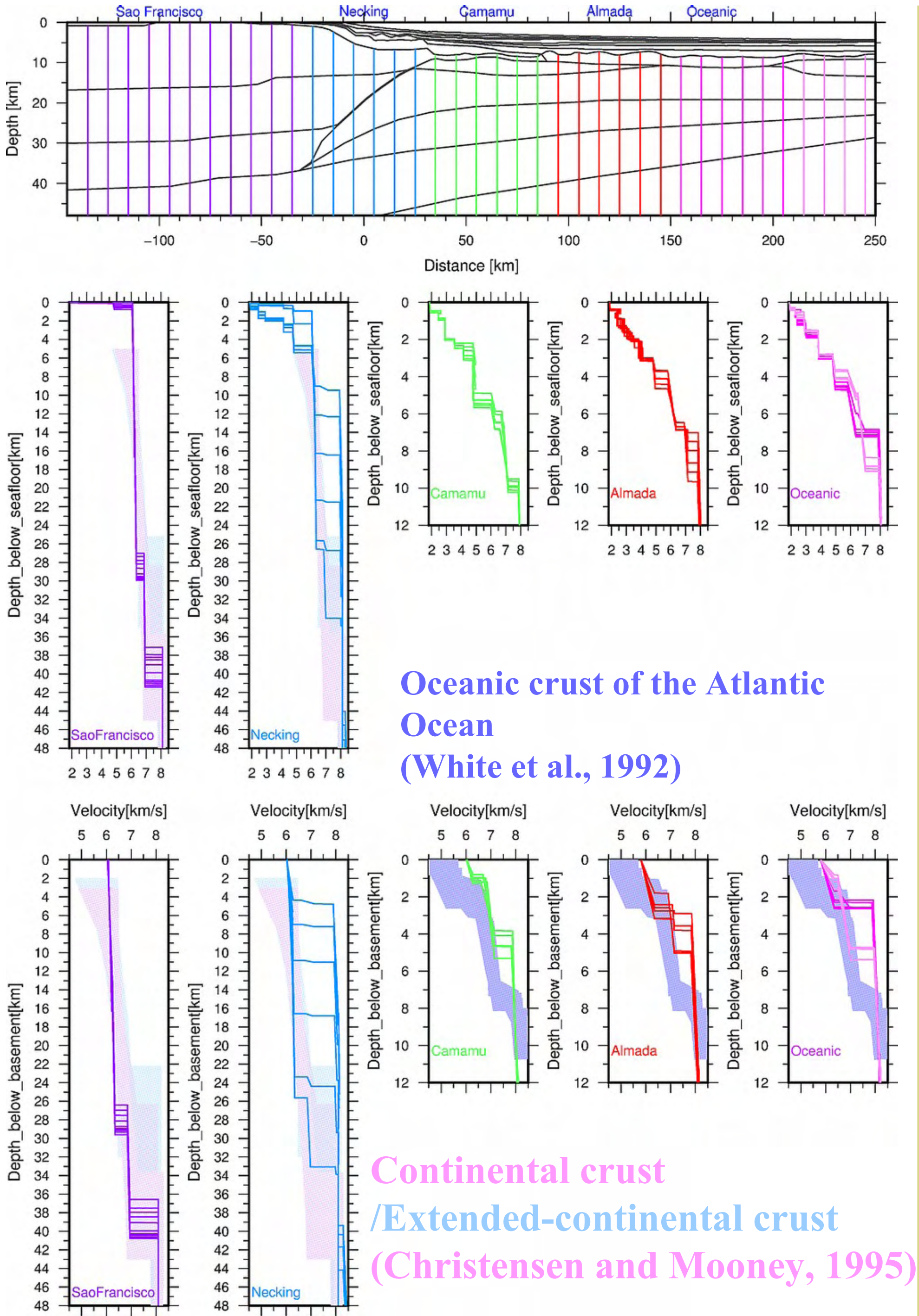


Figure IV.49.

➢**a) Distribution of 1-D velocity profiles extracted from the final P-wave interval velocity model and color coded according to segmentation along the SL09 profile.**

➢**b) P- wave interval velocity as a function of depth seafloor.**

Ex: sedimentary compaction; volcano-sedimantary

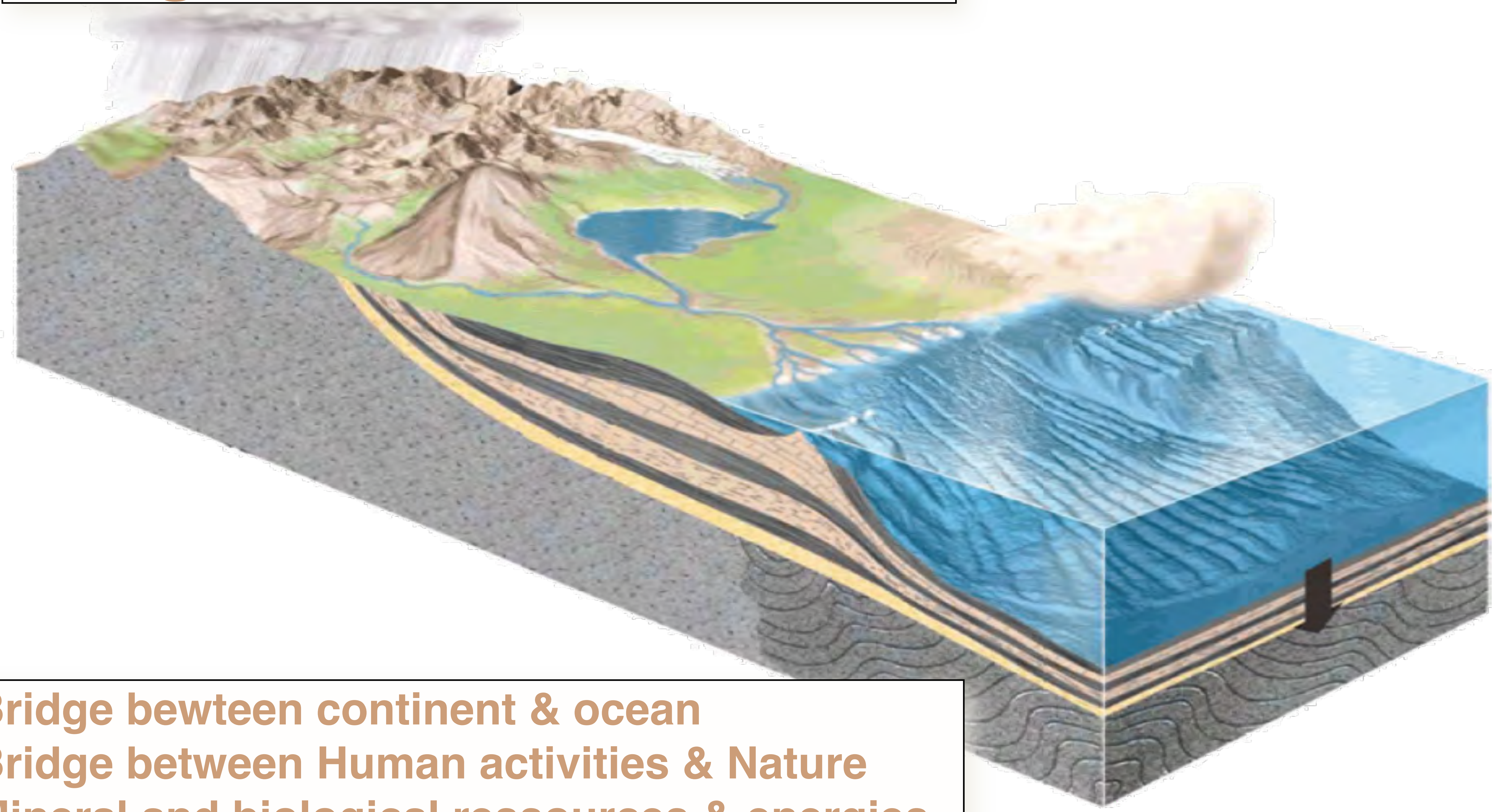
➢**c) P-wave interval velocity as a function of depth basement.**

Ex: extended; exhumed; serpentinized continental crust; proto-oceanic crust

PASSIVE MARGIN AND SEDIMENTARY BASINS

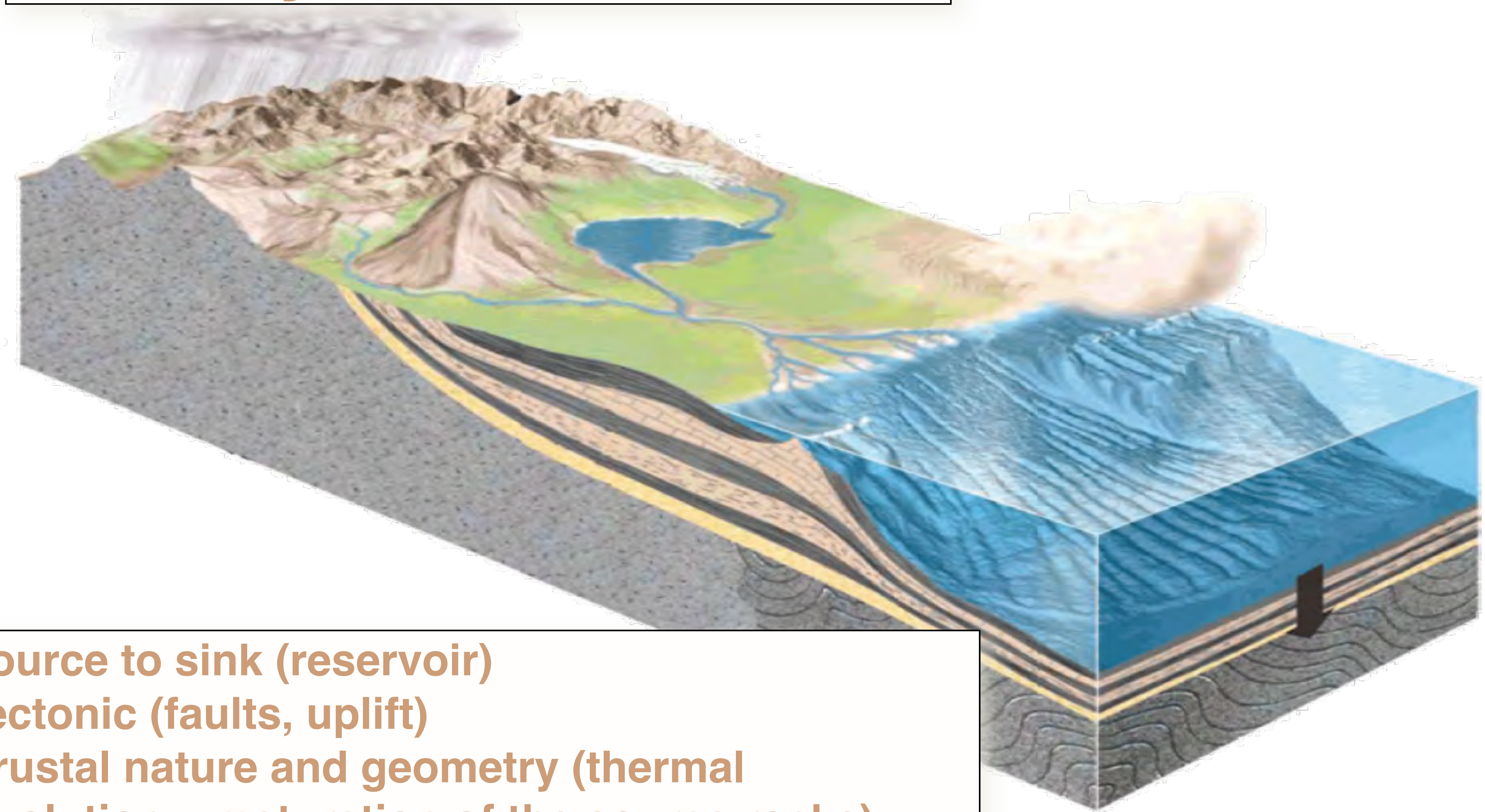
AN HOLISTIC APPROACH

What is a passive margin…



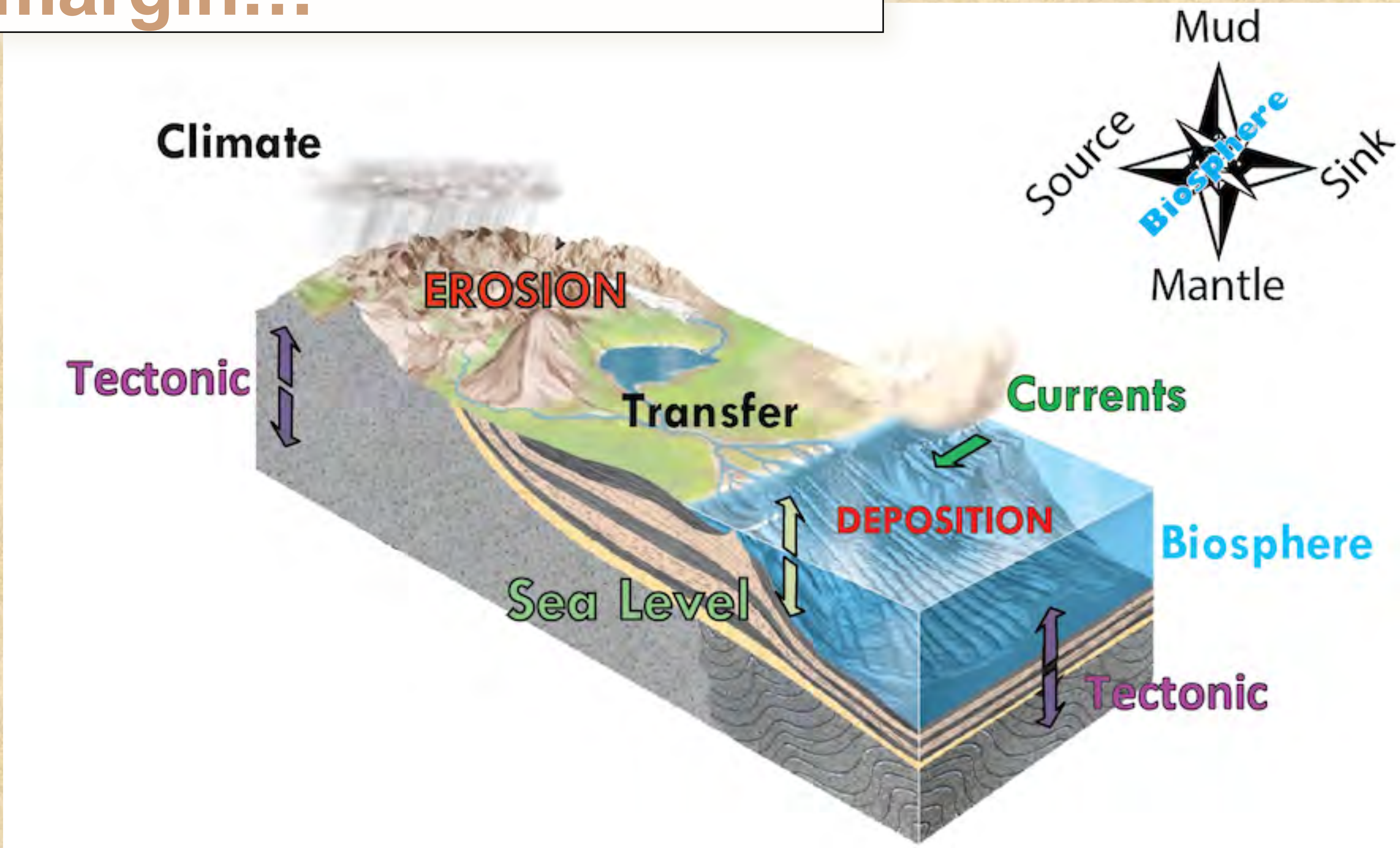
- Bridge bewteen continent & ocean
- Bridge between Human activities & Nature
- Mineral and biological ressources & energies
- Sink of the sediment
- Memory of the earth evolution

For the oil & Gas industry?...



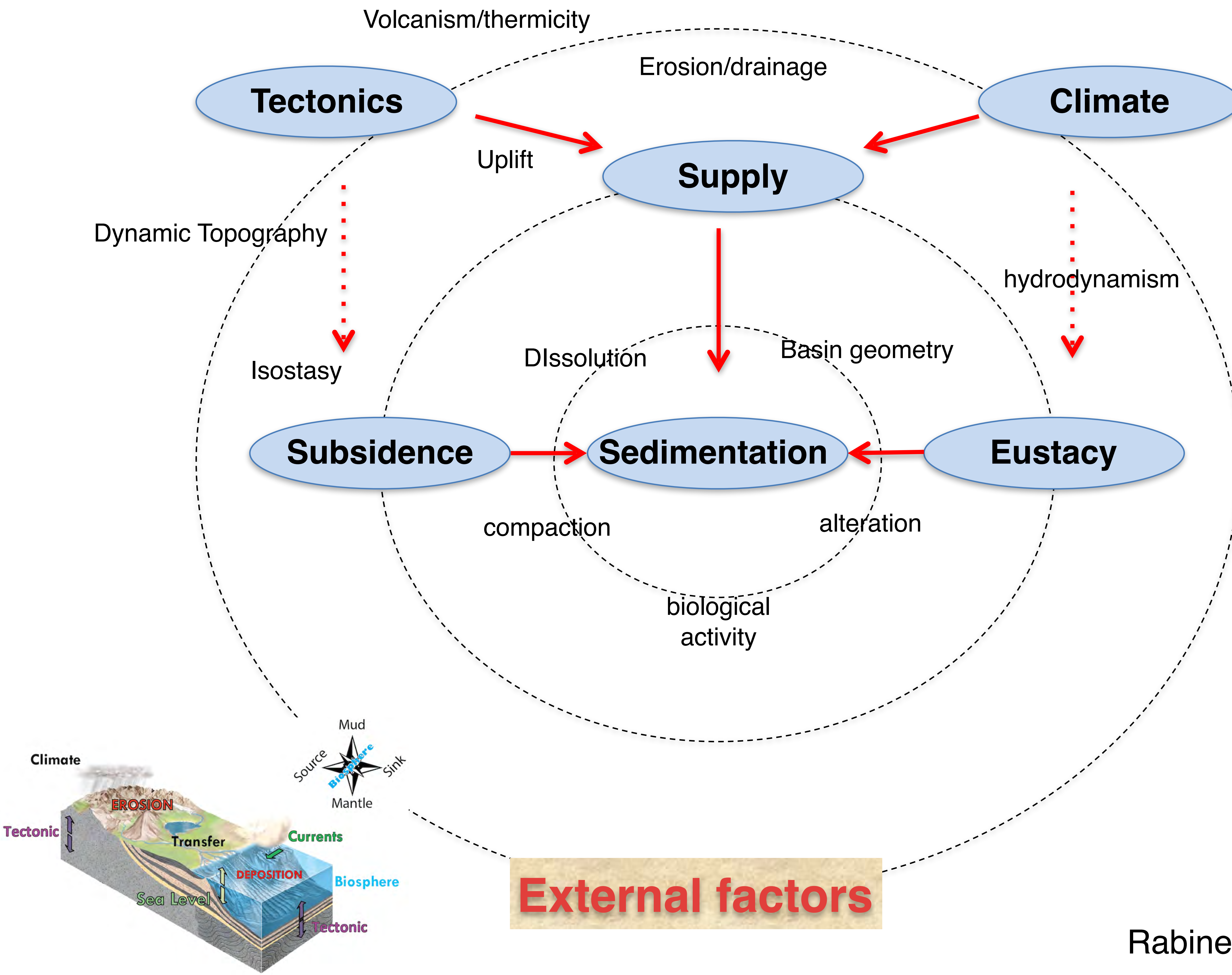
- Source to sink (reservoir)
- Tectonic (faults, uplift)
- Crustal nature and geometry (thermal evolution – maturation of the source rocks)
- Subsidence (bathymetric palaeomarkers and palaeoenvironments)

What is a passive margin...



...Link between deep & surface

Sediment , as the storyteller of the Earth

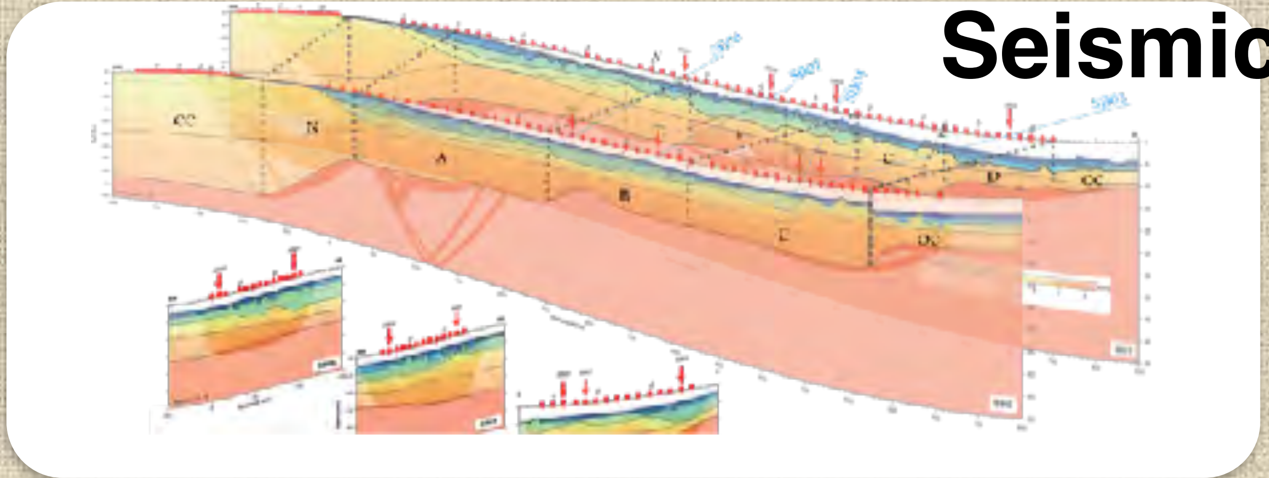


Rabineau, , 2001

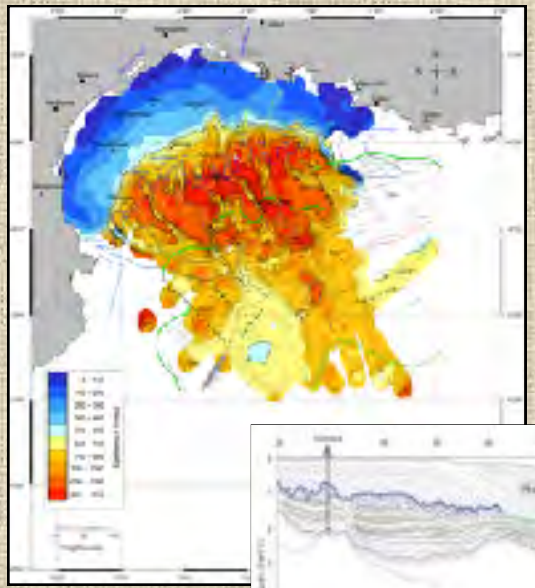
Typology…

Kinematic Reconstruction

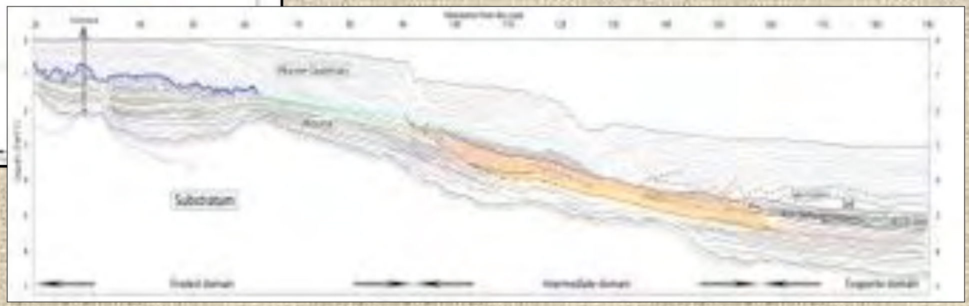
Seismic



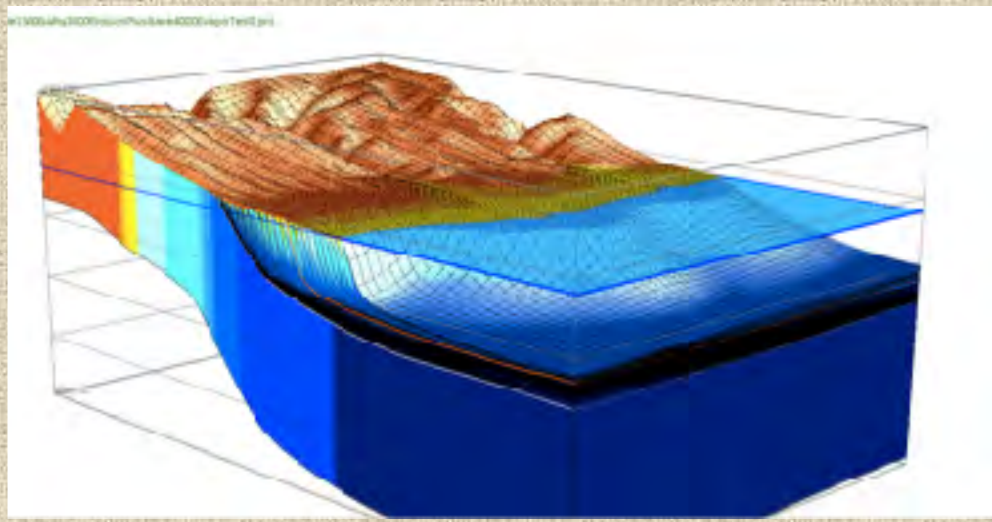
Sedimentary records



Palaeobathymetry
Architecture



Modelling: Falsification tests



First Models : conceptual models...

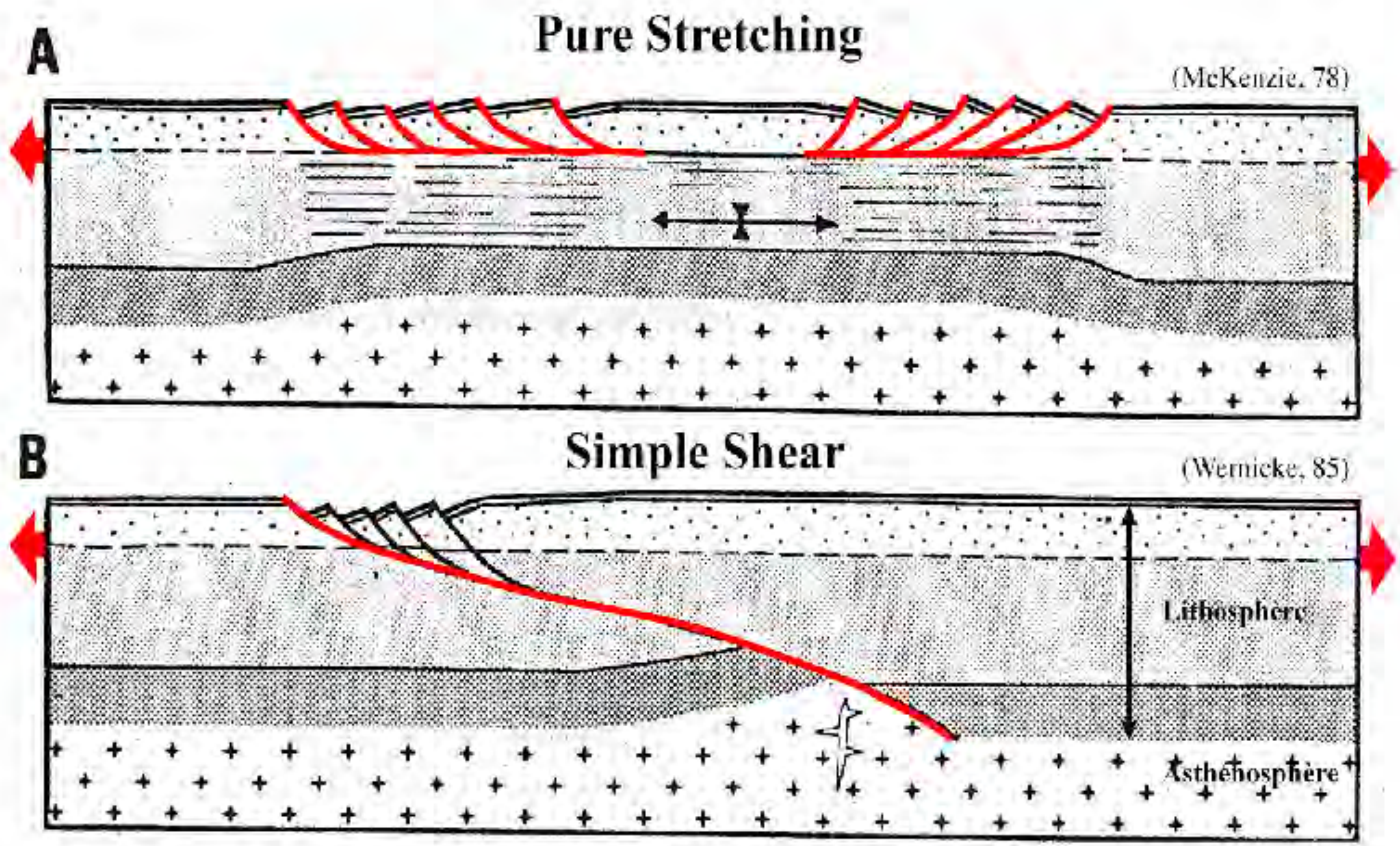
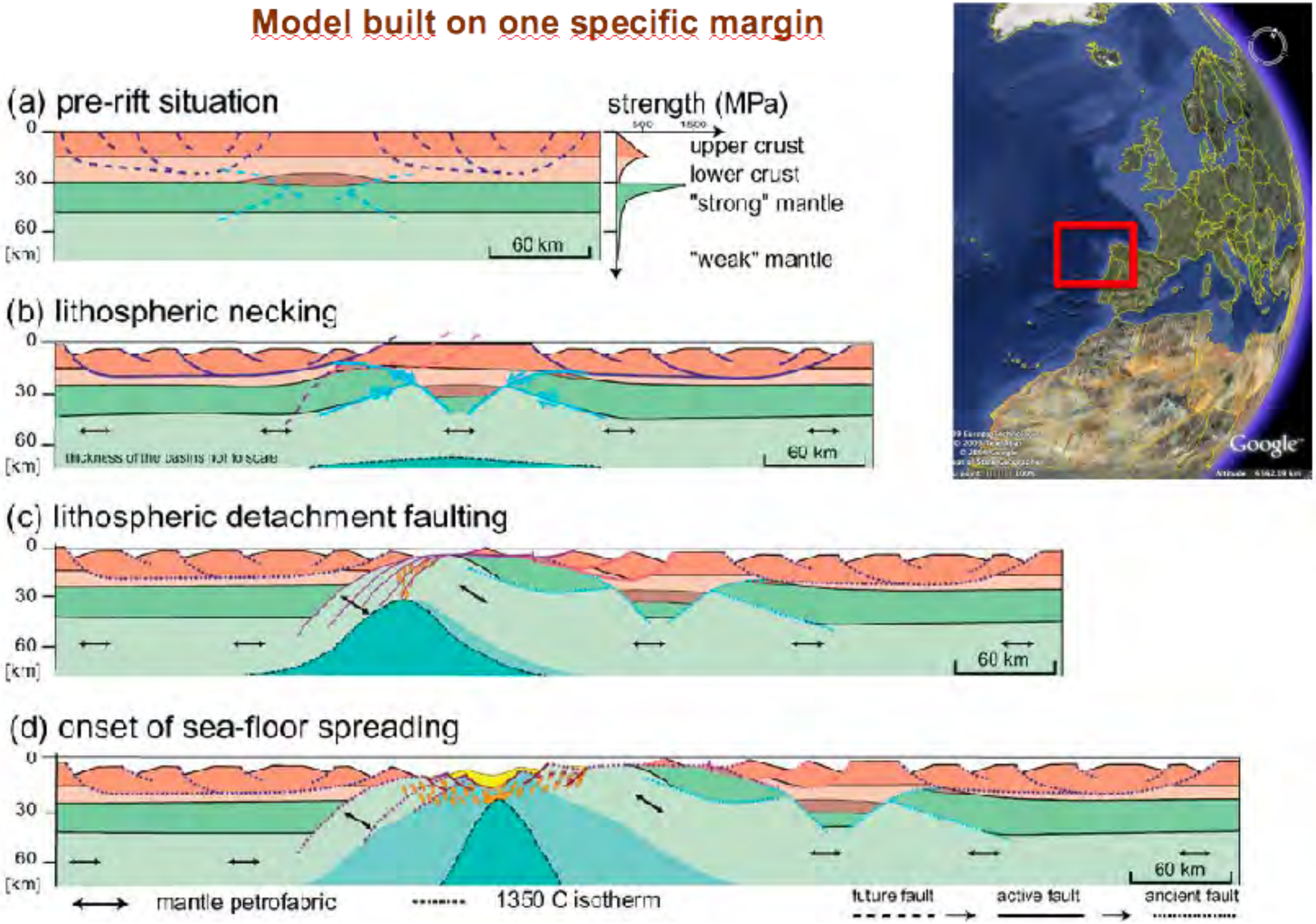


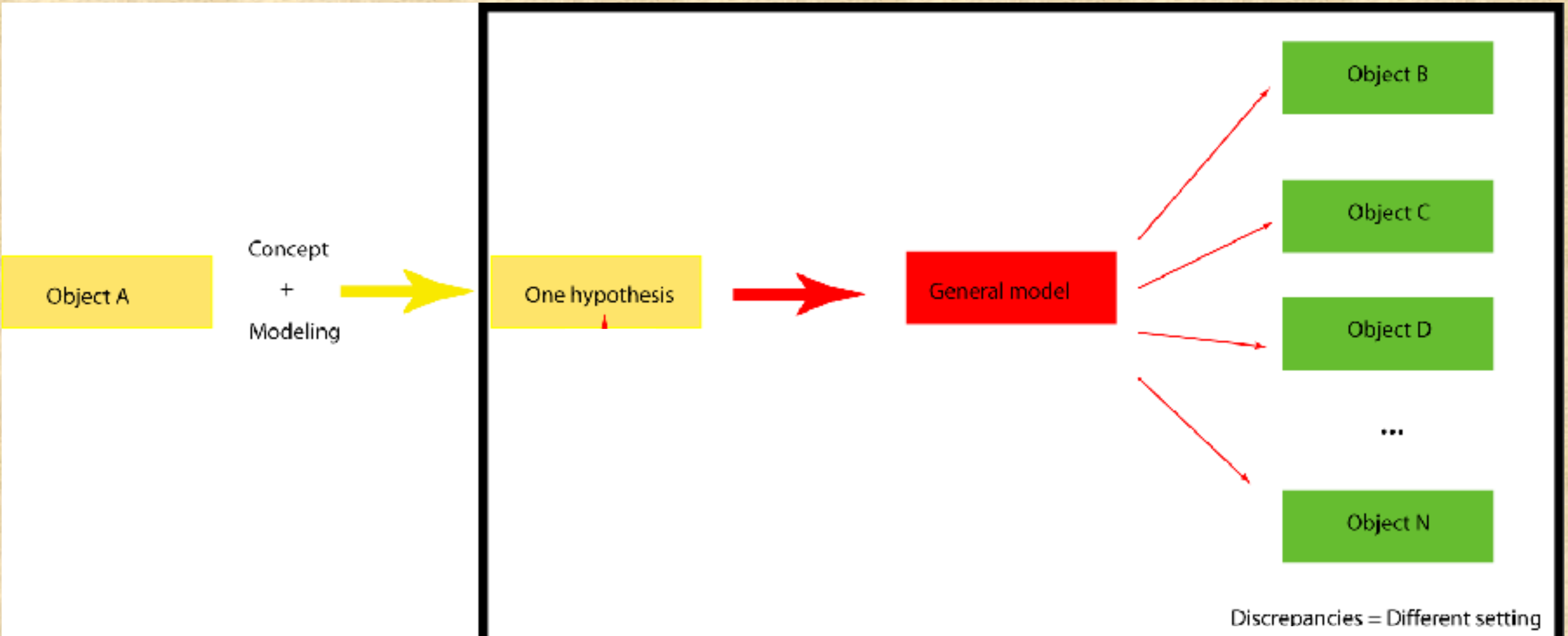
Figure modifiée d'après Lister et al. 86

Model built on one specific margin



Manatschal et al, 2004, After Boillot et al, 1980

One way approach….

