Continental rifting at magma-poor margins and birth of new steady state oceanic ridges: Interactions between thinning continents and the underlying asthenosphere.

M. Pérez-Gussinyé (Royal Holloway), Sascha Brune (Potsdam), Jason Phipps Morgan (RHUL), Tony Lowry (Utah Univ.), Mario Araujo (Petrobras).

Outline

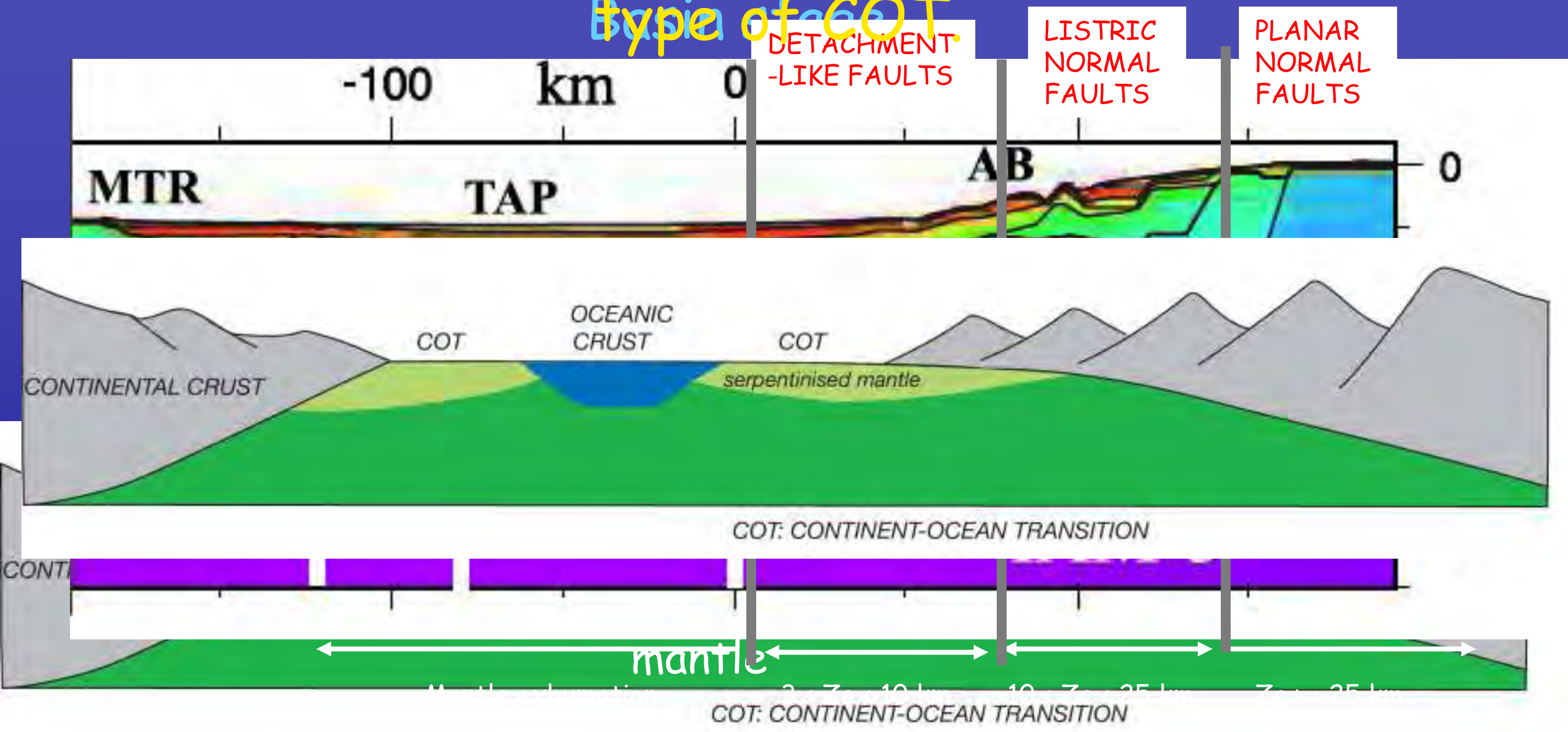
- Kinematics of faulting, crustal thinning & asymmetry formation from observations.
- Dynamics of crustal and lithospheric thinning.
- Relationship between onset of melting/oceanization and strain localisation

3. Relationship between the of pattern of crustal thinning/margin architecture and the type of COT

1- Conjugate margin tectonic asymmetry

2. Change in fault geometry with increasing extension

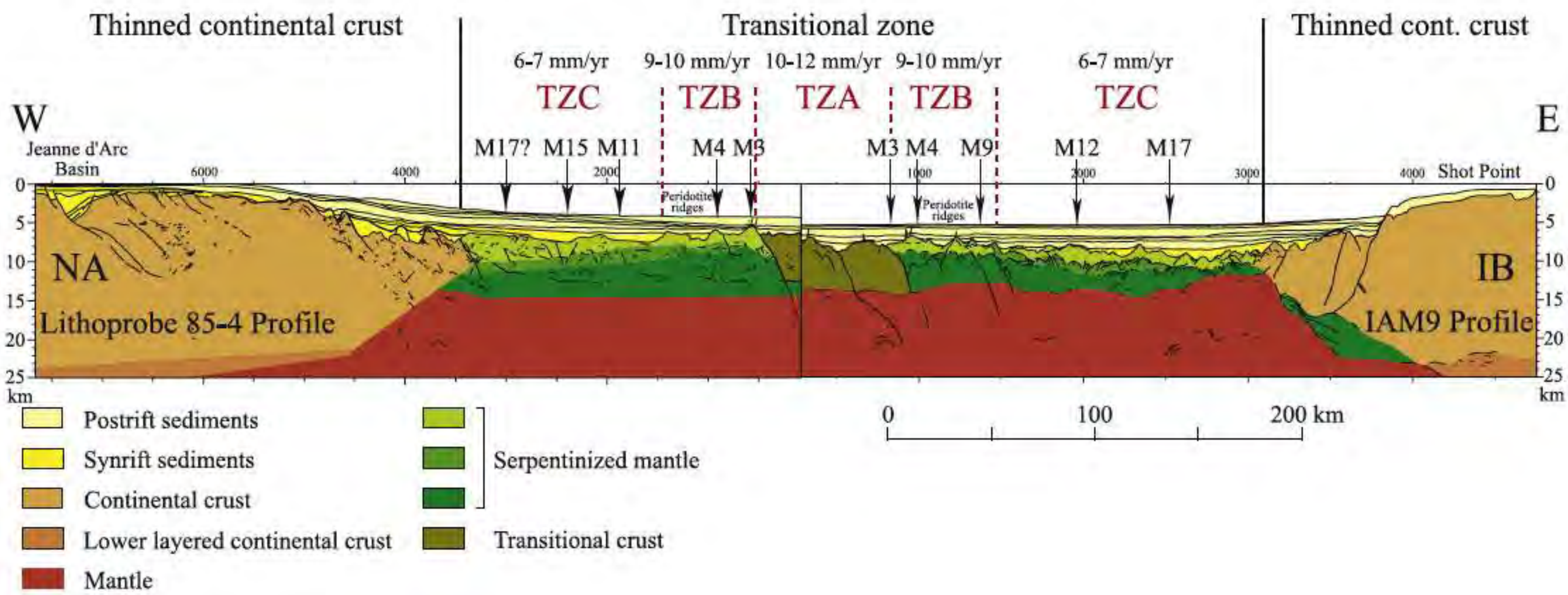
Basin scale



Outline

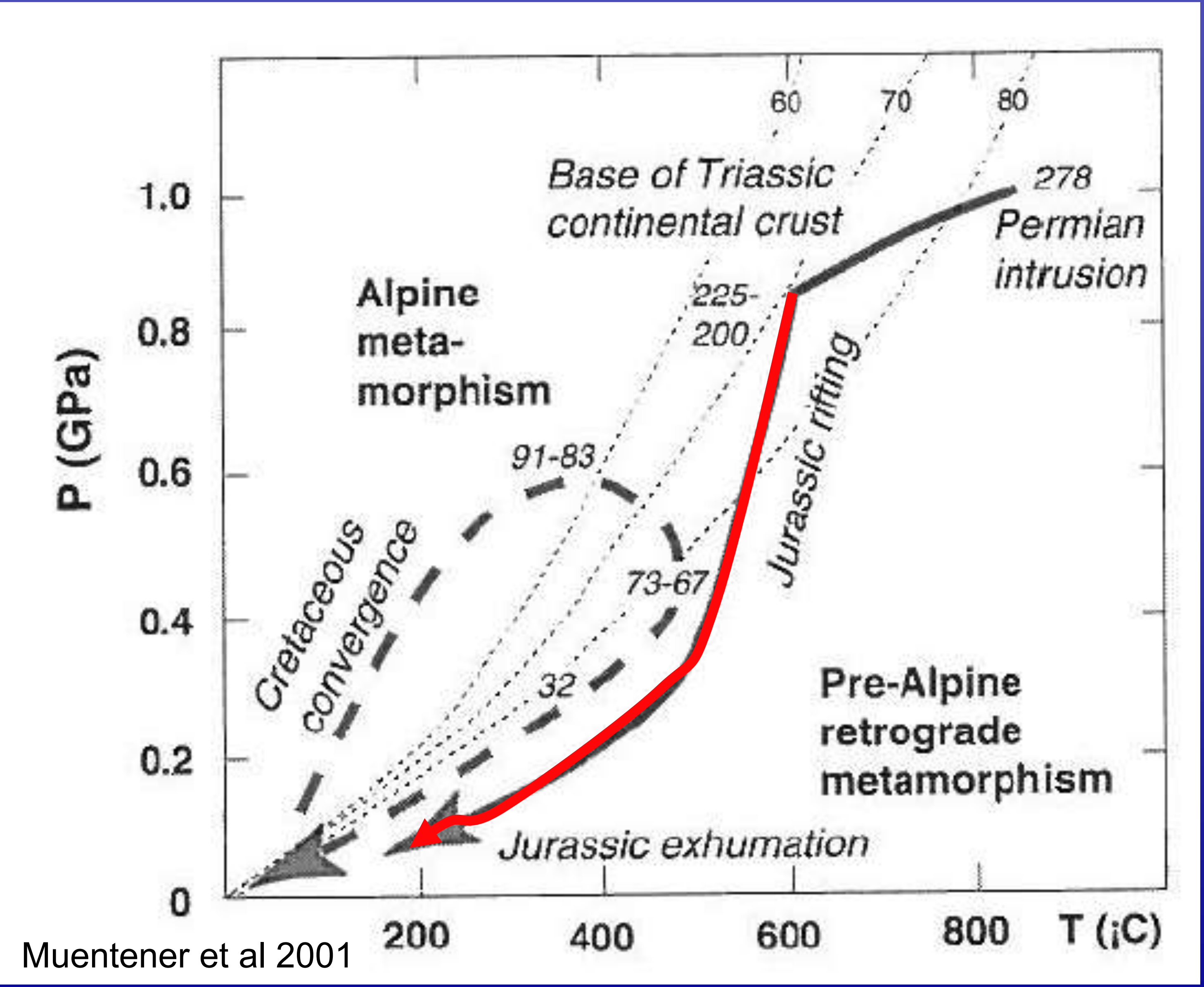
- Kinematics of faulting, crustal thinning & asymmetry formation from observations.

1-West Iberia- Newfoundland margin characteristics

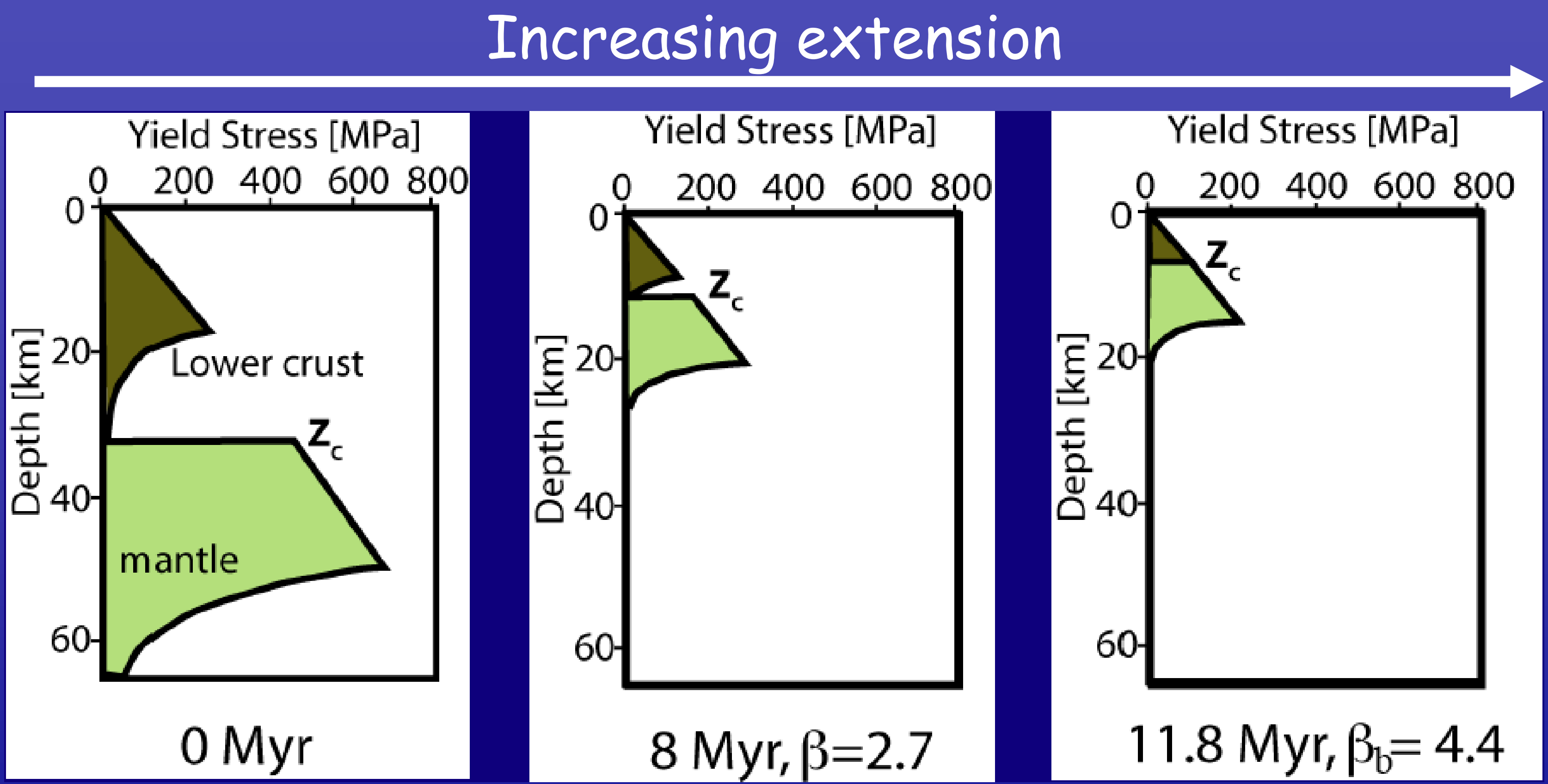


- Very little magmatism.
- Slow extension (ultra-slow end-member)
- Cool Moho (~450-600 C) at the start of rifting (P-T-t data).
- Rather strong lower crust.

Rocks cool during extension



Rocks cool during extension
Lower crust brittle as extension progresses

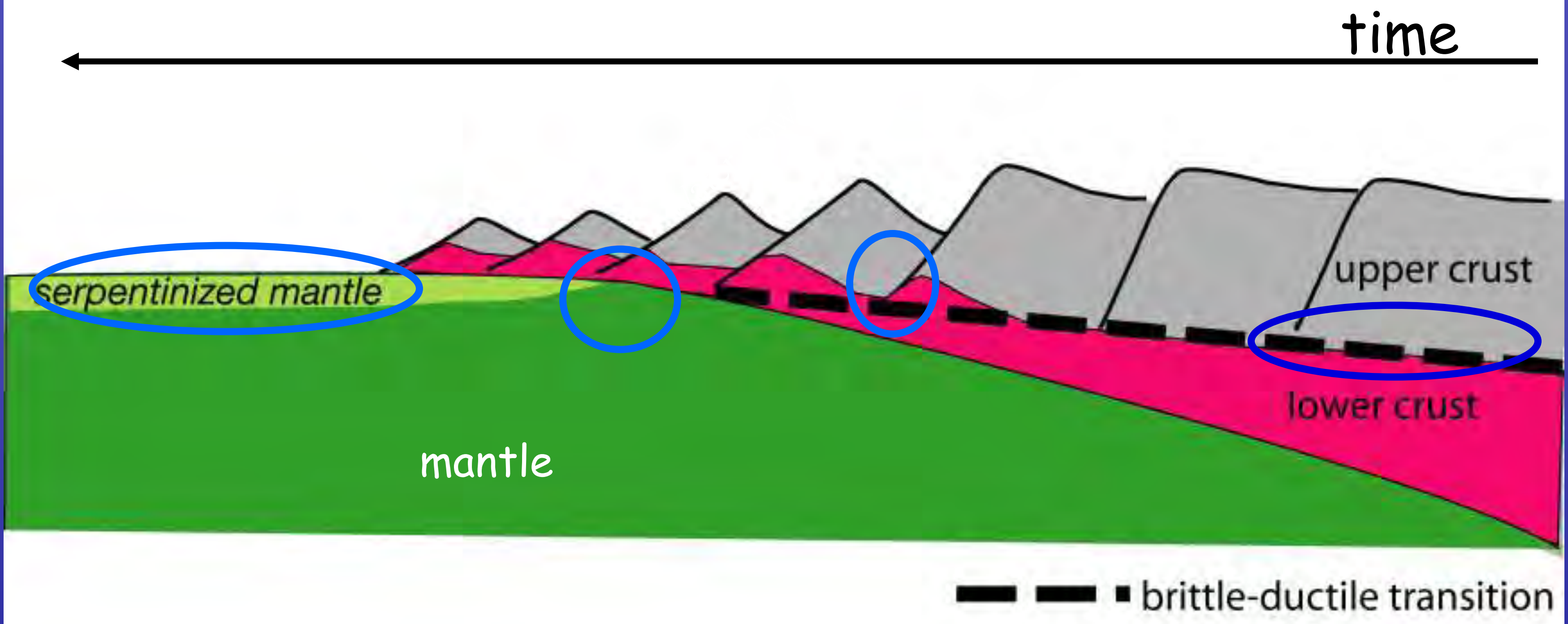


Beginning of extension

Just before crustal break-up

Perez-Gussinye & Reston, JGR, 2001

Rheological evolution at cool NVRMs



•initially lower crust behaves in a ductile manner

•crust thins, deep ductile rocks become brittle, upper and lower crust tightly coupled

•eventually whole crust brittle, faults cut Moho, water reaches mantle: serpentinisation

•top of serpentinised zone forms a weak zone - mantle unroofing occurs

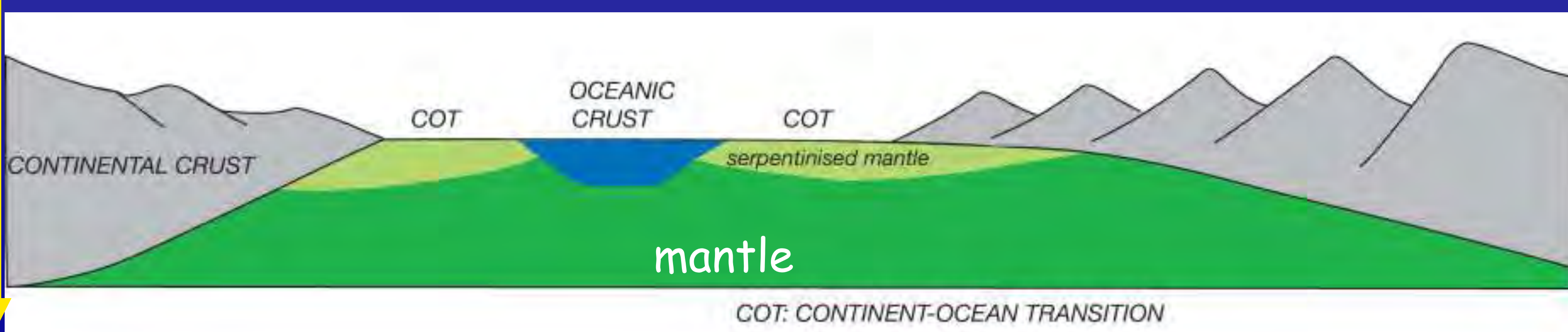
Perez-Gussinye & Reston, 2001

So how do basins and margins really form?

Increasing extension

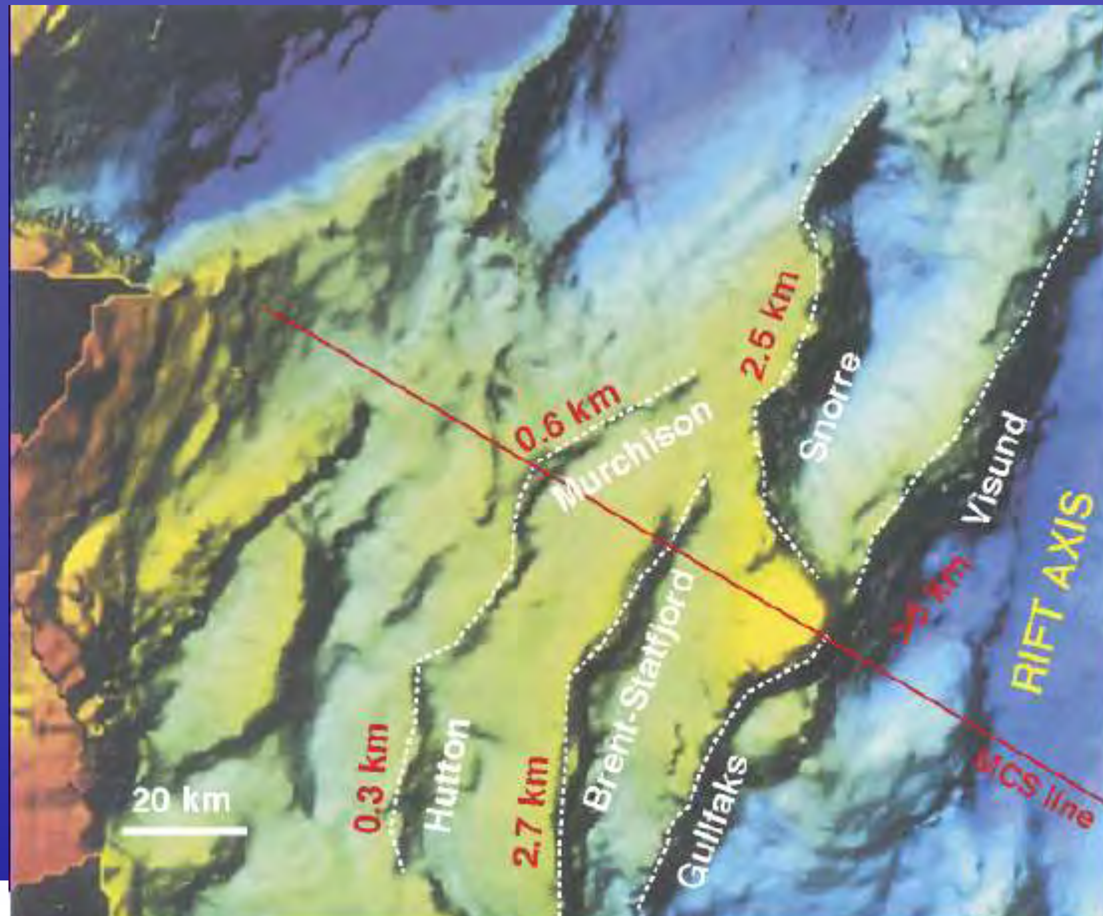
Basin stage

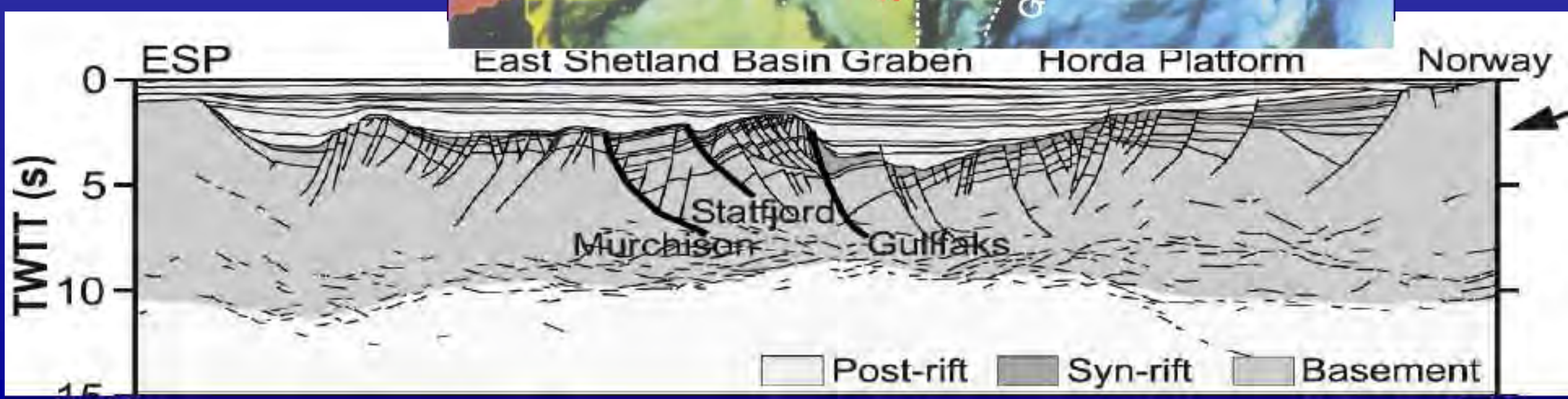
Margin stage

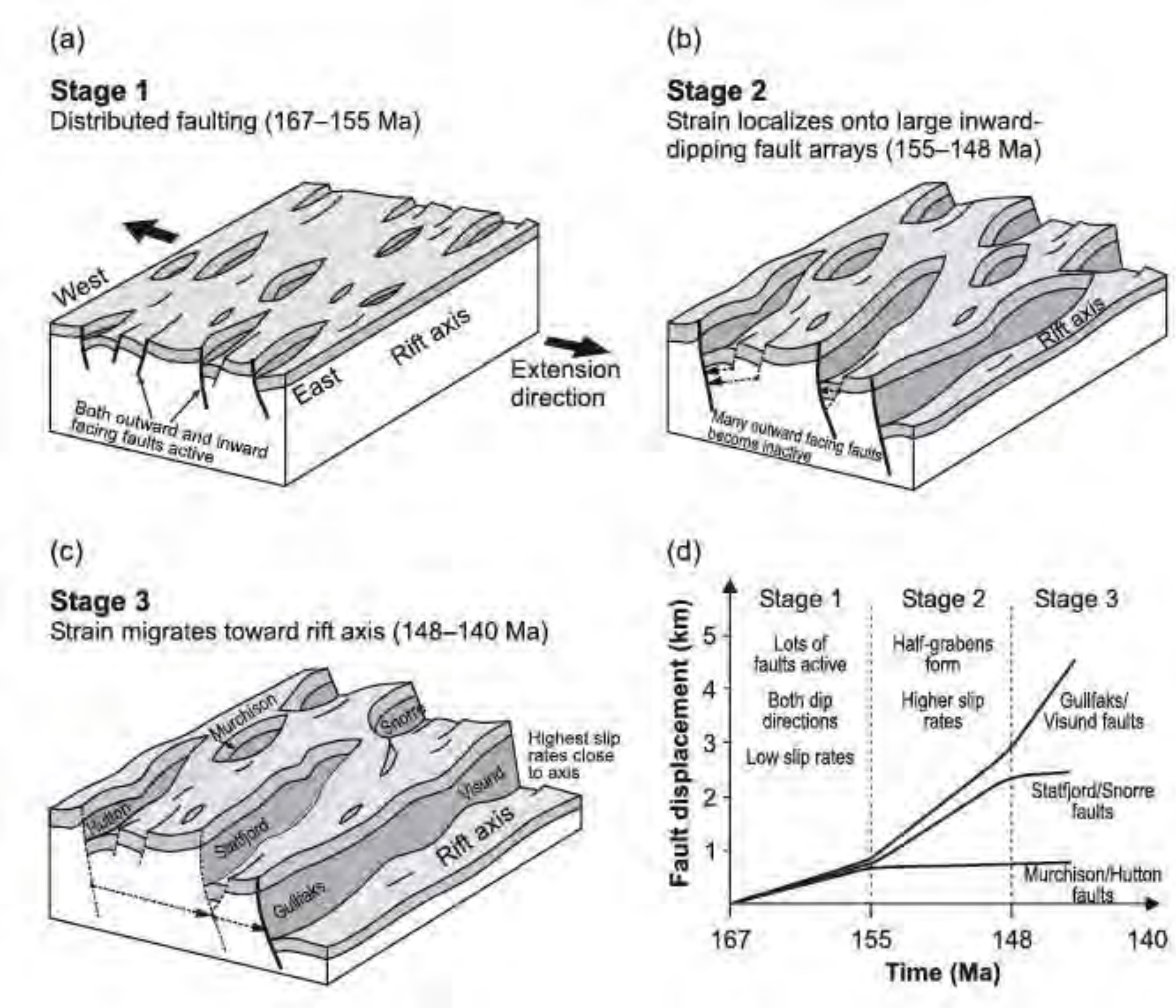


Basin stage : East Shetland Basin

The surface represents the basin bathymetry at the end of the Late Jurassic extension. (Cowie et al., EPSL, 2005)





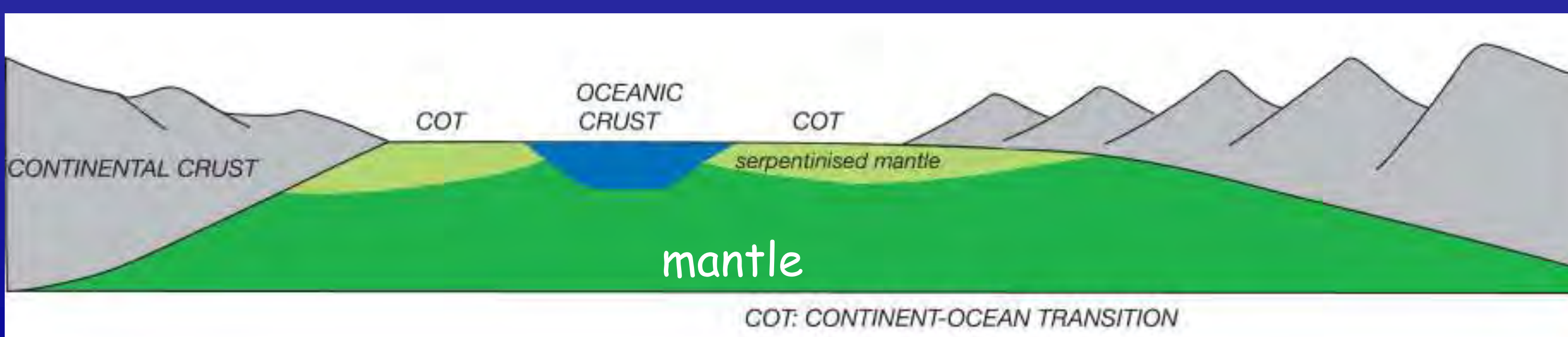

(a)
Stage 1
Distributed faulting (167–155 Ma)
West
East
Rift axis
Extension direction
Both outward and inward facing faults active
(b)
Stage 2
Strain localizes onto large inward-dipping fault arrays (155–148 Ma)
Rift axis
Many outward facing faults becoms inactive
(c)
Stage 3
Strain migrates toward rift axis (148–140 Ma)
Murchison
Snorre
Hutton
Statfjord
Visund
Gullfaks
Rift axis
Highest slip rates close to axis
(d)
Stage 1
Stage 2
Stage 3
Lots of faults active
Both dip directions
Low slip rates
Half-grabens form
Higher slip rates
Gullfaks/ Visund faults
Statfjord/Snorre faults
Murchison/Hutton faults
Fault displacement (km)
5
4
3
2
1
167
155
148
140
Time (Ma)

So how do basins and margins really form?

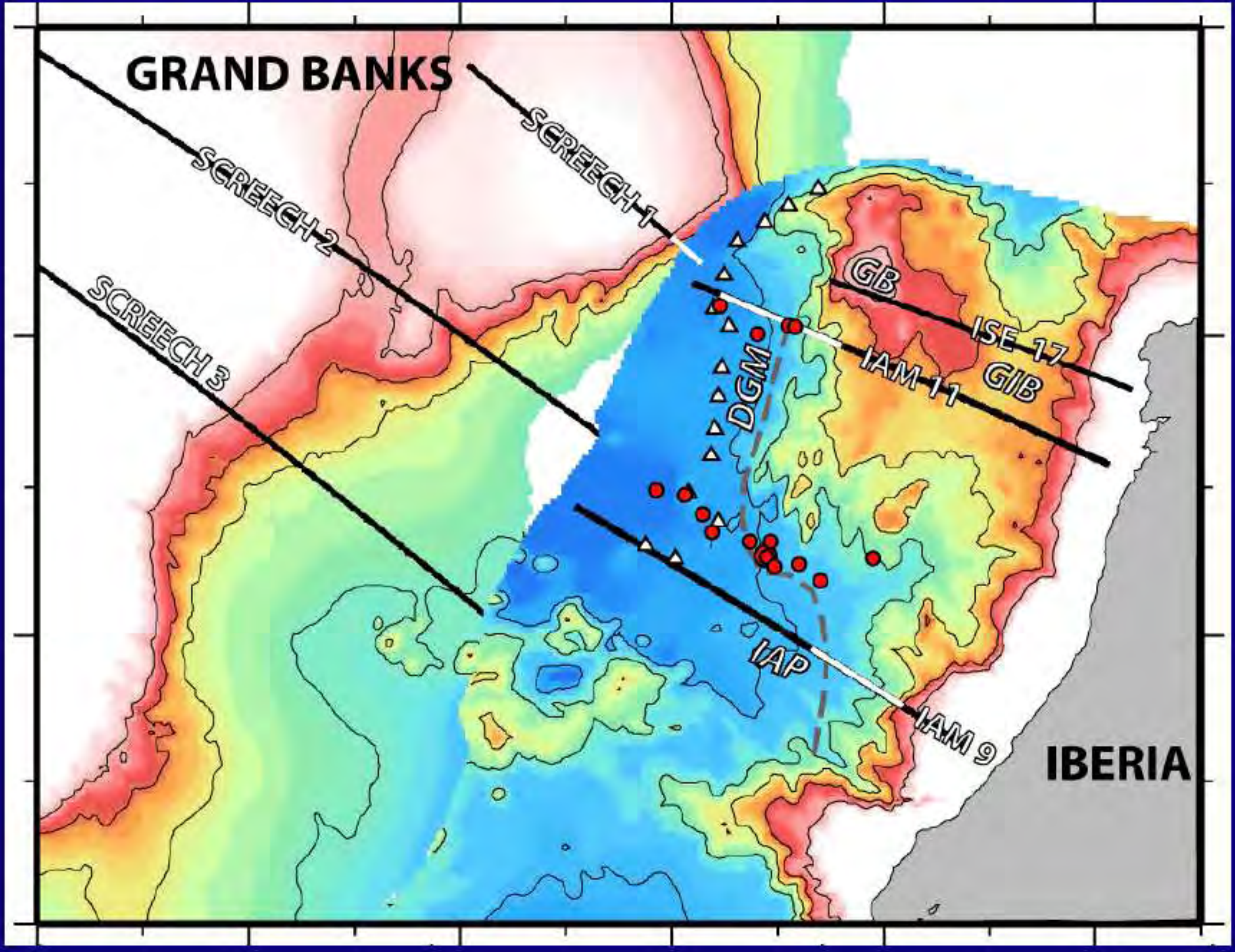
Increasing extension

Basin stage

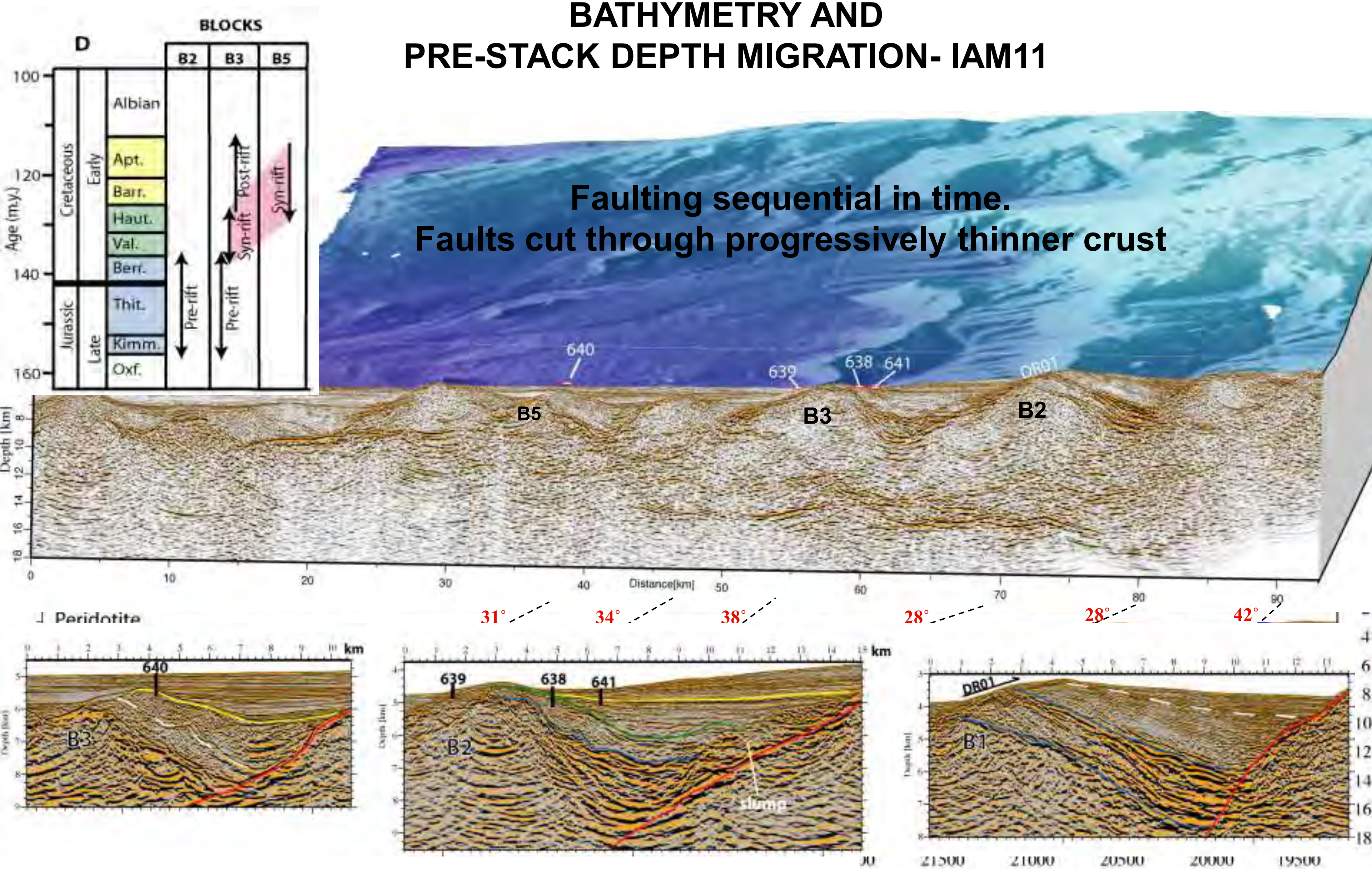
Margin stage



Reconstruction of Iberia-Newfoundland Margins at Anomaly M0



BATHYMETRY AND PRE-STACK DEPTH MIGRATION- IAM11



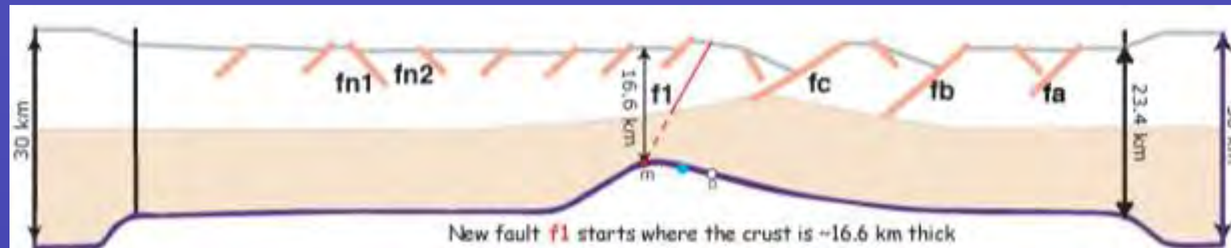
1- Image Pre-Syn rift sediment -> synrift younger basinward

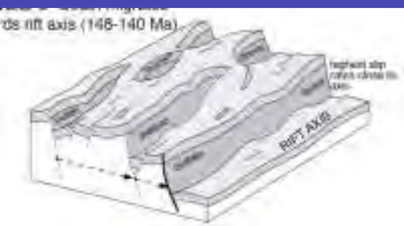
2- Faults start at 65˚-55˚ and rotate to 42˚-28˚.

3- Fault block dimensions decrease basinward.

4- Faults cut progressively thinner brittle layer.