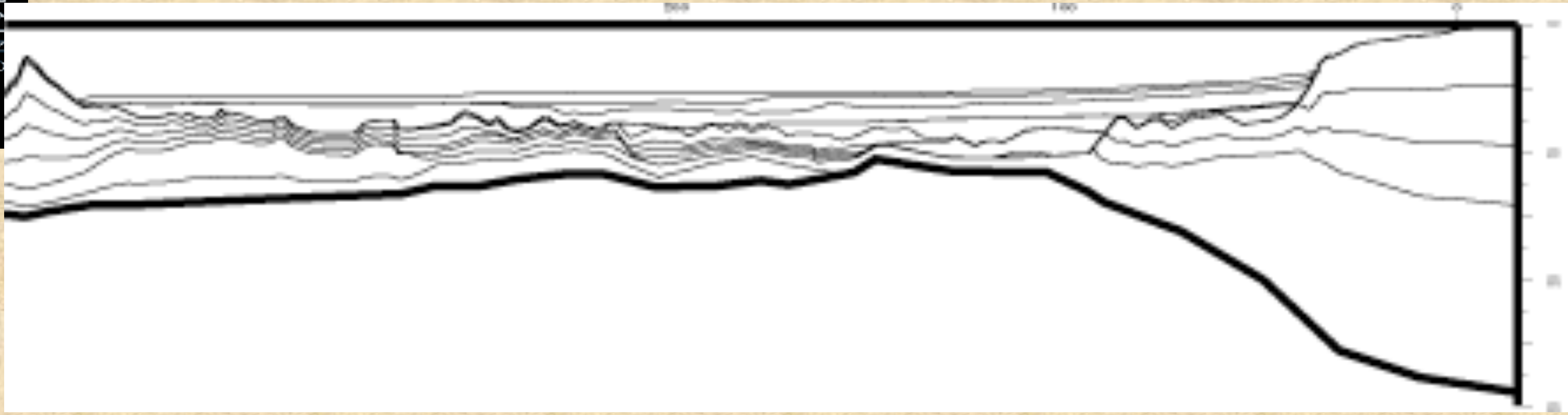


1- Is Object A representative?
2- Are all characteristics commun?
3- Real danger to become Model dependent

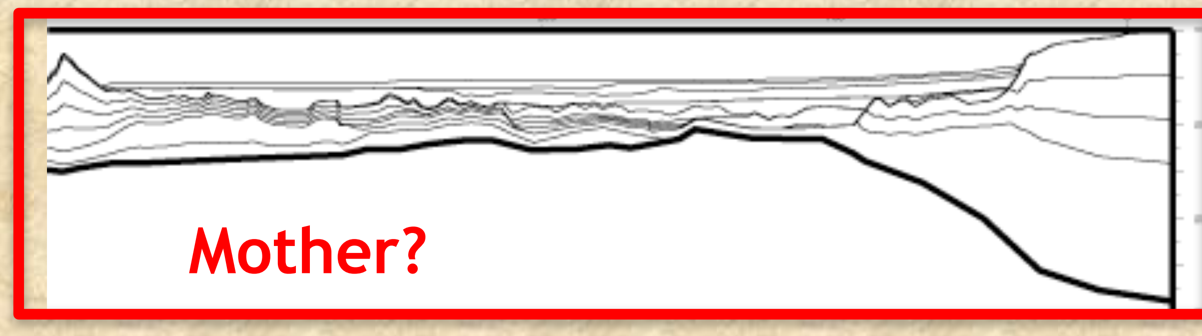
D. Aslanian

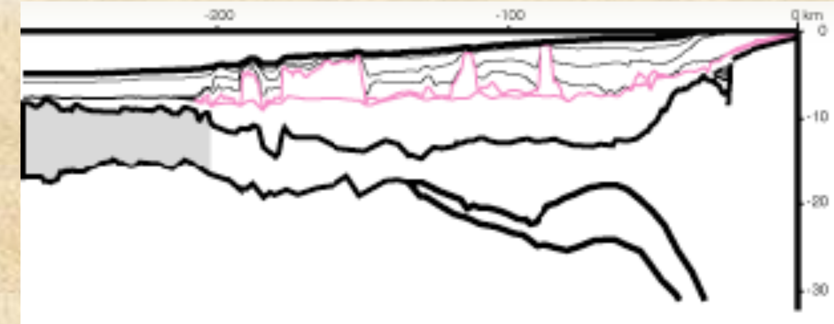
WHAT IS A PASSIVE MARGIN?

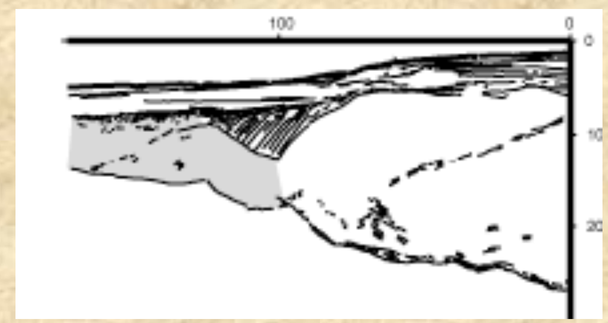
The « Mother »

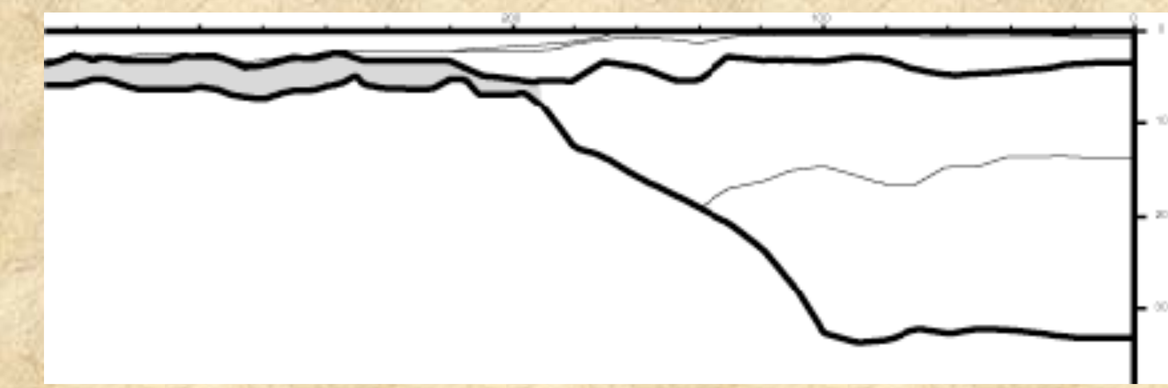


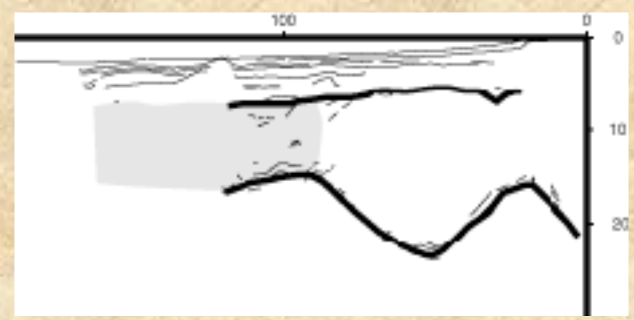
What is a passive margin?…a virtual walk

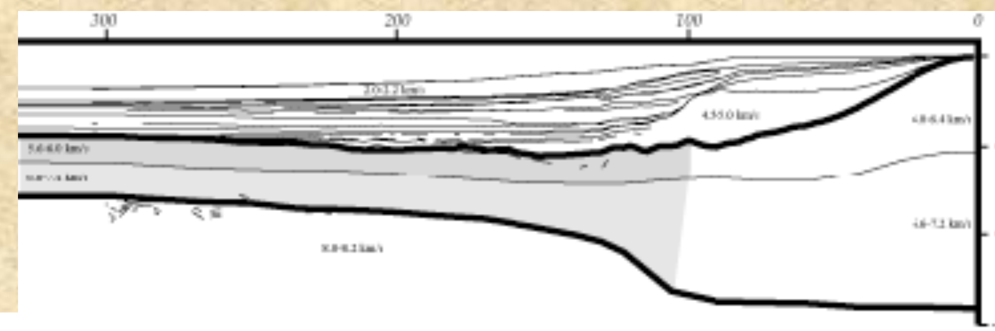




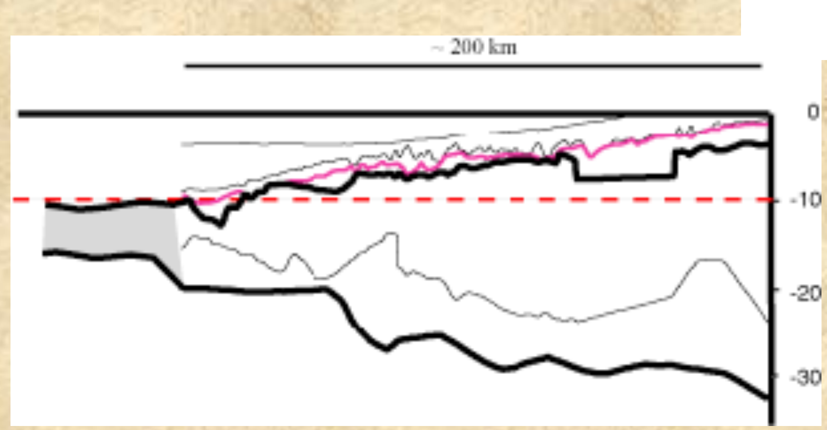


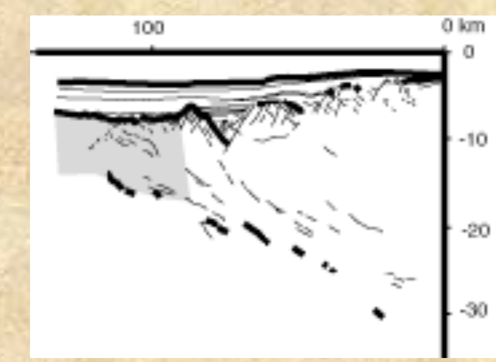




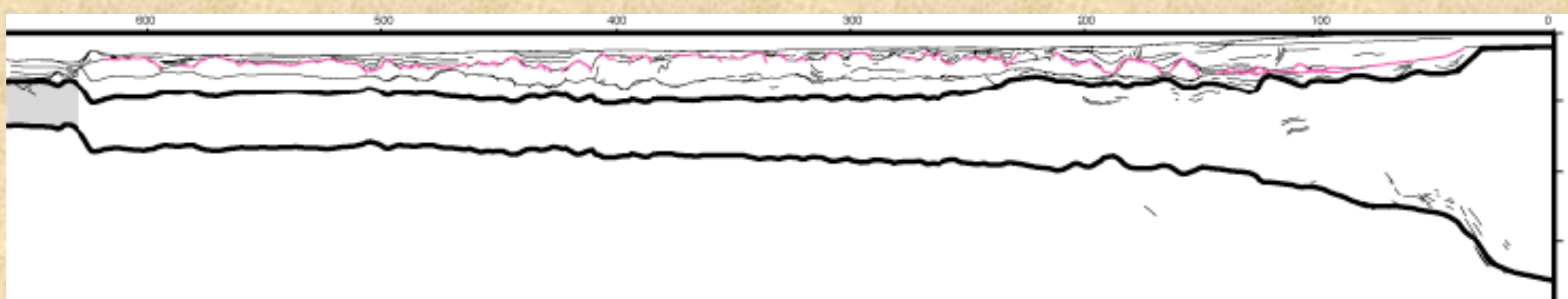


Moulin & Aslanian, 2006



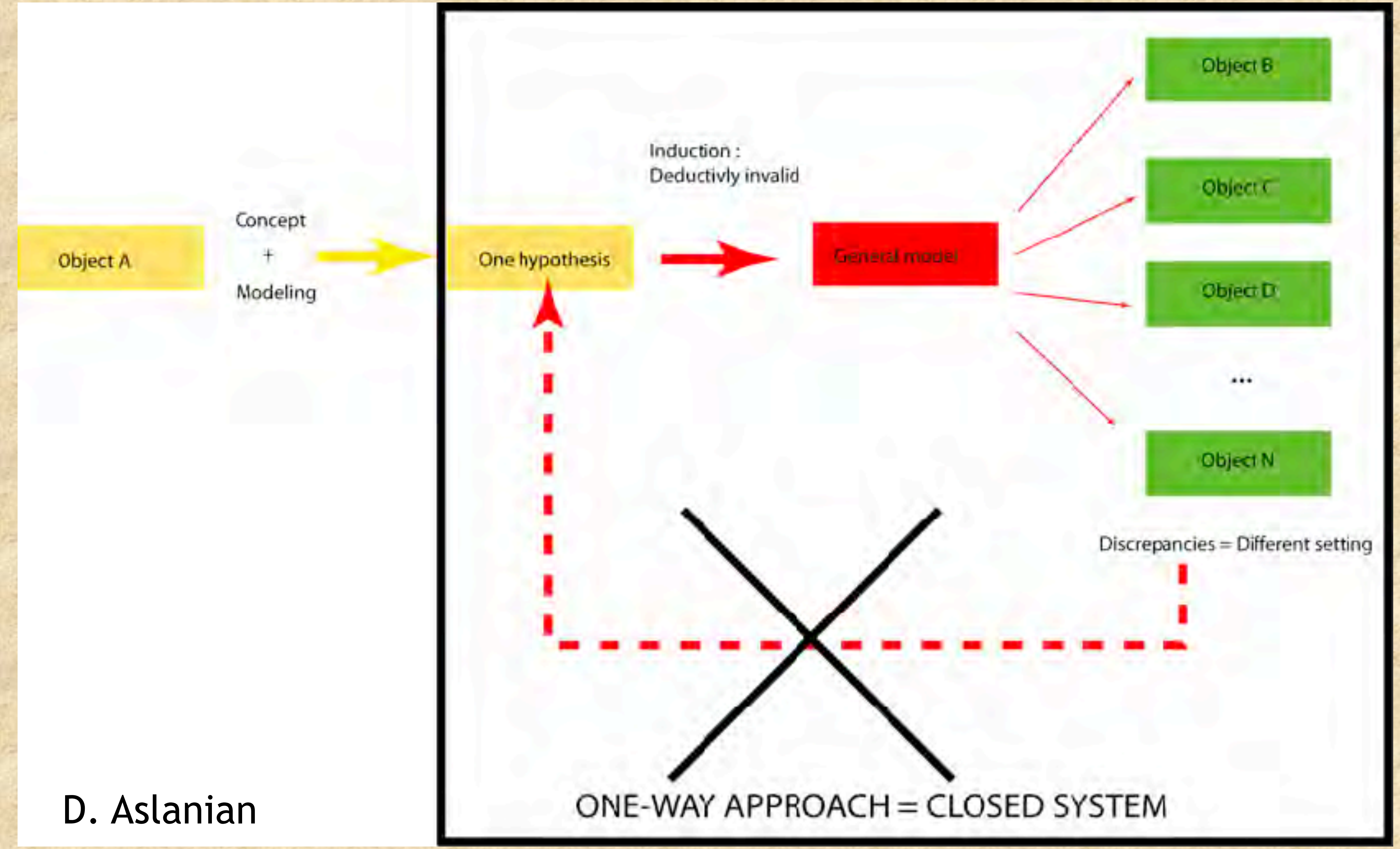


UNIQUE THINNING PROCESS?



Port Elizabeth 16-20 July 2018

Conclusion…



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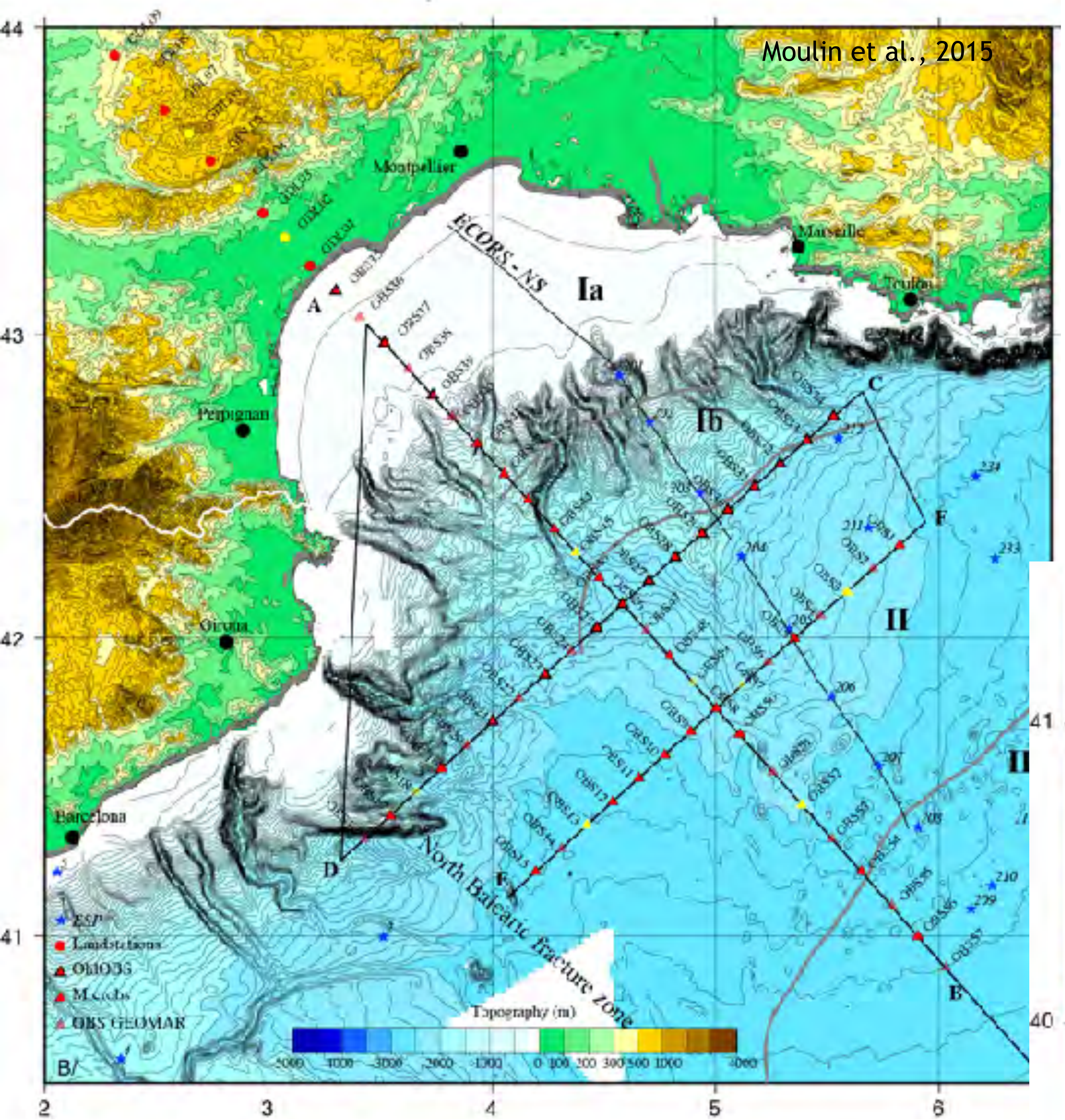
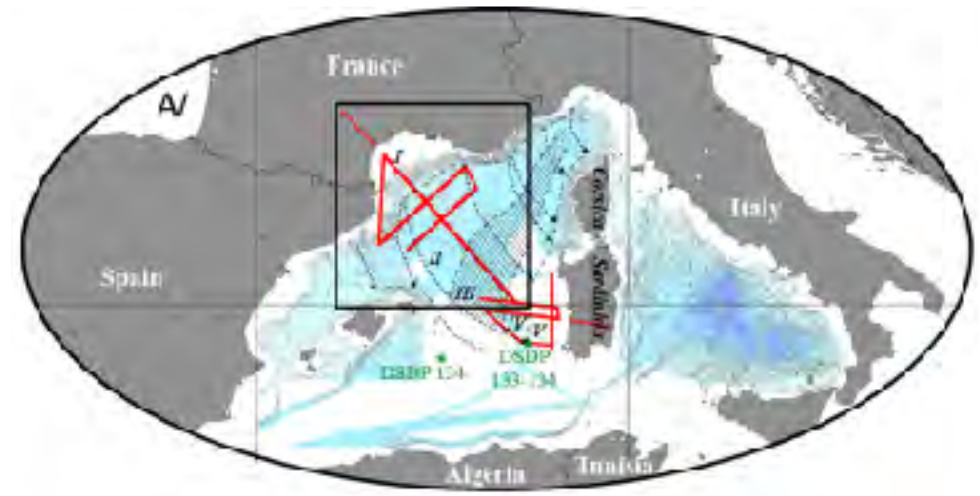
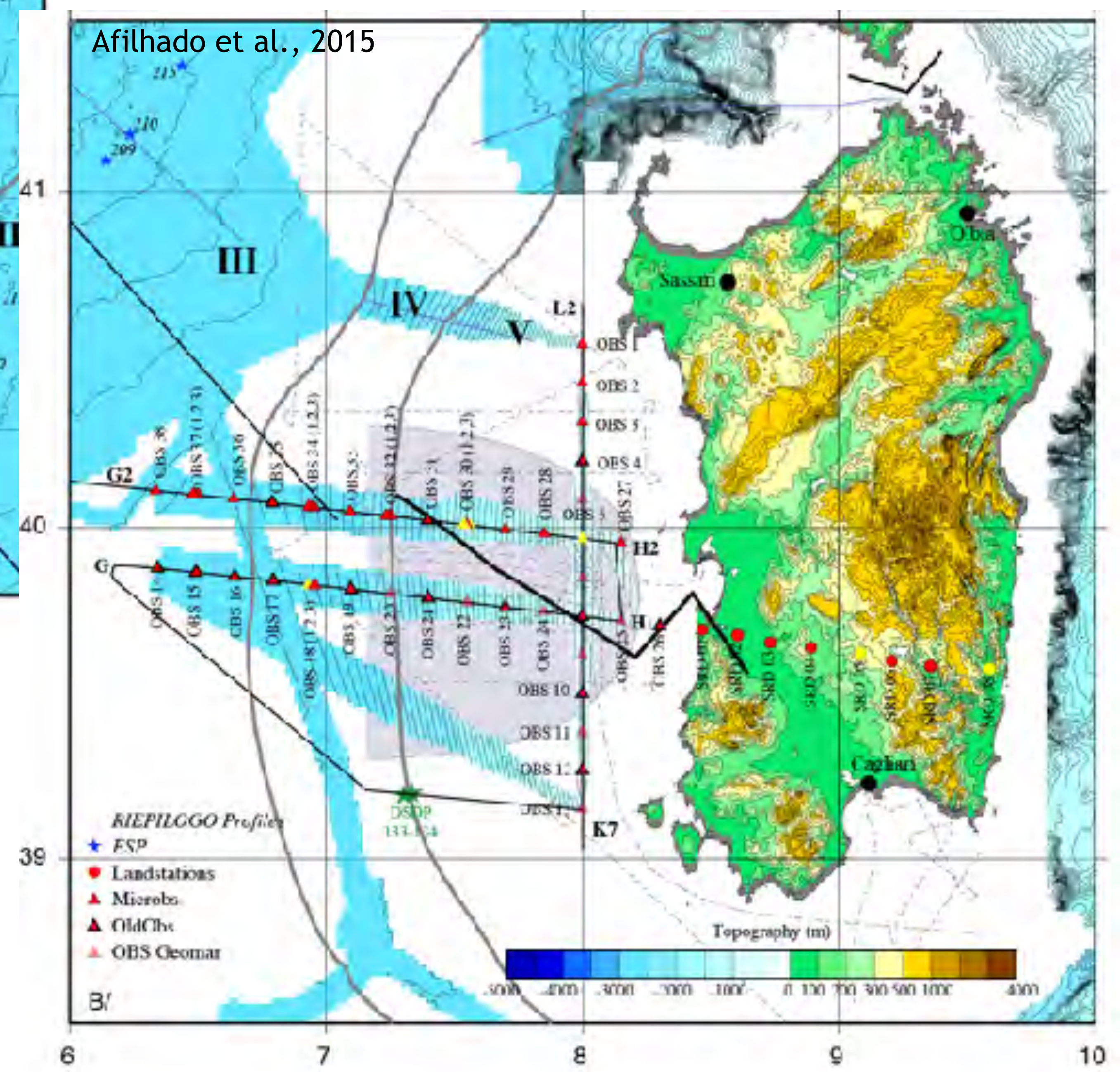
The Sardinia Experiment



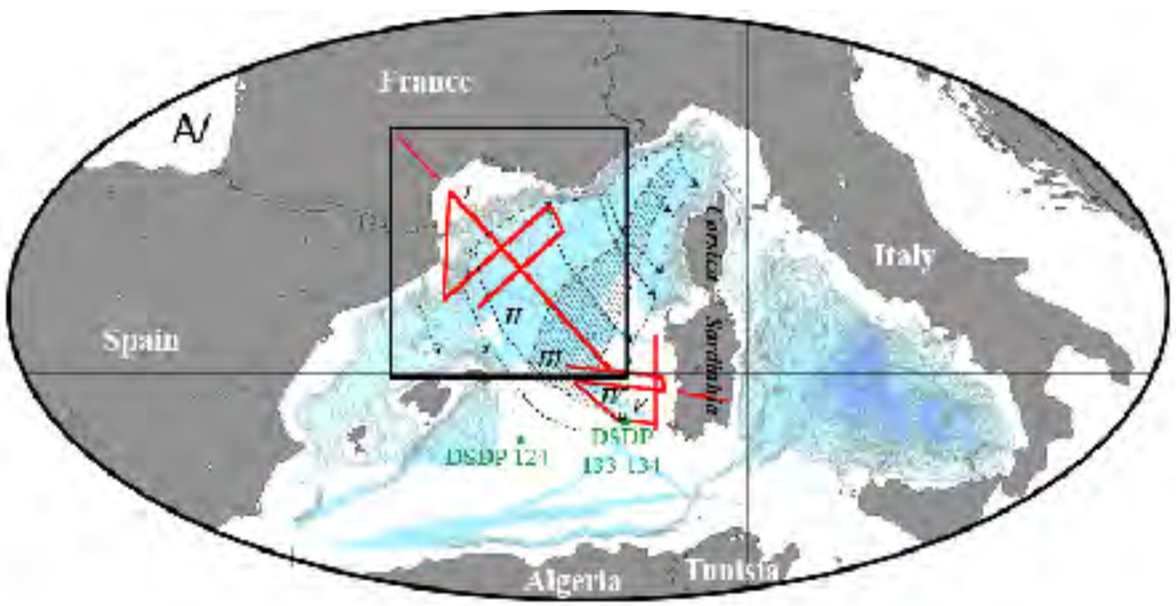


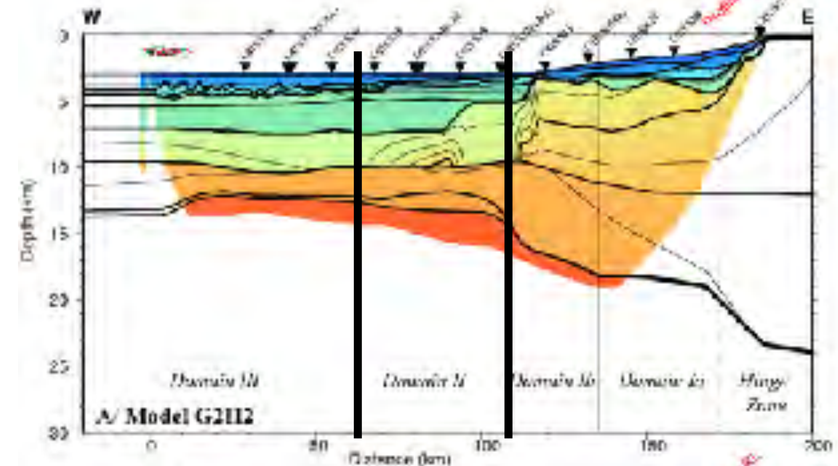


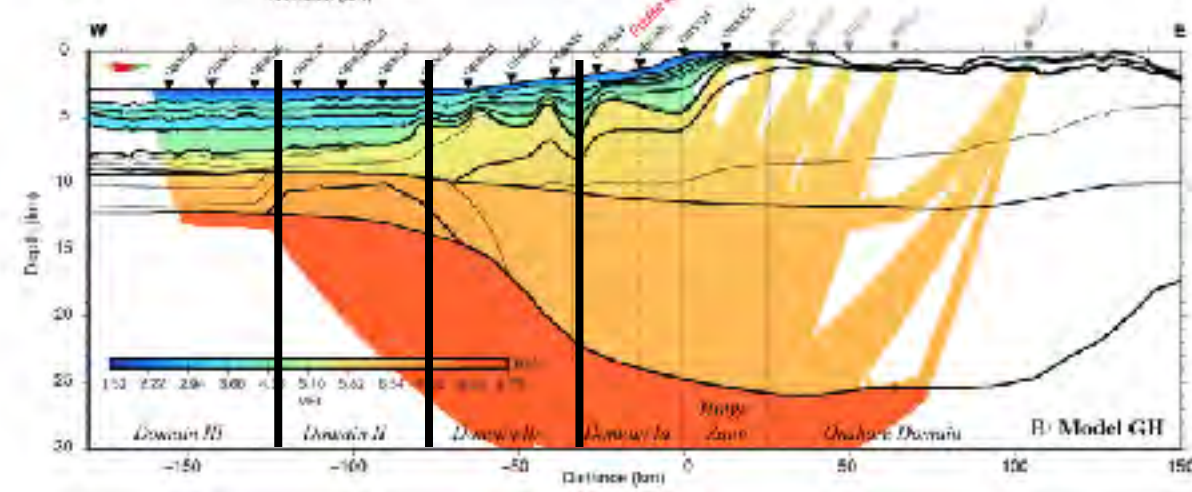
Moulin et al., 2015, Afilhado et al., 2015

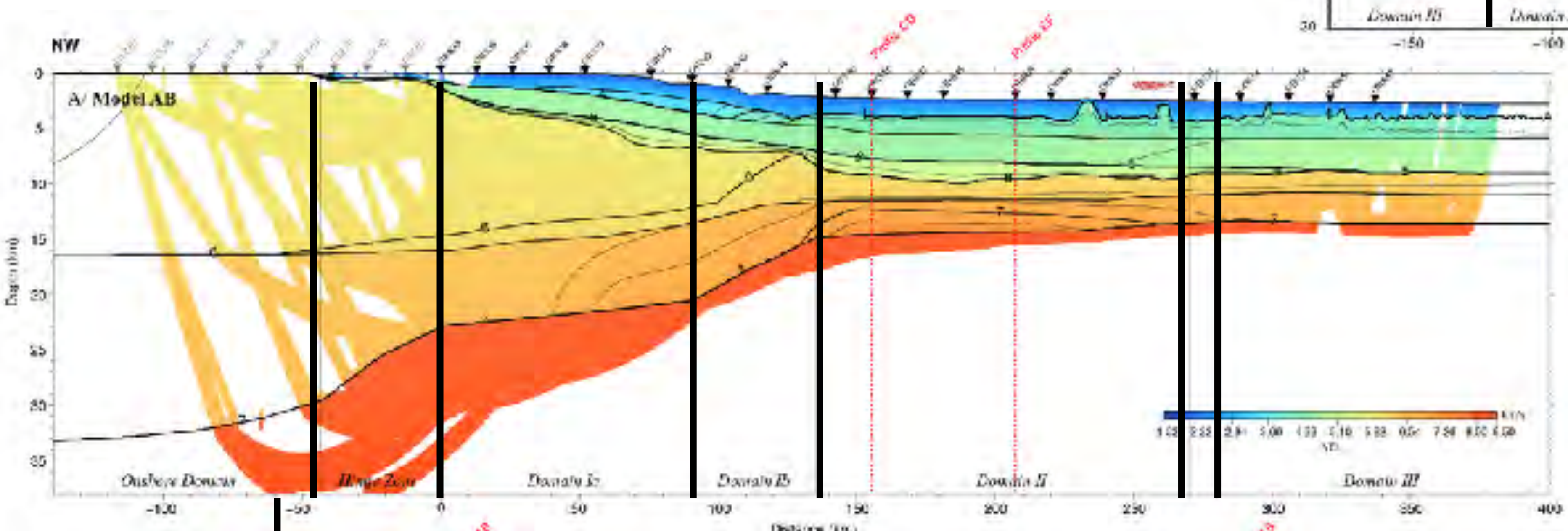
West Sardinian Margin

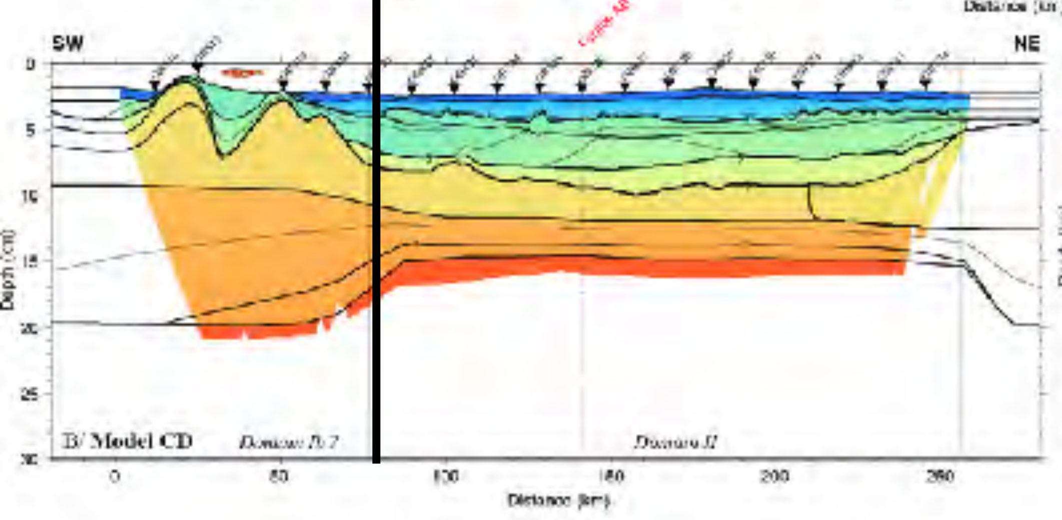
Afilhado et al., 2015

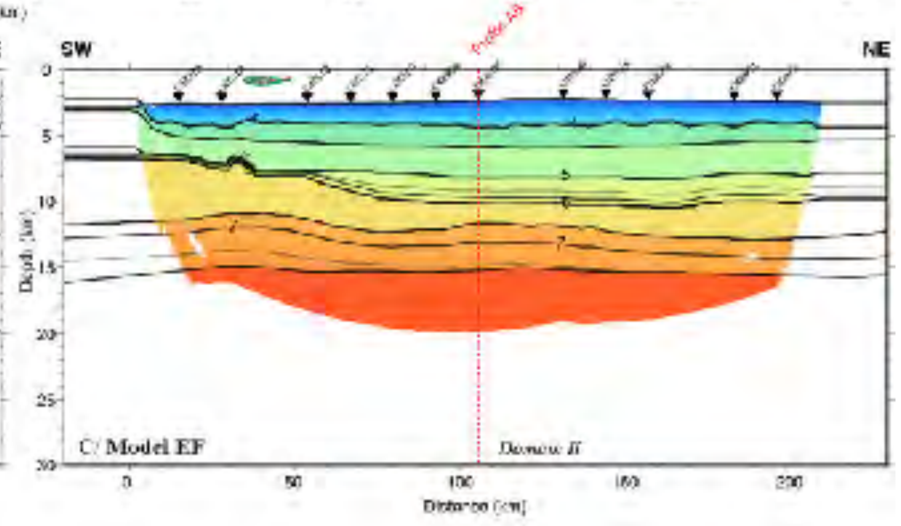








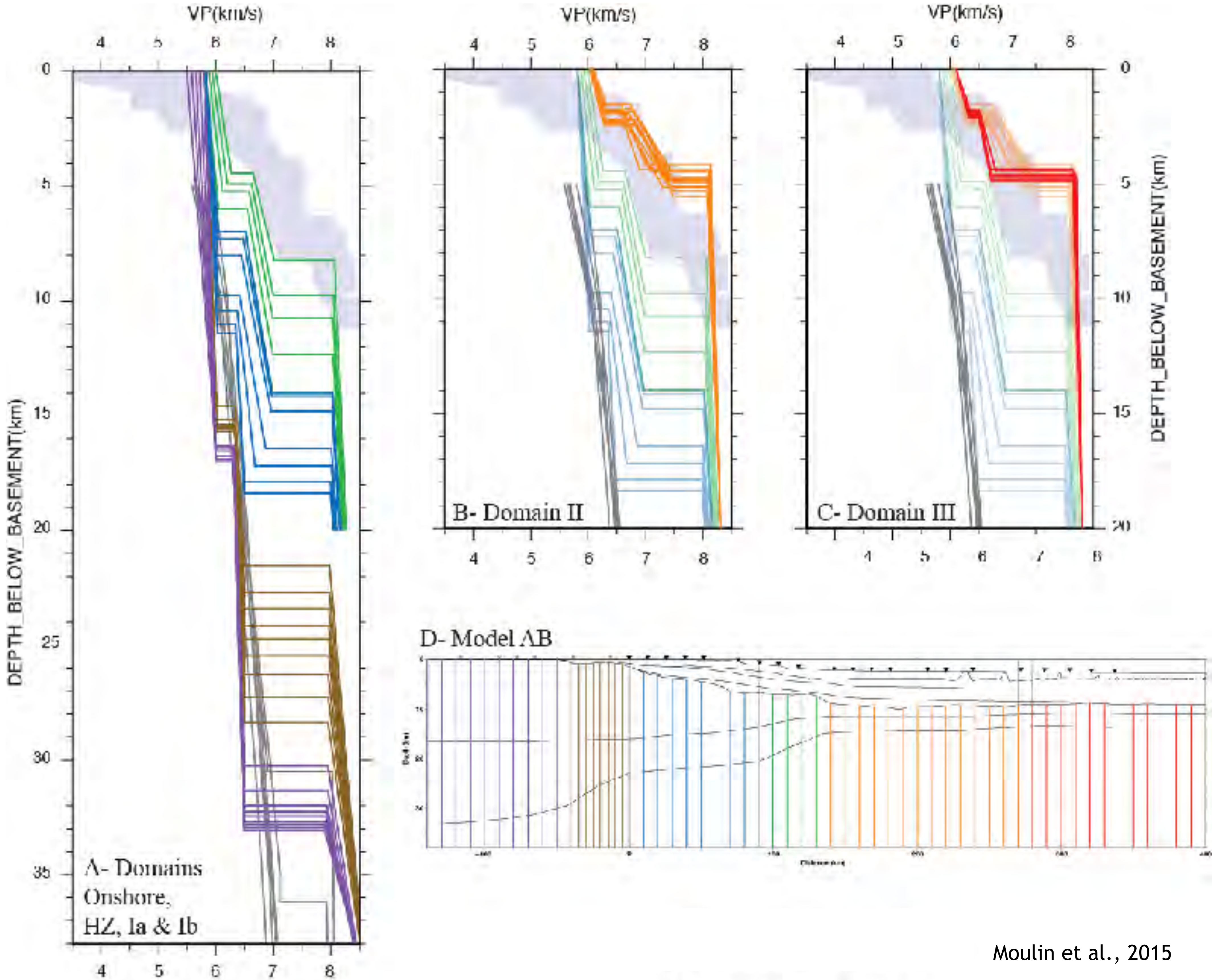




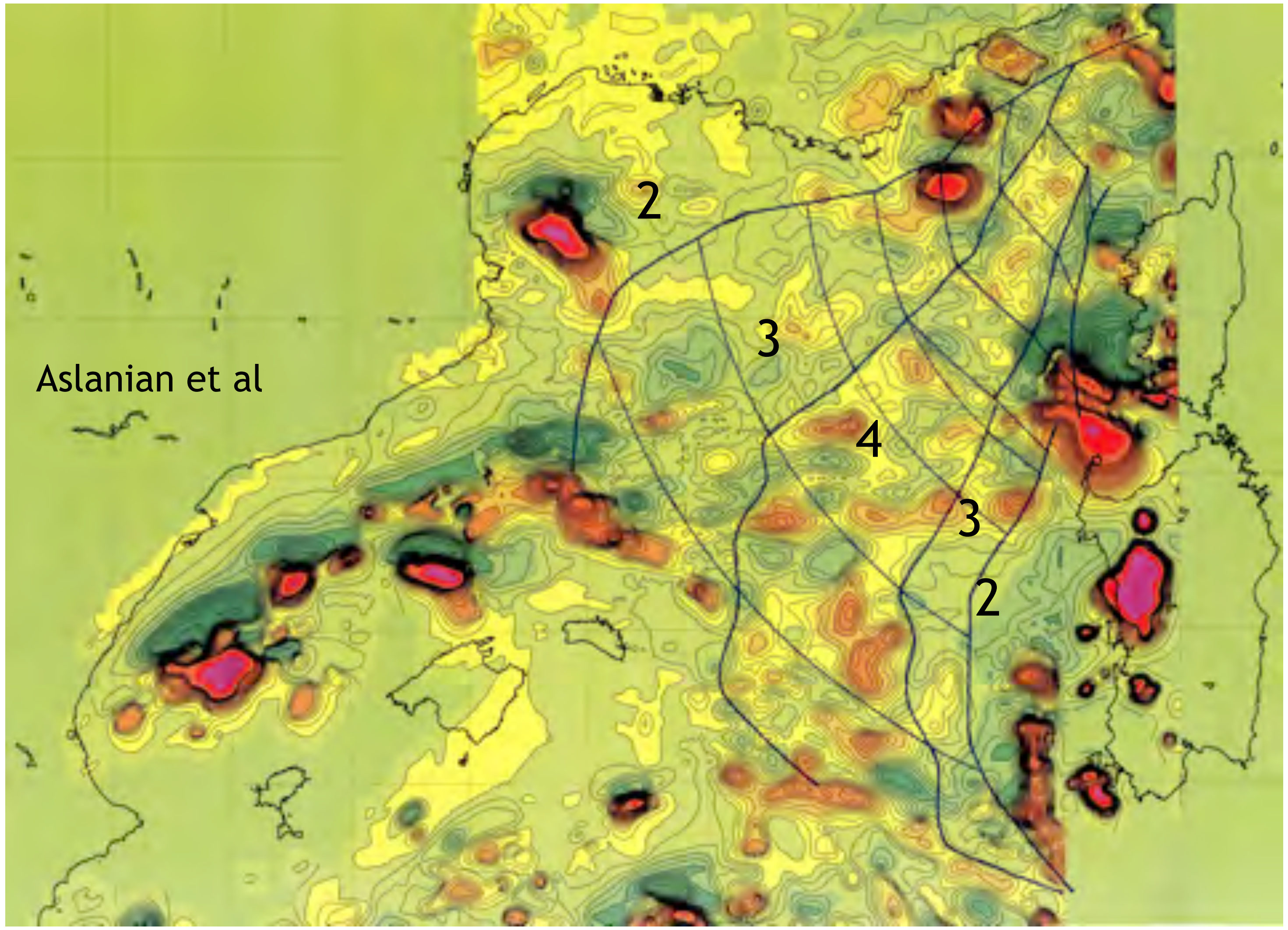
Moulin et al., 2015

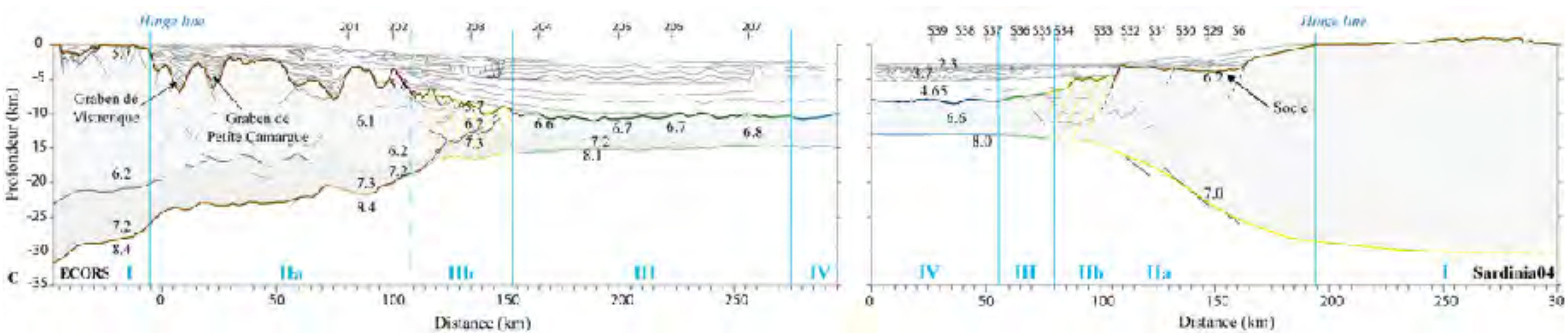
Gulf of Lions Margin

Discussion: *Nature of the Transitional Crust?*

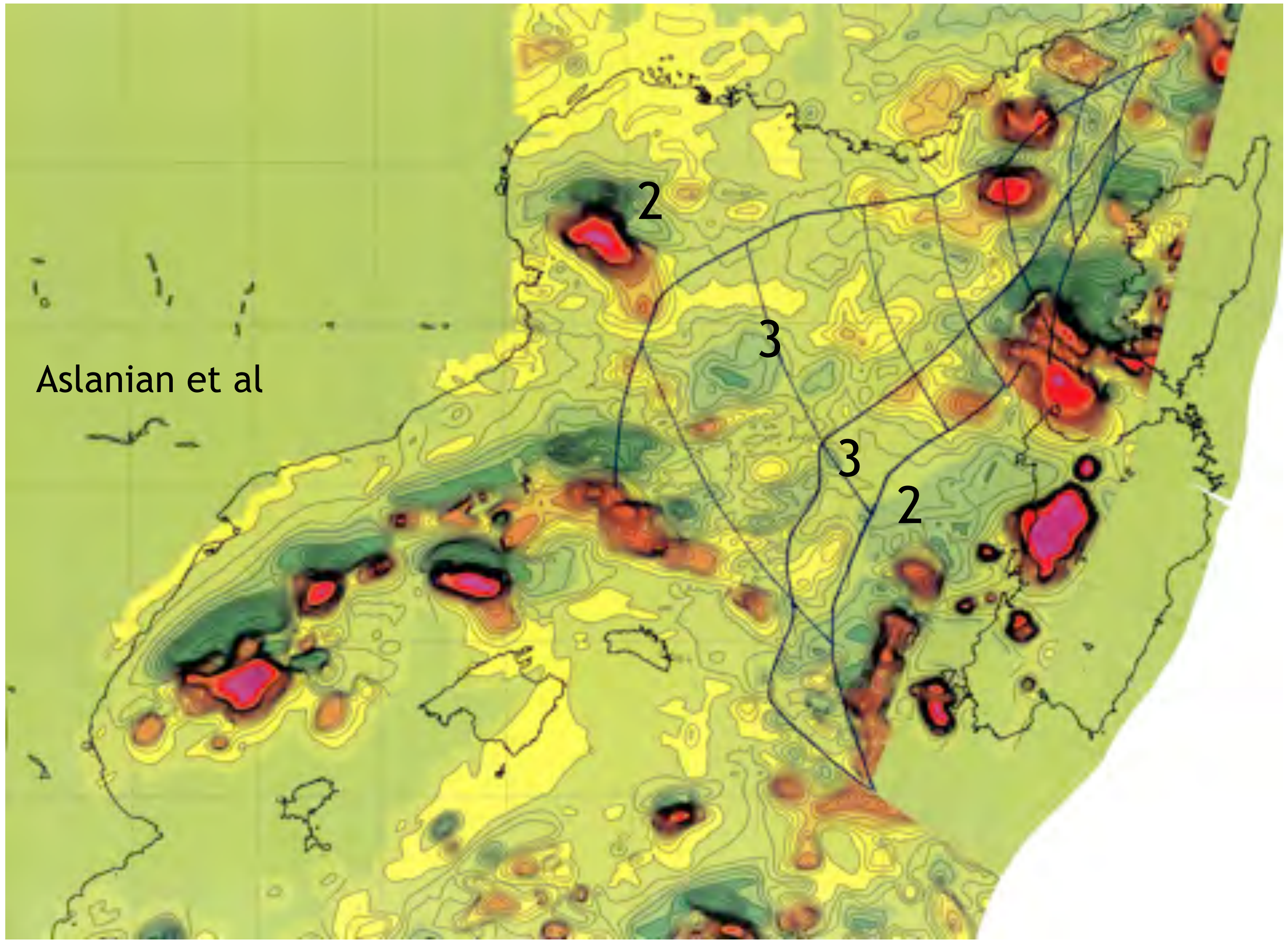


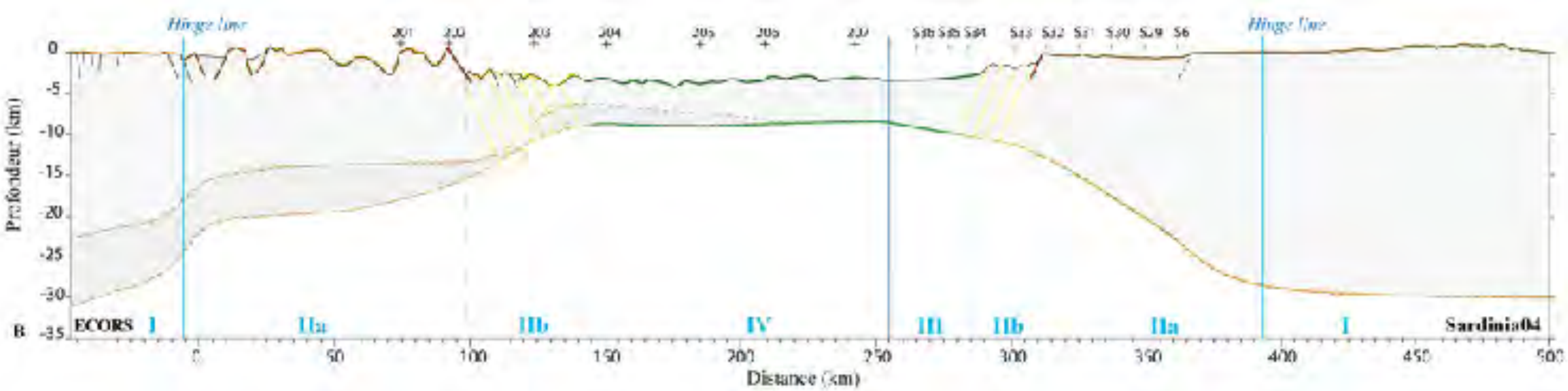
Moulin et al., 2015



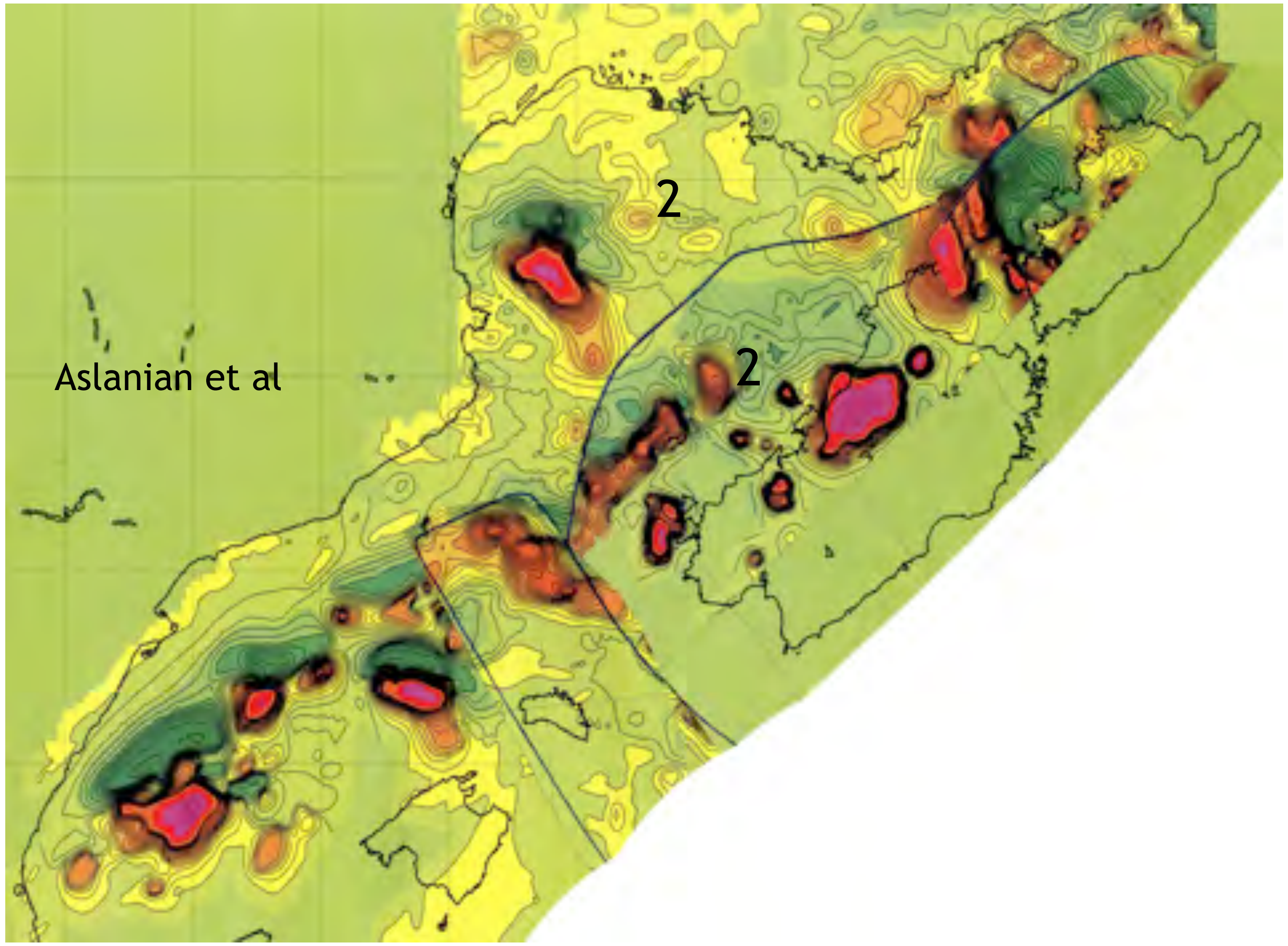


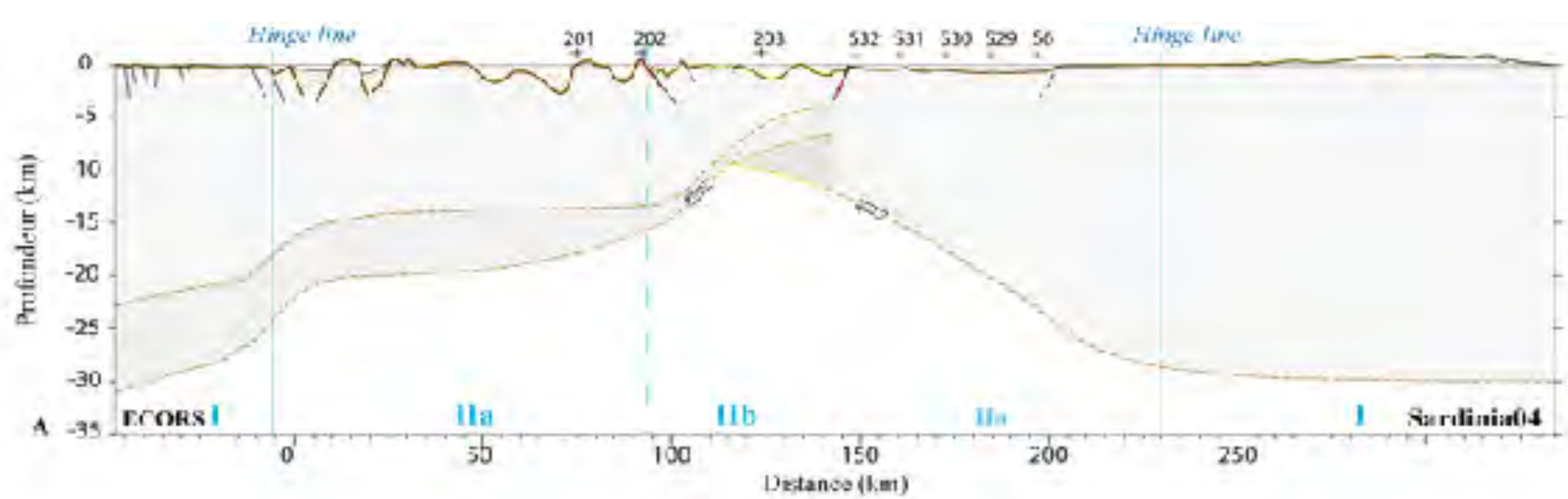
CURRENT STAGE, POST-RIFT





INTERMEDIATE STAGE , JUST BEFORE FIRST SEAFLOOR SPREADING

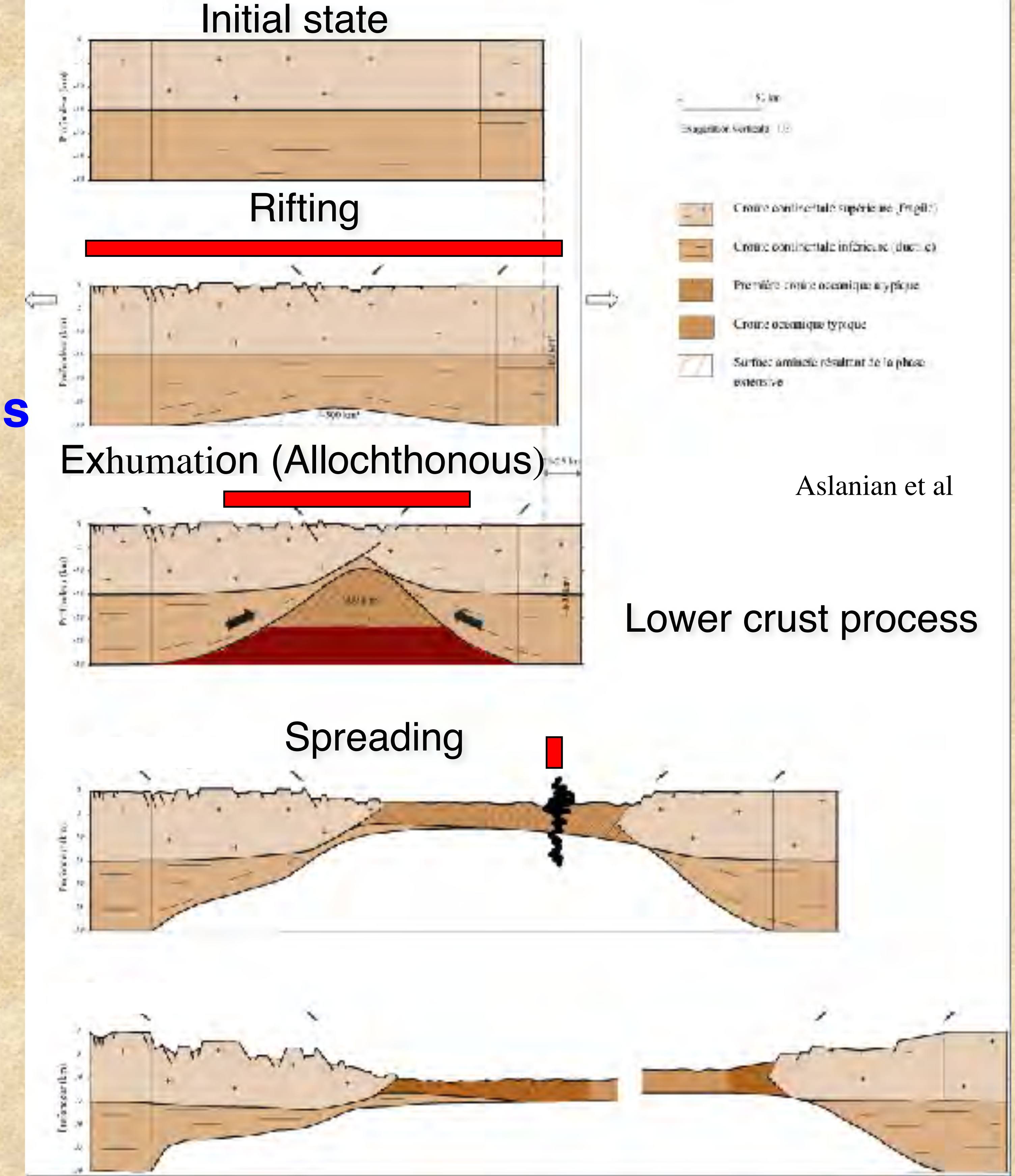




INITIAL STAGE BEFORE RIFTING

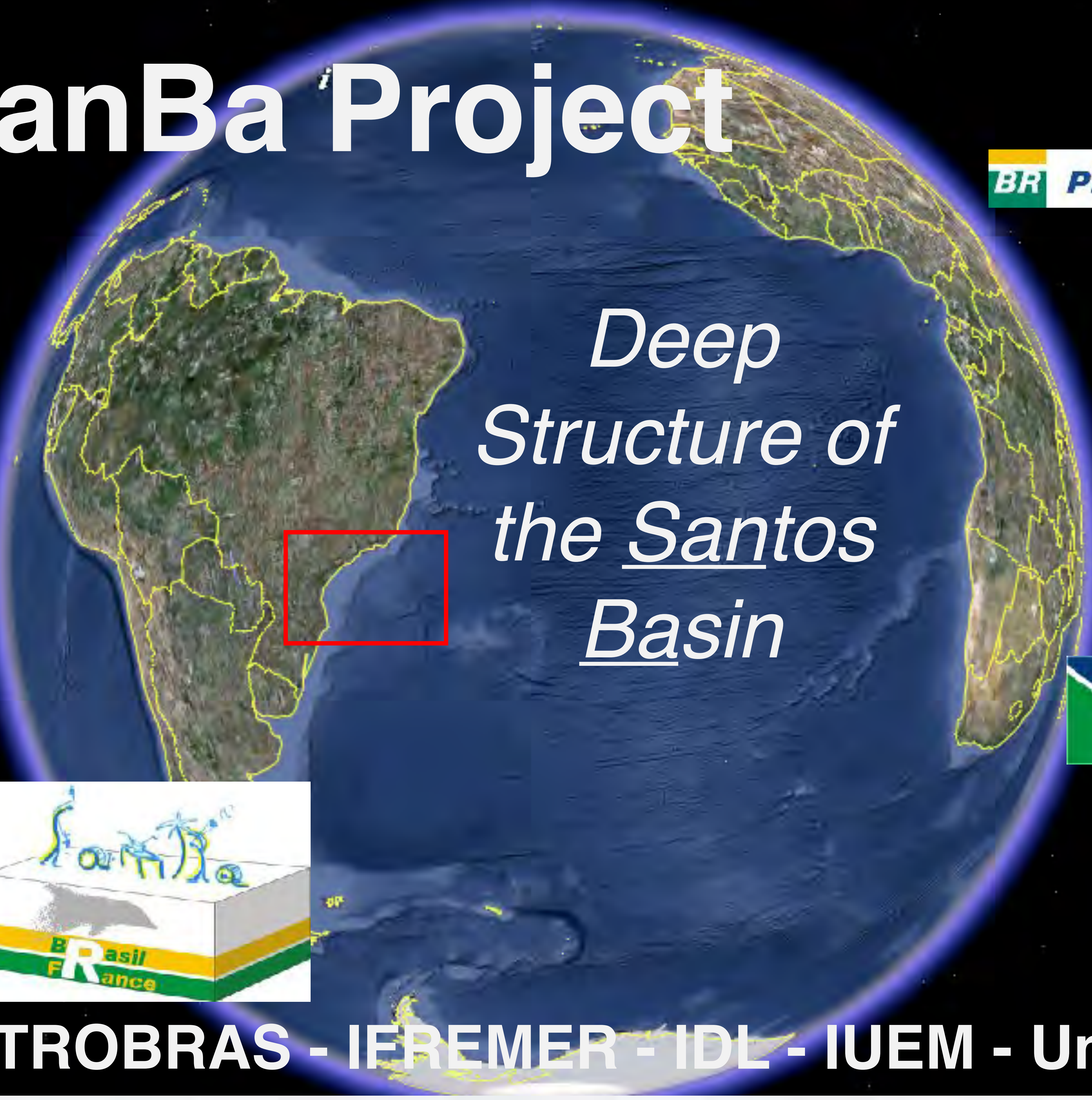
- Three Phases:
  - Rifting
  - Exhumation (main thinning phase)
  - Spreading
- Two stress fields constrictions
- High position troughout the thinning process
- Allochthonous material
- «Missing» Lower Crust
- Symmetry
- Subsidence segmentation
- Proto-oceanic crust with lower Continental crust affinity