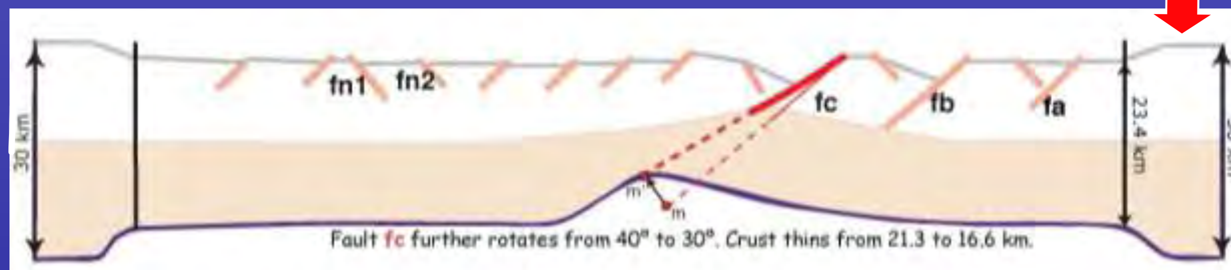
Geometric Model / Stretching Basin Stage





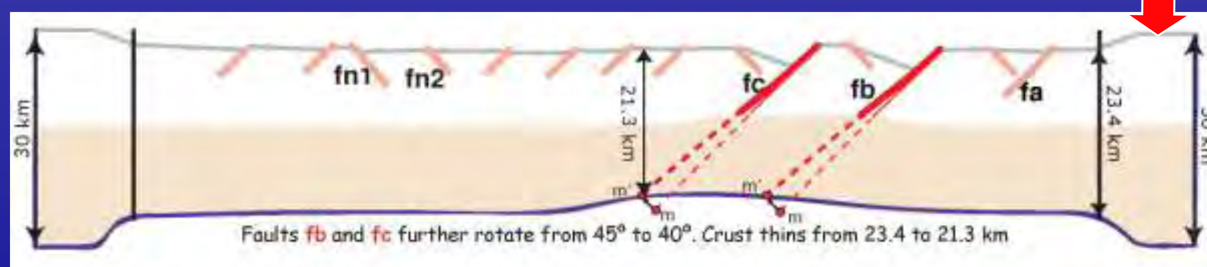
fixed

pull



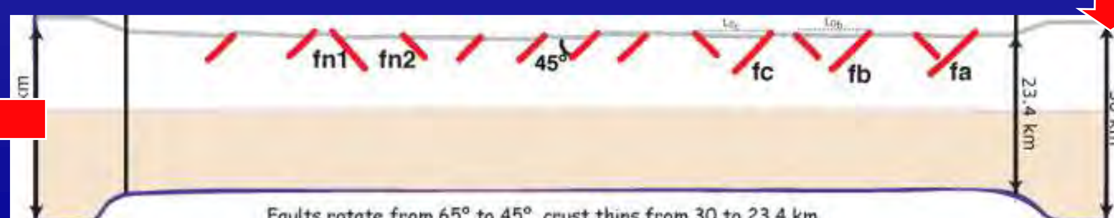
fixed

pull



fixed

pull

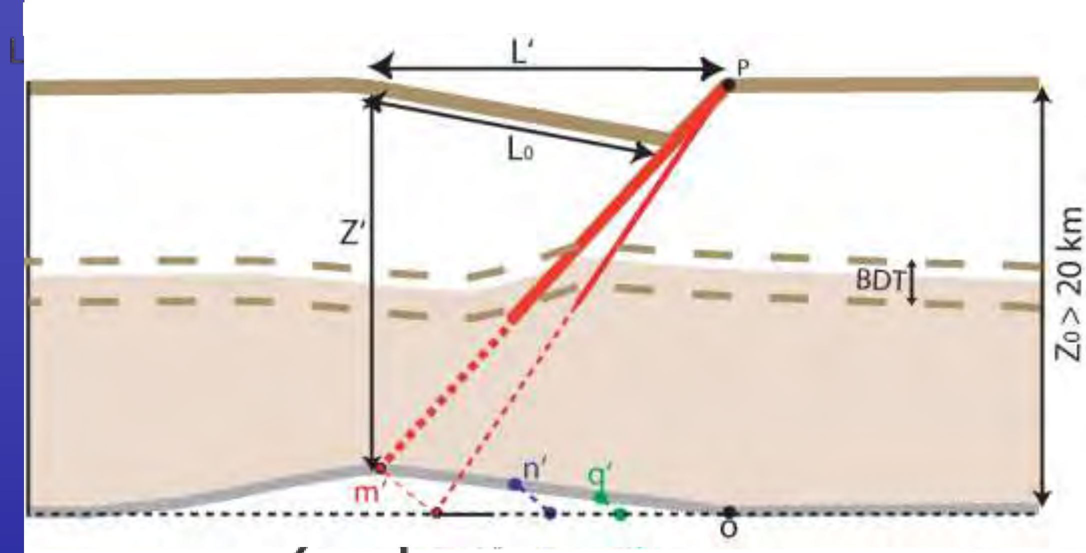


Cowie et al., EPSL, 2005

Ranero & Perez-Gussinye, Nature, 201

Model rules: Basin stage

$$\beta_f = L'/L_0 = \sin\delta_0/\sin\delta' = (Z_0/r)/(Z'/r) = Z_0/Z'$$



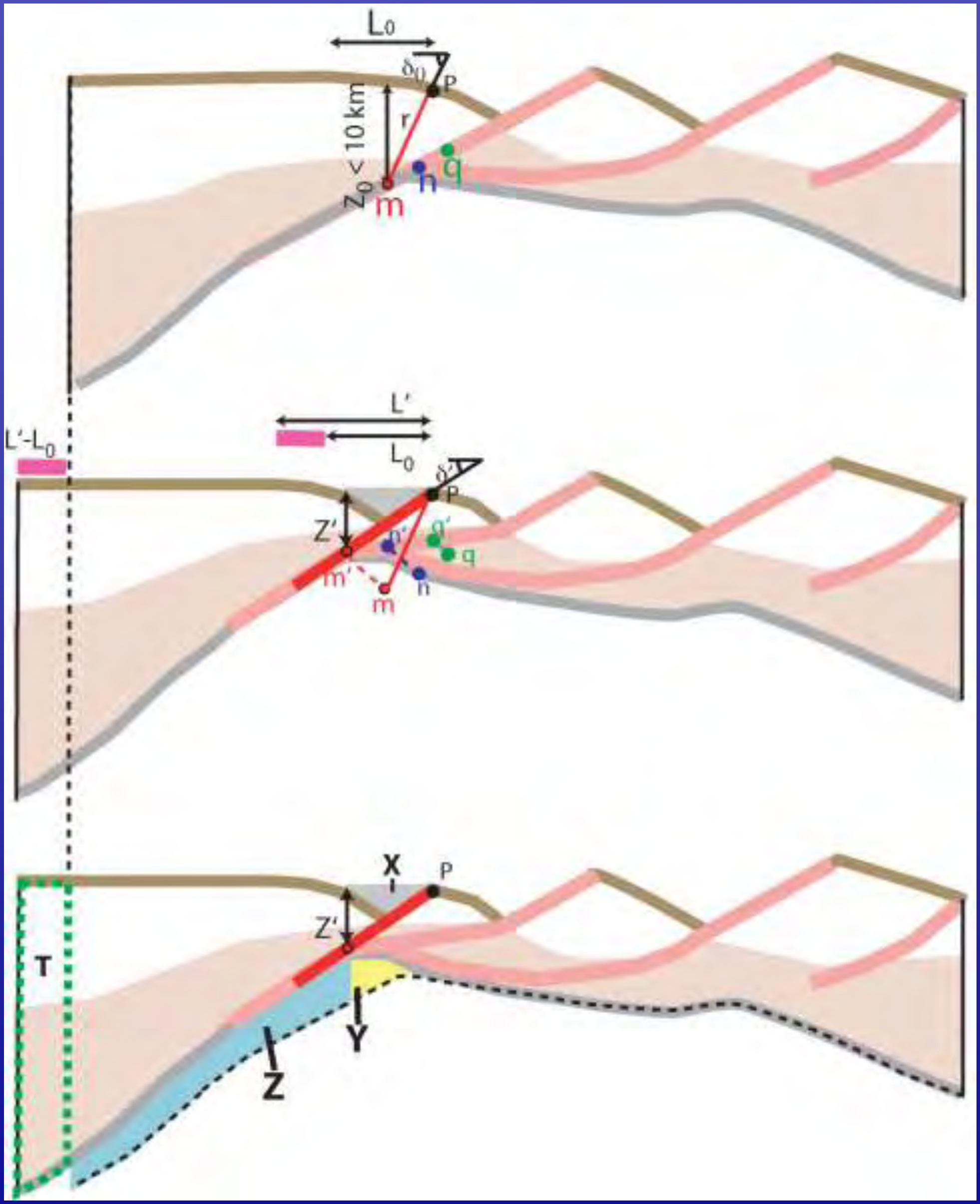
1. Upper crust brittle & lower crust ductile
2. Upper and lower crust extend by the same amount. Lower crust deforms compliant to upper crust.
3. Area conservation: X+Y+Z=T
4. A wide brittle-ductile transition.

Ranero & Perez-Gussinye, Nature, 2011

Model rules

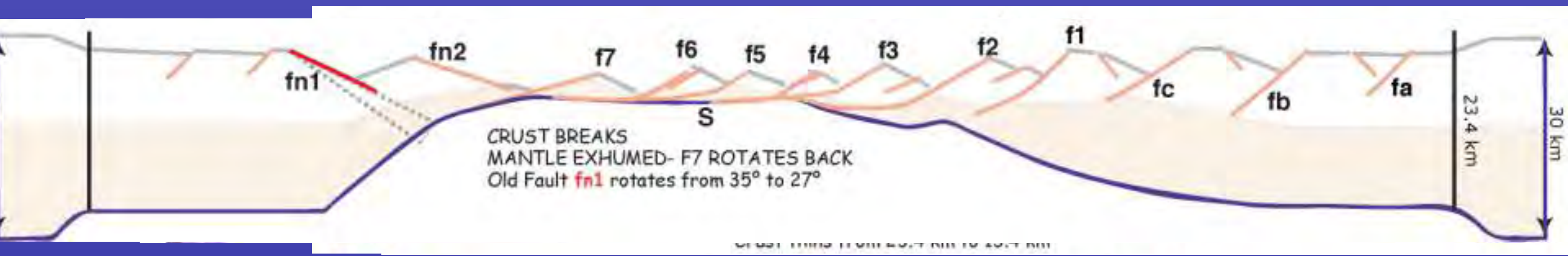
Margin stage:

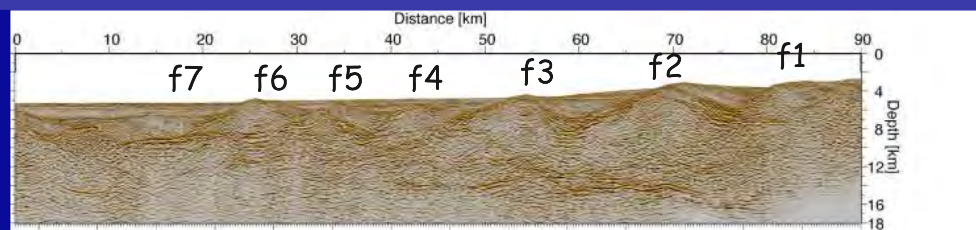
- Lower crust progressively brittle!!
- Upper and lower crust extend by the same amount. Lower crust deforms compliant to upper crust.
- Area conservation: X+Y+Z=T
- Area conservation leads to back-rotation of previous planar faults.



Ranero & Perez-Gussinye, Nature, 2011

Margin stage





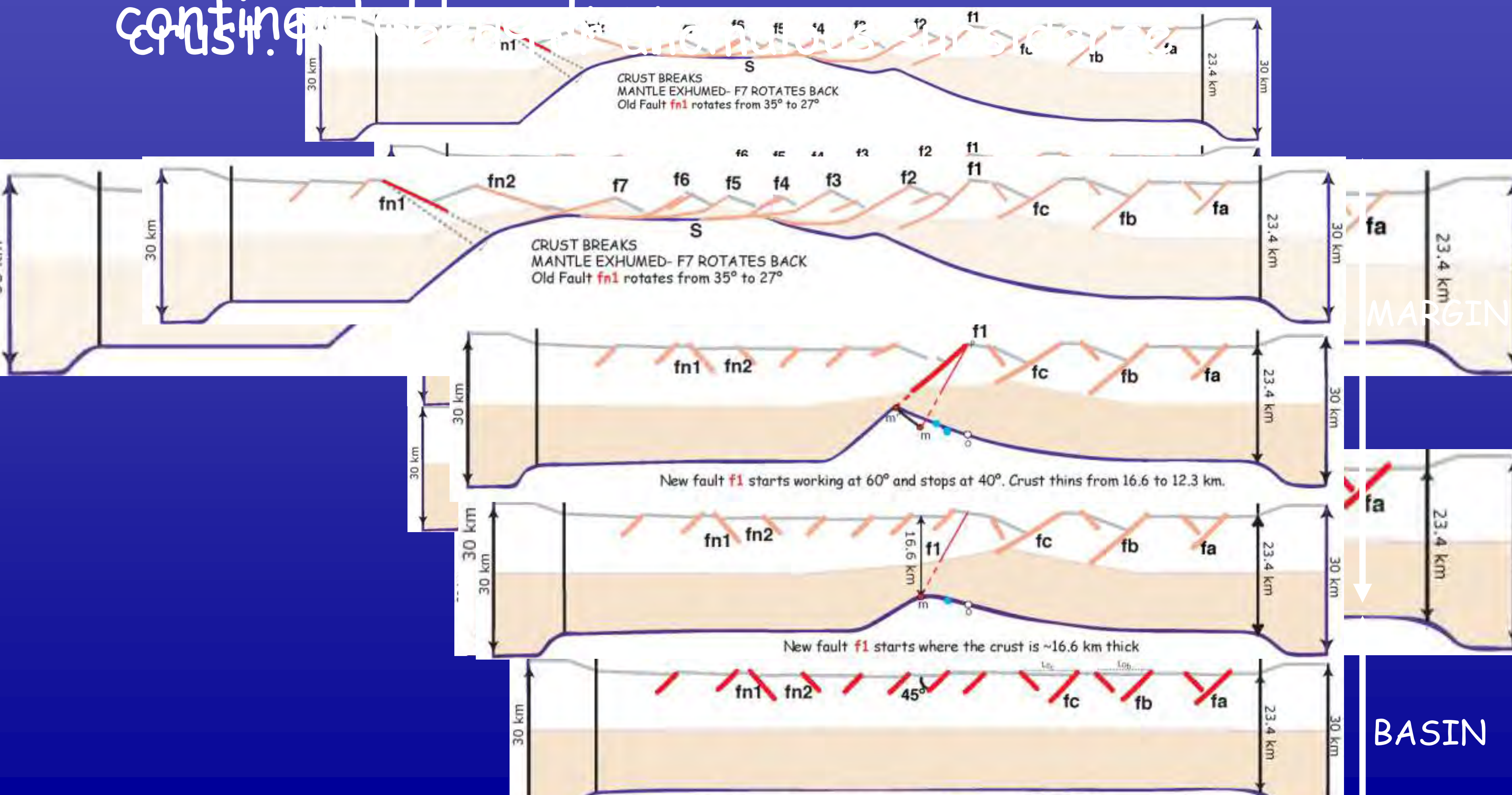
•Detachment fault, S, not active at low angle. It results from an array of sequential normal faults active at ~60°-~30°.

•Asymmetry is the result of the dominant oceanward dip of the sequential fault array.

Ranero & Perez-Gussinye, Nature, 2011

Implications

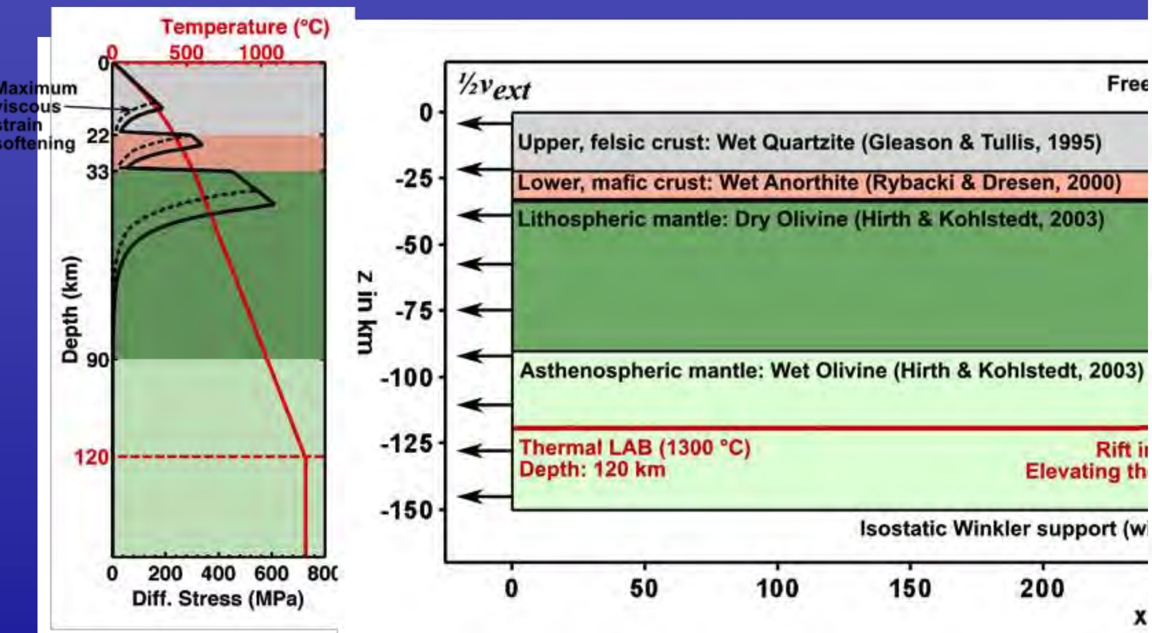
- Occurrence of shallow pre-rift and syn-rift over Andersonian faulting (normal faults at 60°-30°) continental break...
- Peak heat flow moves oceanward: Post rift sedimentation above formerly thinned crust.



Outline

- Kinematics of faulting, crustal thinning & asymmetry formation from observations.
- Dynamics of crustal and lithospheric thinning.

What causes asymmetry formation and crustal hyper-extension?



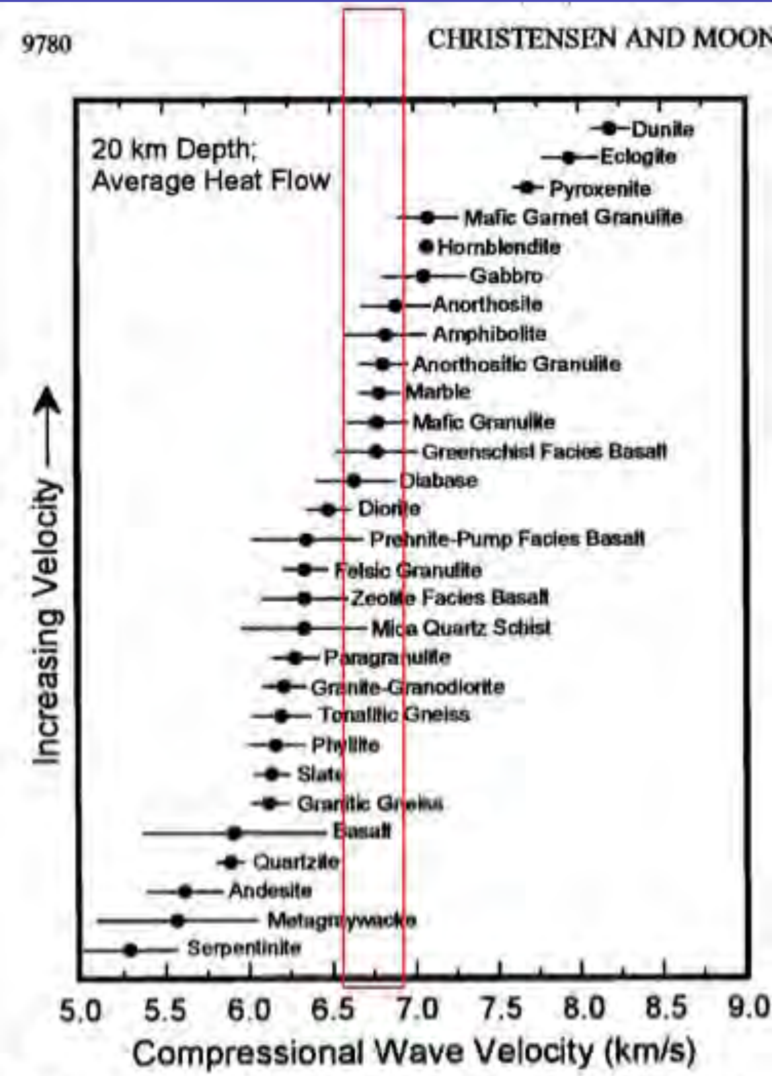
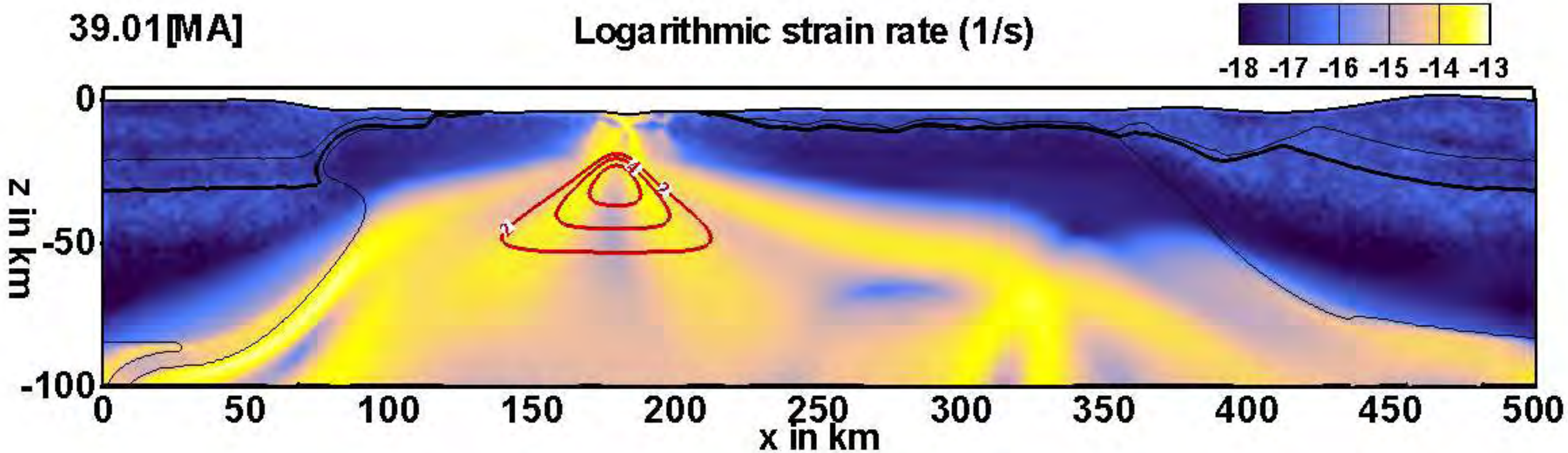


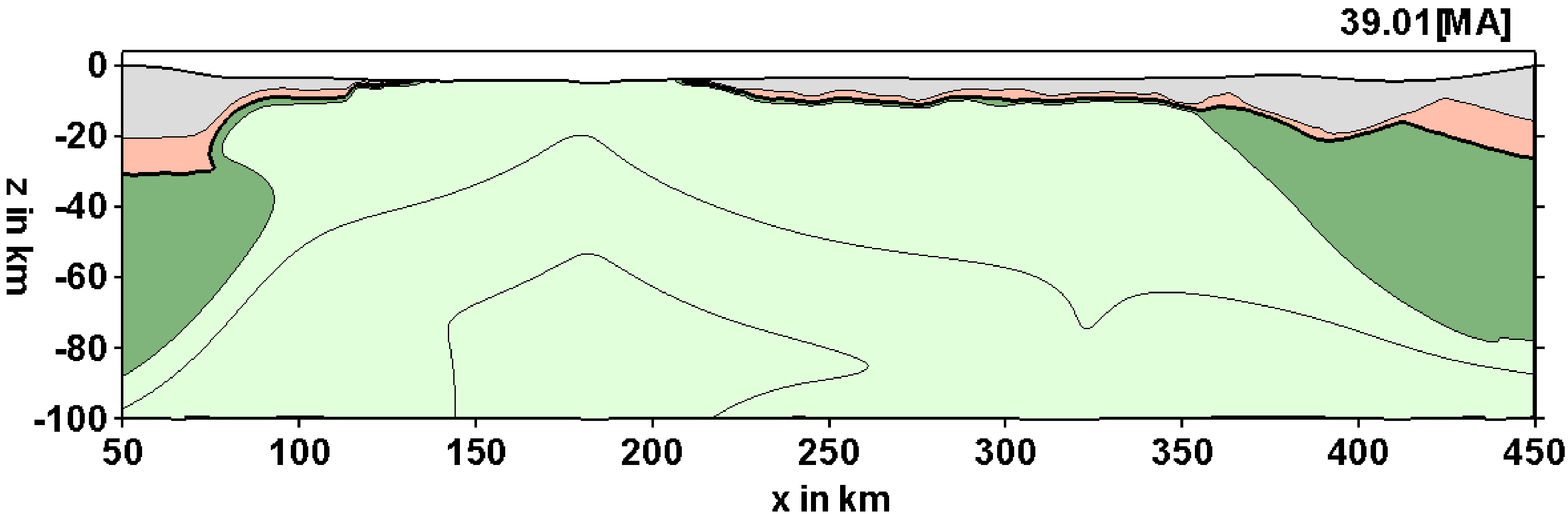
Figure 14. Average compressional wave velocities and standard deviations at 20 km depth and 309°C (average heat flow) for major rock types.