THINNING PRINCIPALLY MAINLY CONCERNS THE LOWER CRUST



Bache et al., 2009, 2010a, 2010b, 2011
Gailler et al., 2009
Rabineau et al., 2005, 2006, 2014
Leroux 2012, Leroux et al., 2014; 2015
Mouilin et al., 2015; Afilhado et al., 2015, Evain, et al., 2015

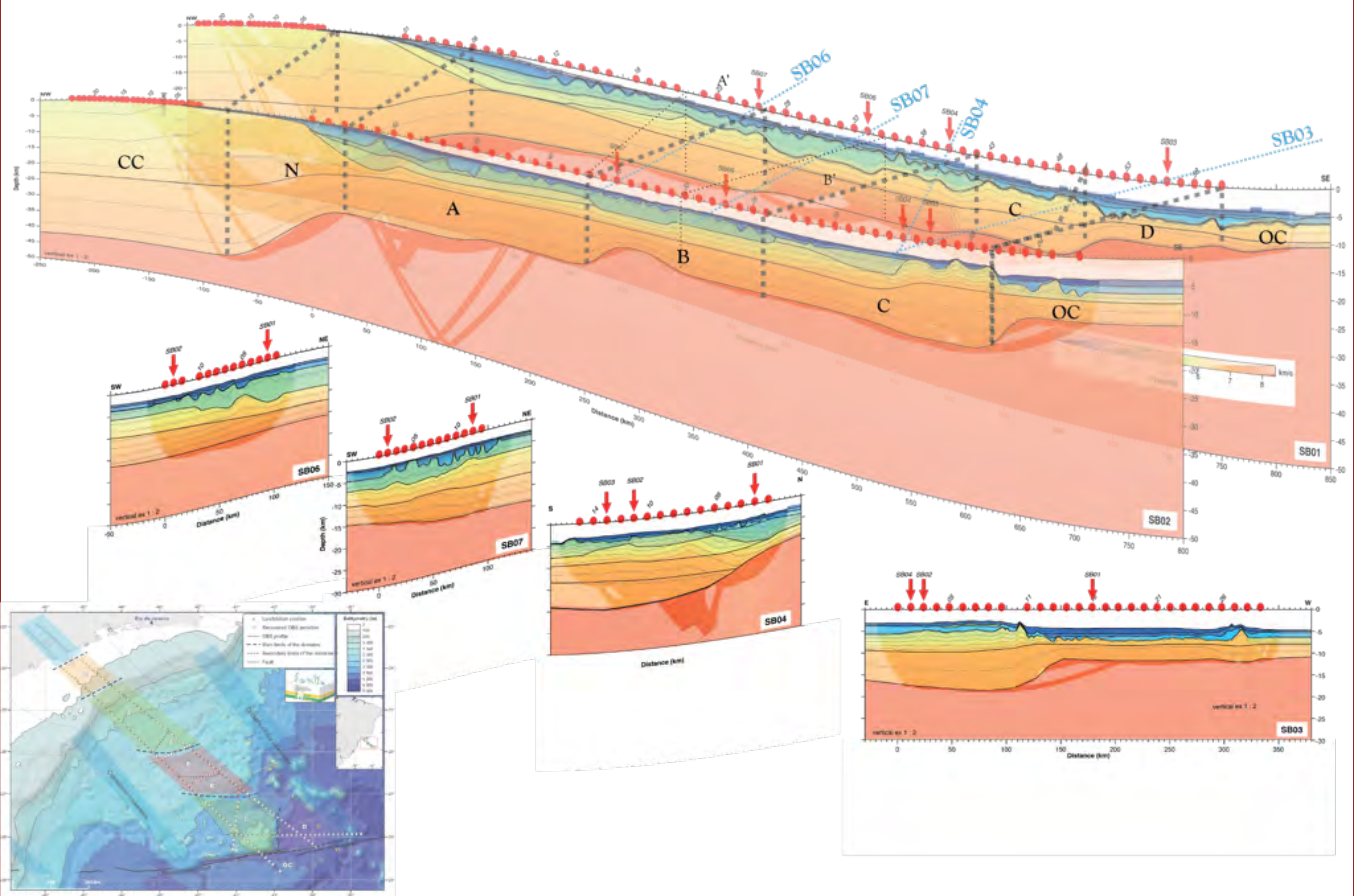
SanBa Project



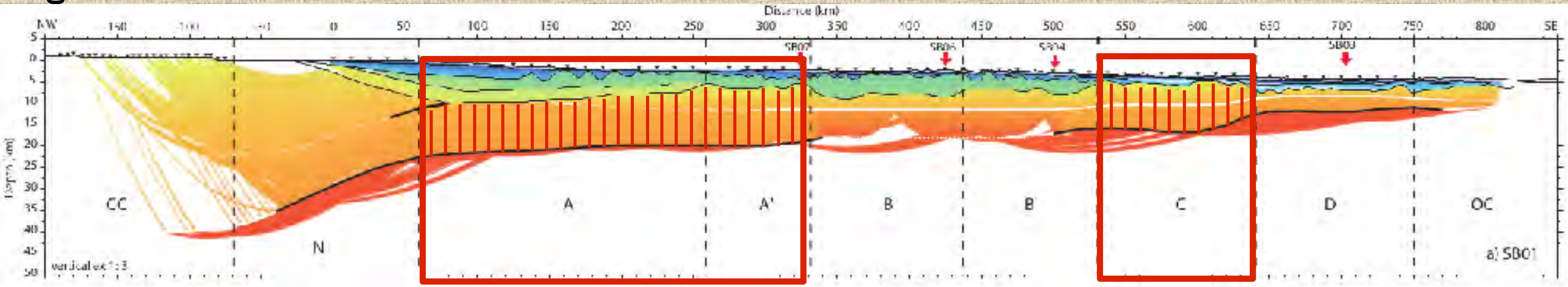
Deep Structure of the Santos Basin

PETROBRAS - IFREMER - IDL - IUEM - UnB

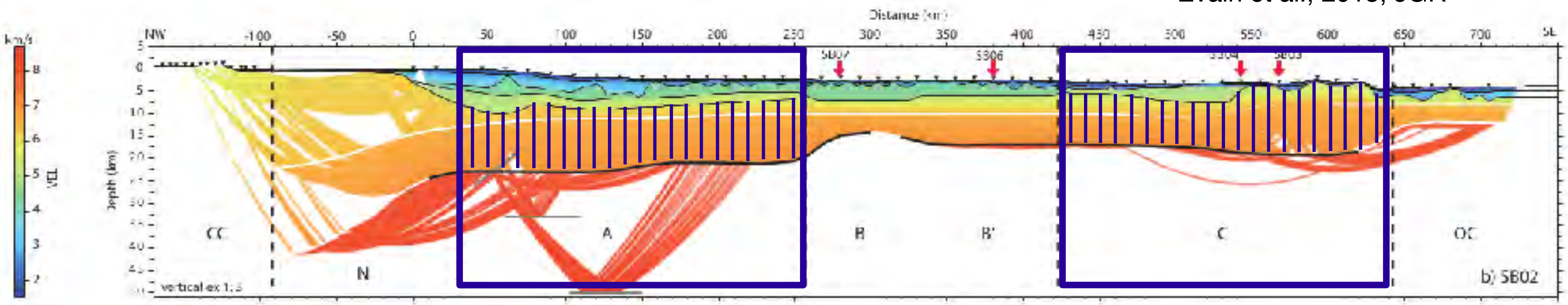
FINAL RESULTS
1- SEGMENTATION

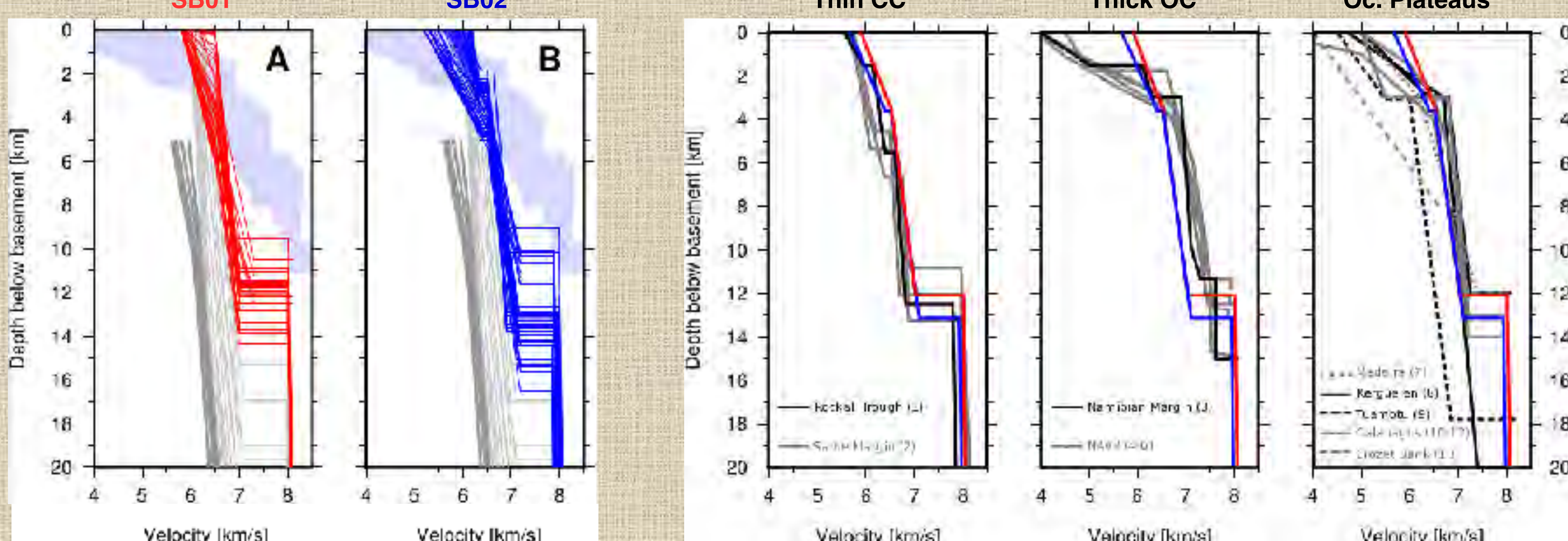


Domains A & C : thin continental crust



Evain et al., 2015, JGR

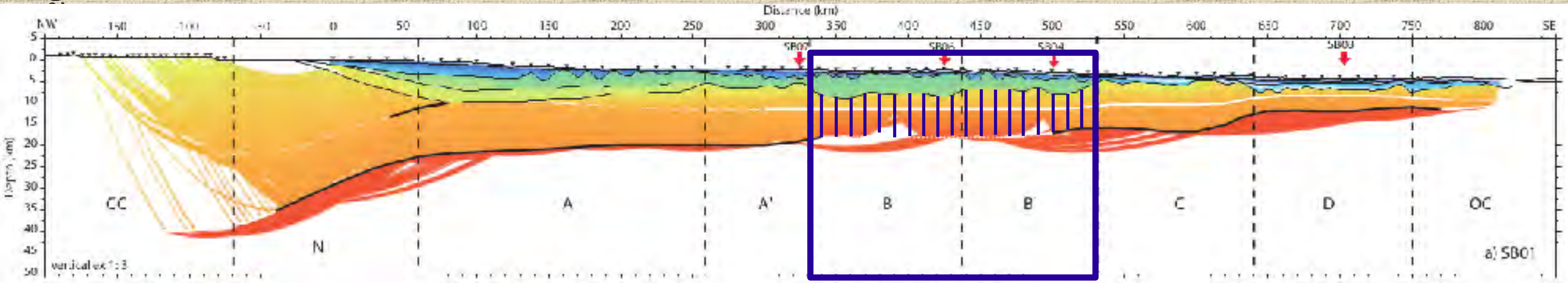




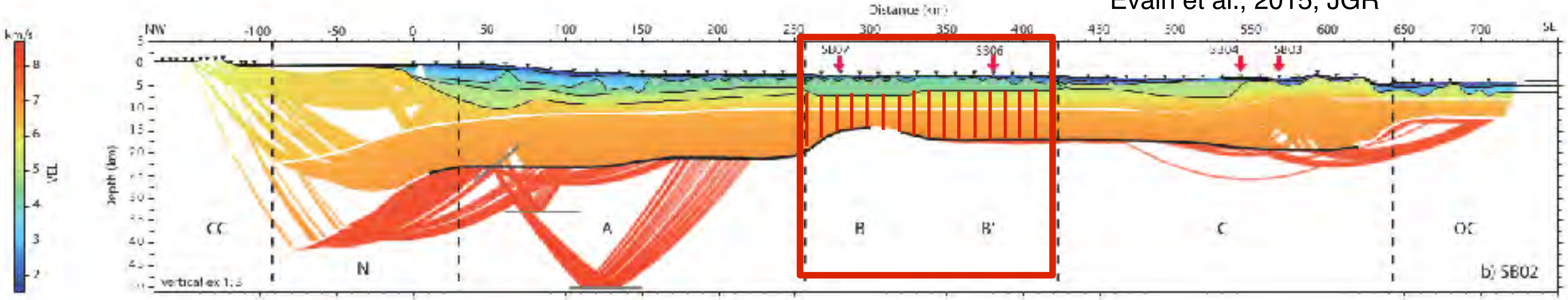
Maryline Moulin

015

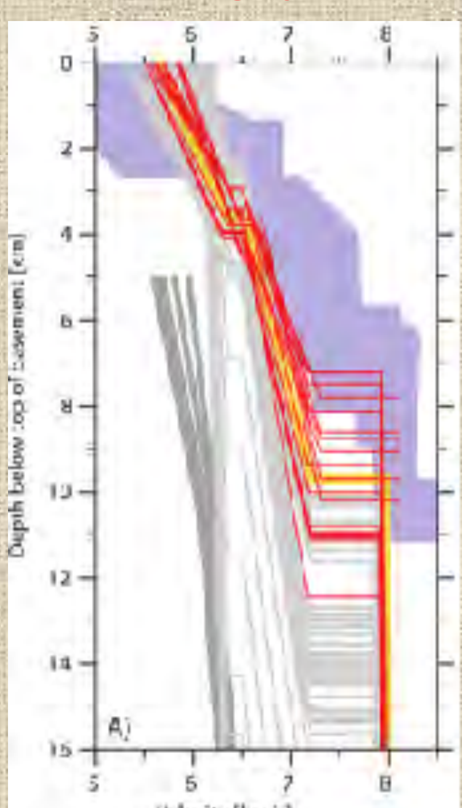
Central Domain B



Evain et al., 2015, JGR



SB02



SW Domain B

Thinner crust is 7-11 km
In continuity of A & C
Top velocities 5.5-5.8 km/s
Bottom velocity is 7.1 km/s
Clear Moho
Unaltered Mantle (8 km/d)

Thin Continental Crust

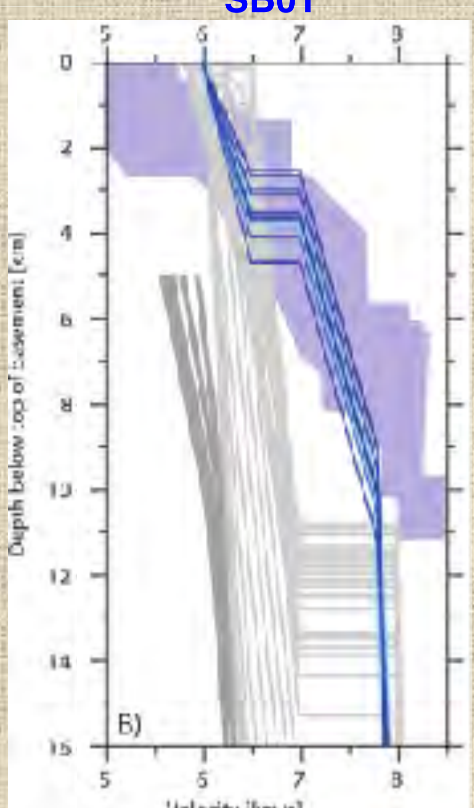
NE Domain B

Anomalous crust
Various hypothesis :
Intruded CC

Atypical (high vel.) OC
Exhumed lower CC
with altered mantle

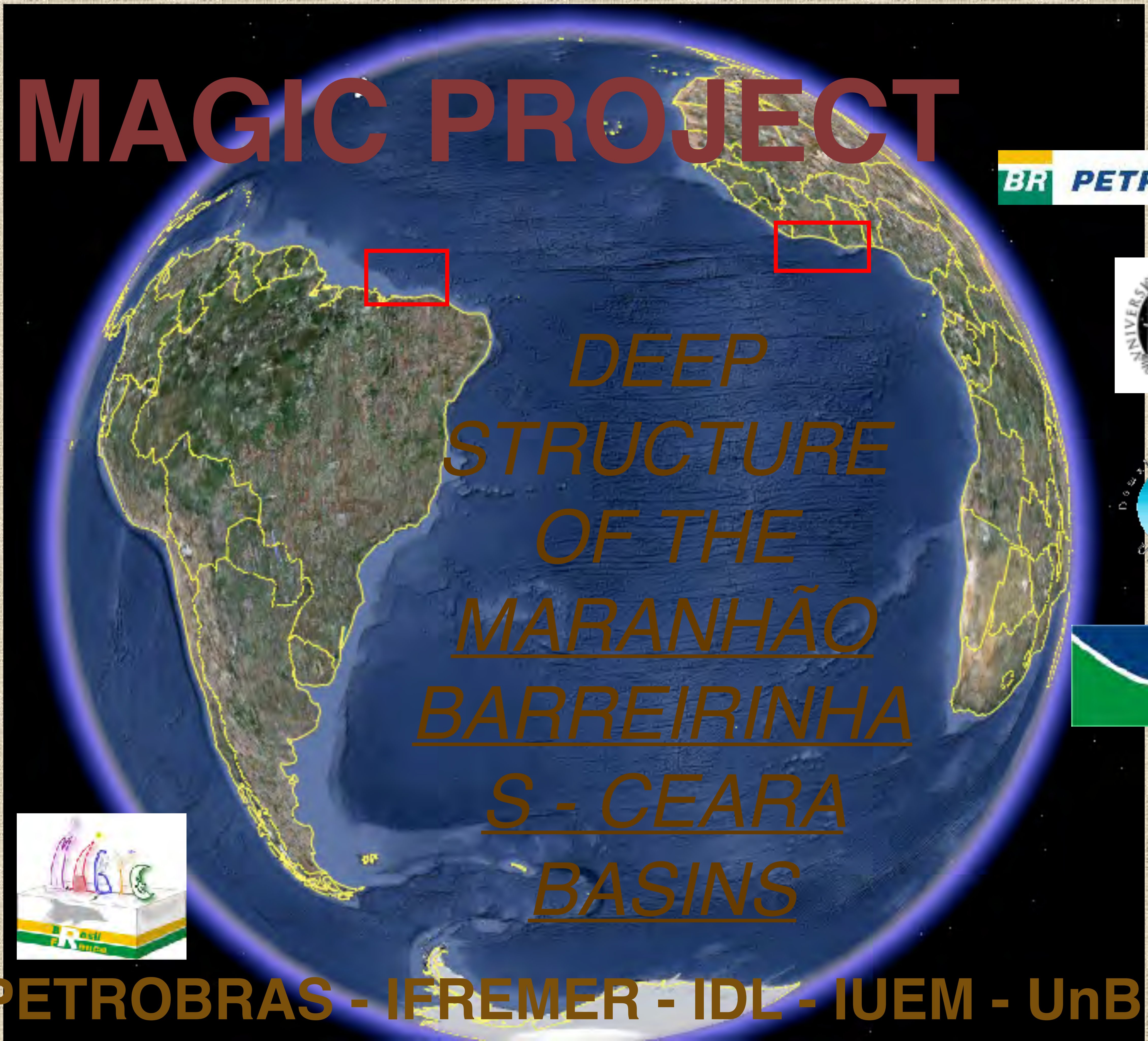
Heterogeneous crust ?
Proto-oceanic crust

SB01



Maryline Moulin

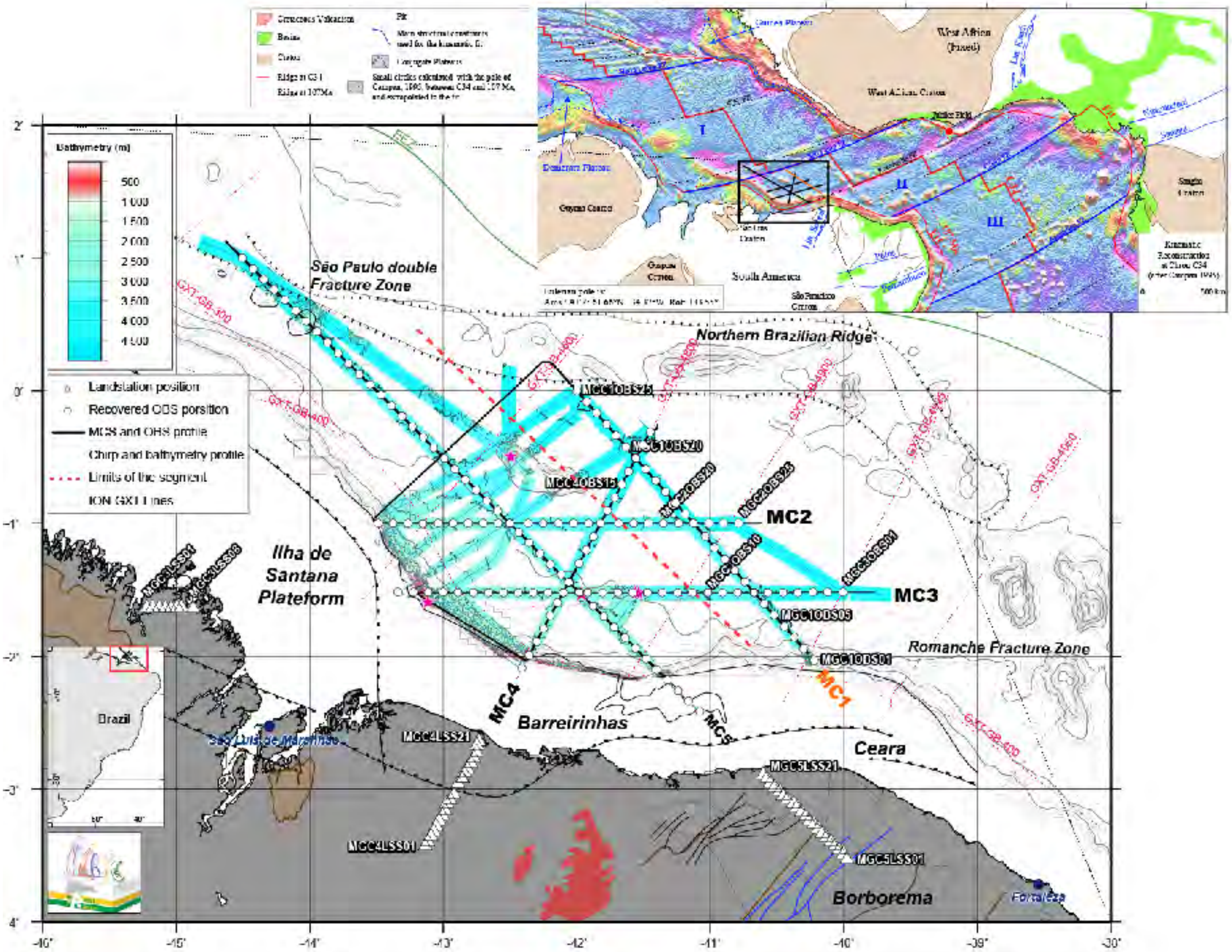
MAGIC PROJECT



DEEP STRUCTURE OF THE MARANHÃO BARREIRINHAS - CEARA BASINS

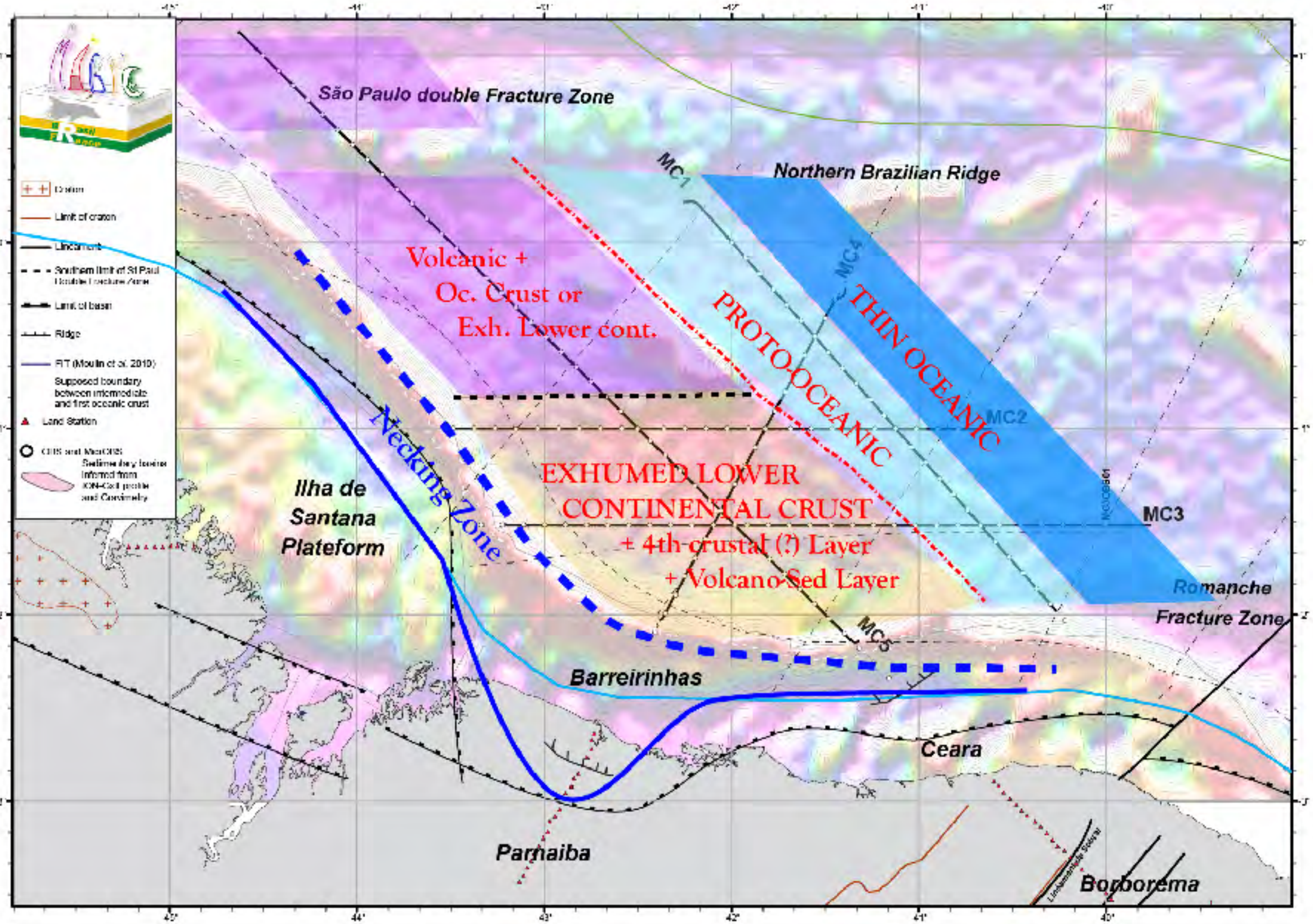
PETROBRAS

PETROBRAS - IFREMER - IDL - IUEM - UnB

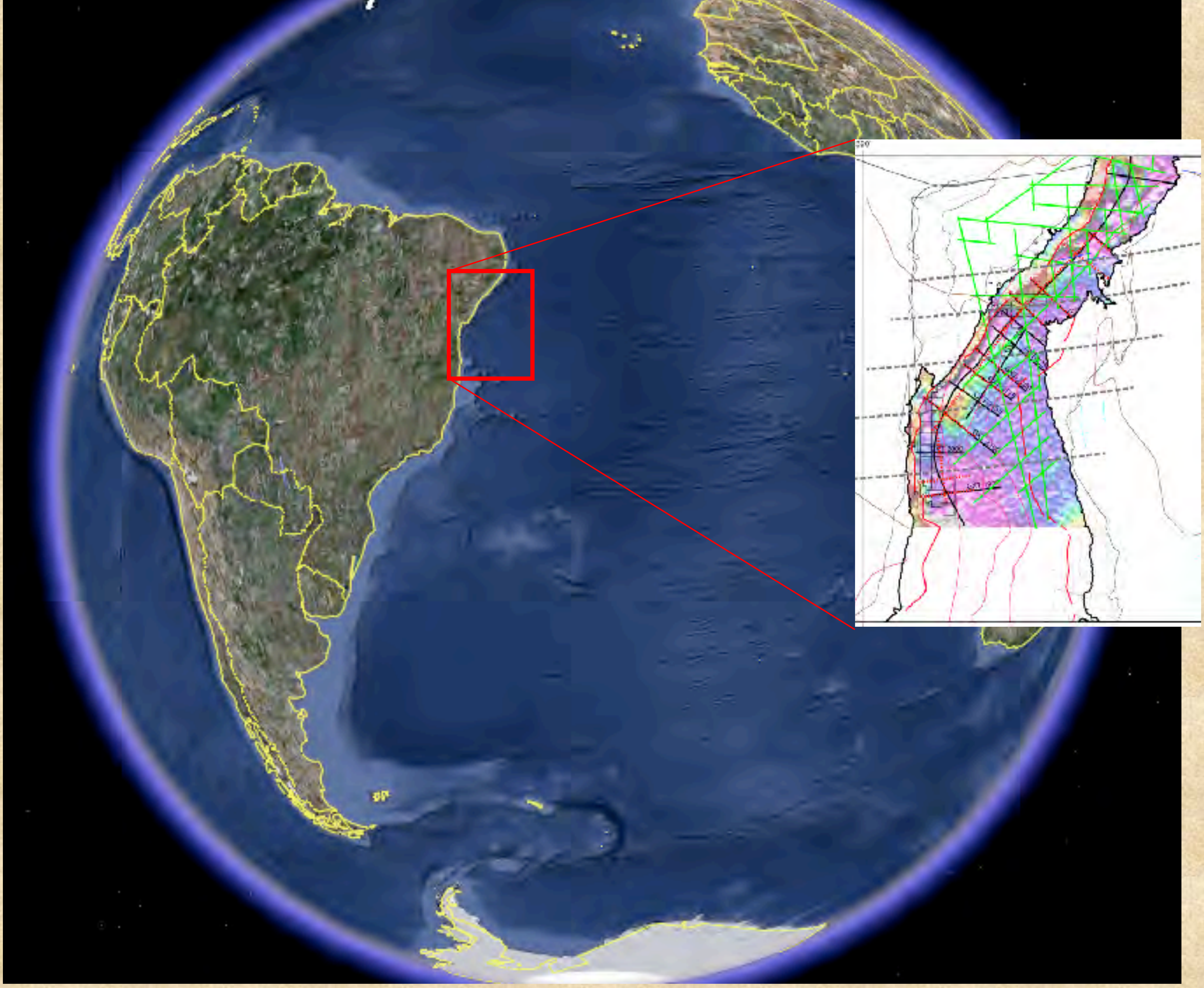


Moulin et al., in prep.

Interpretation from wide-angle



SALSA 2013



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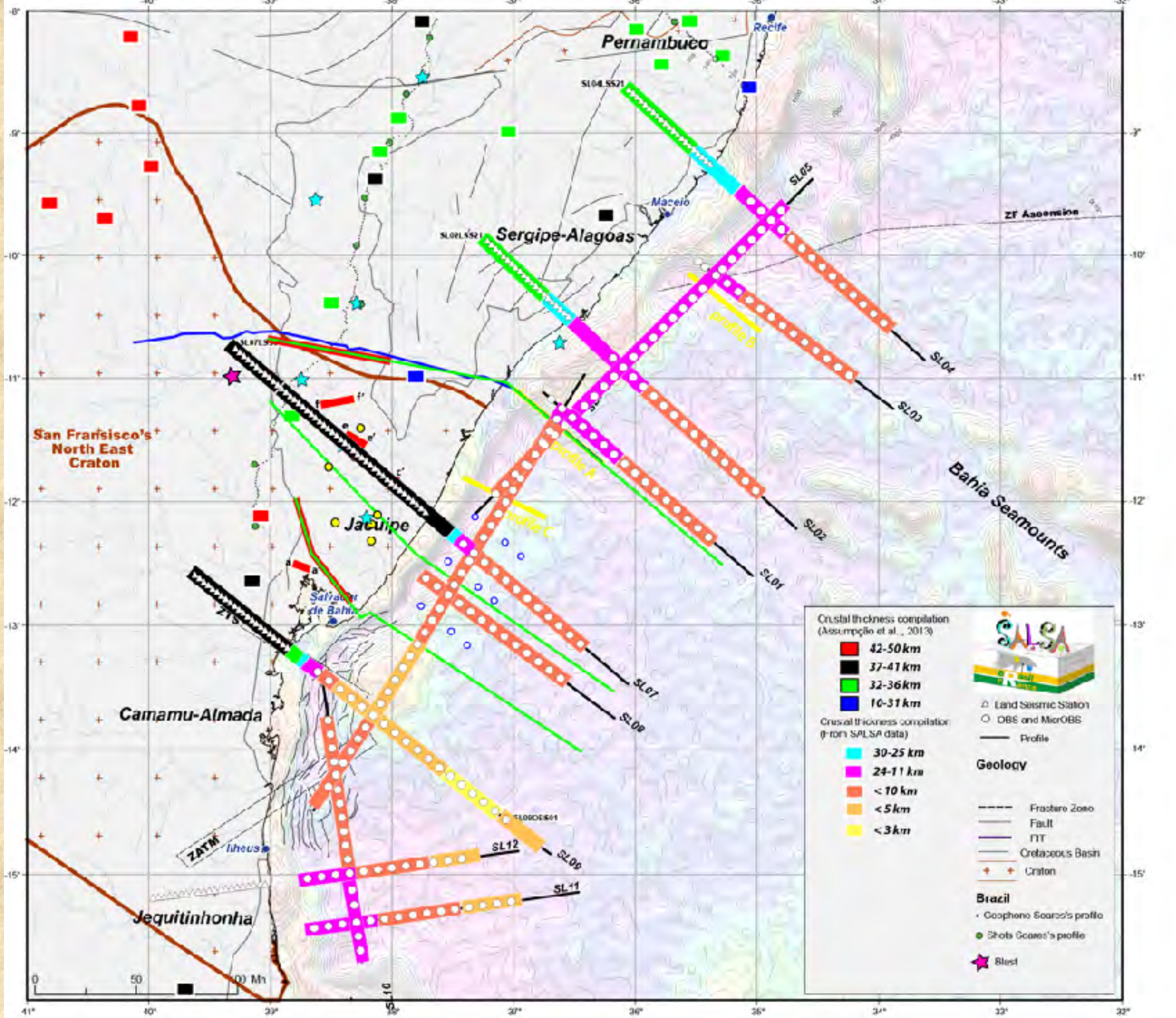
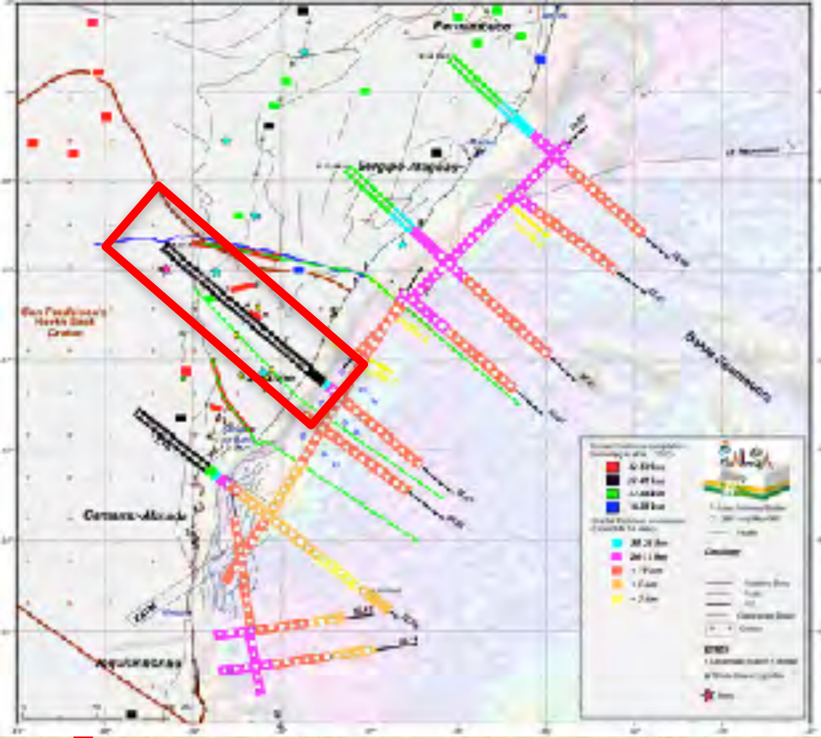
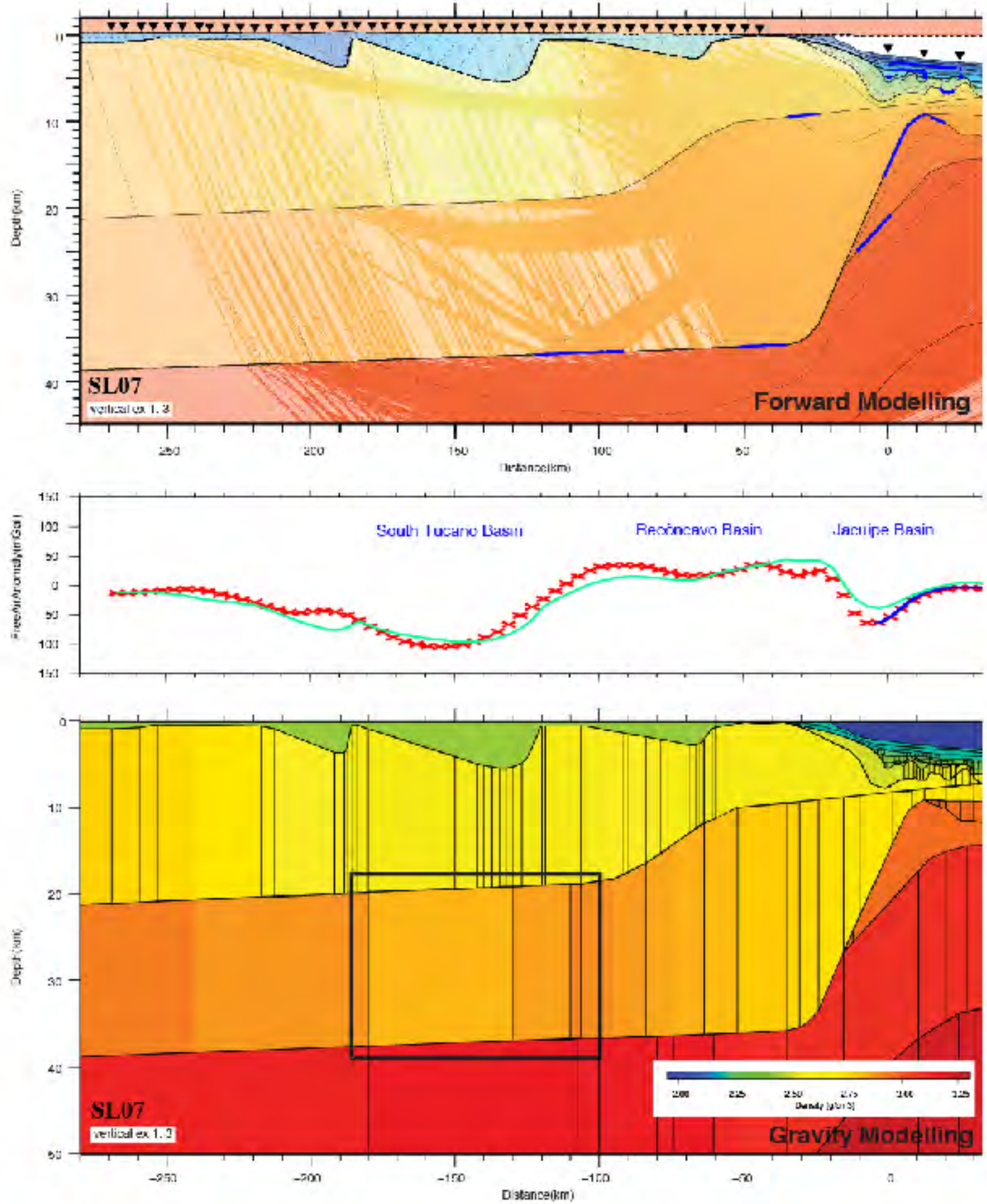
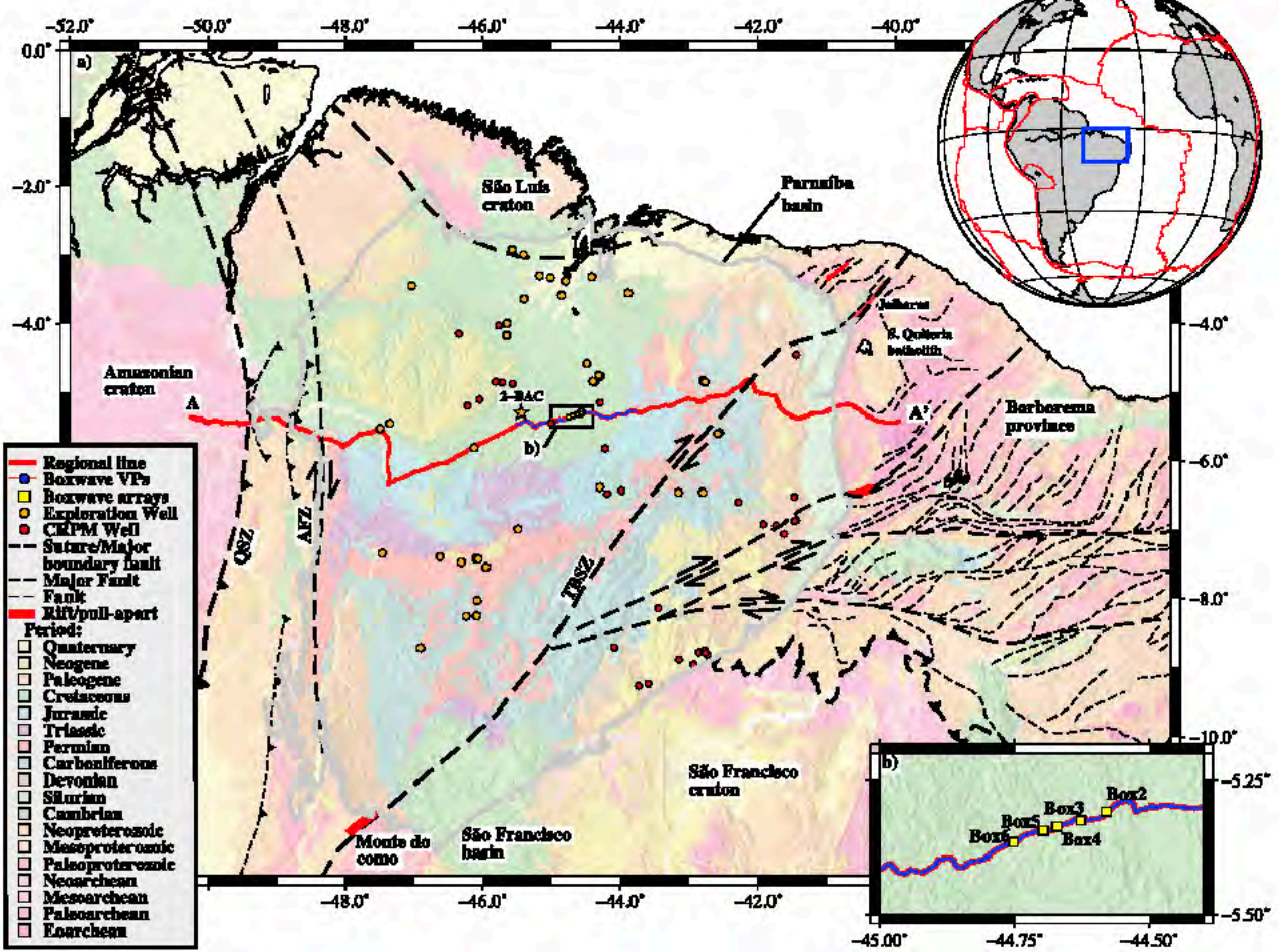


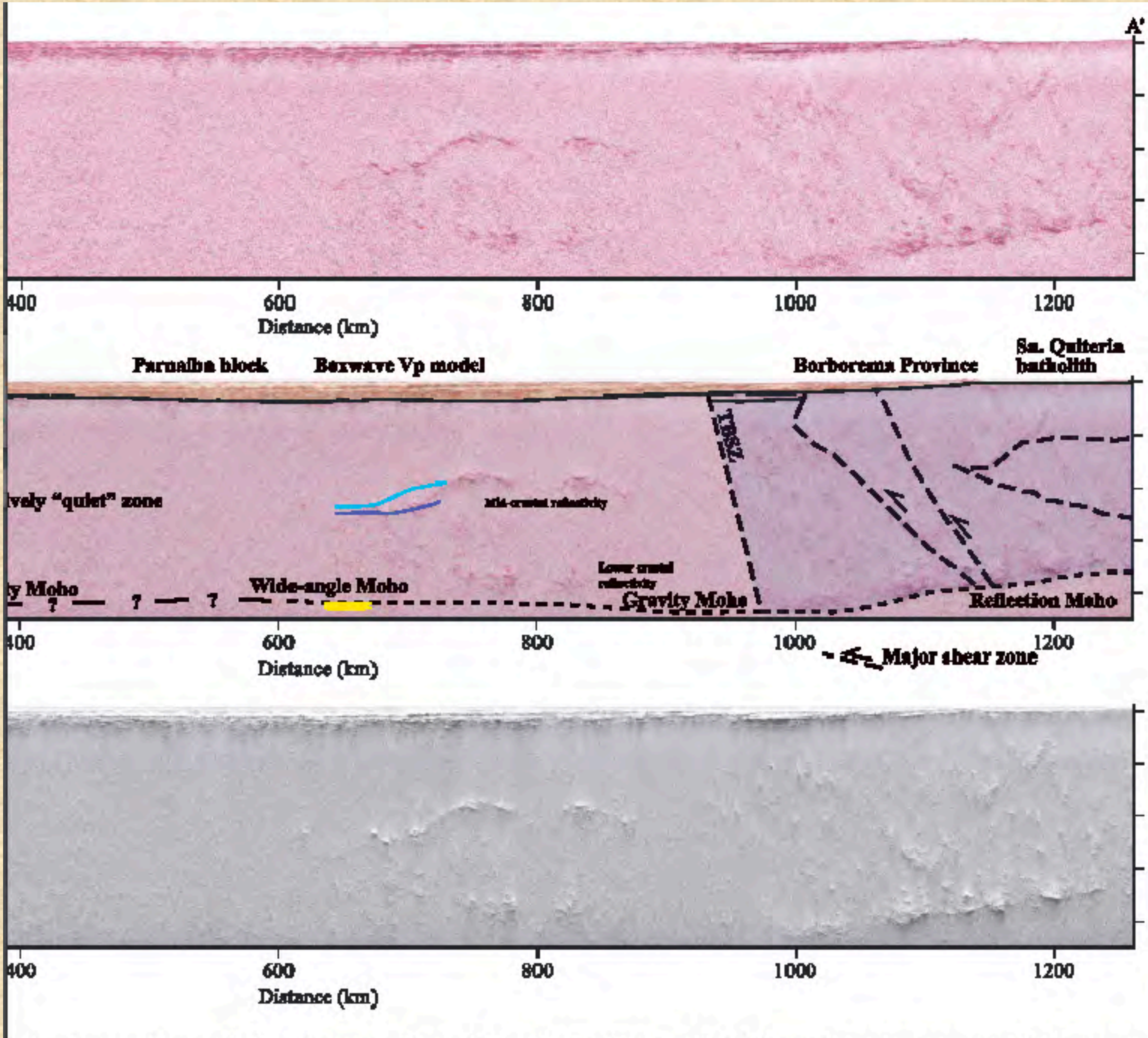


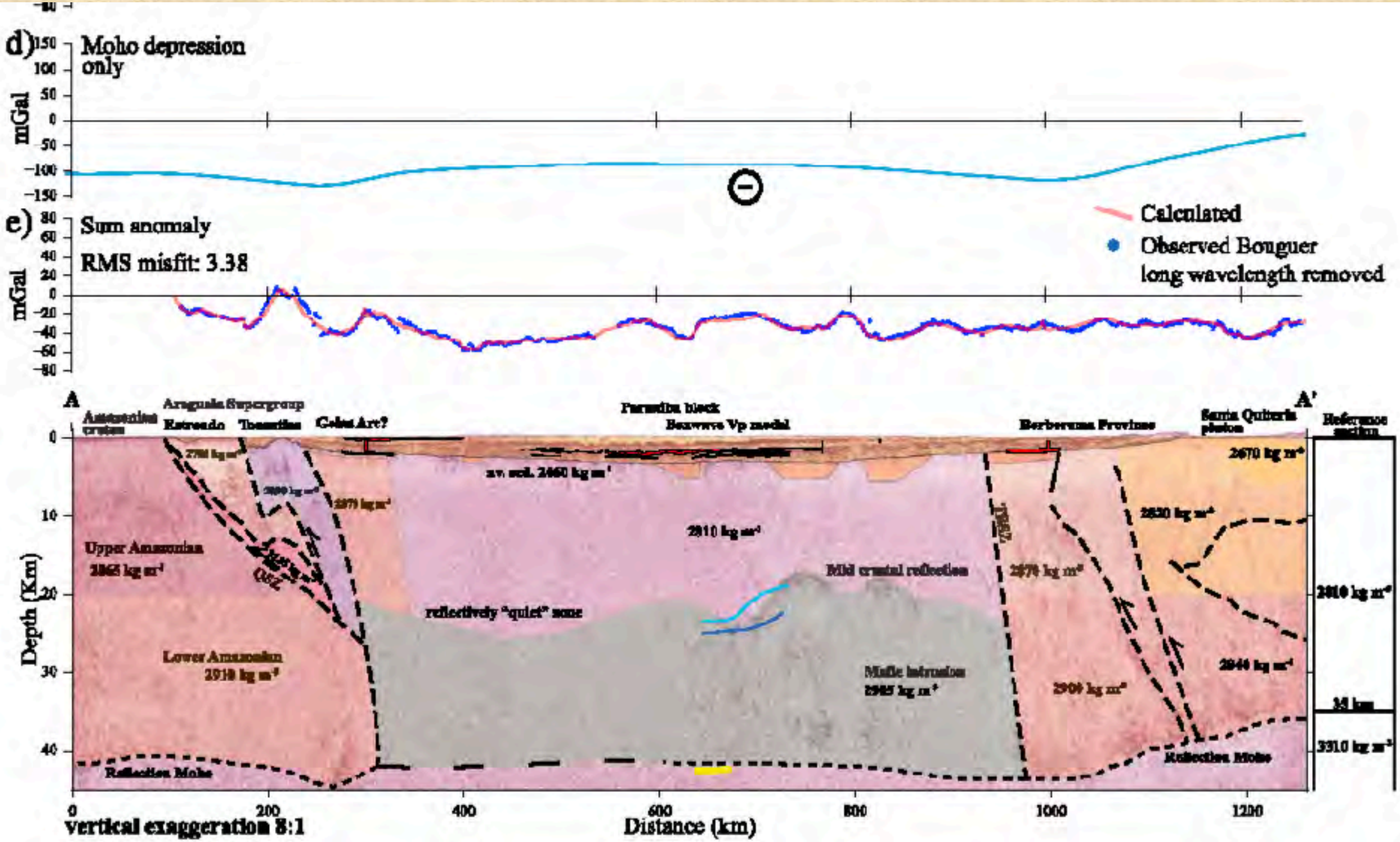


Port Elizabeth 16-20 Ju

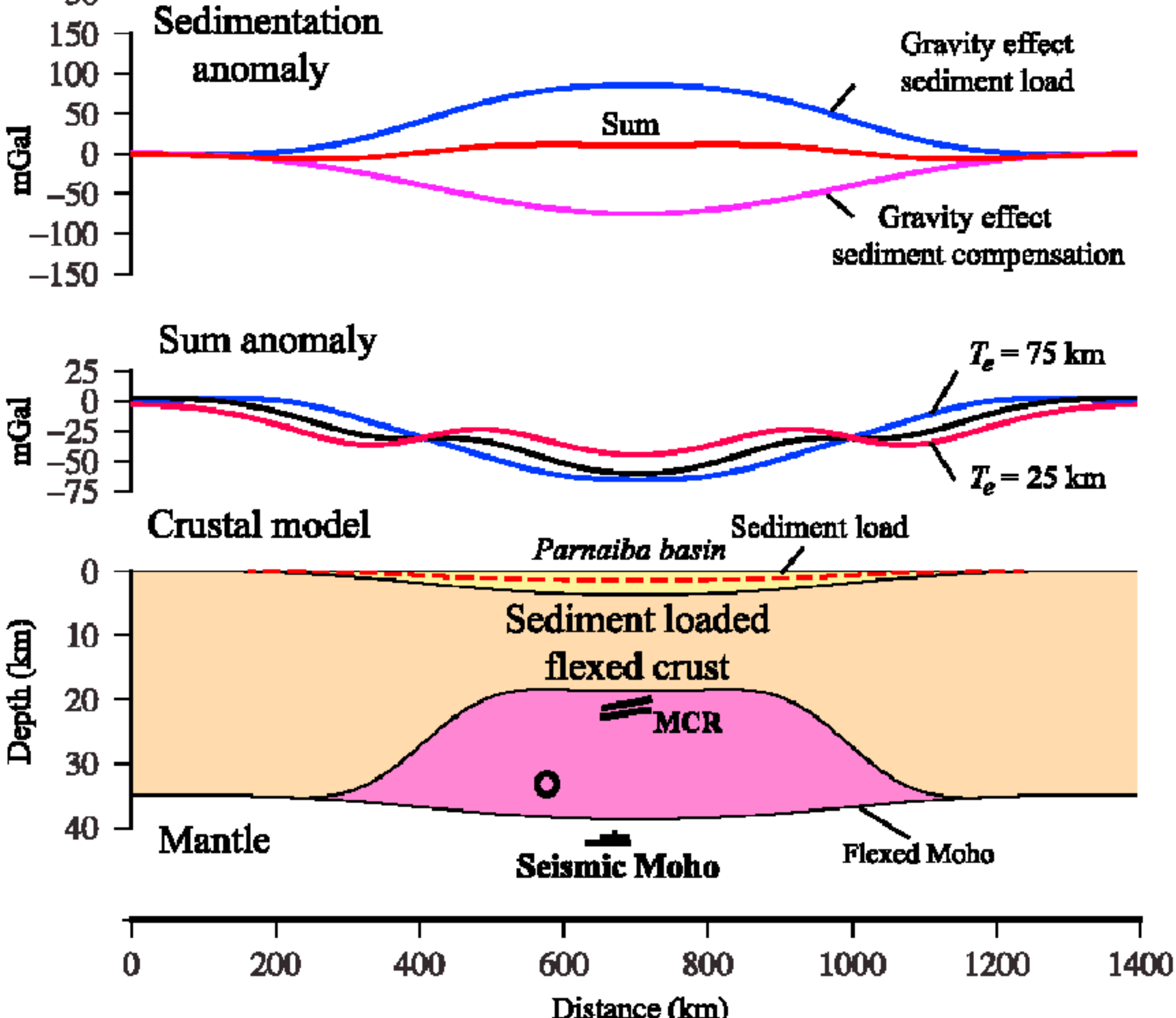


a)
São Luís craton
Parnaíba basin
Amazonian craton
A
A'
2-BAC
b)
Jaibaras
S. Quitéria batholith
Borborema province
TBSZ
AFZ
OSZ
São Francisco craton
São Francisco basin
Monte do carmo
Regional line
Boxwave VPs
Boxwave arrays
Exploration Well
CRPM Well
Suture/Major boundary fault
Major Fault
Fault
Rift/pull-apart
Period:
Quaternary
Neogene
Paleogene
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Cambrian
Neoproterozoic
Mesoproterozoic
Paleoproterozoic
Neoarchean
Mesoarchean
Paleoarchean
Eoarchean
Box2
Box3
Box4
Box5
Box6


A'
400
600
800
1000
1200
Distance (km)
Parnaiba block
Baxwave Vp model
Borborema Province
Sa. Quiteria batholith
TBSZ
ively "quiet" zone
Mid-crustal reflectivity
Lower crustal reflectivity
y Moho
Wide-angle Moho
Gravity Moho
Reflection Moho
Major shear zone

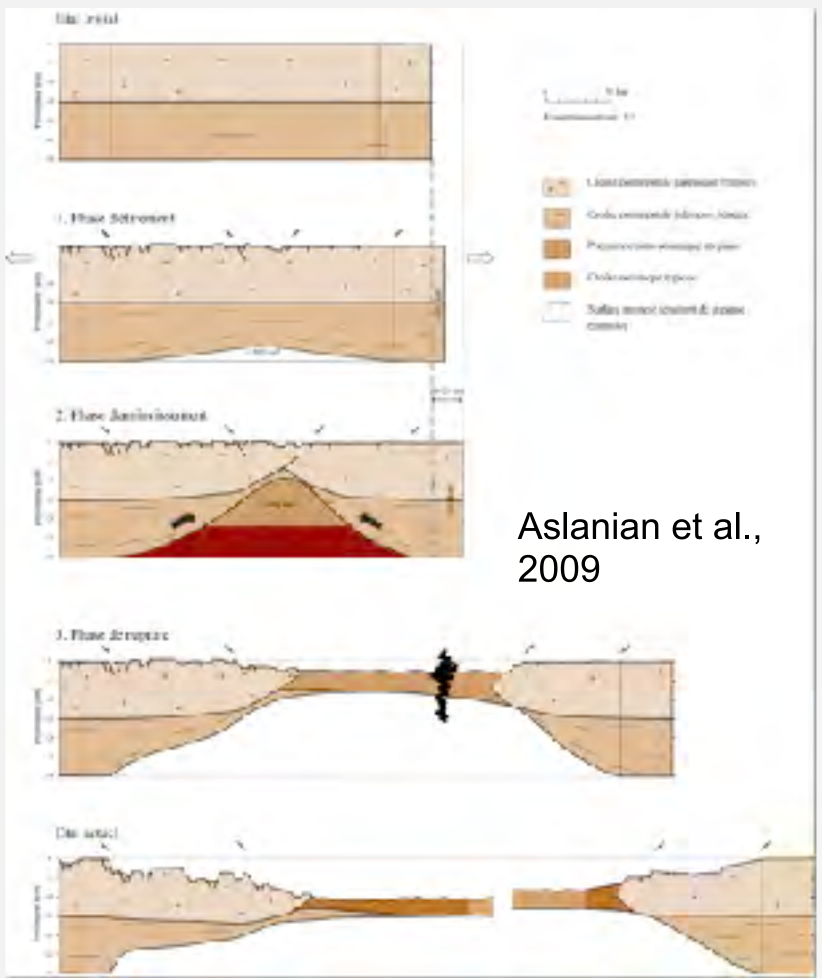


d)
Moho depression only
mGal
150
100
50
0
-50
-100
-150
e)
Sum anomaly
RMS misfit: 3.38
Calculated
Observed Bouguer long wavelength removed
80
60
40
20
0
-20
-40
-60
-80
A
A'
Araguaia Supergroup
Paraíba block
Beaswave Vp model
Borborema Province
Reference section
2670 kg m⁻³
av. sed. 2460 kg m⁻³
2810 kg m⁻³
Upper Amazonian
2865 kg m⁻³
Mid crustal reflection
2870 kg m⁻³
2810 kg m⁻³
reflectively "quiet" zone
Lower Amazonian
2910 kg m⁻³
Mafic intrusion
2985 kg m⁻³
2900 kg m⁻³
2940 kg m⁻³
35 km
3310 kg m⁻³
Reflection Moho
Depth (Km)
0
10
20
30
40
200
400
600
800
1000
1200
vertical exaggeration 8:1
Distance (km)

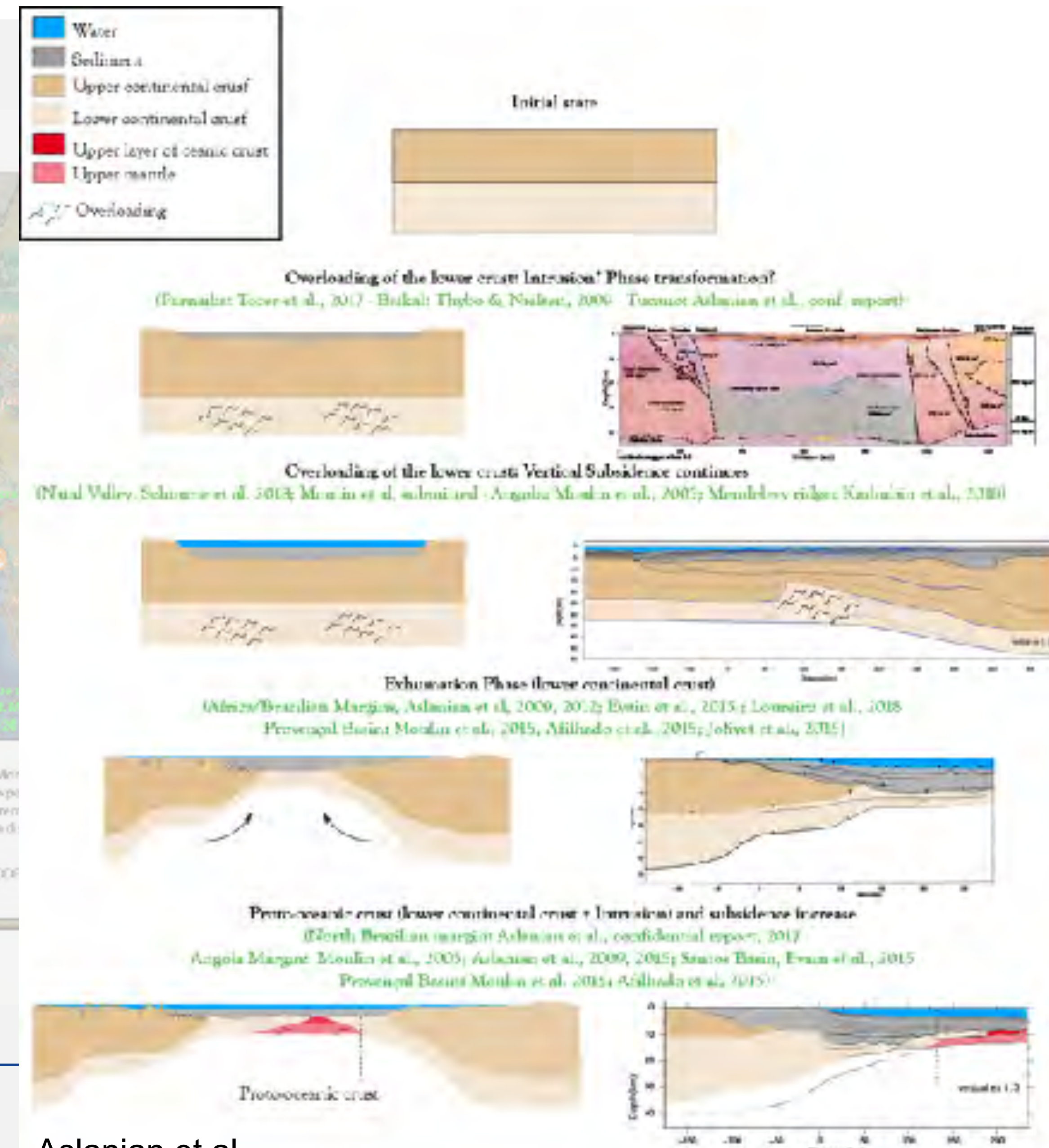


Port Elizabeth 16-20 July 2018

1 - Thinning ≠ stretching
2 - Sedimentary basin ≠ crustal thinning
3 - Vertical movement (subsidence) ≠ Horizontal movement
4 - Crucial role of the lower continental crust & Intrusions
5 - Impact of the thermal evolution



Aslanian et al., 2009



Parnaiba

Natal

Aslanian et al., 2018

Sedimentology

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Marine Sedimentation and Controlling factors

Dr. Marina RABINEAU (CNRS)

ACCRA, GHANA Univ., AEON-ESSRI, UBO, IFREMER, CIRAD : EOL SCHOOL

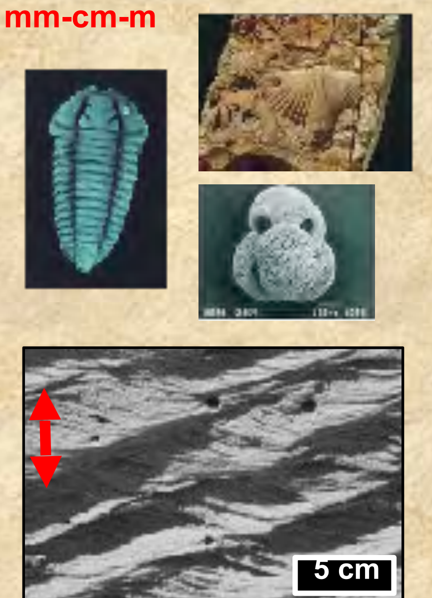
FIELD APPROACH

1280 × 720 - youtube.com

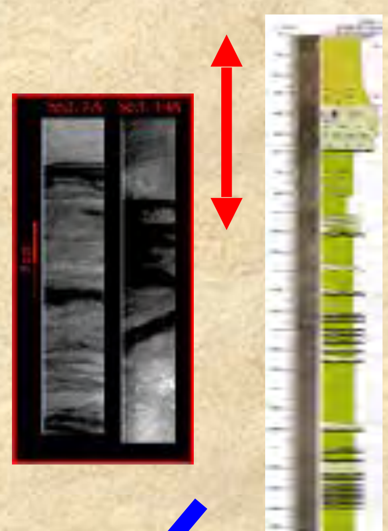
+ SPATIAL SCALE :

Surface

Microscope, Sed. Structure
mm-cm-m



Cores, outcrops
1-20 m



Outcrops
100 m

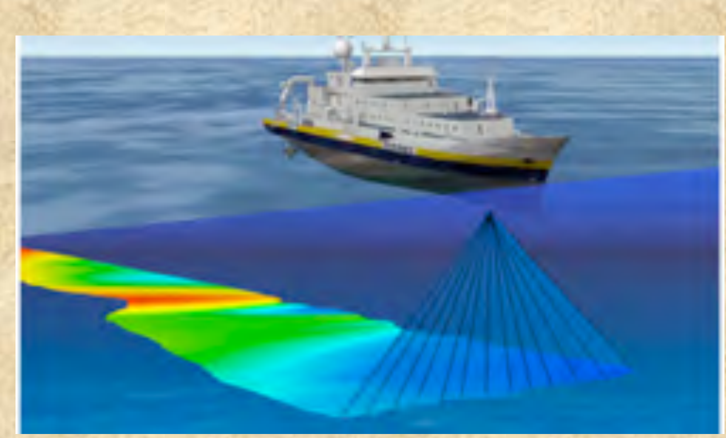
Basin
Drills
10 km

j	1 j	1 a
a	1 a	100 a
ka	1 ka	10 ka
Ma	1 Ma	10 Ma
Ma	10 Ma	100 Ma

+ TIME SCALE :