Brune, Heine, Perez-Gussinye, Sobolev, submitted 2013

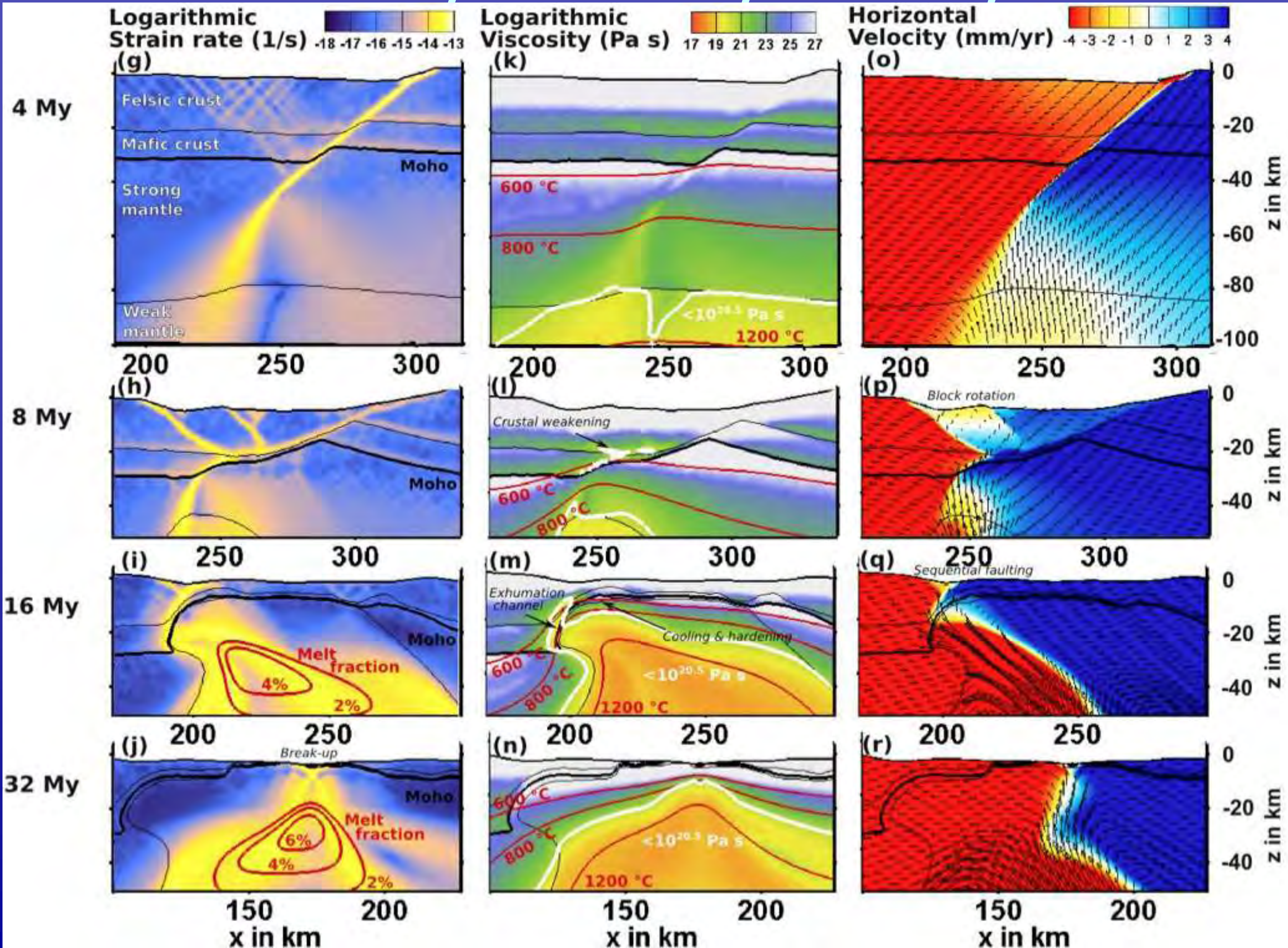
Model evolution



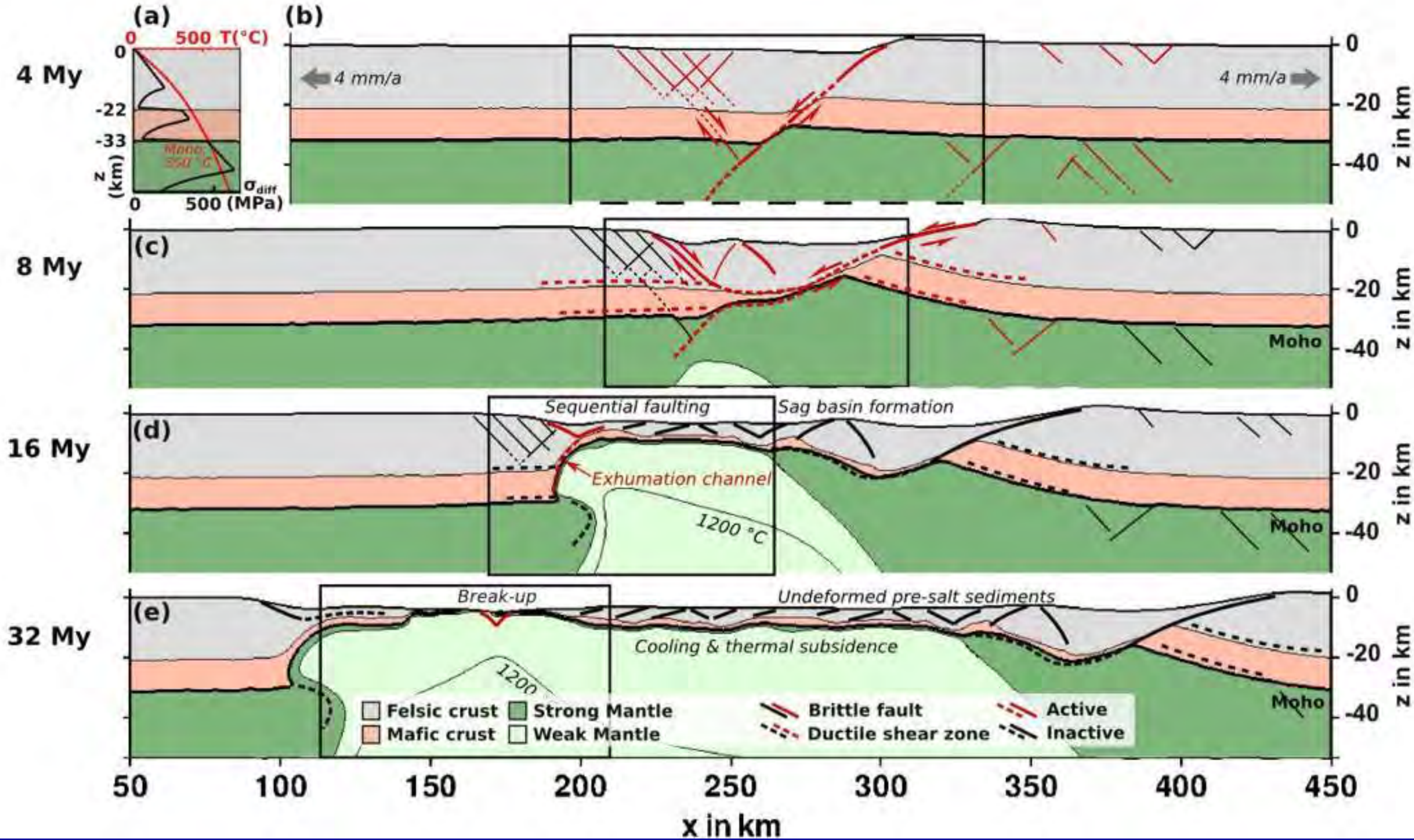
Full extension velocity - 8 mm/yr



How and why does asymmetry form?



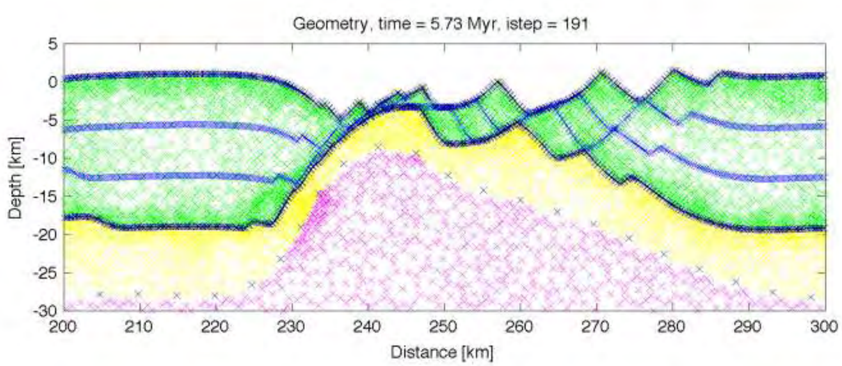
Fault pattern evolution – distributed vs sequential

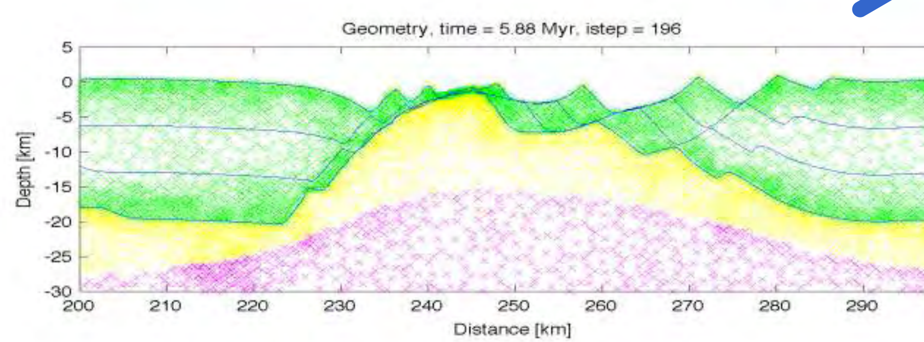


Factors influencing wide margin width

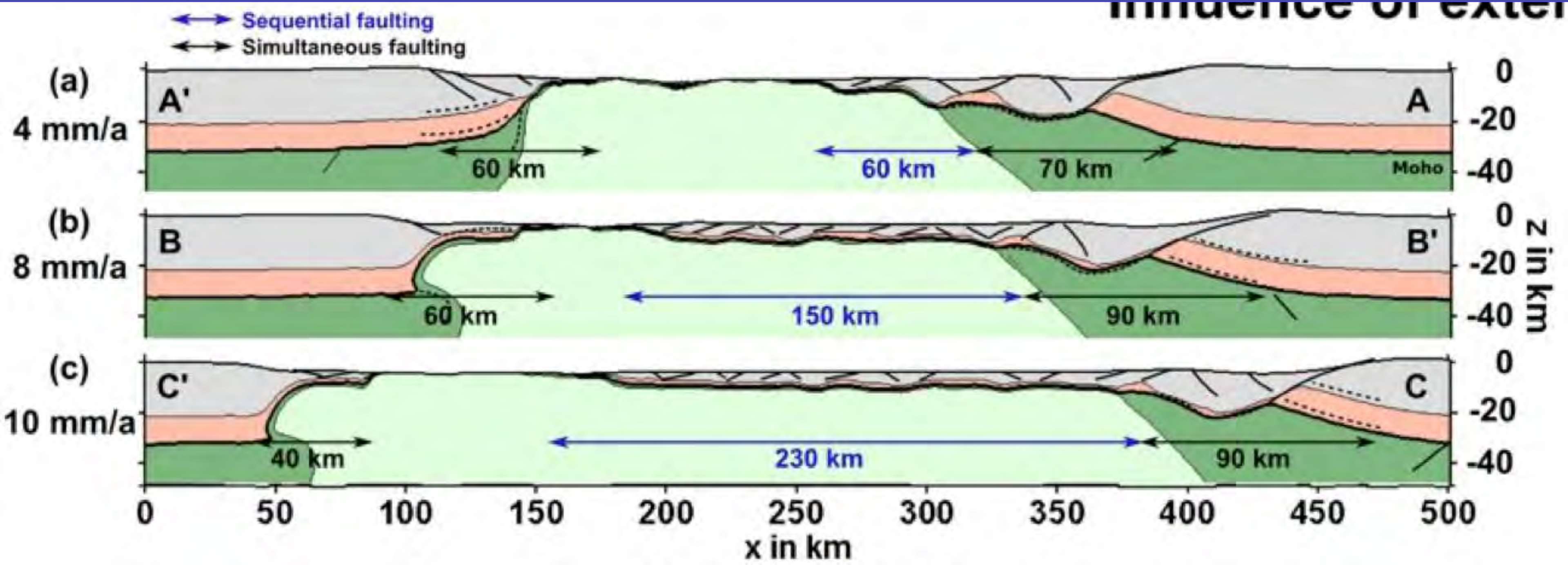
- The width of the wide margin depends on lower crustal rheology during extension.
- A weak lower crust, promotes a longer initial phase of distributed faulting and a longer phase of sequential faulting since crustal thinning is less efficient, due to flow of lower crust towards the tip of the active fault.