Back/Forth

Ocean Engineering



Design and installation of oceanographic instrumentation and vehicles

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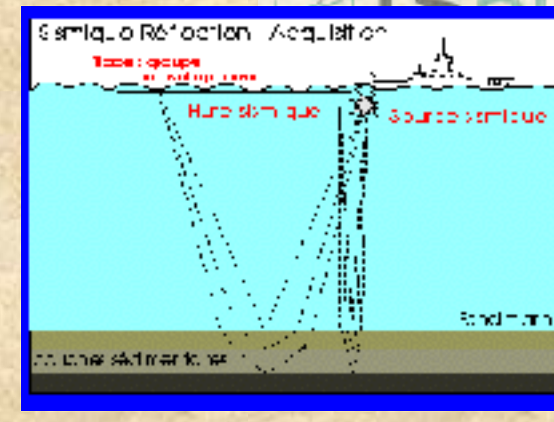
GEOPHYSICAL APPROACH



+ SPATIAL SCALE :

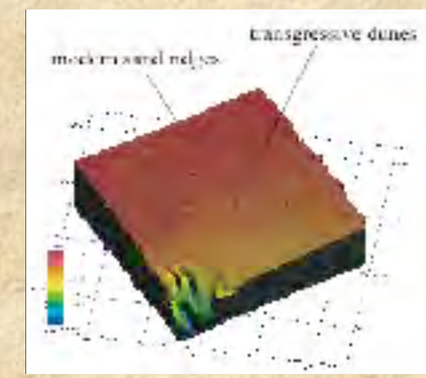
Surface

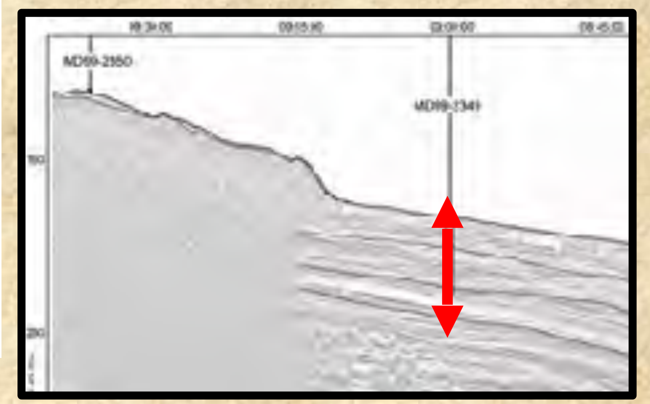
mm-m

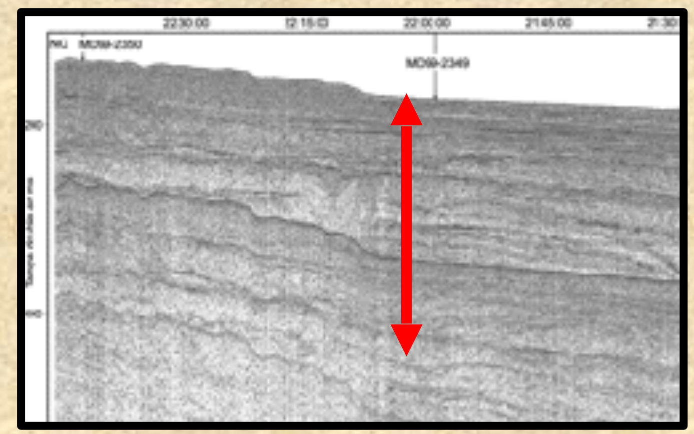
Sed. Bodies
1-20 m

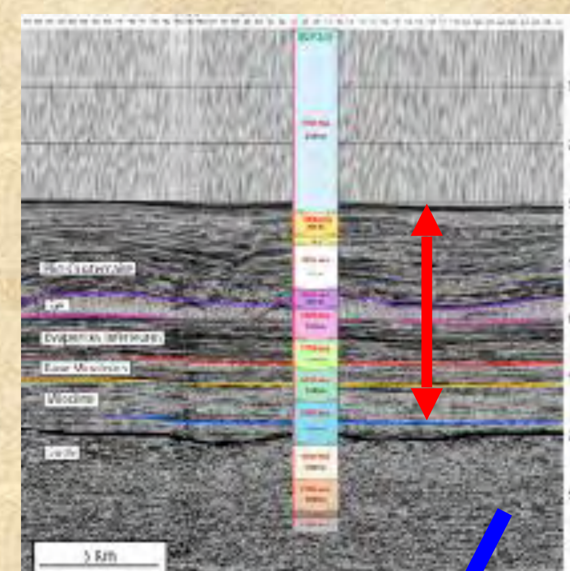
Stack sedimentary Sequences
100-500 m

Basin-Drill 10 km









Bathymetry Imagery

Chirp

Sparker

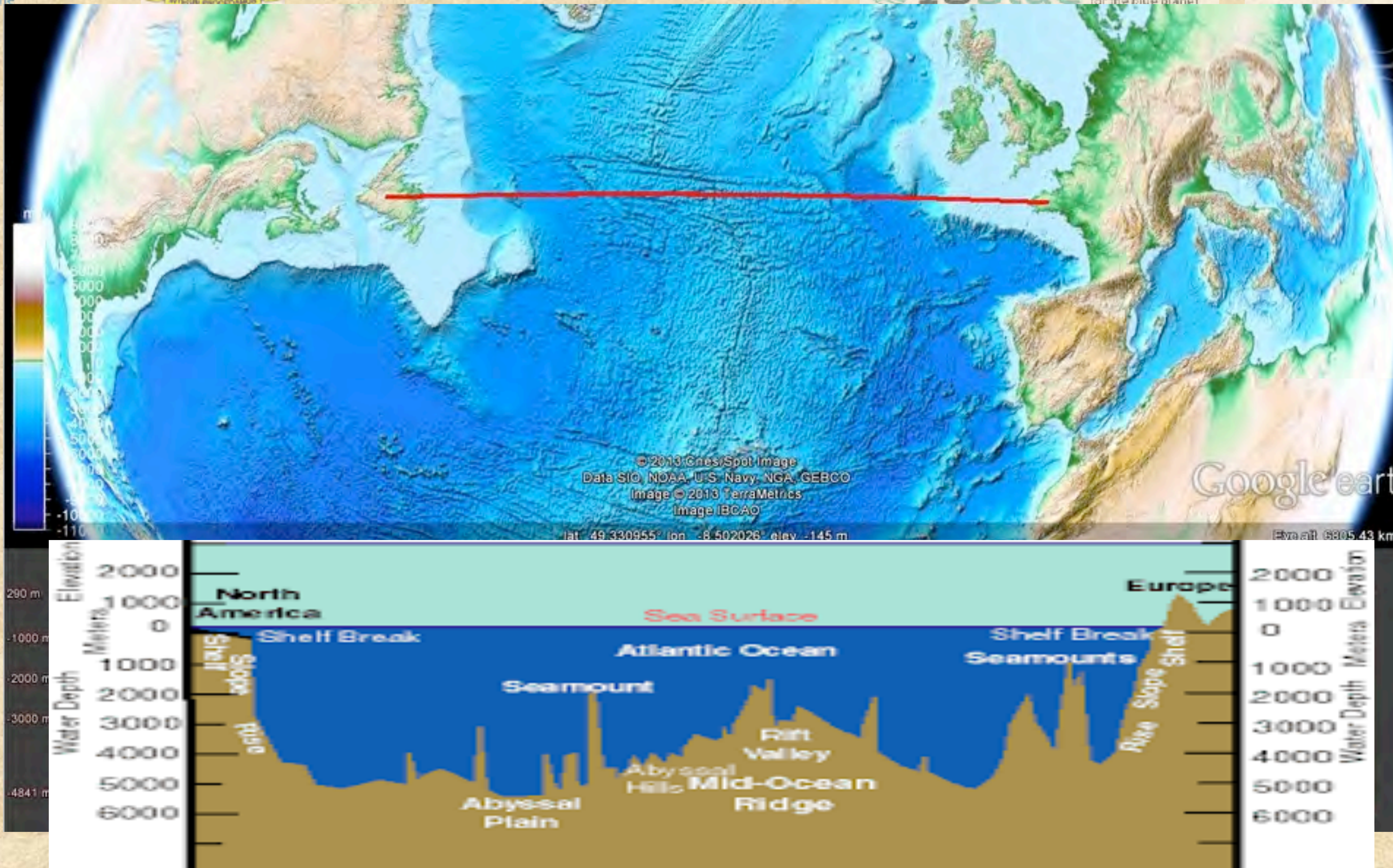
j	1 j	1 a
a	1 a	100 a
ka	1 ka	10 ka
Ma	1 Ma	10 Ma
Ma	10 Ma	100 Ma

+ TIME SCALE :

Back/Forth

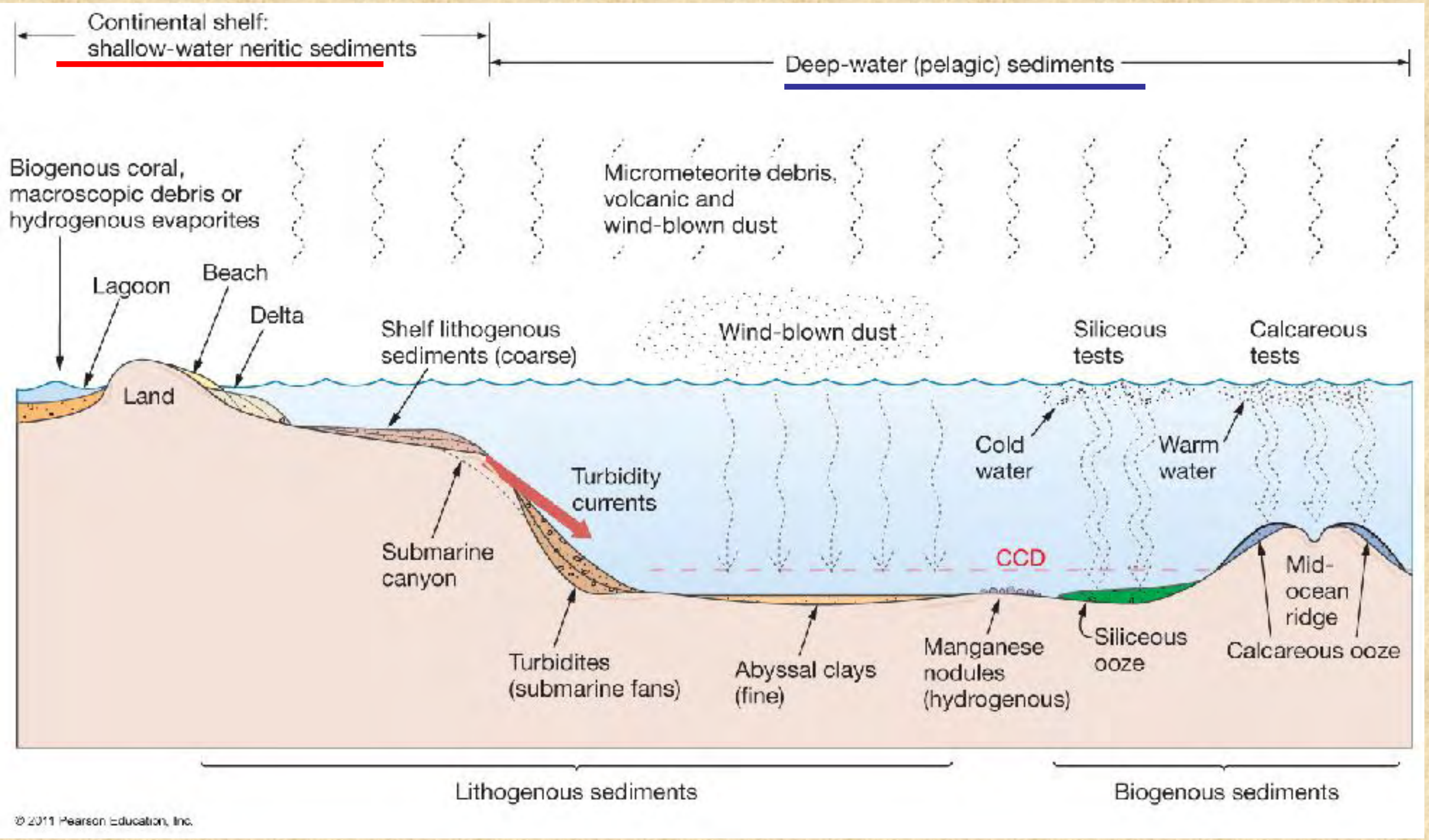
Marine Sedimentology

- What types of sediments can be found on the ocean floor ?
- What variety of marine environments of deposition ?
- Key controls on sedimentology in marine systems
- Reconstructing history of the Earth
- Knowledge for the future

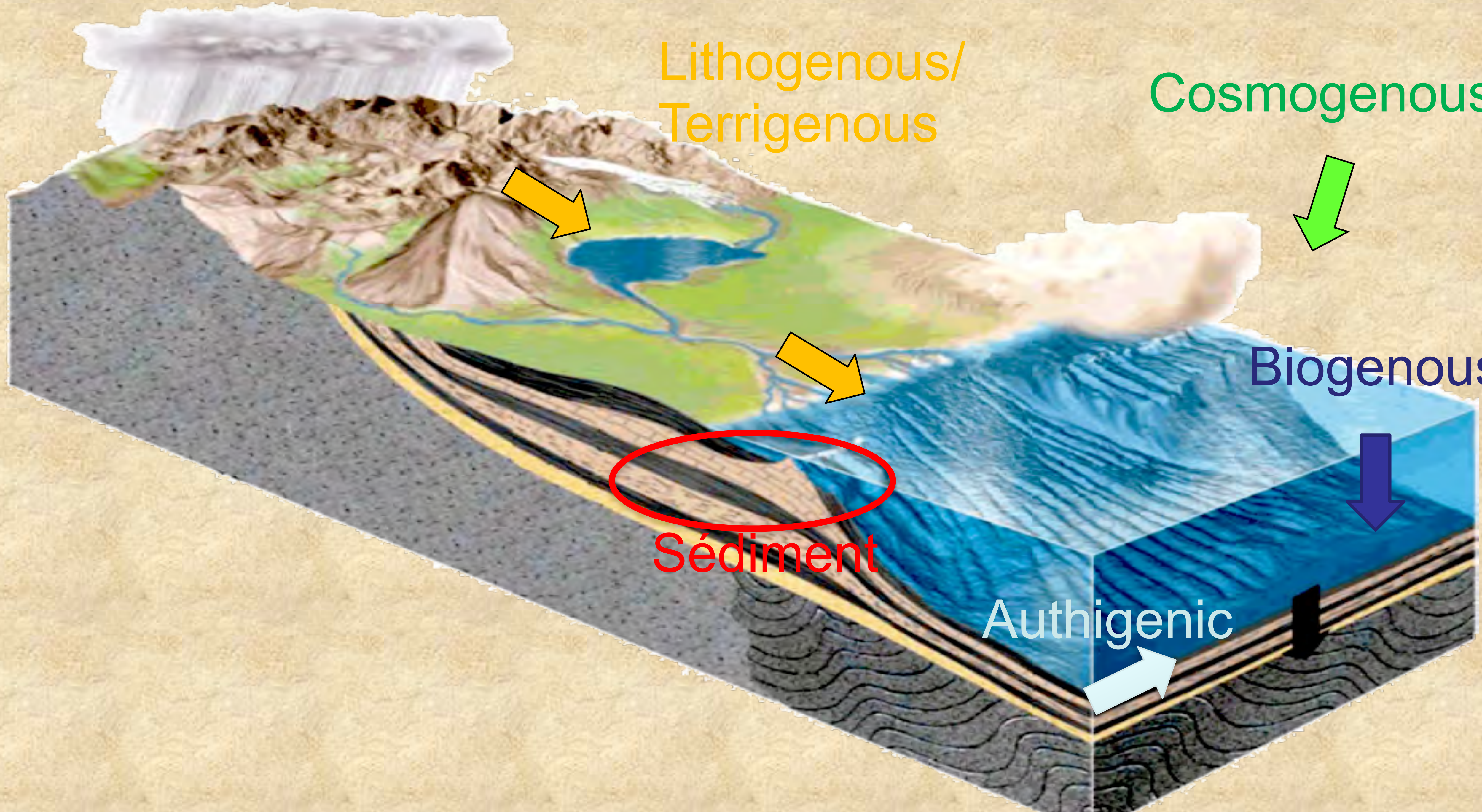


Variable Morphologies

Variety of sedimentary environments



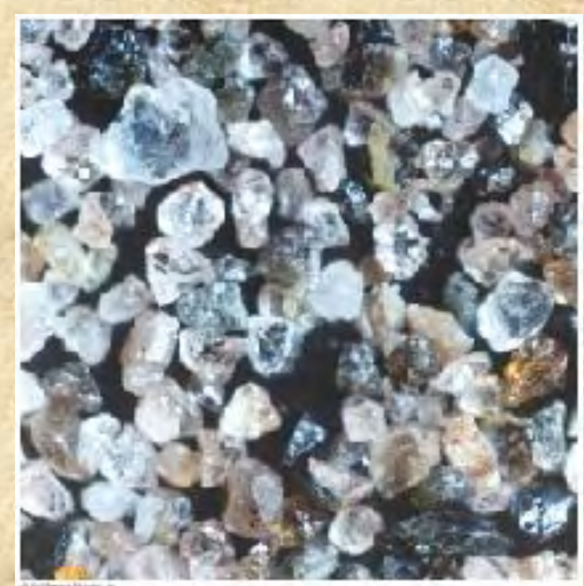
Sediment : Storyteller of the Earth



Terrigeneous Sediments

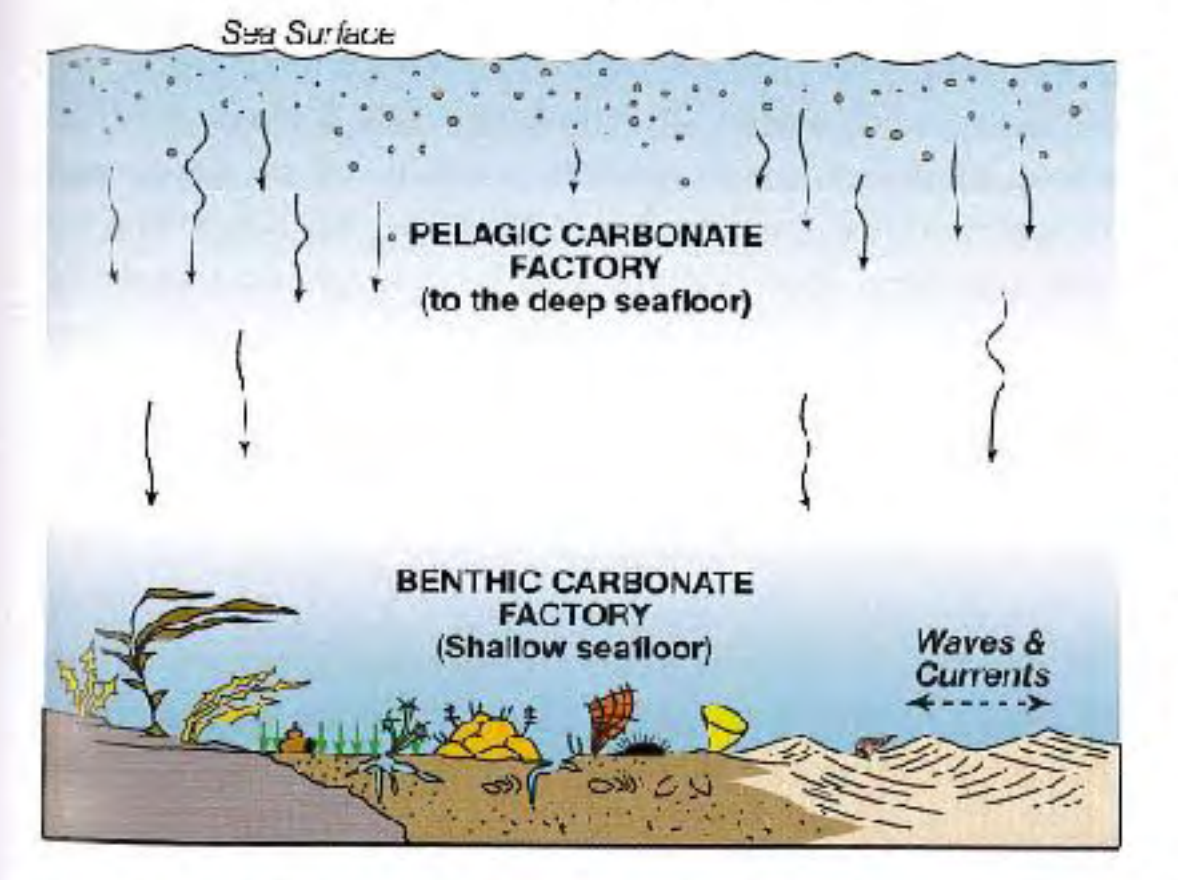
- Small particles eroded and transported
- Carried to ocean : Streams, Rivers, Wind, Glaciers , Gravity
- Greatest quantity on continental margins

- Reflect composition of rock from which they derived from
- Coarser sediments closer to shore
- Finer sediments farther from shore
- Mainly mineral quartz (SiO_2)



A Ressource :
for construction, buildings

Biogenous Sediment

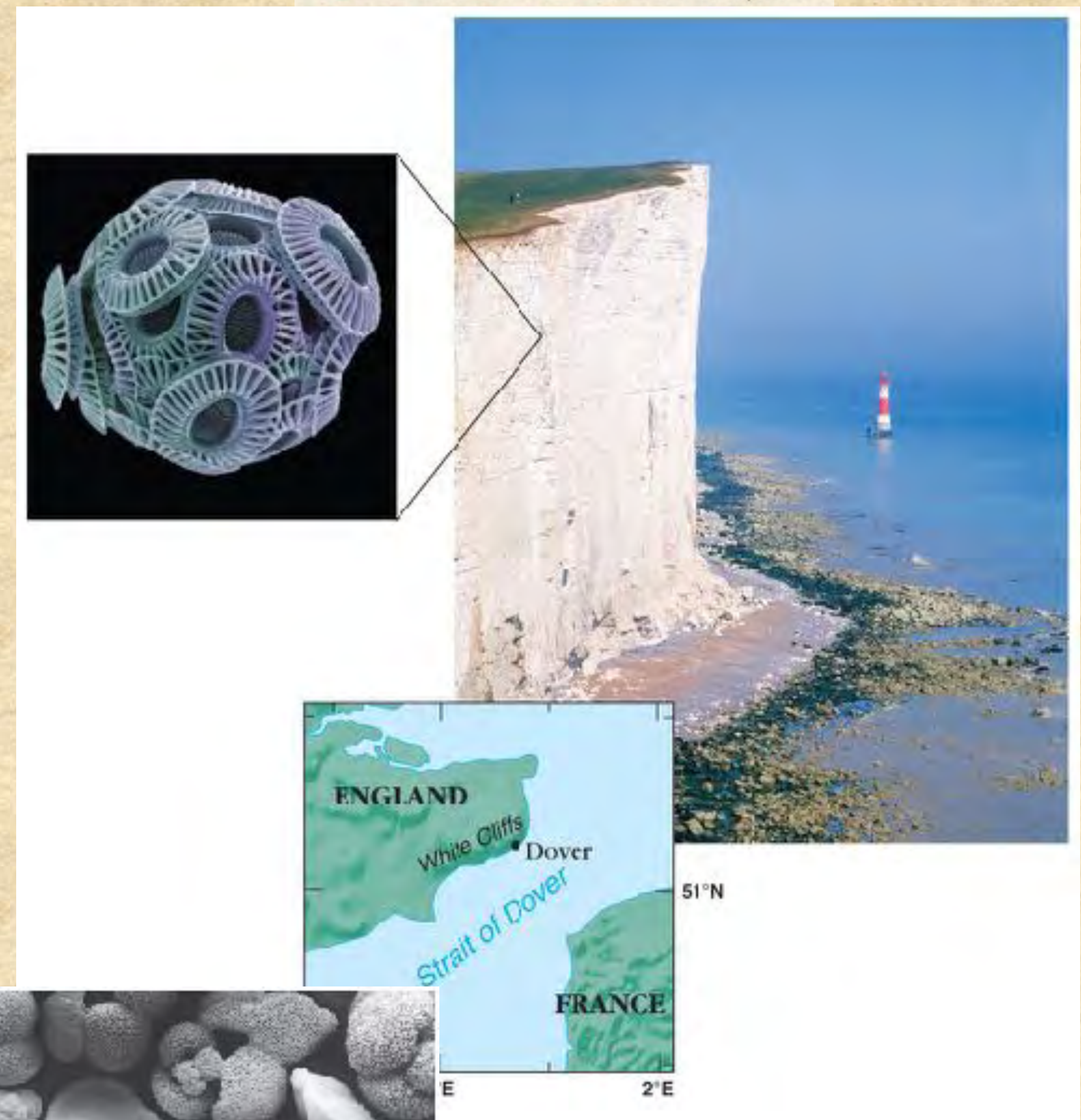


- Hard remains of once-living organisms
- Two major types:
  - Macroscopic
    - Visible to naked eye
    - Shells, bones, teeth
  - Microscopic
    - Tiny shells or tests
    - Biogenic ooze
    - Mainly algae and protozoans

- Two most common chemical compounds:
  - Calcium carbonate ($CaCO_3$)
  - Silica (SiO_2 or $SiO_2 \cdot nH_2O$)

Calcium Carbonate Sediments

- Coccolithophores
  - Also called *nannoplankton*
  - Photosynthetic algae
  - Coccoliths – individual plates from dead organism
  - Rock chalk
    - Lithified coccolith-rich ooze



- Foraminifera
  - Protozoans
  - Use external food
  - Calcareous ooze


(c)

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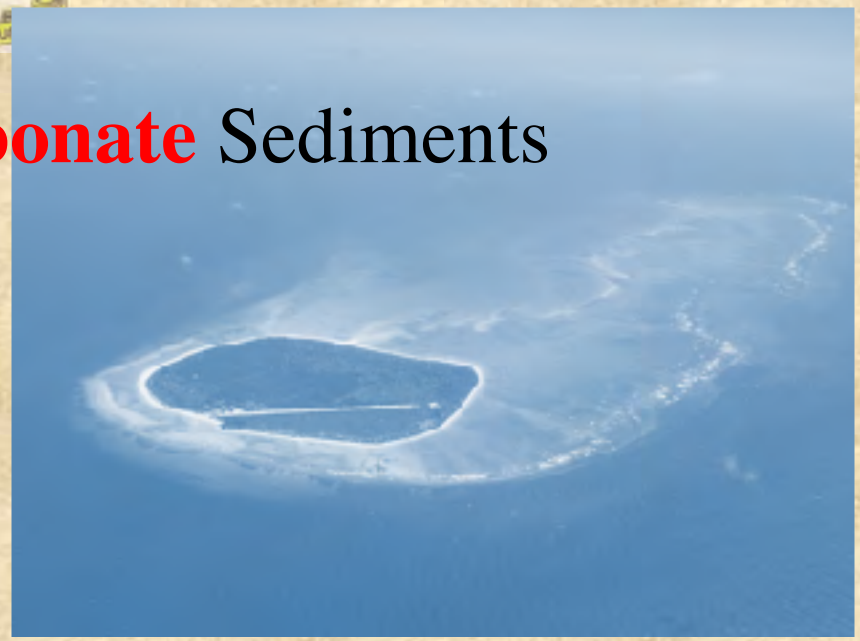
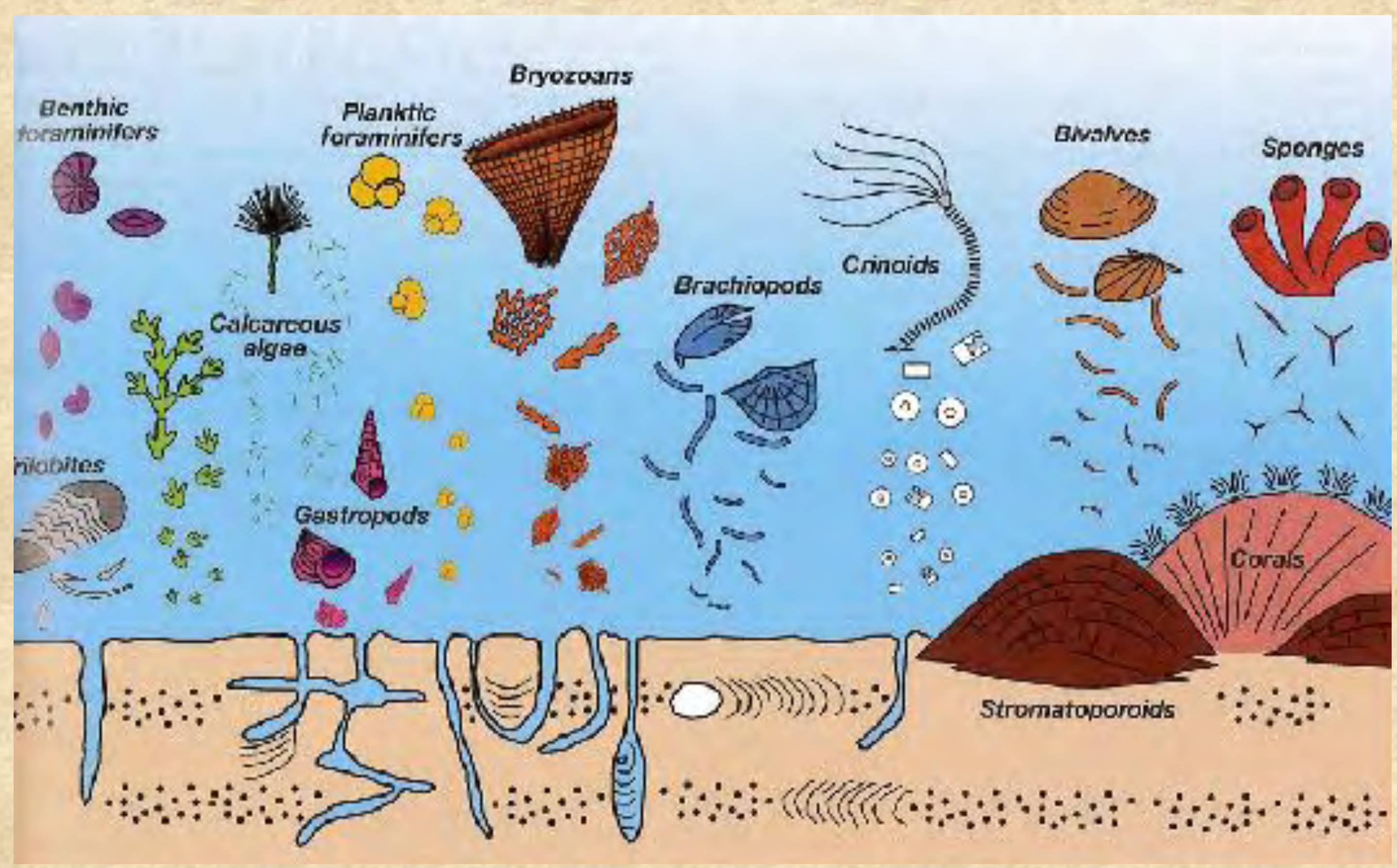
Calcium Carbonate Sediments



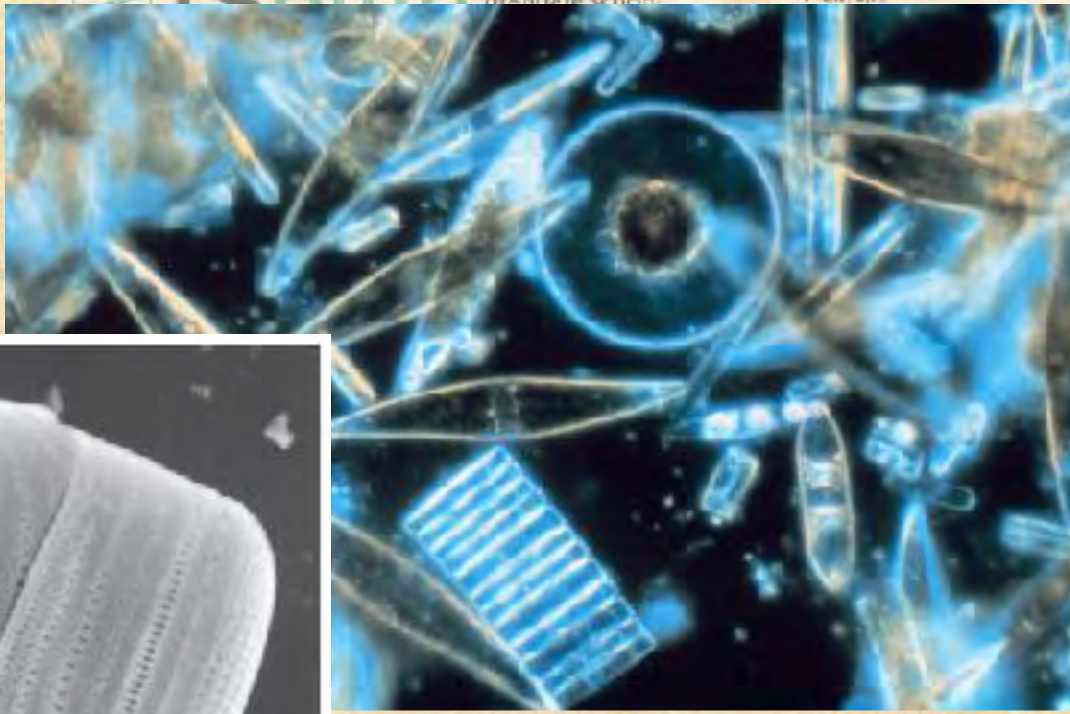
Reefs
- Corals
- Sponges…
- Warm, shallow-ocean

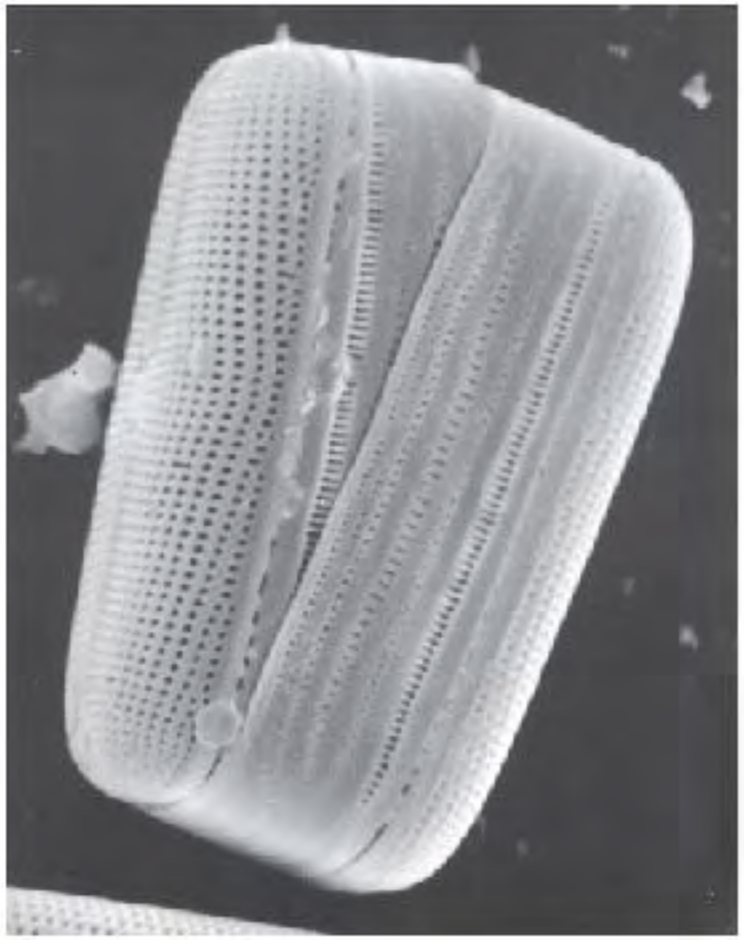
Stromatolites (microbial mat)
- Fine layers of carbonate
- Warm, shallow-ocean, high salinity
- Cyanobacteria



Silica Sediments

- Diatoms
  - Photosynthetic algae
  - Diatomaceous earth
- Radiolarians
  - Protozoans
  - Use external food





(a)

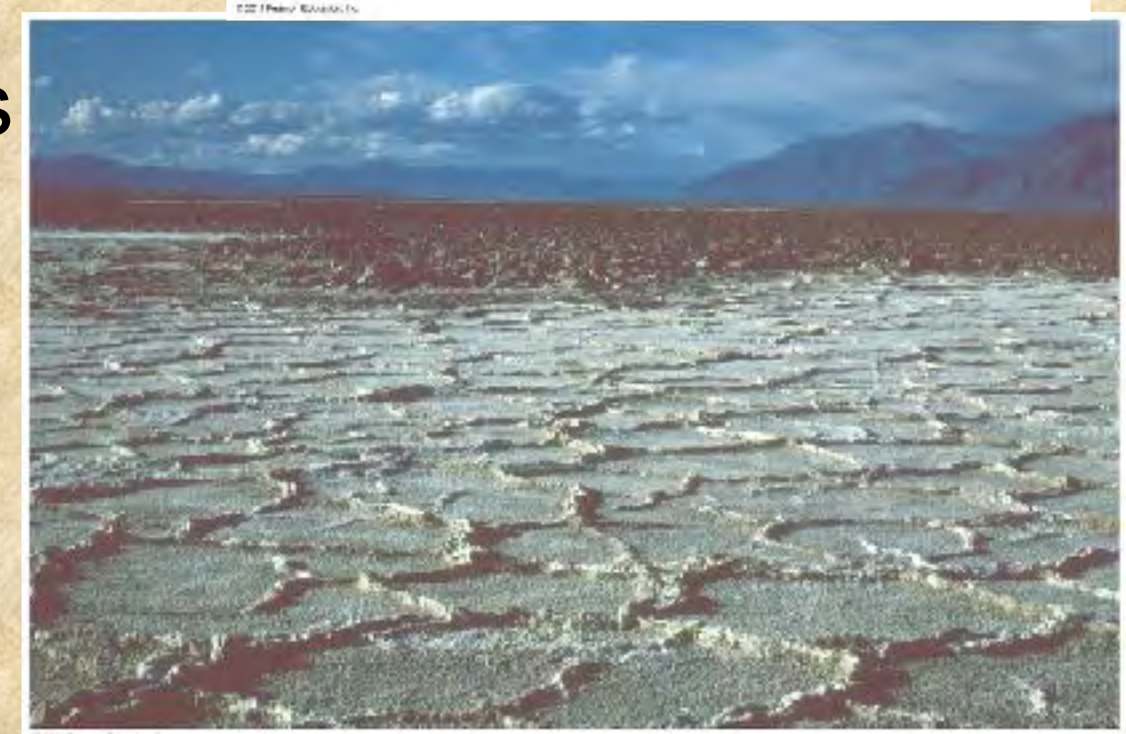
(b)

- Tests from diatoms and radiolarians
  - generate siliceous ooze.

Authigenic Marine Sediments

- Minerals precipitate directly from seawater
  - Manganese nodules
  - Phosphates
  - Carbonates
  - Metal sulfides
  - Evaporites
- Small proportion of marine sediments
- Distributed in diverse environments

(a)



- Metal sulfides
  - Contain:
    - Iron
    - Nickel
    - Copper
    - Zinc
    - Silver
    - Other metals

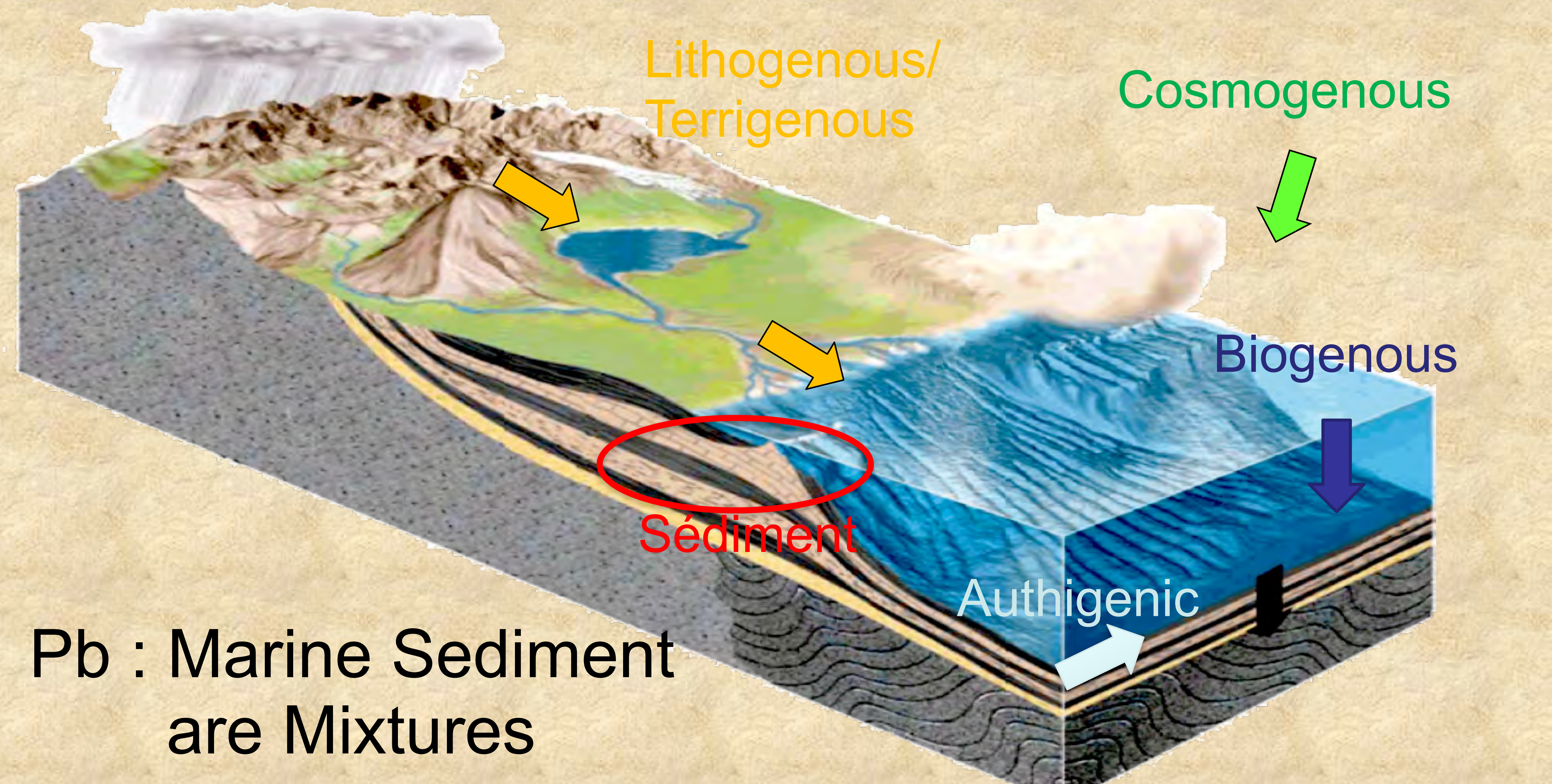
  - Associated with hydrothermal vent

Sediments are a Ressource for humans ?

Construction (sand, clay, plaster…)
Agriculture (maerl, calcareous…)
Cosmetics,
Food, health
Electronic devices (Rare Earth…)

But also: problems with pollution by human activities
⇒ Algae proliferation
⇒ Quarries, mining pollution
⇒ Toxic bacteria

- Terrigenous – derived from land
- Biogenous – derived from organisms
- Authigenic – derived from water-ground interactions (pcpt°-recrystalisation)
- Cosmogenous – derived from outer space

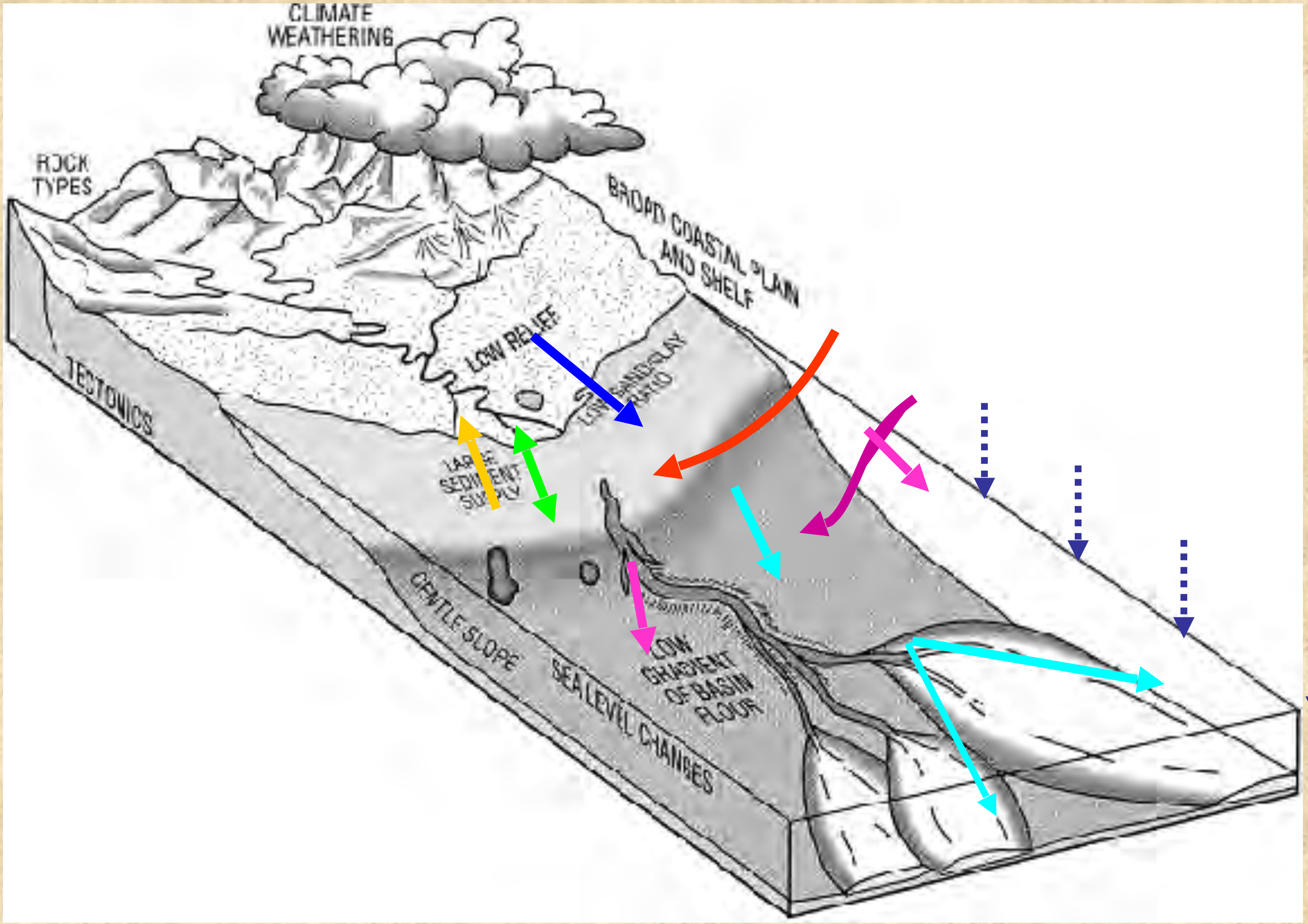


Pb : Marine Sediment
are Mixtures

A location problem

Different environments, different Sedimentary Processes

- Rivers >Delta/Estuary
- Tides
- Waves (storms)
- Littoral drift (circulation)
- Contour currents
- Turbidity currents >deep sea fans
- Slumps, canyons
- Hémipelagic sedimentation



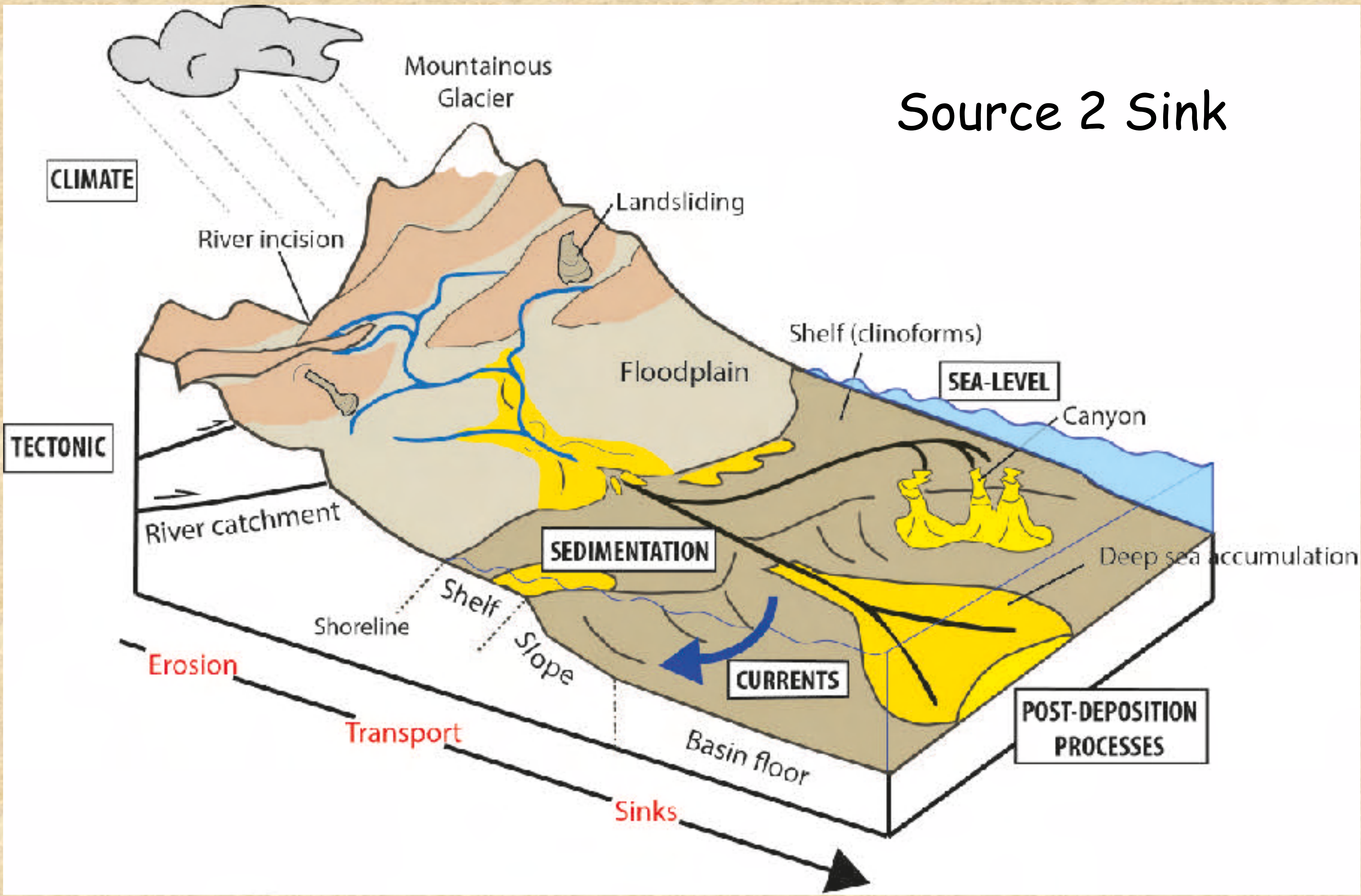
Need for a Source2Sink 3D study

Look in details to decipher
Nature and origin of sediment

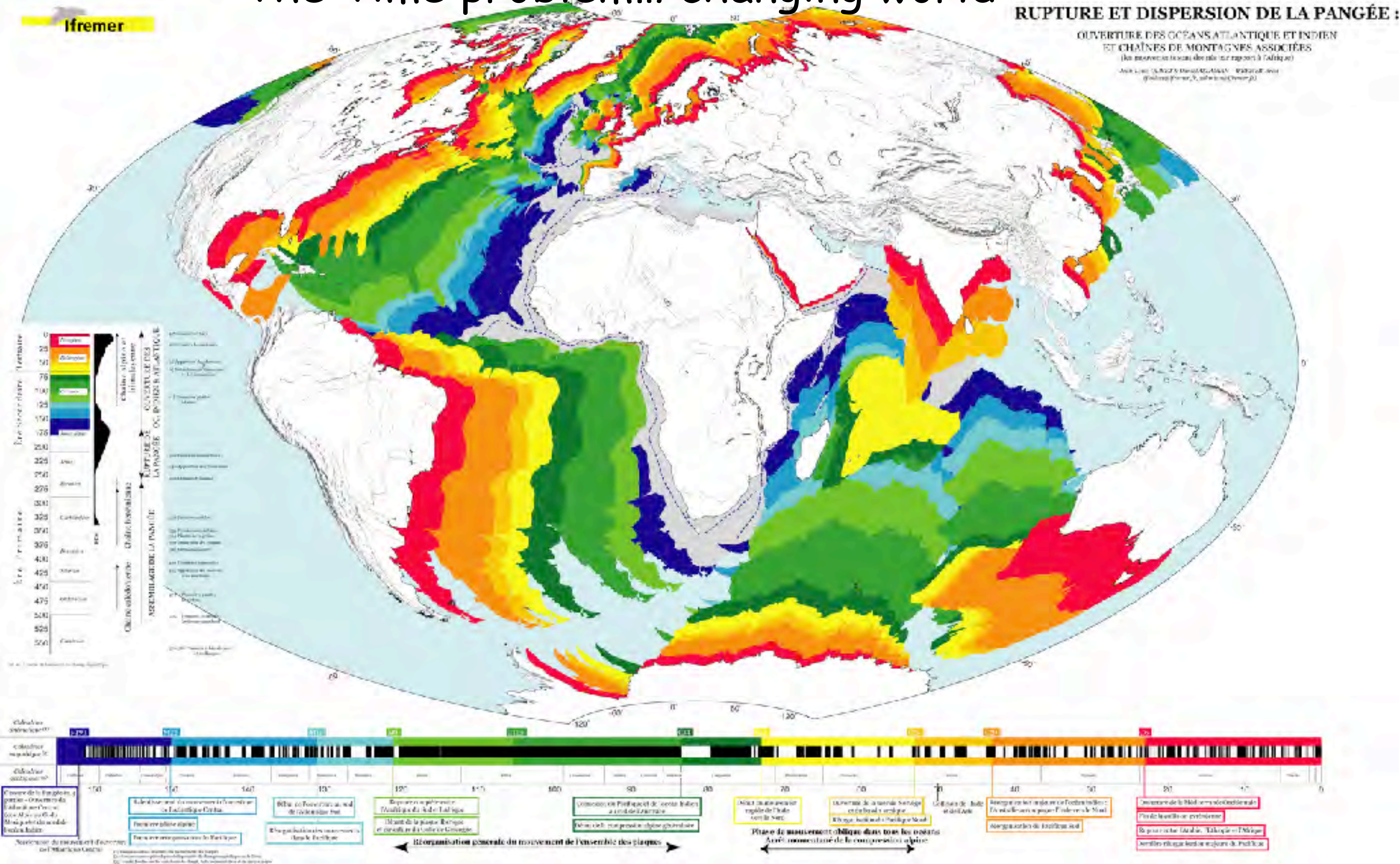
Plane beds

Cross beds

Source 2 Sink



The Time problem… changing world



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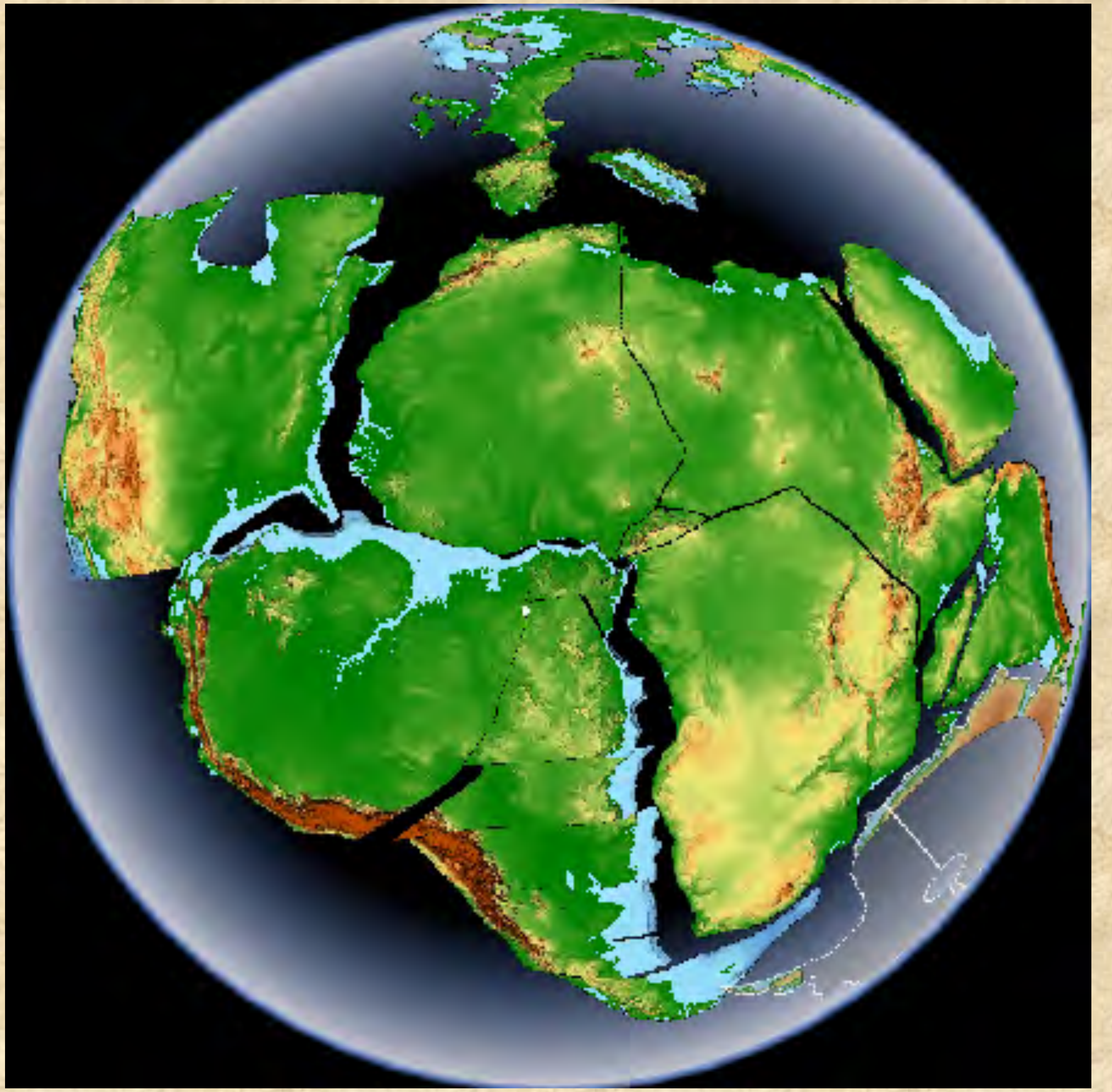
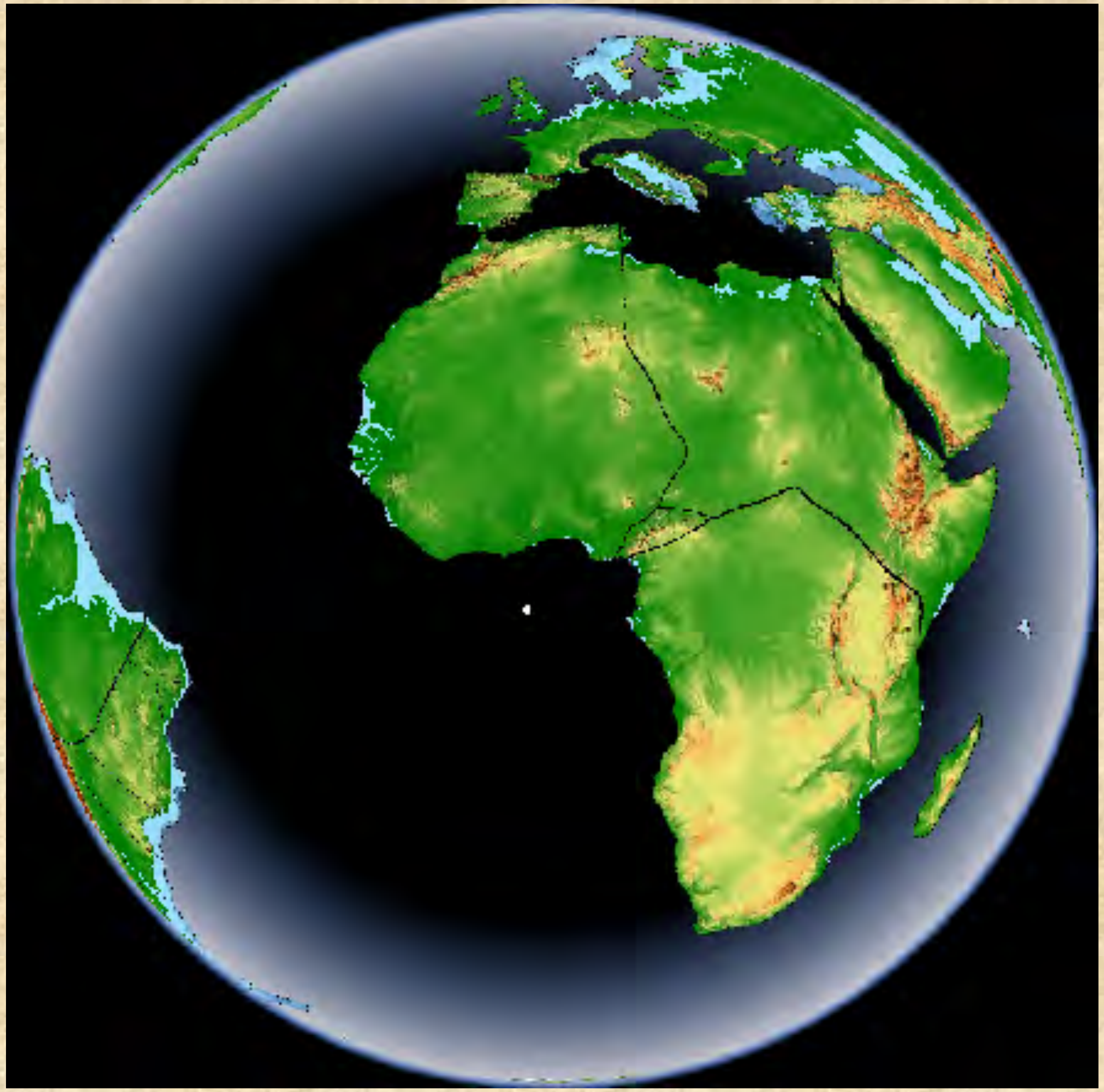
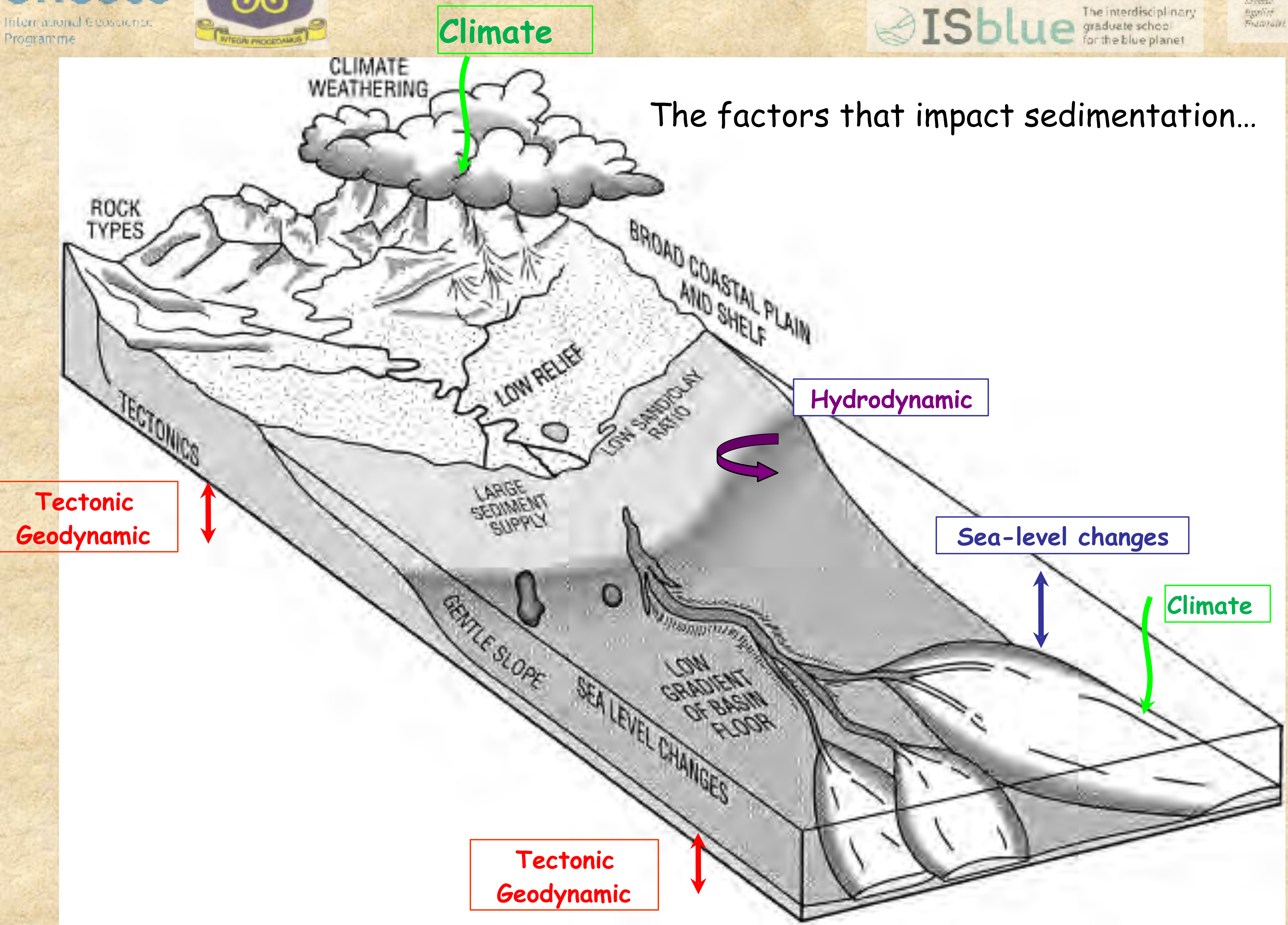