Weaker lower crust

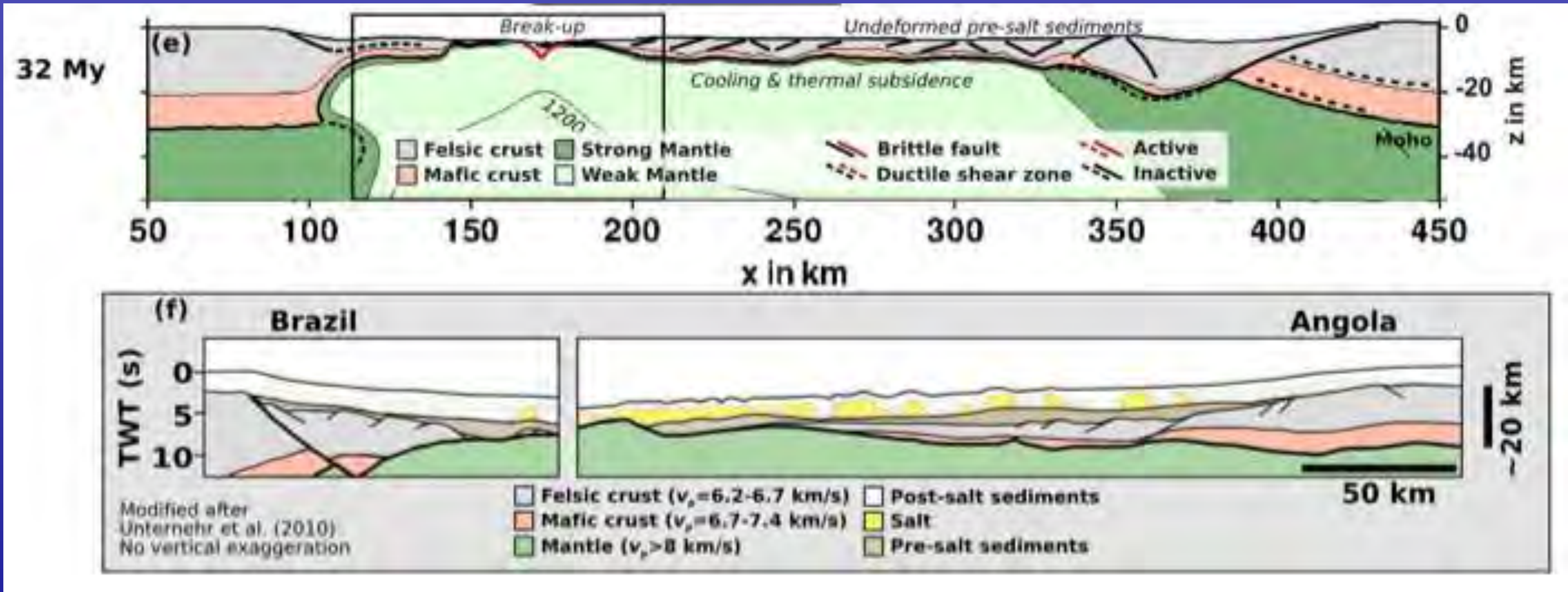




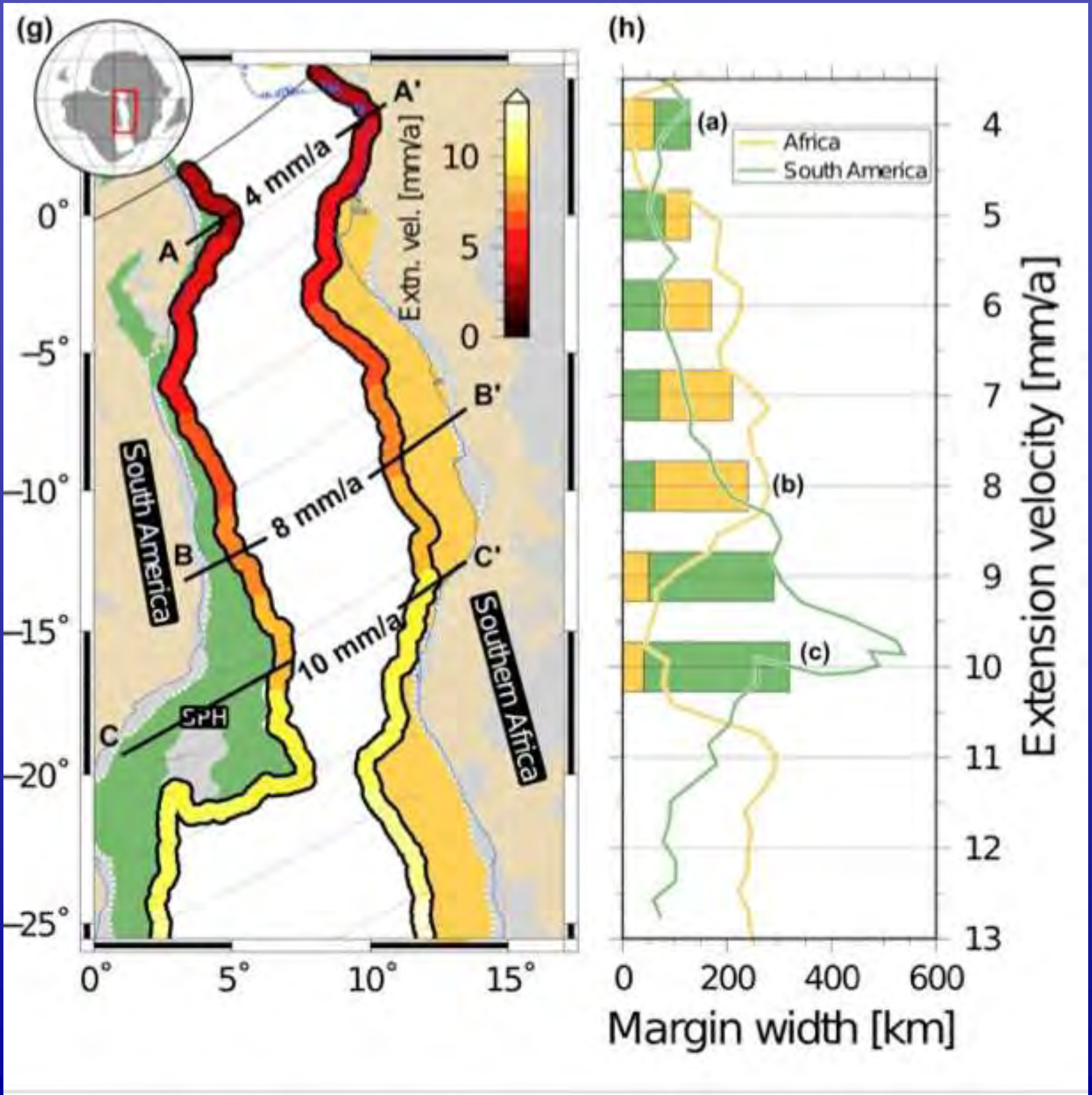
Influence of extensional velocity



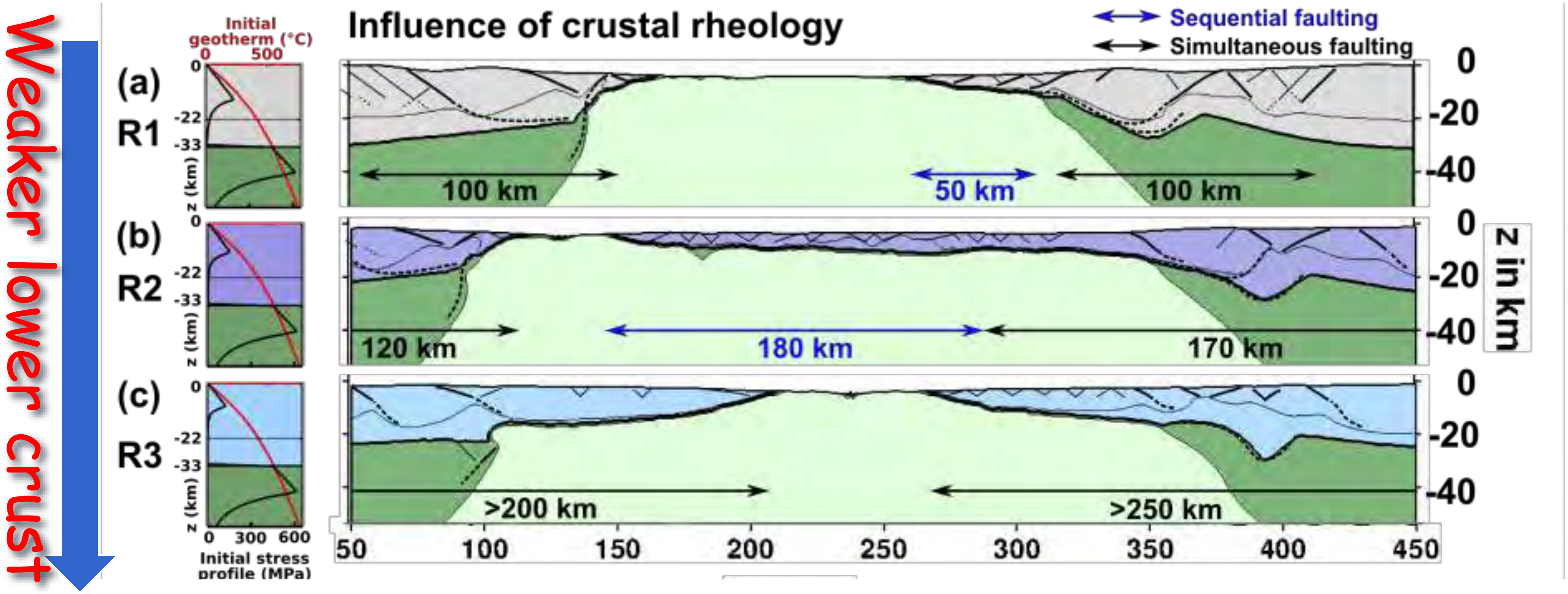
Comparison to Brasil/Angola margin



Width and assymmetry of African/Brazilian margins



Influence of lower crustal rheology

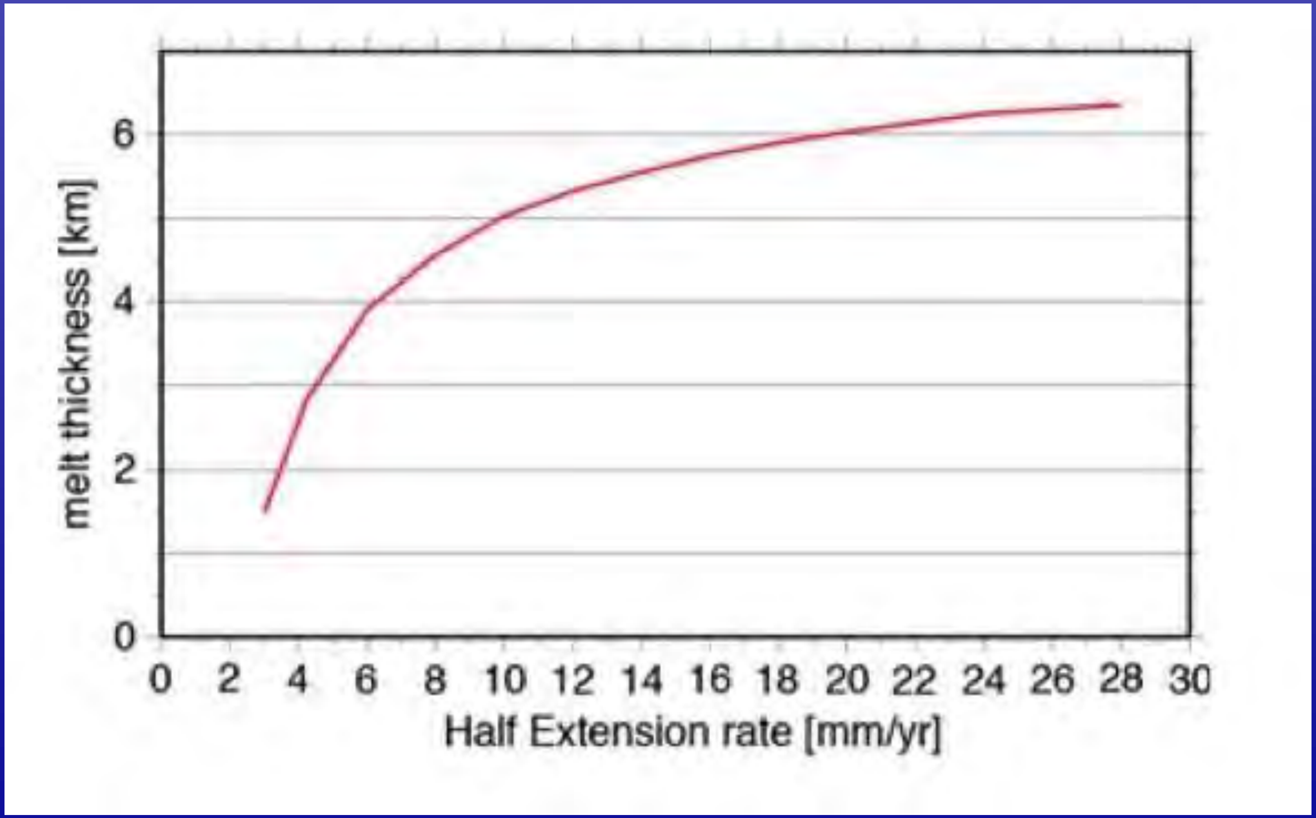


Outline

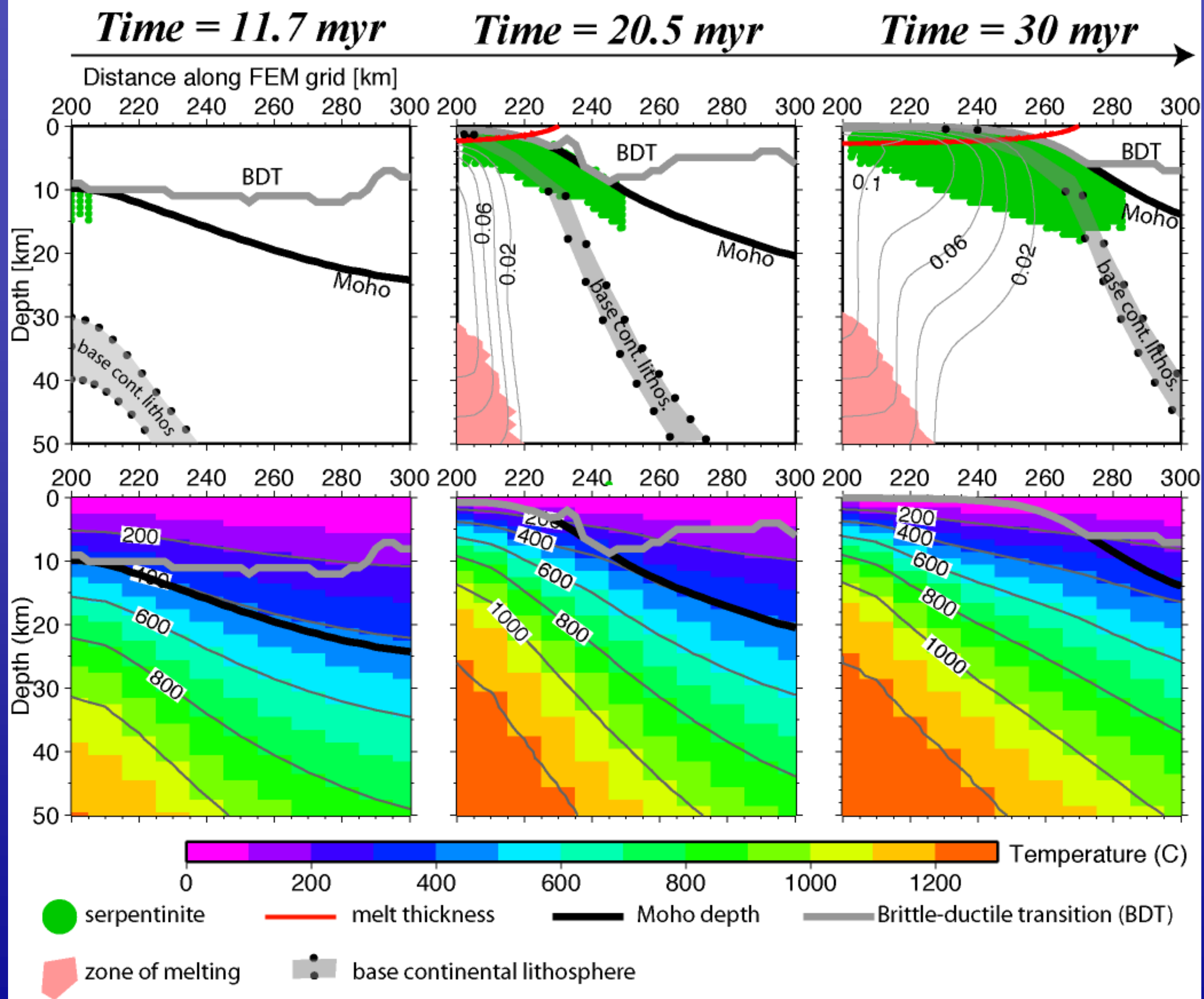
- Kinematics of faulting, crustal thinning & asymmetry formation from observations.
- Dynamics of crustal and lithospheric thinning.
- Relationship between onset of melting/oceanization and strain localisation

MARIA – 3 MONTHS OLD

- WITHOUT STRAIN LOCALISATION MELTING DEPENDS MOSTLY ON EXTENSION VELOCITY



SLOW VELOCITY = 4.2 mm/yr (half extension)
NORMAL MANTLE TEMPERATURE =1300 C



SERPENTINISATION STARTS BEFORE MELTING

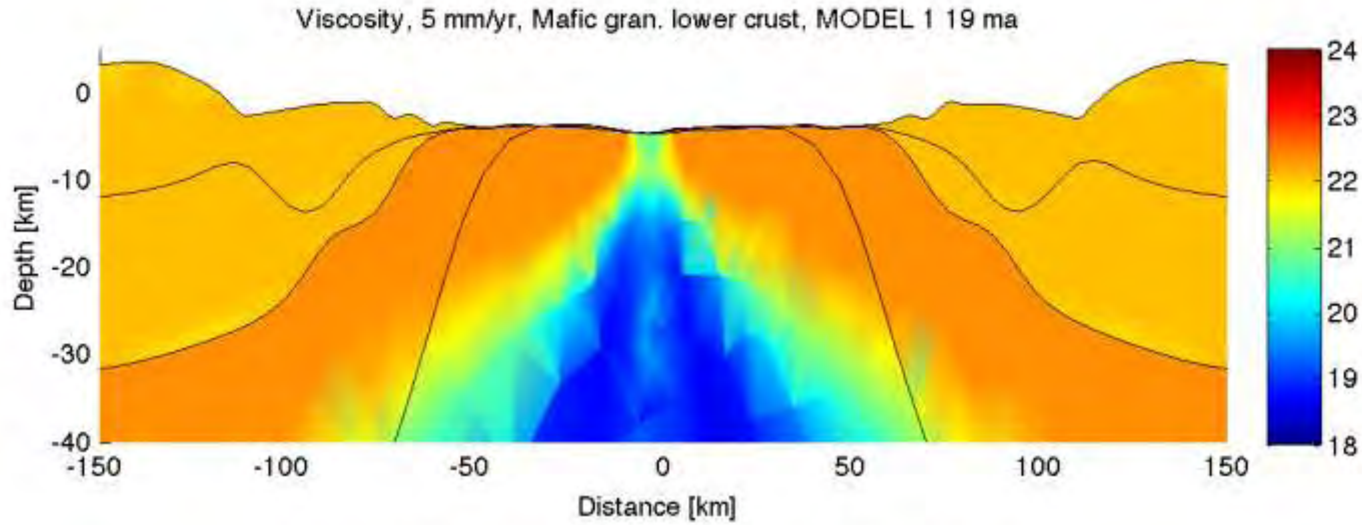
Perez-Gussinye et al., EPSL, 2006

Melting & Localisation

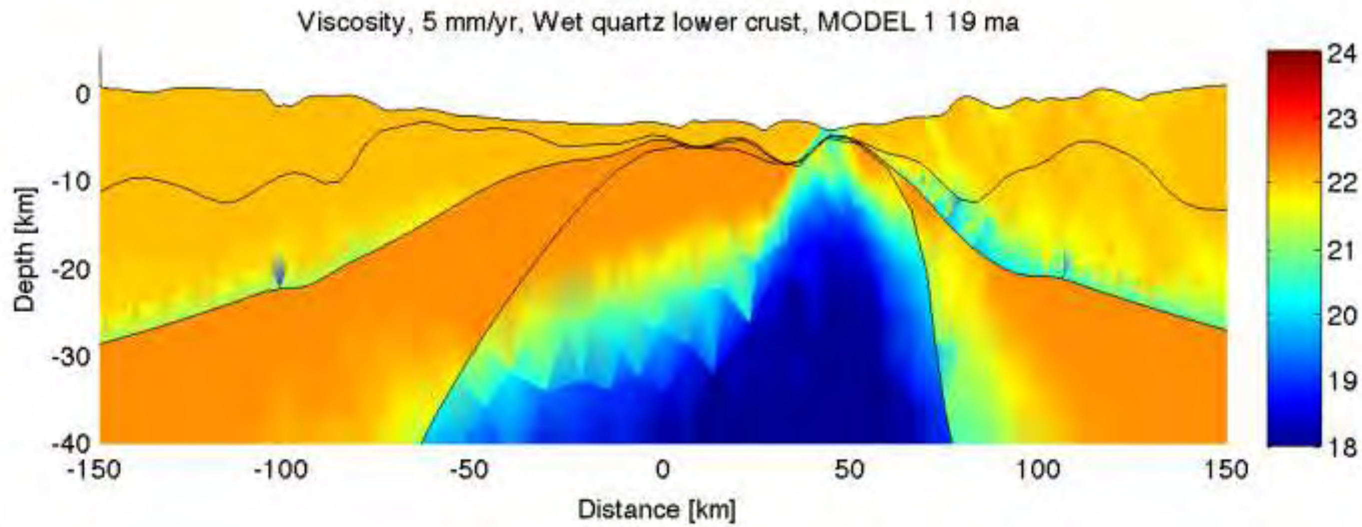
- In rift experiments that include strain localisation, it can be seen that the onset of melting and amount of melting, is not only a function of velocity but also of strain localisation during rifting.

5 mm/yr half extension

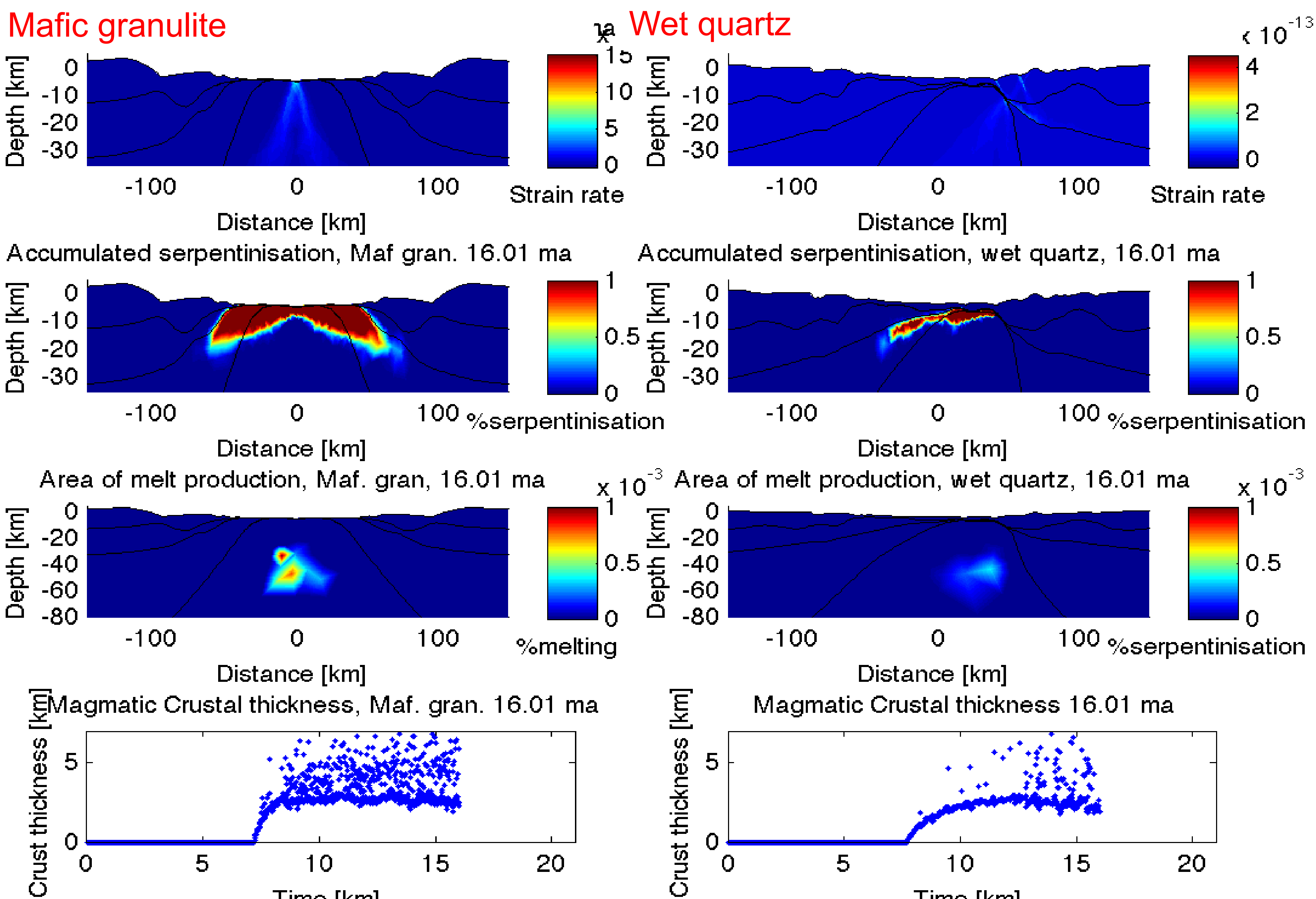
Mafic granulite lower crust



Wet quartz lower crust



Melting, Localisation and lower crustal rheology



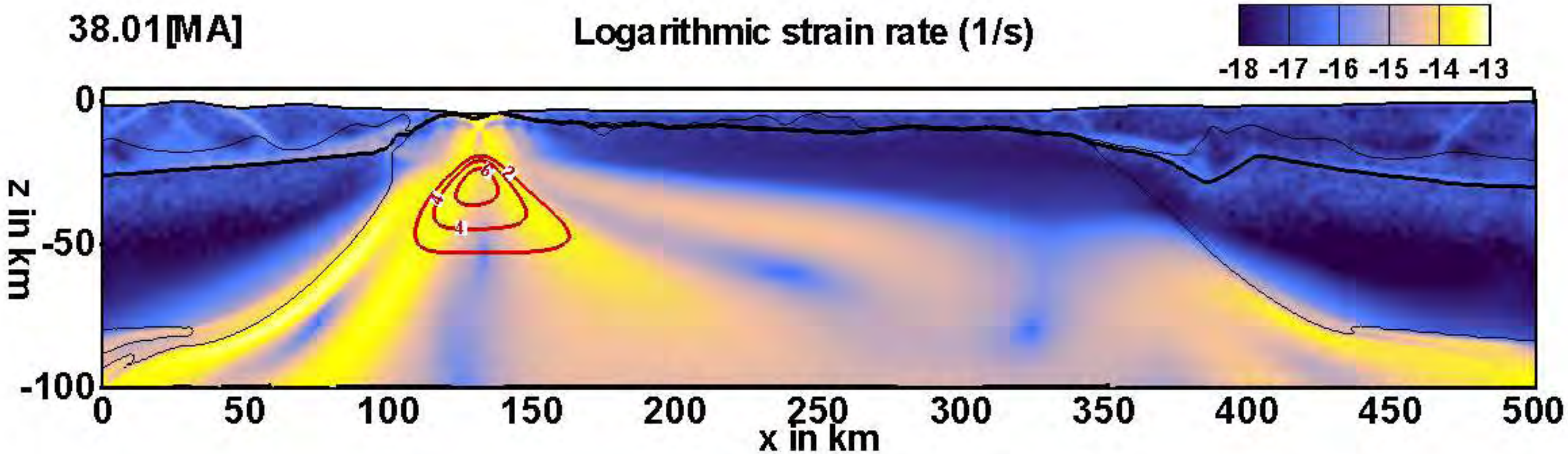
Summary

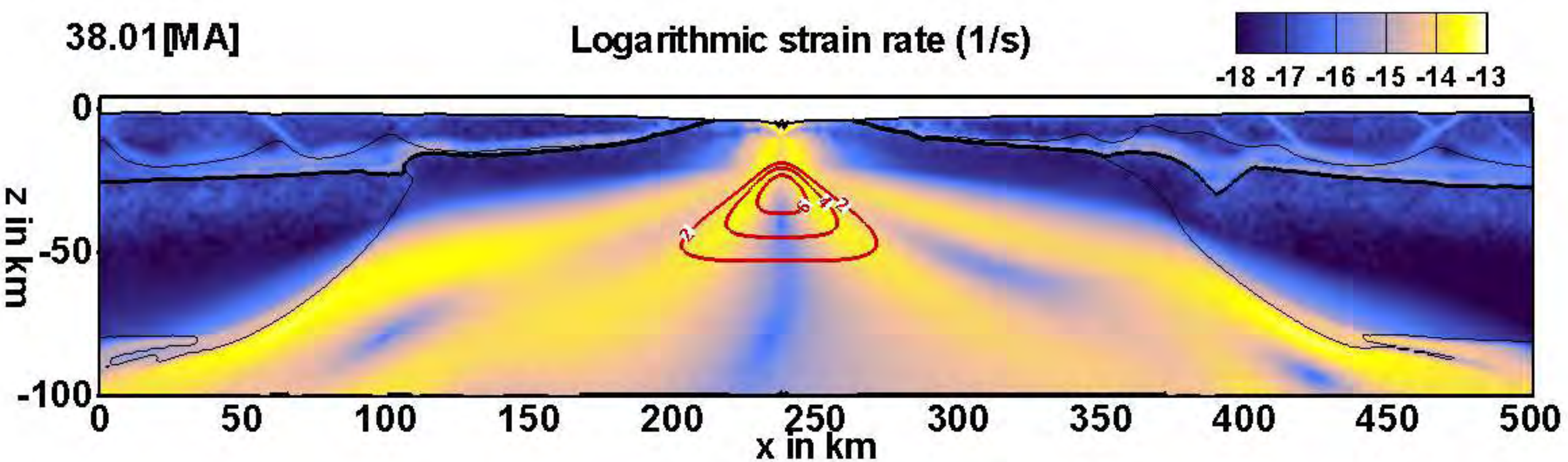
- Asymmetry of conjugate margins is the result of the emergence of an array of faults that are sequential in time and consistently dip towards the ocean.

- The emergence of this sequential fault pattern arises due to progressive strain localisation and coupling between lithospheric/asthenospheric layers (upper brittle crust and ductile lower crust and mantle).

- The width of the wide margin depends on lower crustal rheology. Weak lower crust tends to promote wide margins with thinned (<10 km) crust over 200 km. Very weak lower crust would result in symmetric margins.

- Onset of melting and serpentinisation is also related to lower crustal rheology and its ability to couple deformation from upper crust to mantle lithosphere.


38.01[MA]
Logarithmic strain rate (1/s)
-18 -17 -16 -15 -14 -13
z in km
0
-50
-100
x in km
0 50 100 150 200 250 300 350 400 450 500

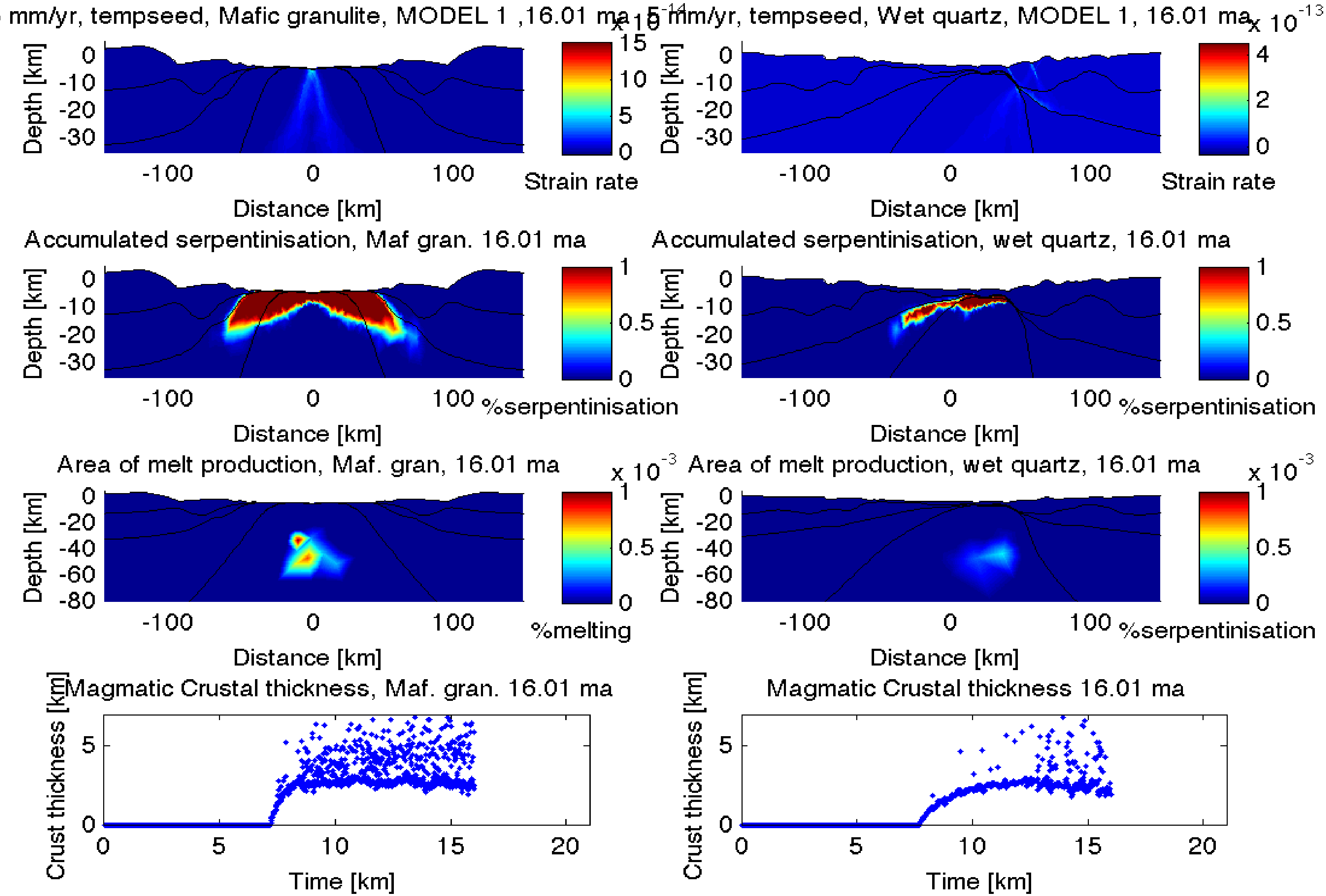

38.01[MA]
Logarithmic strain rate (1/s)
-18 -17 -16 -15 -14 -13
z in km
0
-50
-100
x in km
0 50 100 150 200 250 300 350 400 450 500

Serpentinisation

Serpentinisation & Localisation

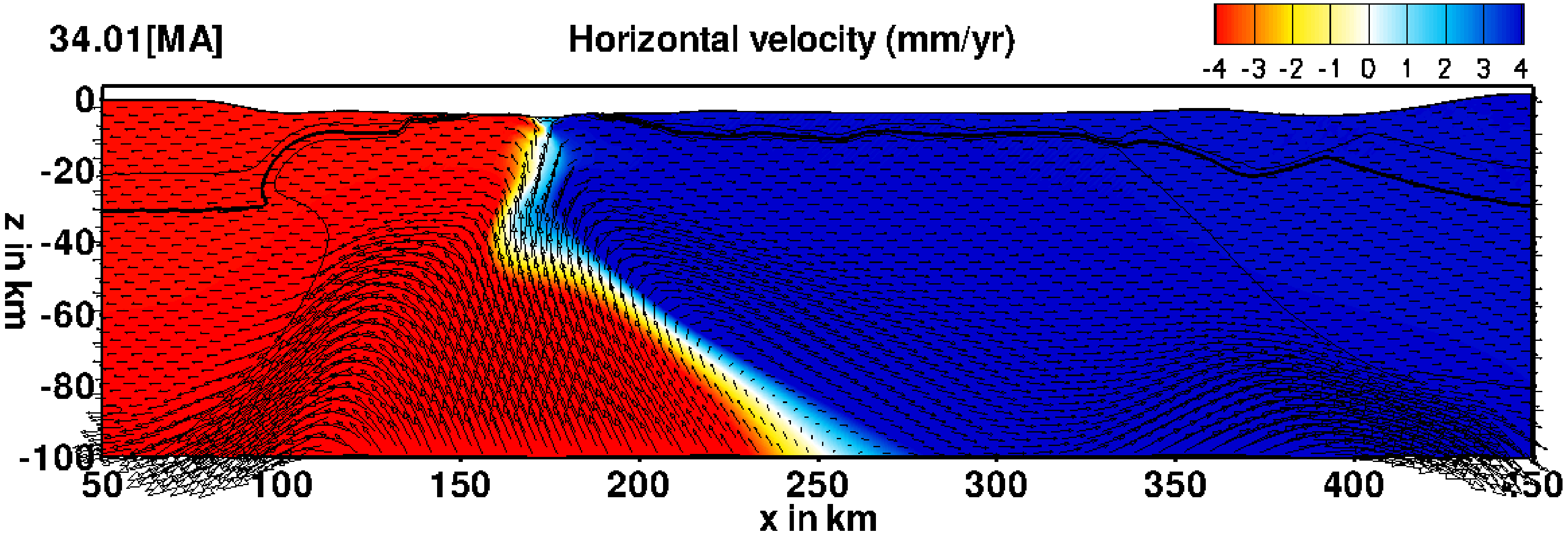
- Here we set serpentinisation to occur when the entire crust is brittle and the temperature in the mantle is less than 500 C. At the moment the code does not require the crust above the mantle to be deforming. If this would be required the amount of serpentinisation would be less than predicted in the models.
- As for melting, in experiments where mantle flow is homogeneous (no localisation), serpentinisation mainly depends on velocity, with slower extension velocities promoting serpentinisation.
- In rift experiments that include strain localisation, it can be seen that the onset of serpentinisation and its amount, is not only a function of velocity but also of strain localisation during rifting.
- Localisation depends on lower crustal rheology and initial conditions.
- For a strong lower crust rheology and slow extension mantle exhumation and serpentinisation occurs. With the same slow velocity, but weaker lower crustal rheology, mantle exhumation may not occur.

Serpentinisation, Localisation and lower crustal rheology



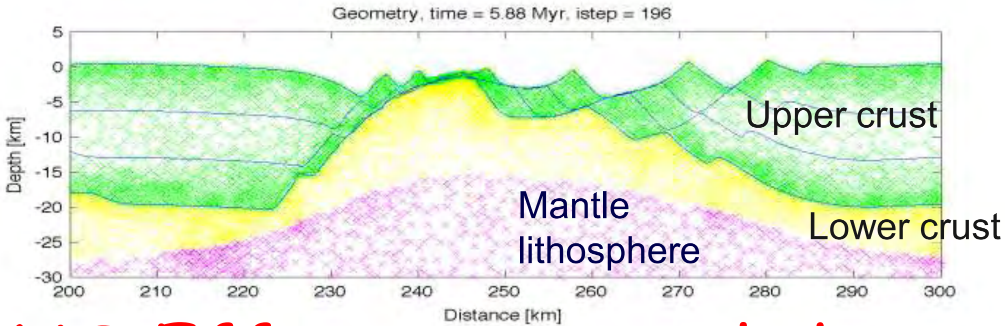
Model evolution

Horizontal velocity



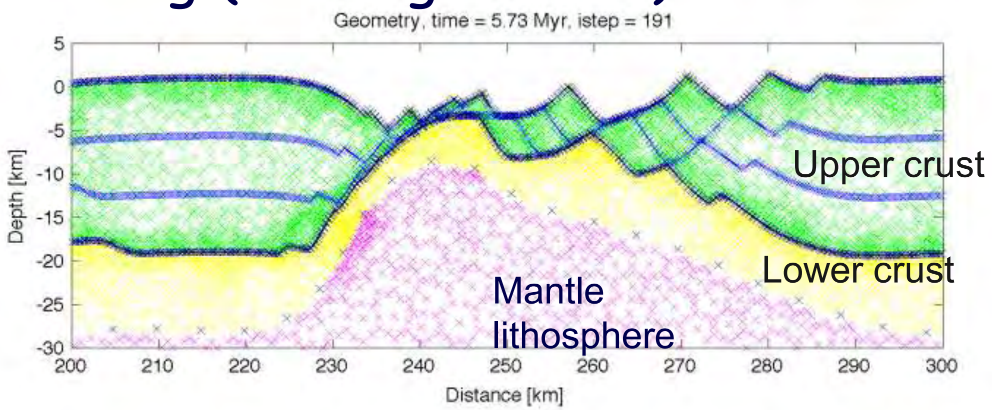
Full extension velocity – 8 mm/yr
Sequential faults active at high exhumation velocity.

Full Extension velocity ~8 mm/yr
weak (wet quartz) lower crust



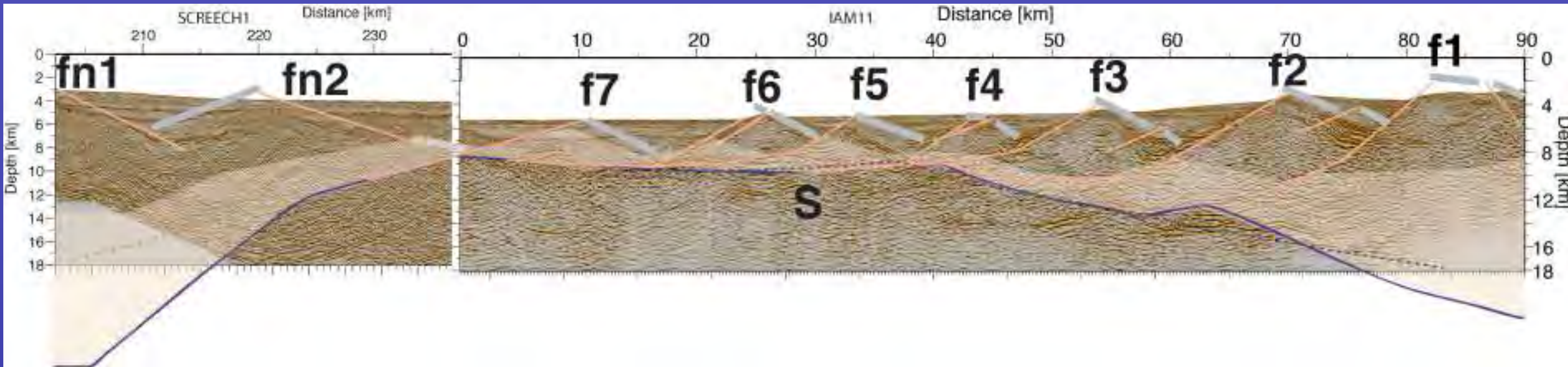
NO Effective crustal thinning

Full Extension velocity ~8 mm/yr
strong (mafic granulite) lower crust



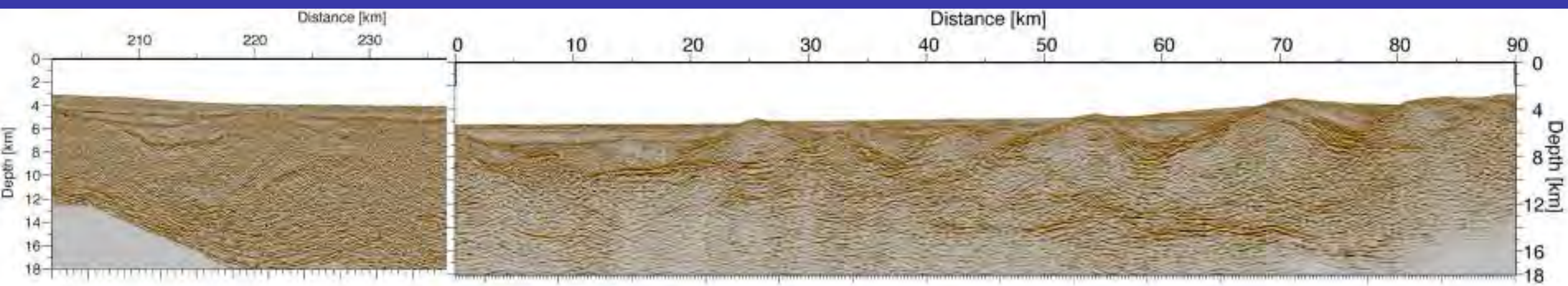
Effective crustal thinning

Asymmetry and detachment faults?



Newfoundland

West Iberia



•Detachment fault, S, not active at low angle. It results from an array of sequential normal faults active at ~60°-~30°.

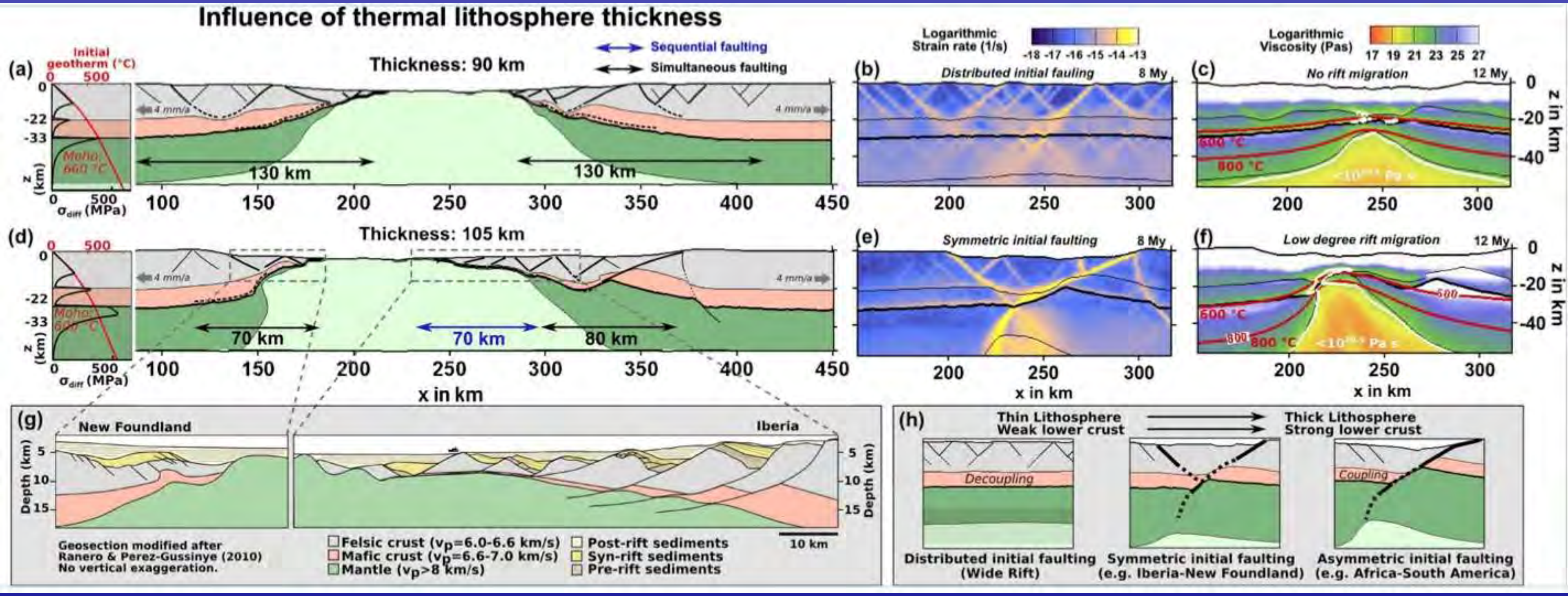
•Asymmetry is the result of the dominant oceanward dip of the sequential fault array.

Ranero & Perez-Gussinye, Nature, 2011

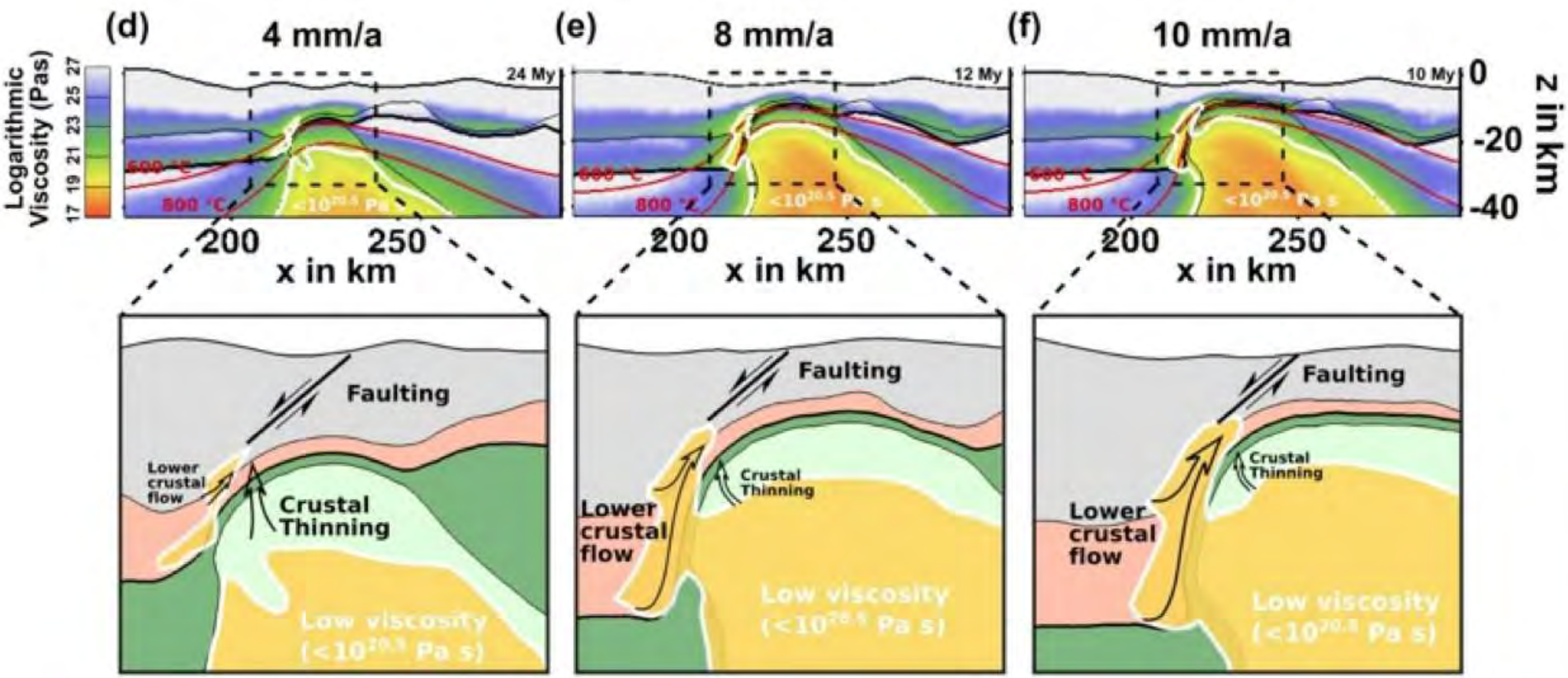
Factors influencing wide margin width

- The width of the wide margin depends on lower crustal rheology during extension.
- A weak lower crust, promotes a longer initial phase of distributed faulting and a longer phase of sequential faulting since crustal thinning is less efficient, due to flow of lower crust towards the tip of the active fault.
- Weaker lower crust may be due to intially weak crust, to raised heat-flow (thin lithosphere) or high extension velocity which inhibits conductive cooling during rifting.

West Iberia/Newfoundland - Influence of lithospheric thickness



Influence of extensional velocity



Lower crust is kept at higher temperature for faster velocities

New methodology to forward model Seismic sections

- New numerical methodology to forward model crustal scale seismic sections.

- Focus on understanding quantitative consequences for subsidence, heat flow and sedimentary architecture predicted by the ‘sequential faulting’ conceptual model for ultra-slow, magma-poor margin development (presented in Ranero & Pérez-Gussinyé, Nature, 2010).

How and why does asymmetry form?

- Asymmetry of conjugate margins is the result of the emergence of an array of faults that are sequential in time and consistently dip towards the ocean.