200 Ma

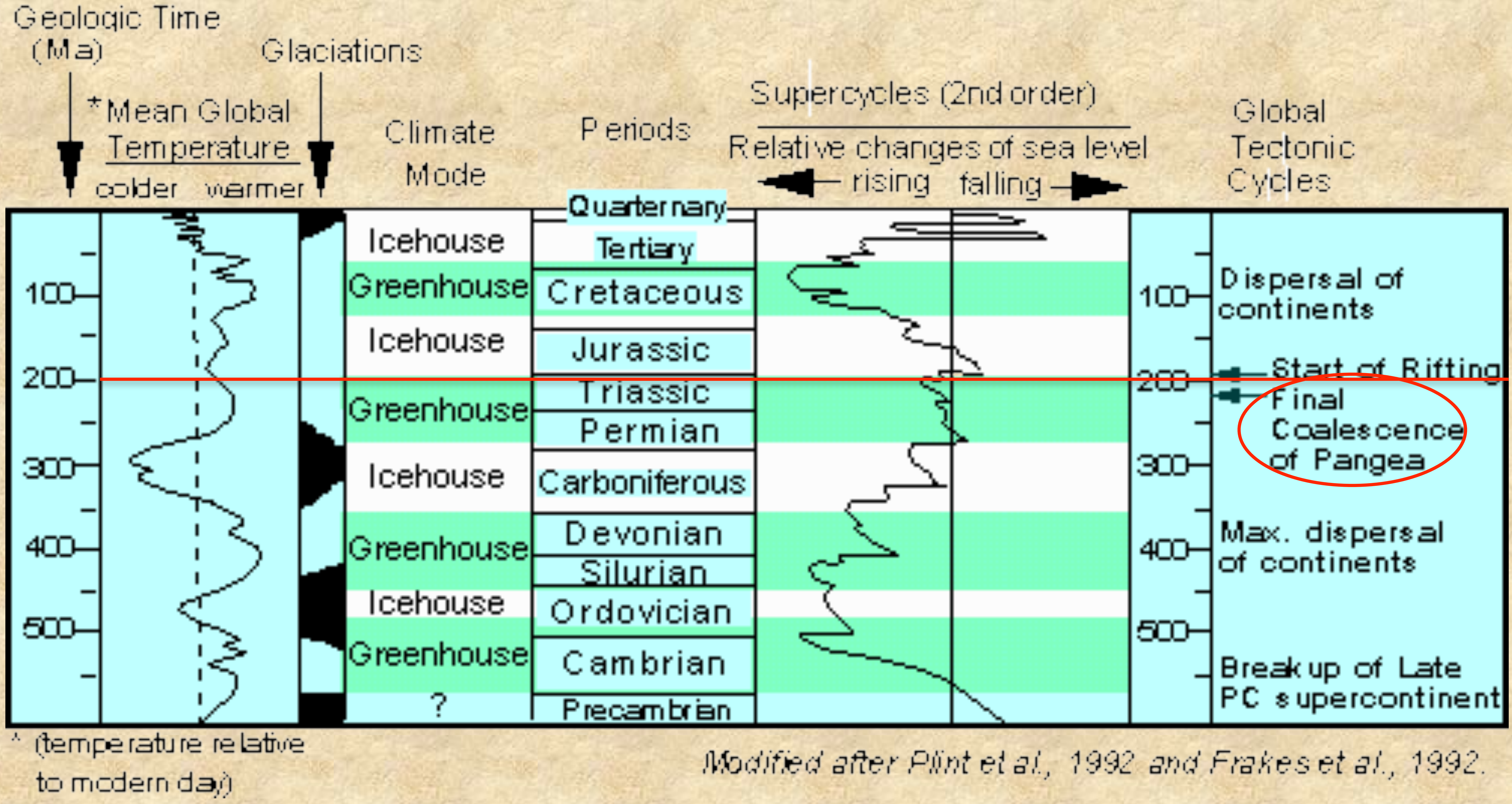


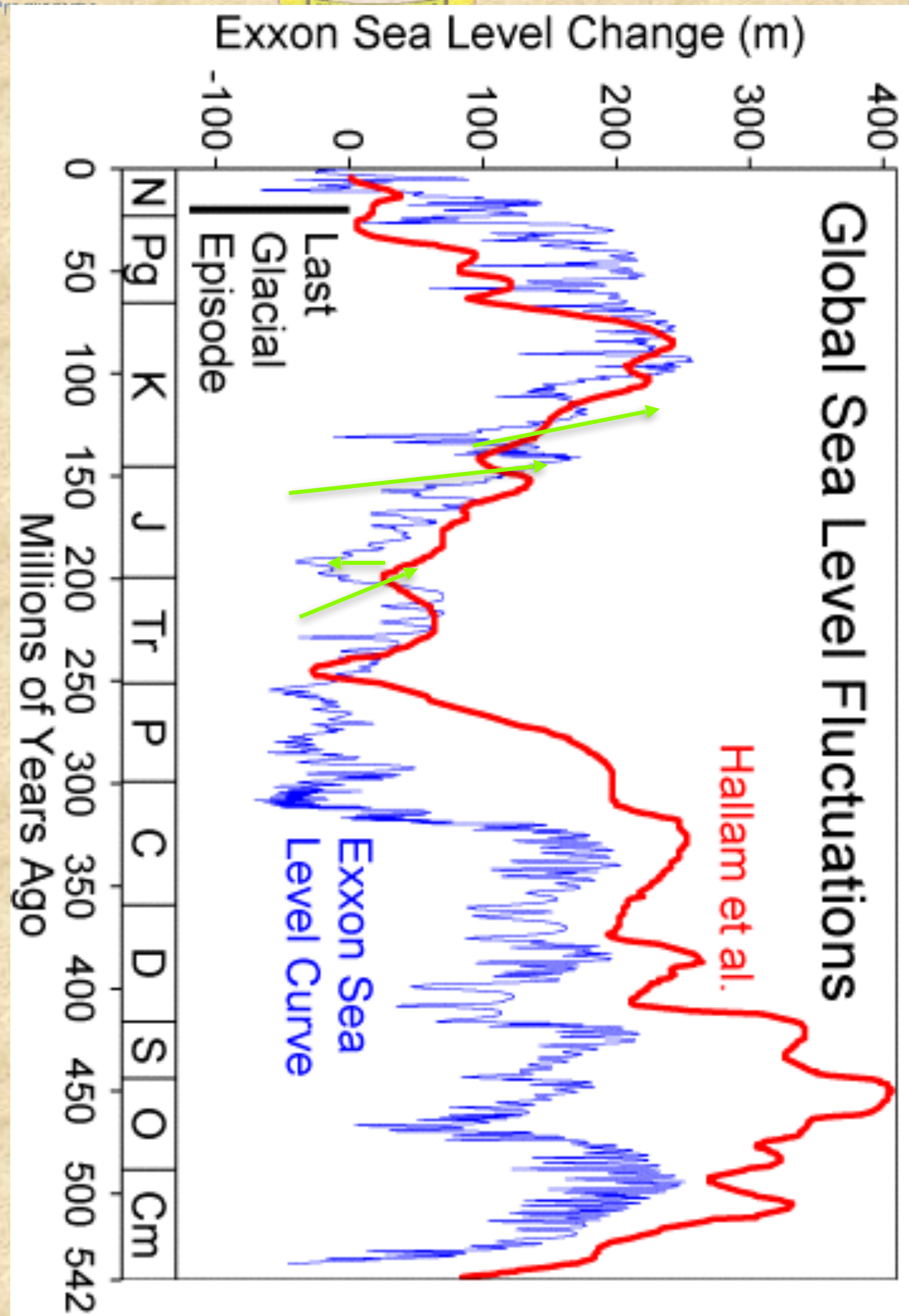
0 Ma

The factors that impact sedimentation…



Climate change



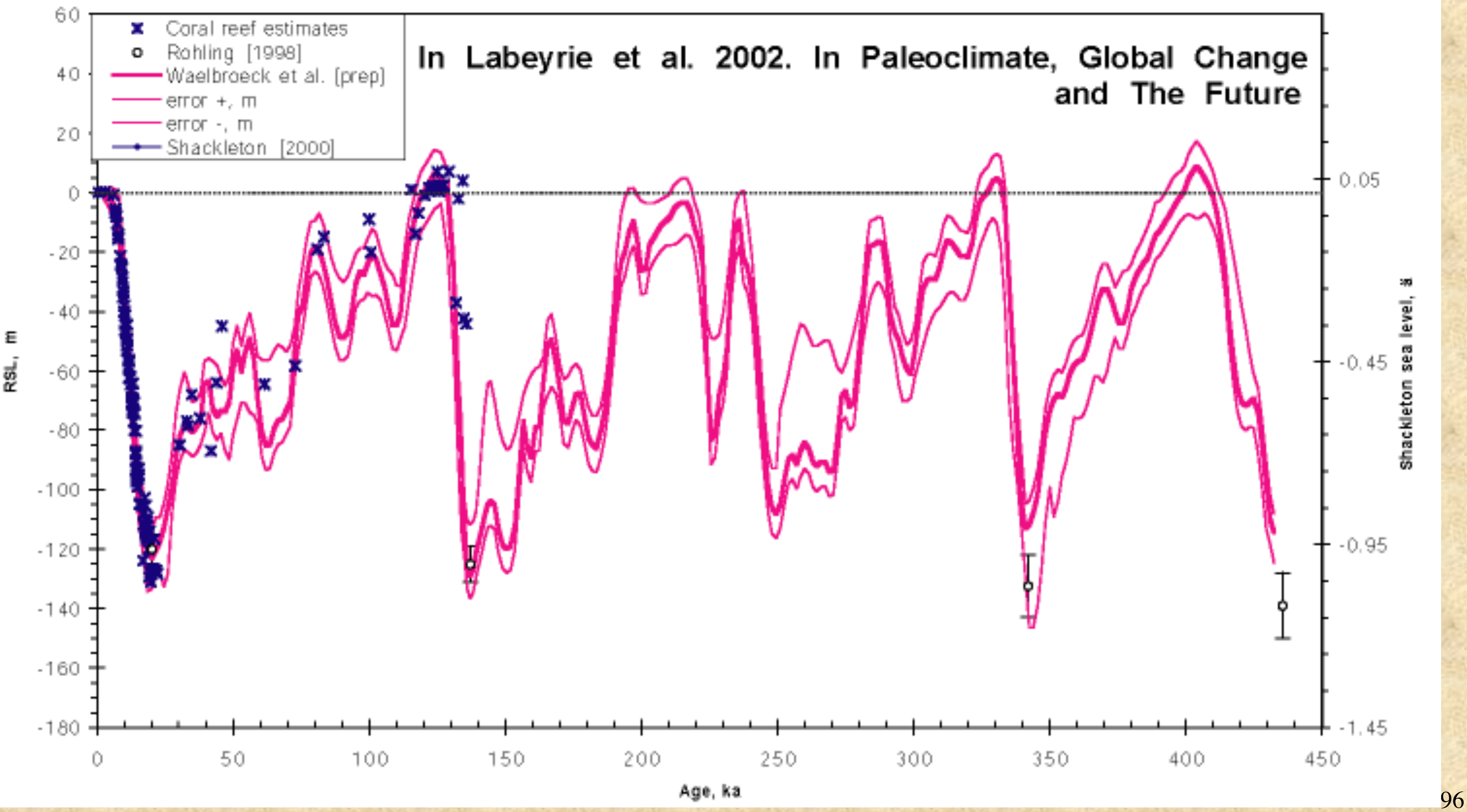


• Cycles 1e order: 2 cycles 400 and 200 Ma
Origin: variation of oceanic ridges, geodynamic, plate tectonics

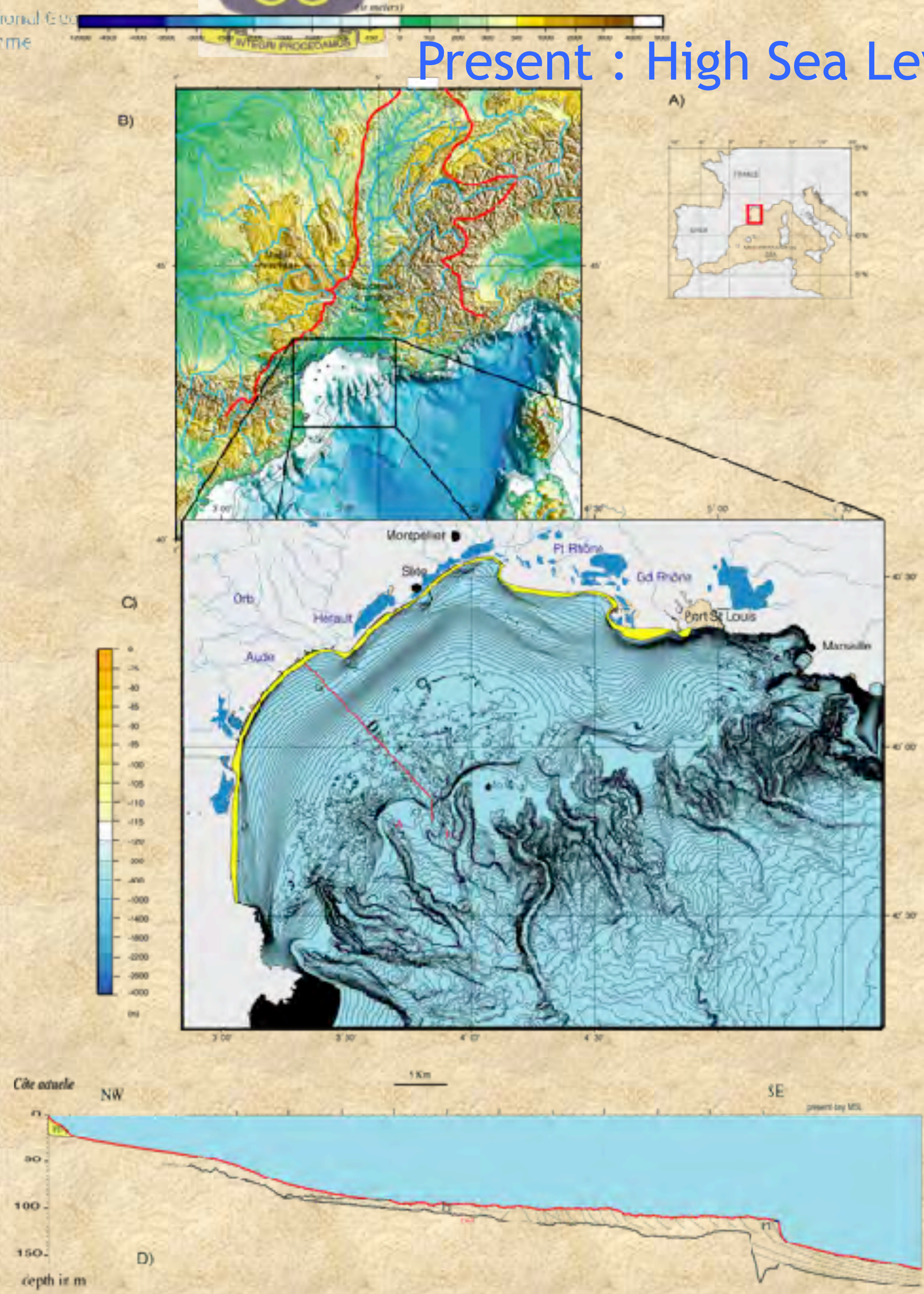
• Cycles 2e order: cycles 10 to 100 Ma
oceanic ridges activity

•Cycles de 3rd order: cycles < 3 Ma
Origin: glacio or tectono-eustaticy

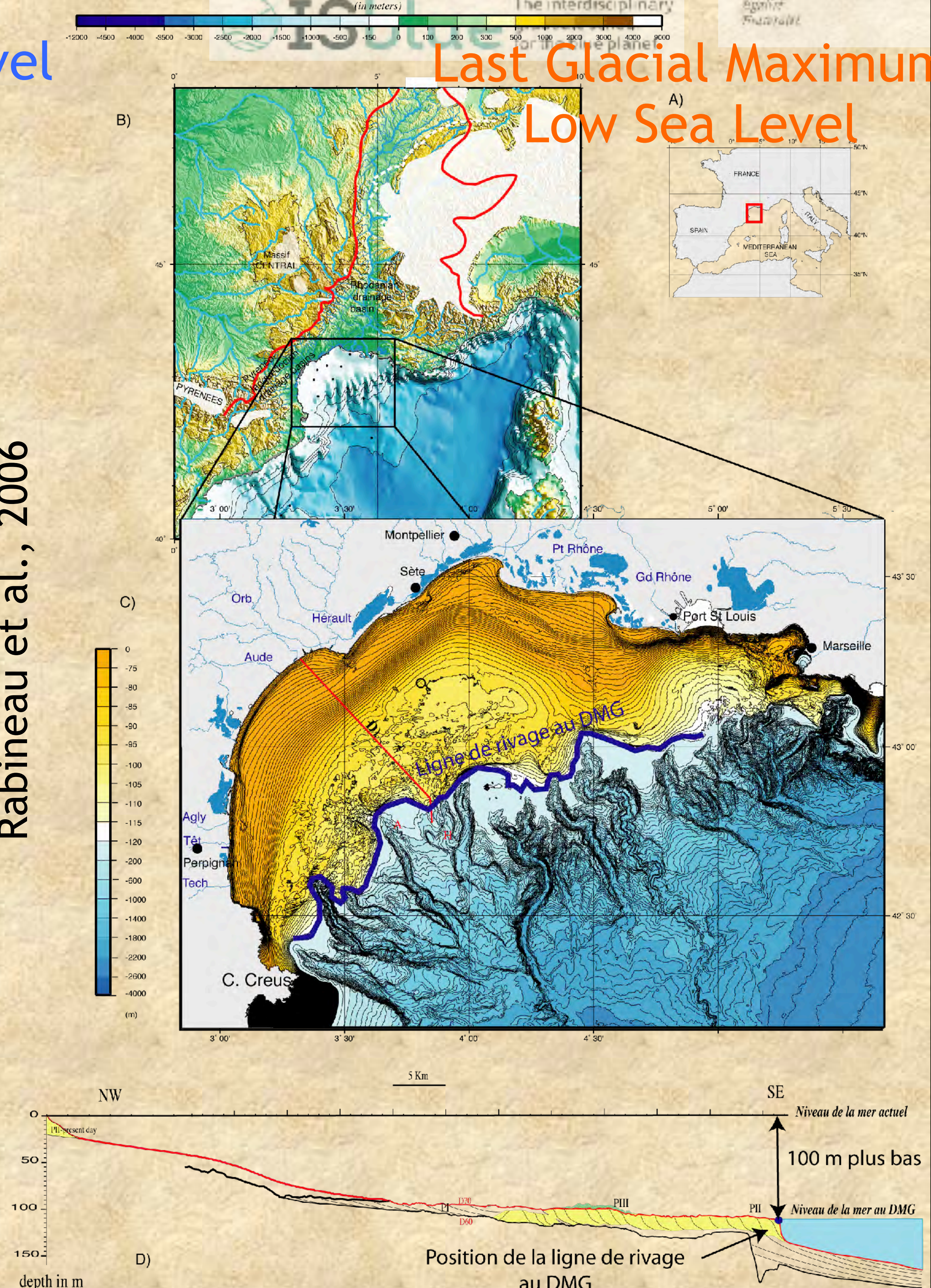
Sea Level Changes Over Four Glacial Cycles



Present : High Sea Level

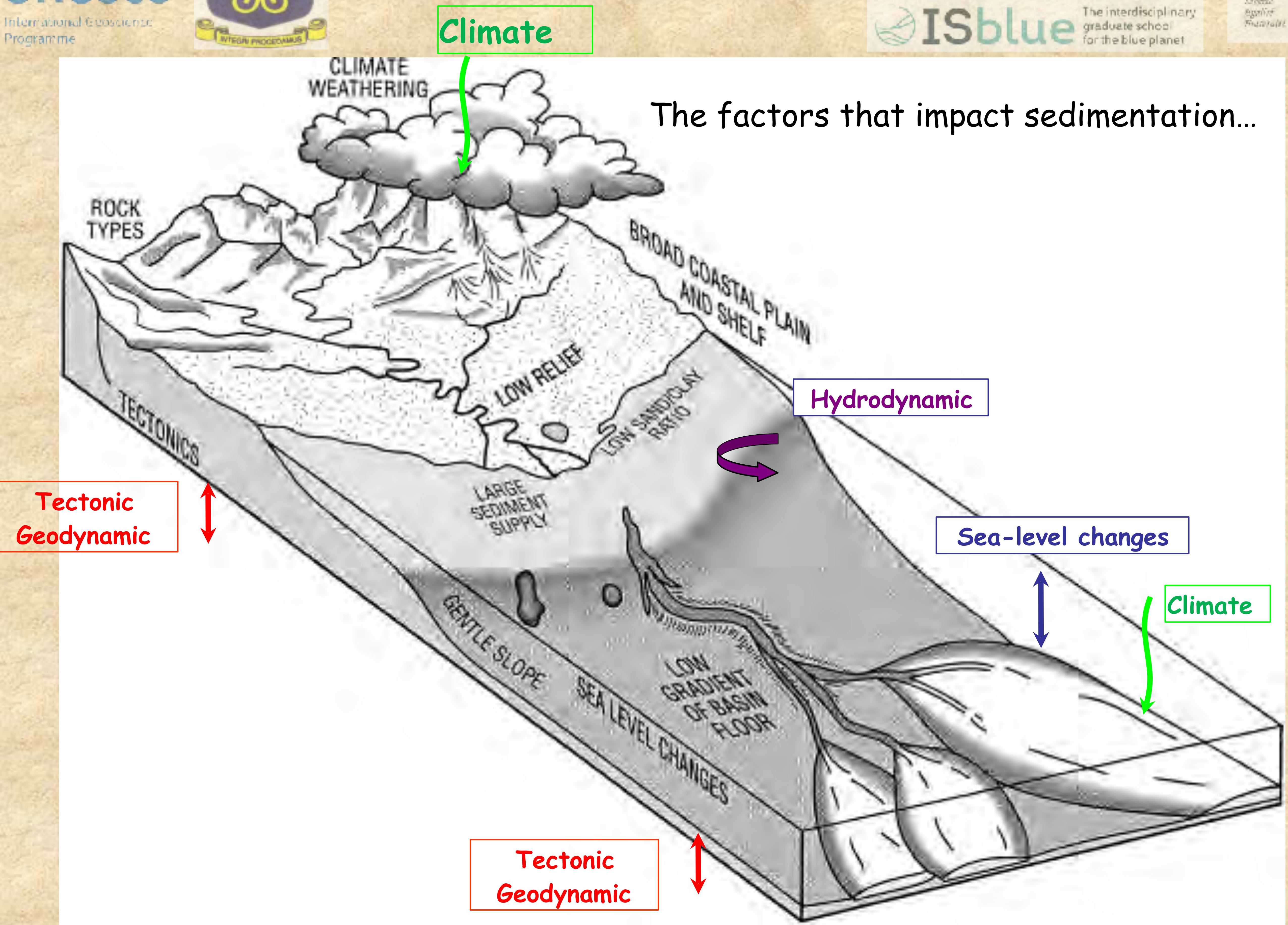


Last Glacial Maximum Low Sea Level



Rabineau et al., 2006

The factors that impact sedimentation…



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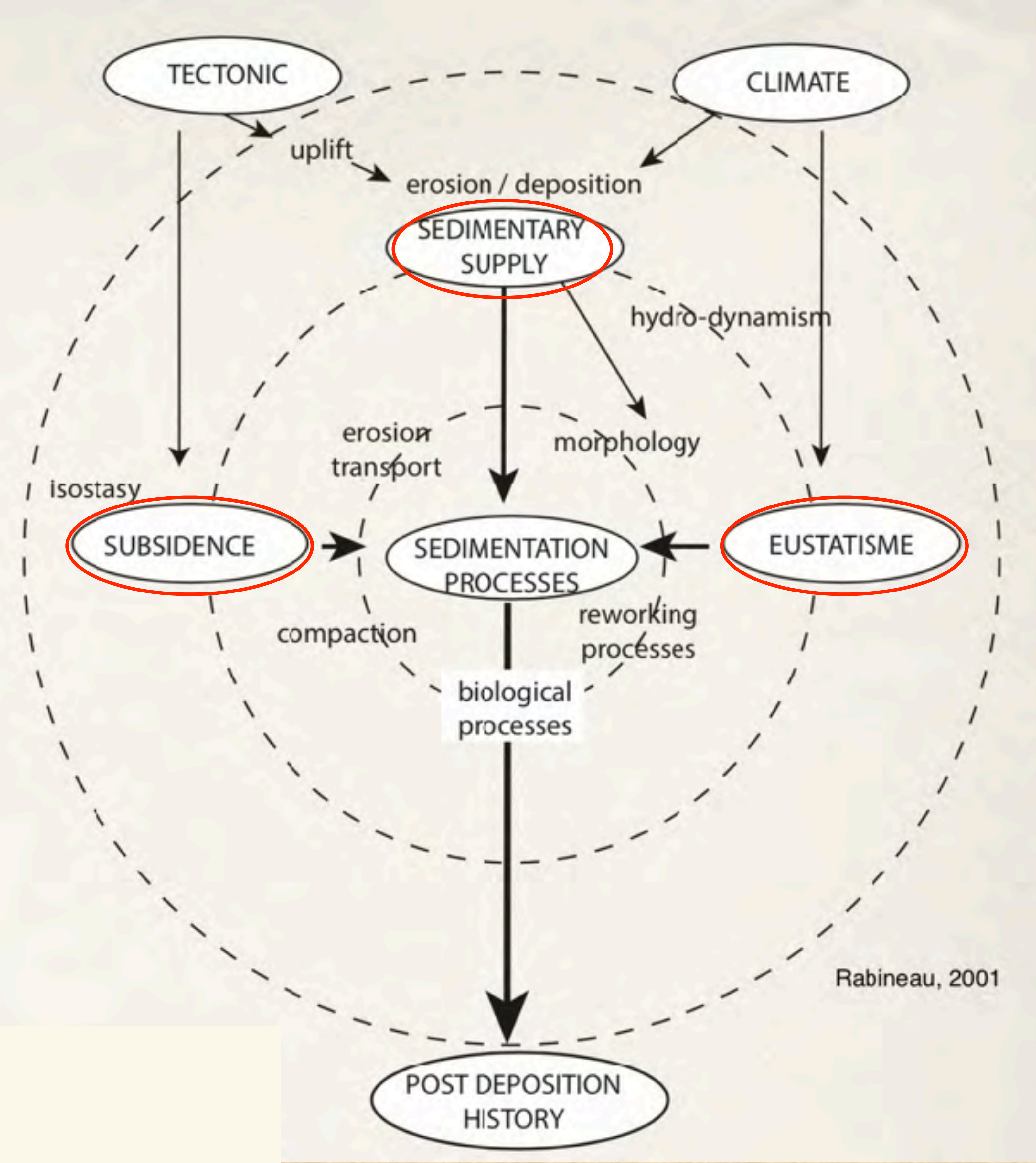

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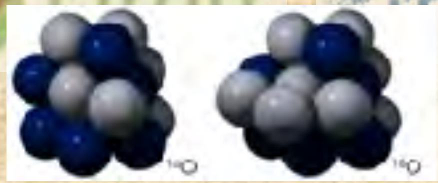
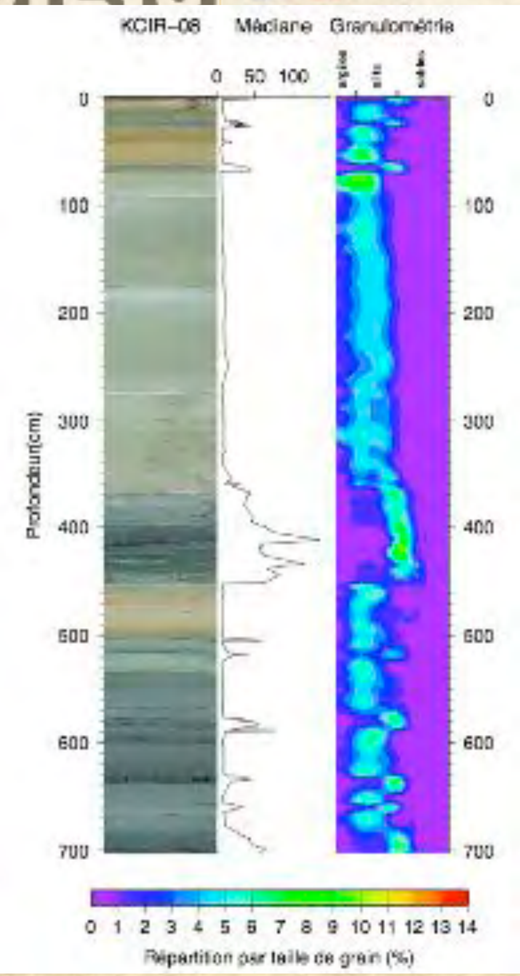
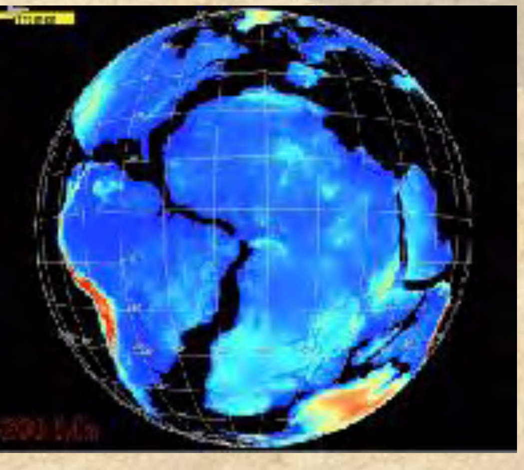
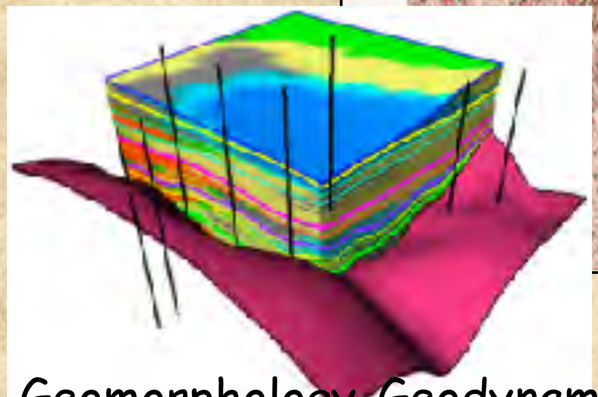
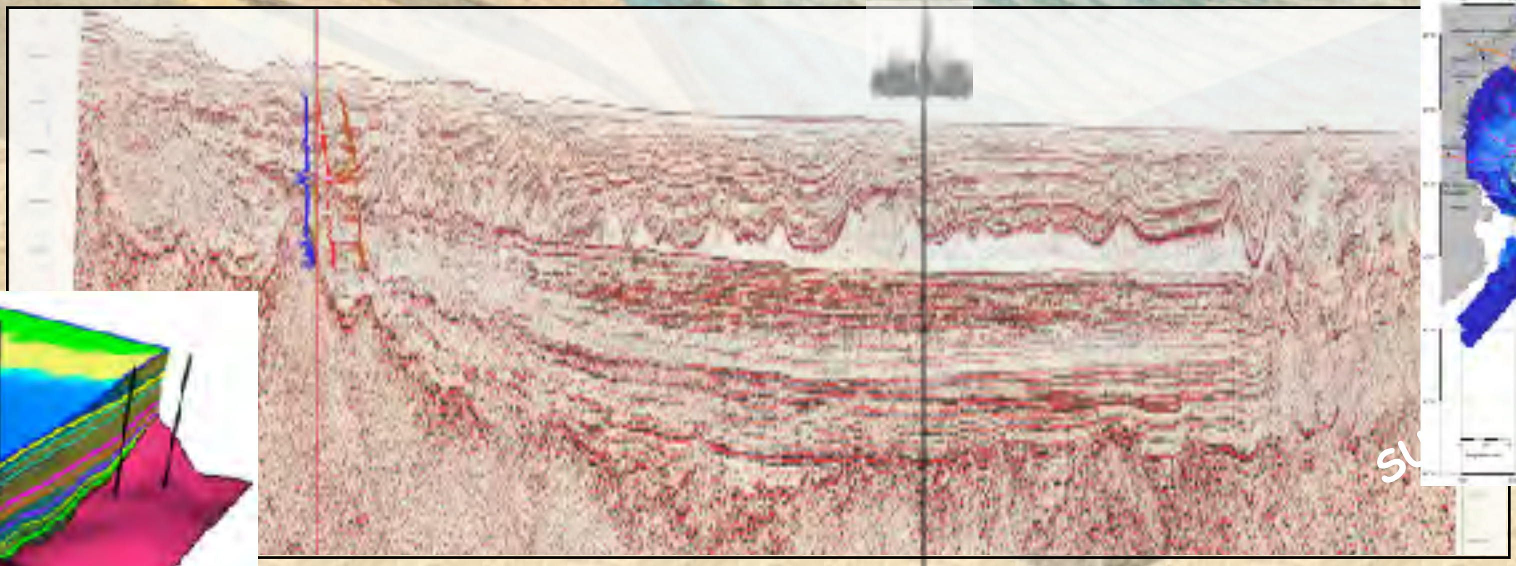
Data & Methods

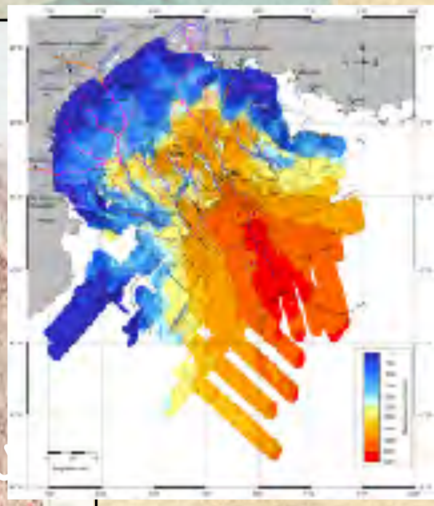












Geophysic-Geochemistry-Geomorphology-Geodynamic-Micropaléontology-Microbiology-Sedimentology