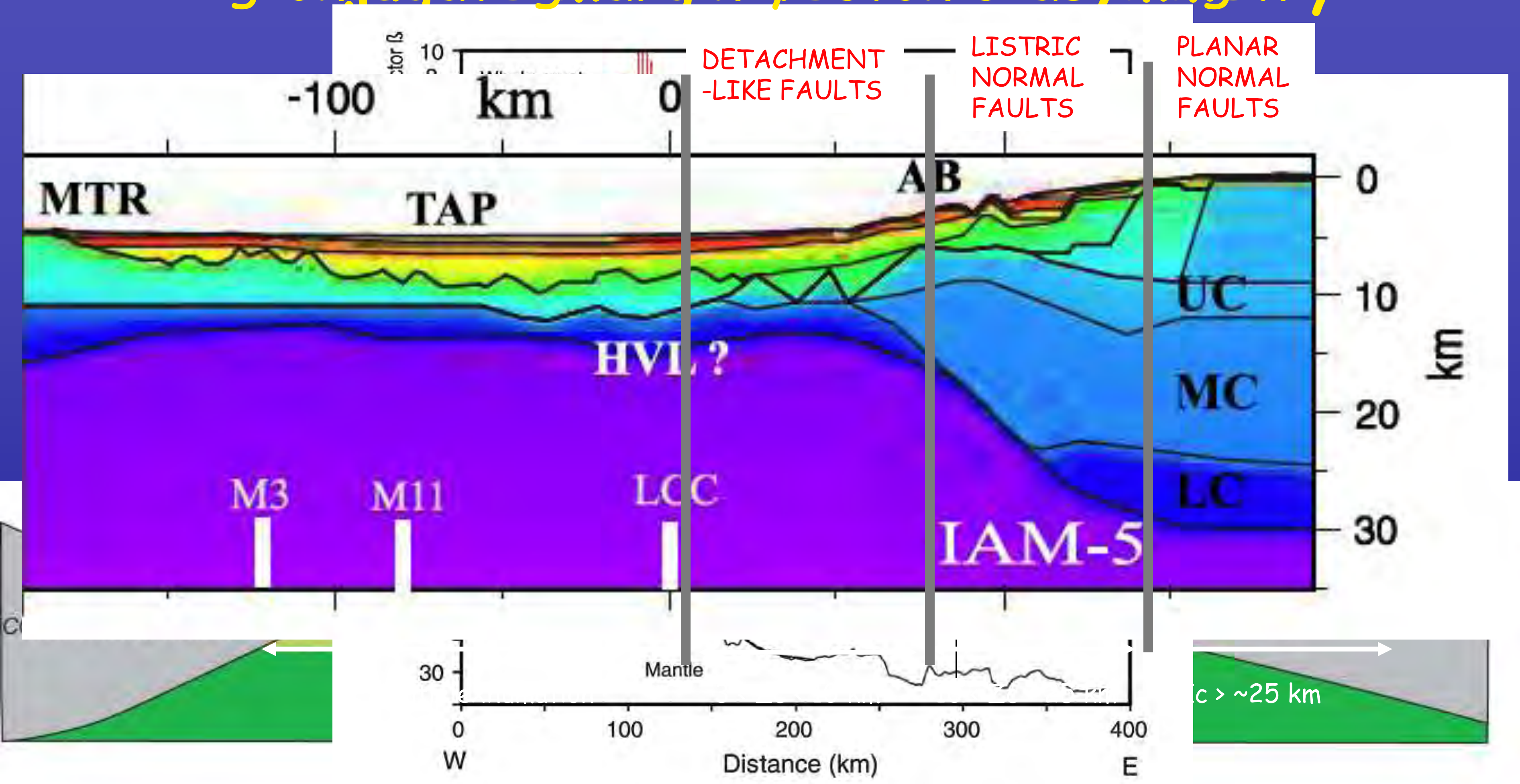
- The emergence of this sequential fault pattern arises due to progressive strain localisation and coupling between lithospheric/asthenospheric layers (upper brittle crust and ductile lower crust and mantle).

- When coupling occurs, faults continue as shear zones within lower crust and mantle. This brings the asthenosphere closer to the surface in the hangingwall of the first fault where the coupling has occurred.

- Asthenospheric uplift leads to weakening of this hangingwall, and hence the future deformation occurs in this location. At this moment, faulting becomes sequential in time and dominant rift faults all dip in the same direction, e.g. towards the future ocean.

2. Estimated extension from faults & crustal thinning

1. Conjugate margin tectonic asymmetry



New numerical model: Kinematic (faulting) + Dynamic (lower crust and mantle)

At each time step:

1- determine kinematic velocities for brittle layer (from faults).

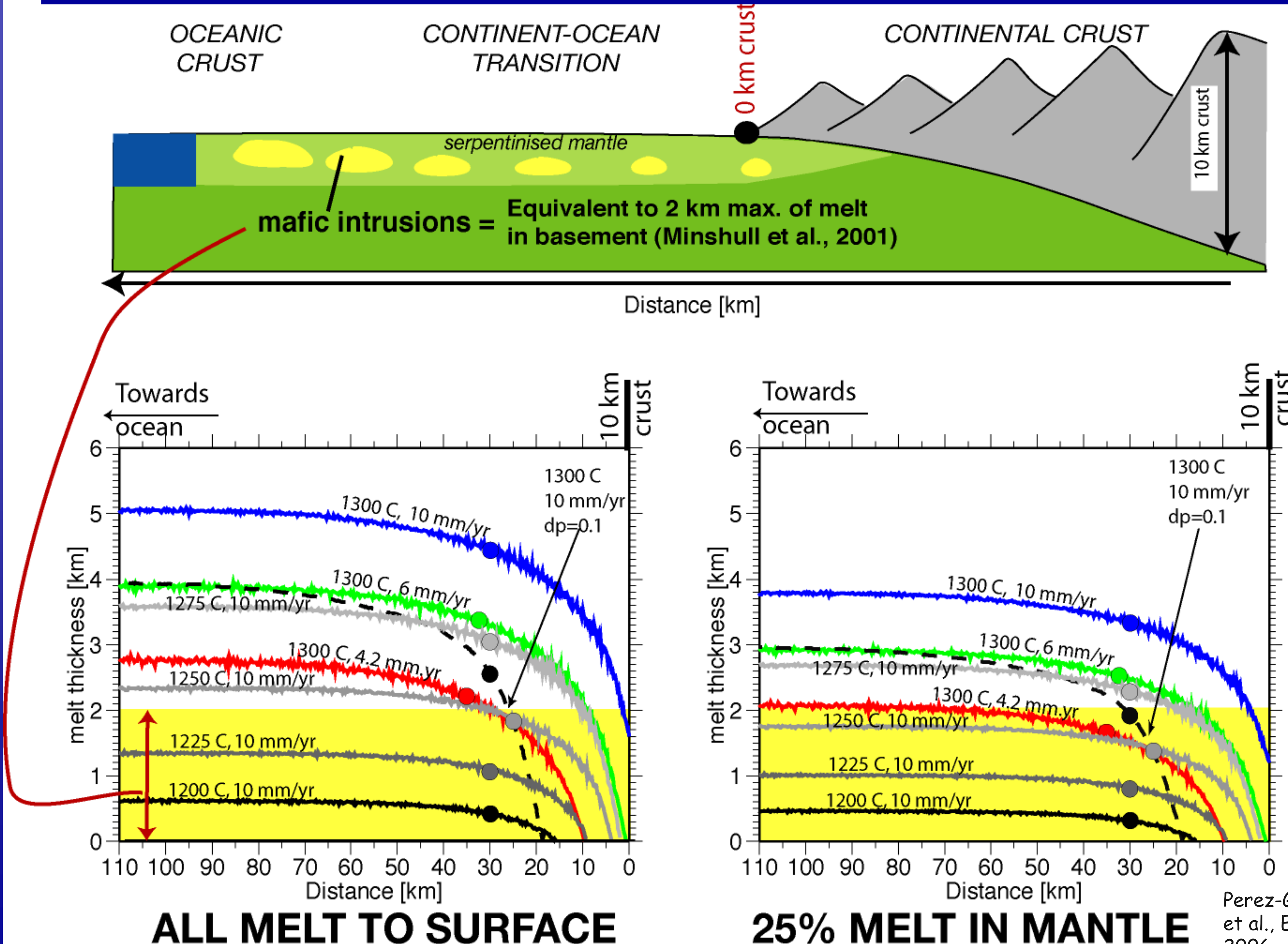
2- determine flexure due to fault offset, to Moho thinning and asthenospheric uplift in time step --> convert to flexural velocity.

3- solve Stoke equation for flow of ductile layers (given a rheology for lower crust and mantle).

4- solve for temperature.

5- update coordinates of fem mesh

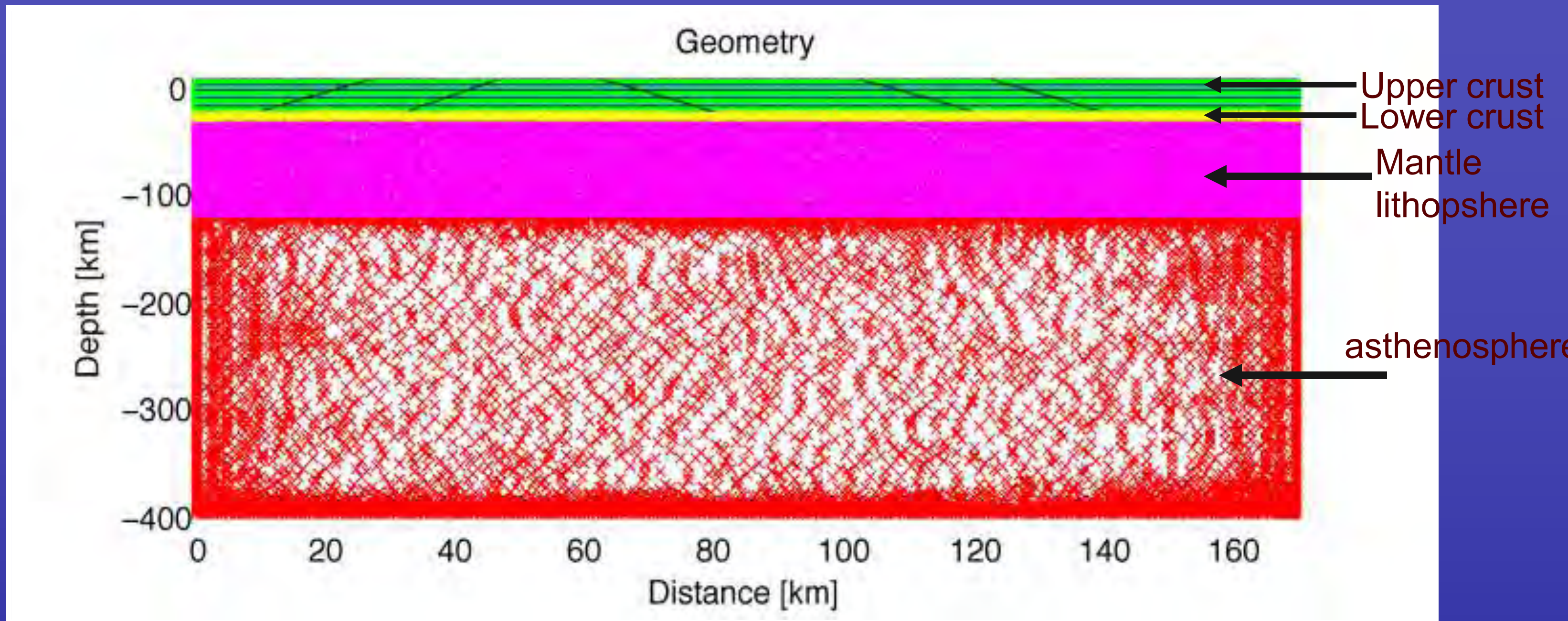
Previous results – homogenous mantle flow



Perez-Gussinye et al., EPSL, 2006

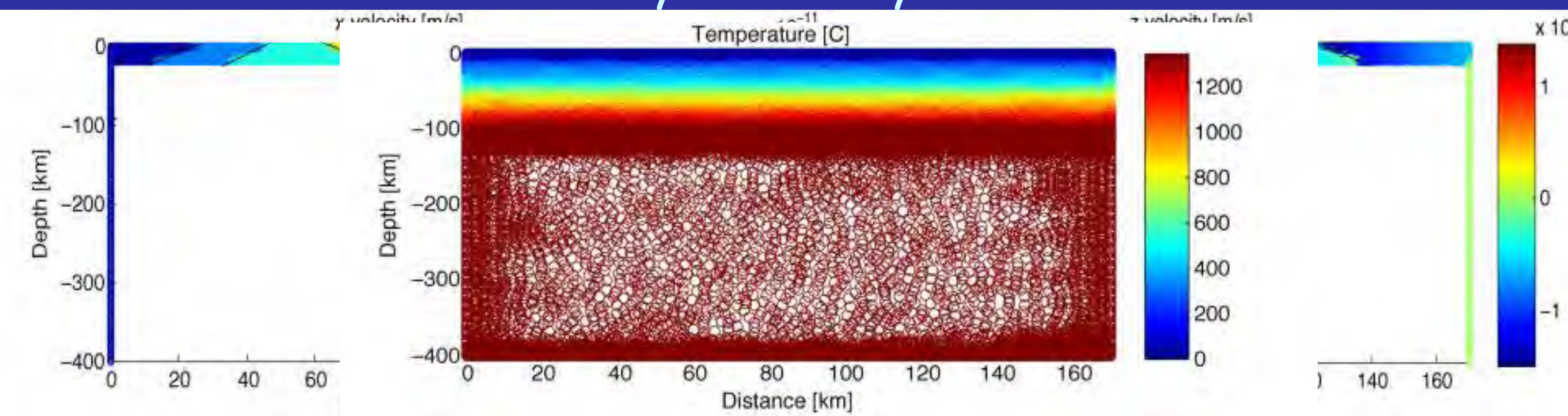
Kinematic + Dynamic model setup

Rheology:
Non-newtonian viscosities

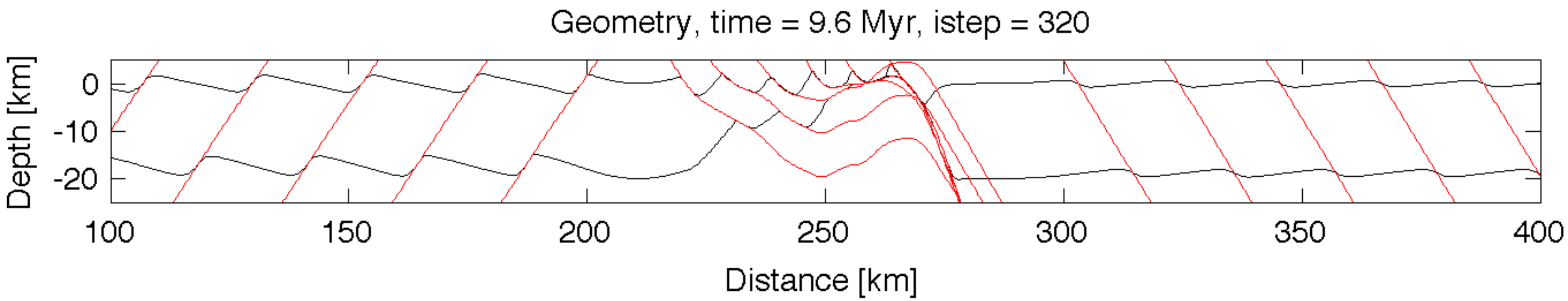


Initial temperature conditions

Velocity boundary conditions



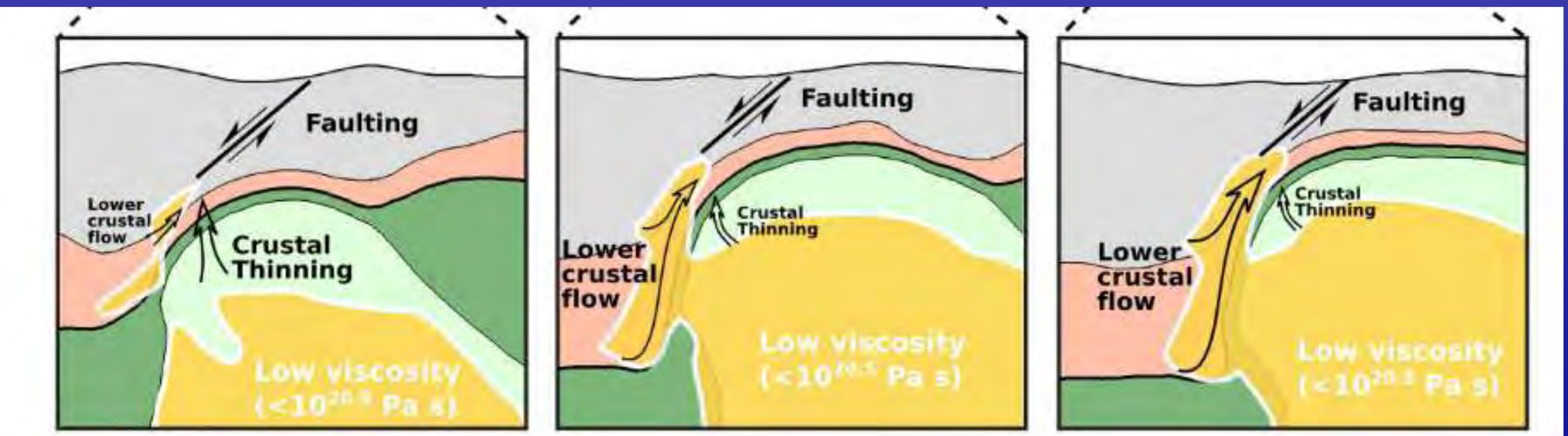
Fault Geometry evolution



- Faults planar
- Back rotation of upper part of faults due to flexure
- ‘Flattening/Listrification’ of deeper part of fault due to activity of next faults

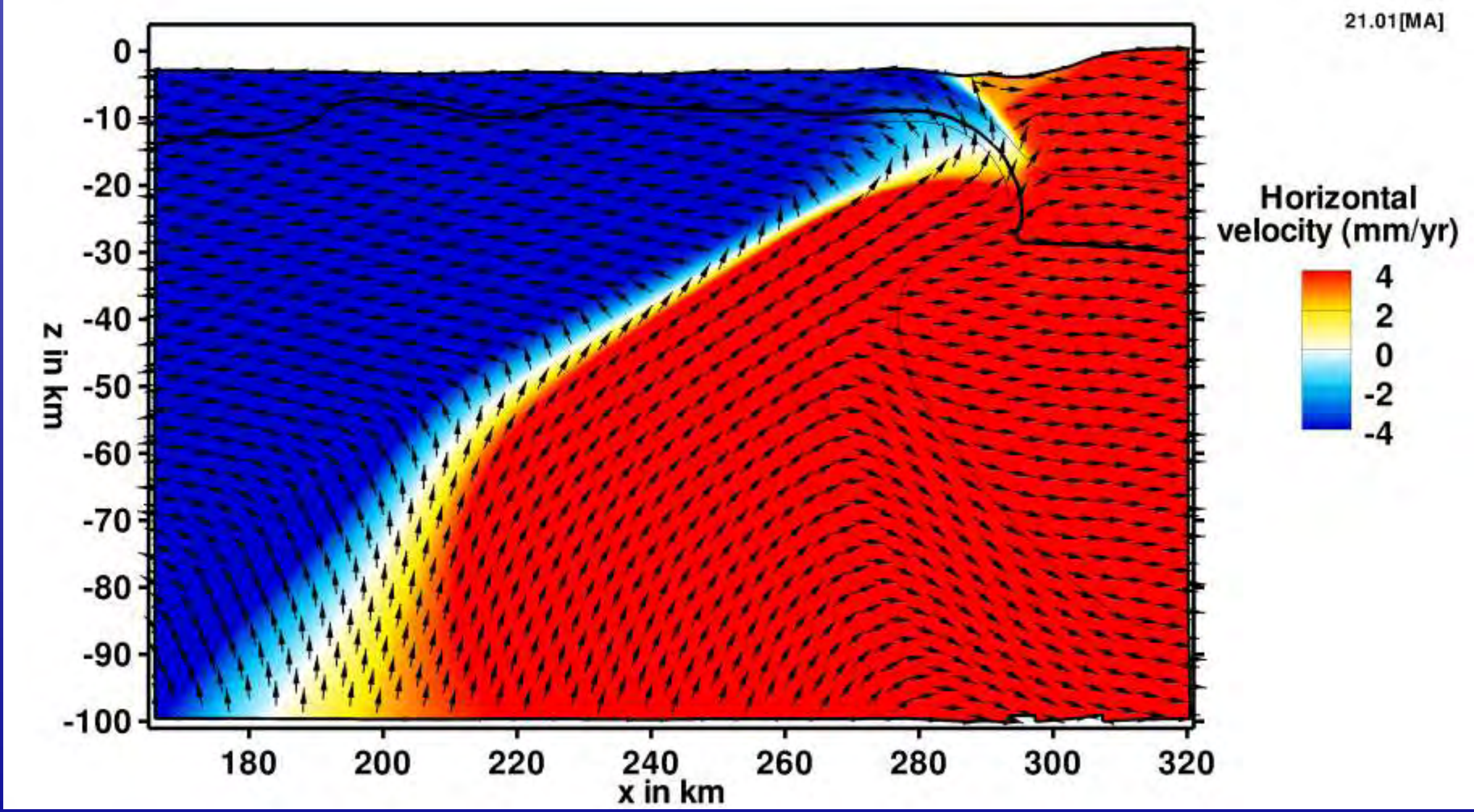
Factors influencing wide margin width

- The width of the wide margin depends on lower crustal rheology during extension.
- A weak lower crust, promotes a longer initial phase of distributed faulting and a longer phase of sequential faulting since crustal thinning is less efficient, due to flow of lower crust towards the tip of the active fault.



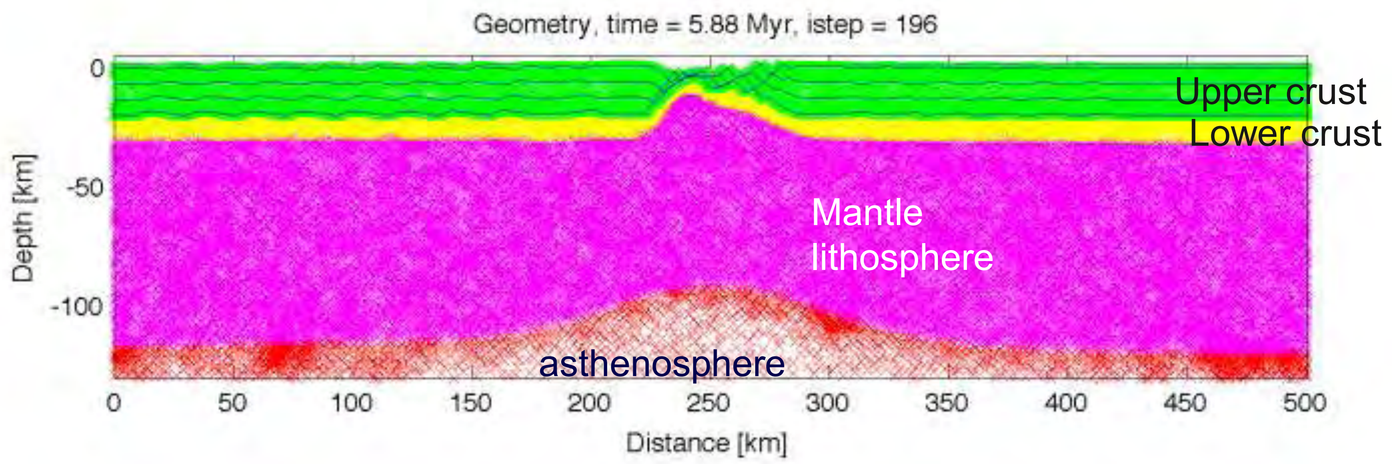
Weaker lower crust

Slow extension velocity 4 mm/yr, strong mafic granulite lower crust fully dynamic model (Sascha Brune, Potsdam)

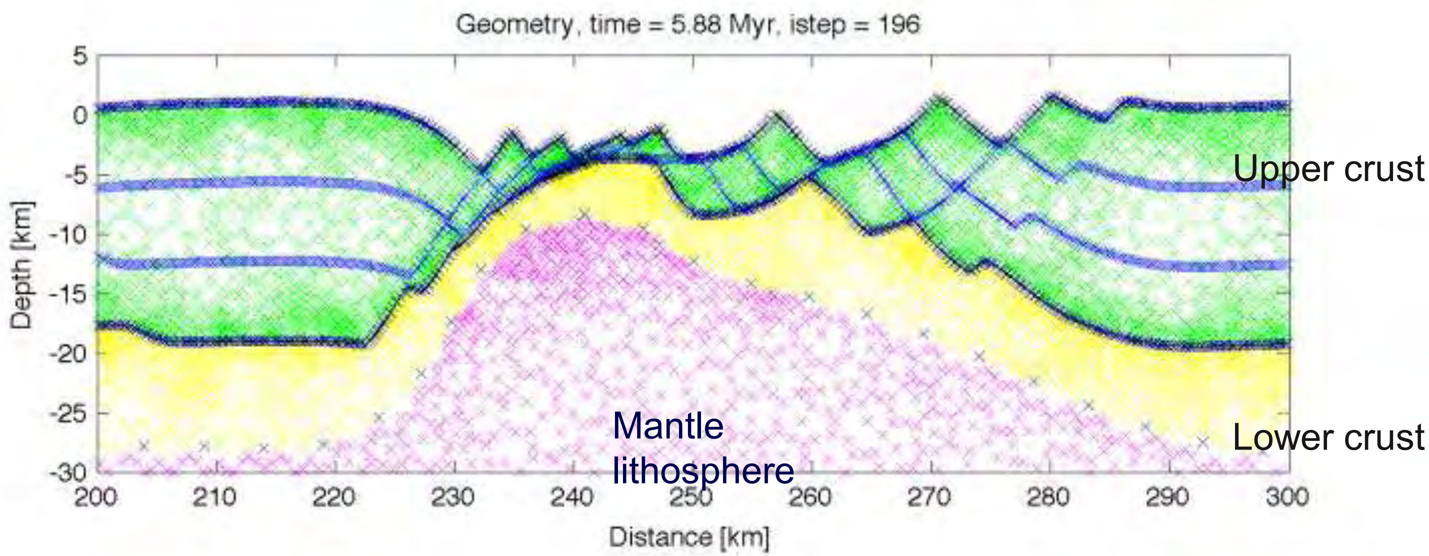


Brune, Heine, Perez-Gussinye, Sobolev, in prep.

Slow extension velocity ~4 mm/yr strong (mafic granultite) lower crustal rheology

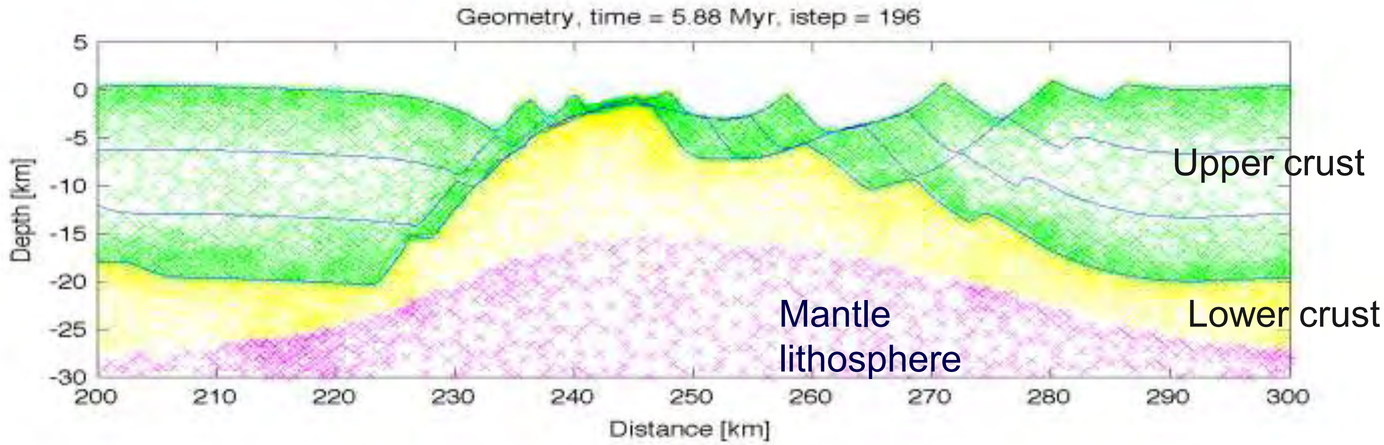


Slow extension velocity ~4 mm/yr strong (mafic granultite) lower crustal rheology

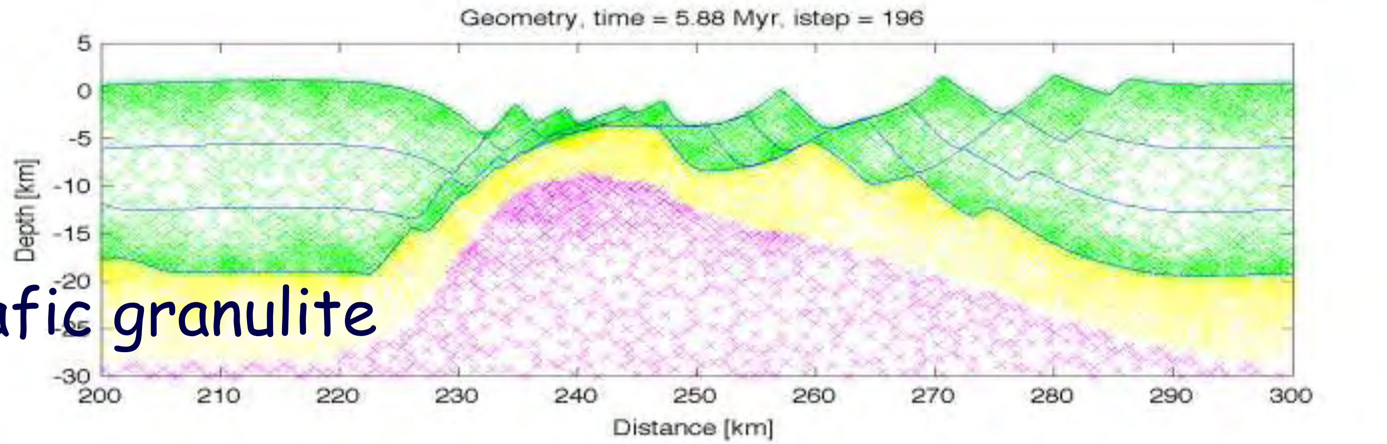


Effective crustal thinning due to sequential faulting

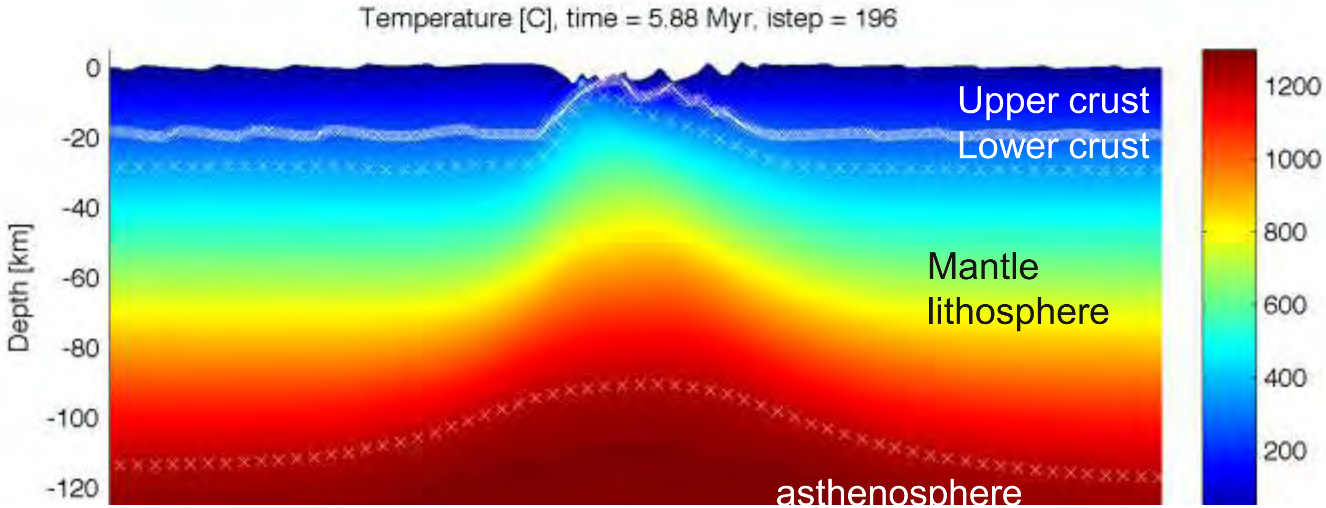
Slow extension velocity ~4 mm/yr weak (wet quartz) lower crustal rheology



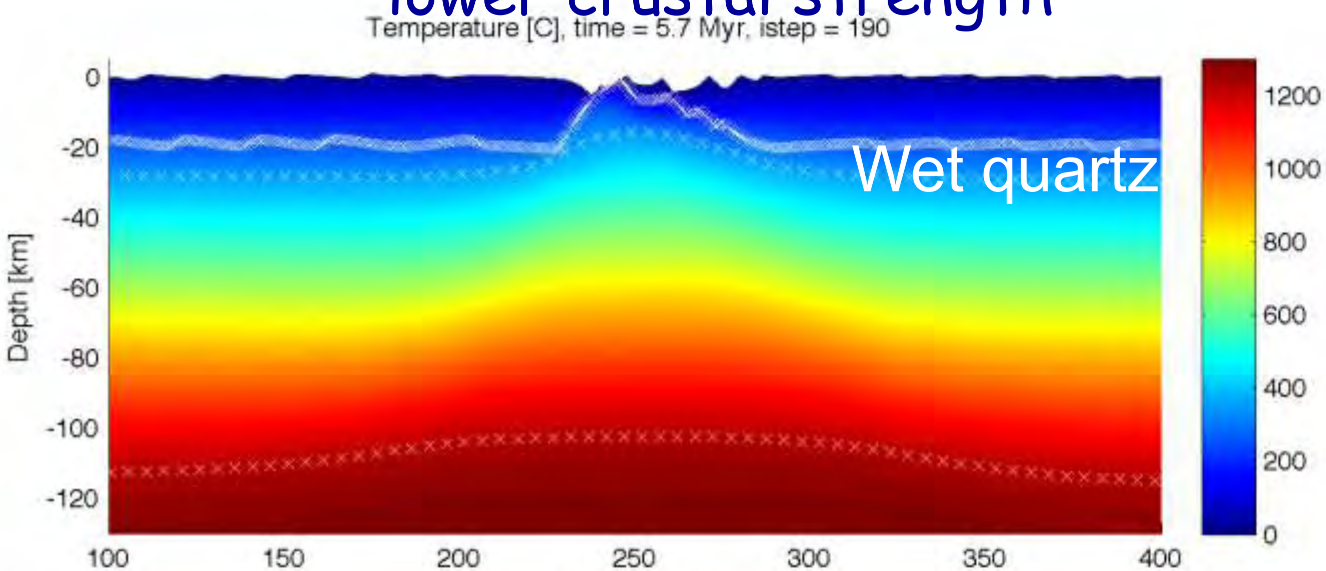
NO Effective crustal thinning due to sequential faulting



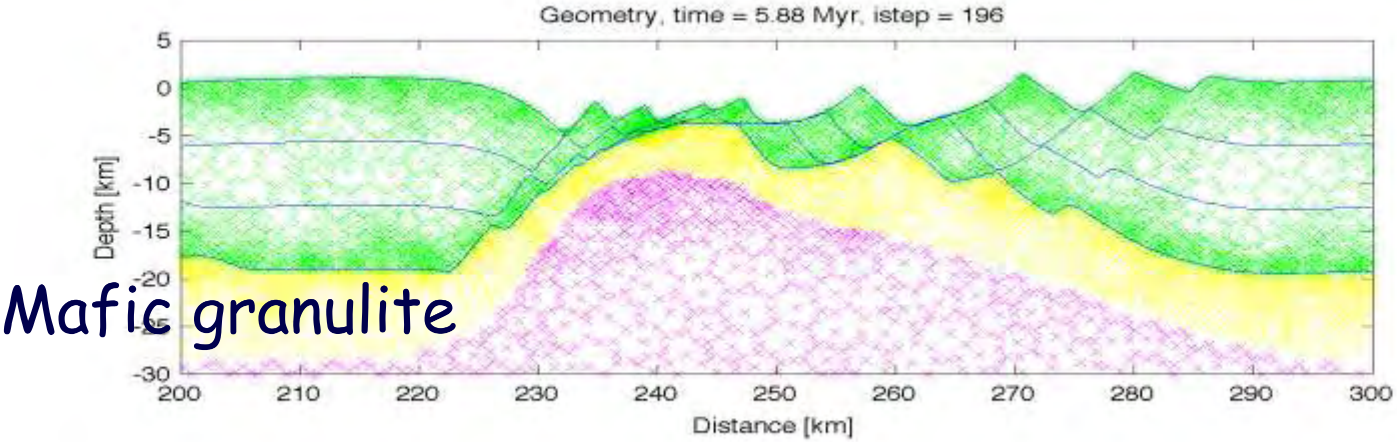
Slow extension velocity ~4 mm/yr strong (mafic granultite) lower crustal rheology

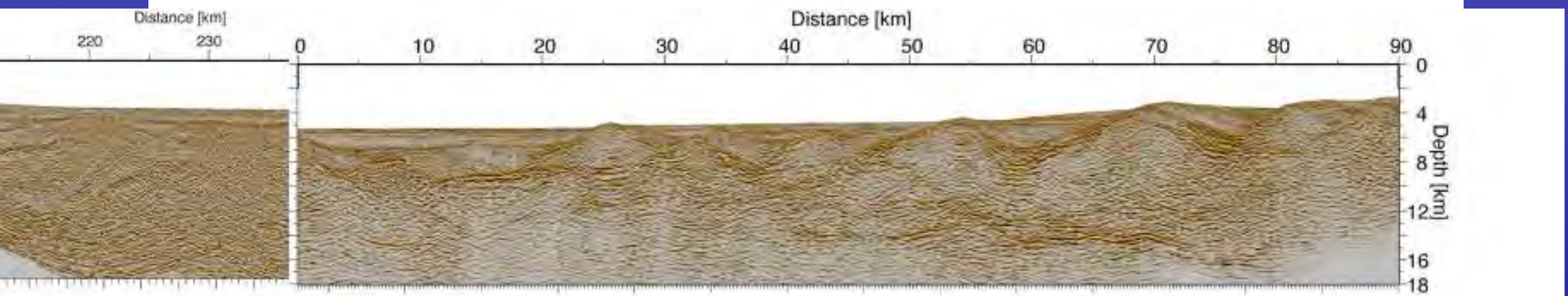


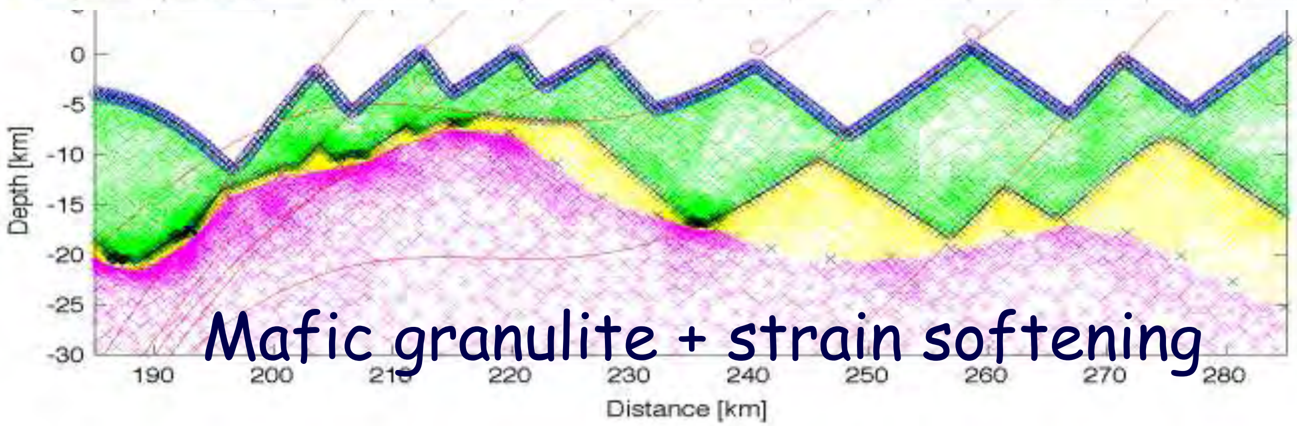
Asymmetry of temperature, increasing with lower crustal strength



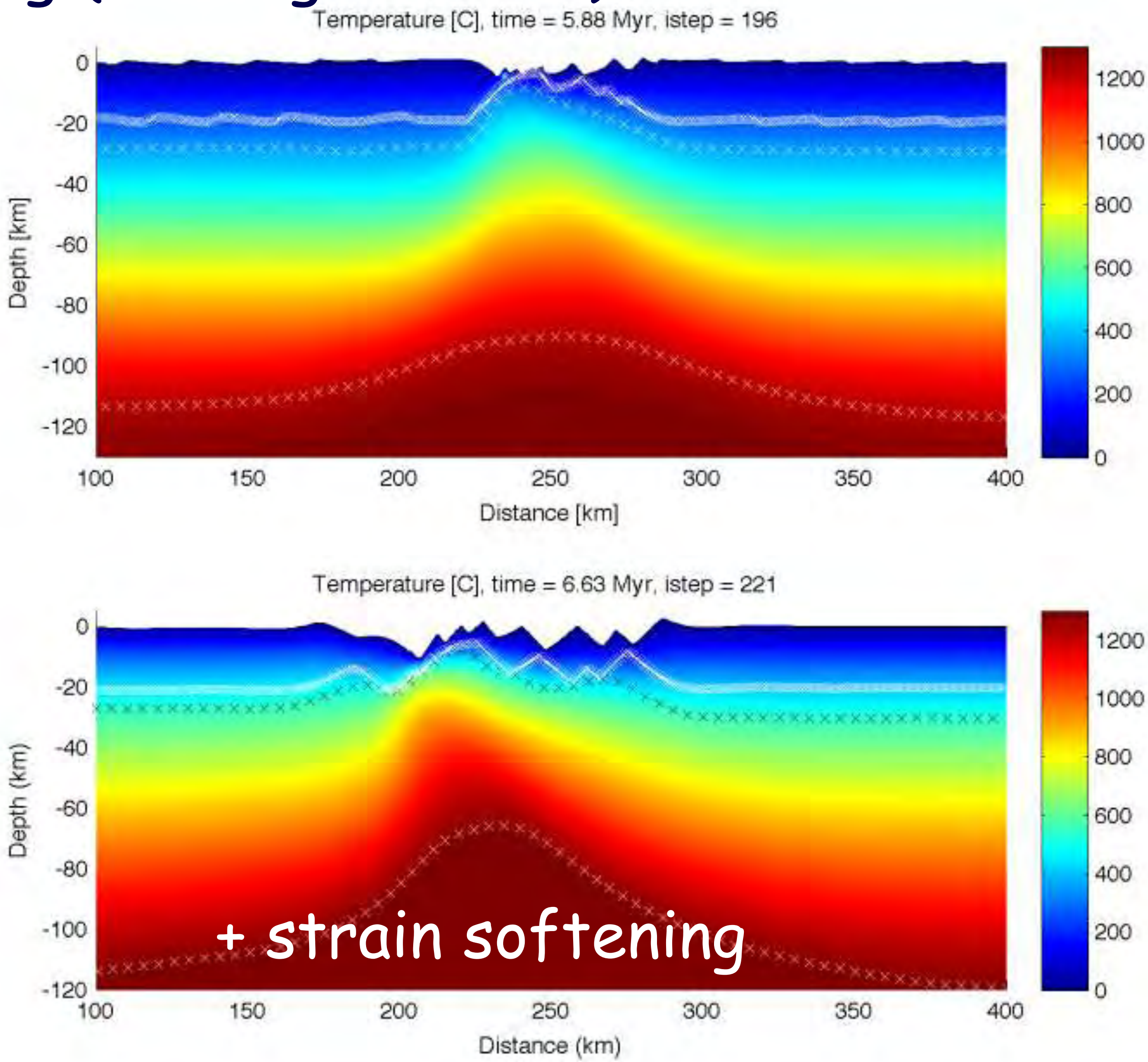
Brittle-like behaviour of lower crust







Slow extension velocity ~4 mm/yr
strong (mafic granultite) lower crustal rheology

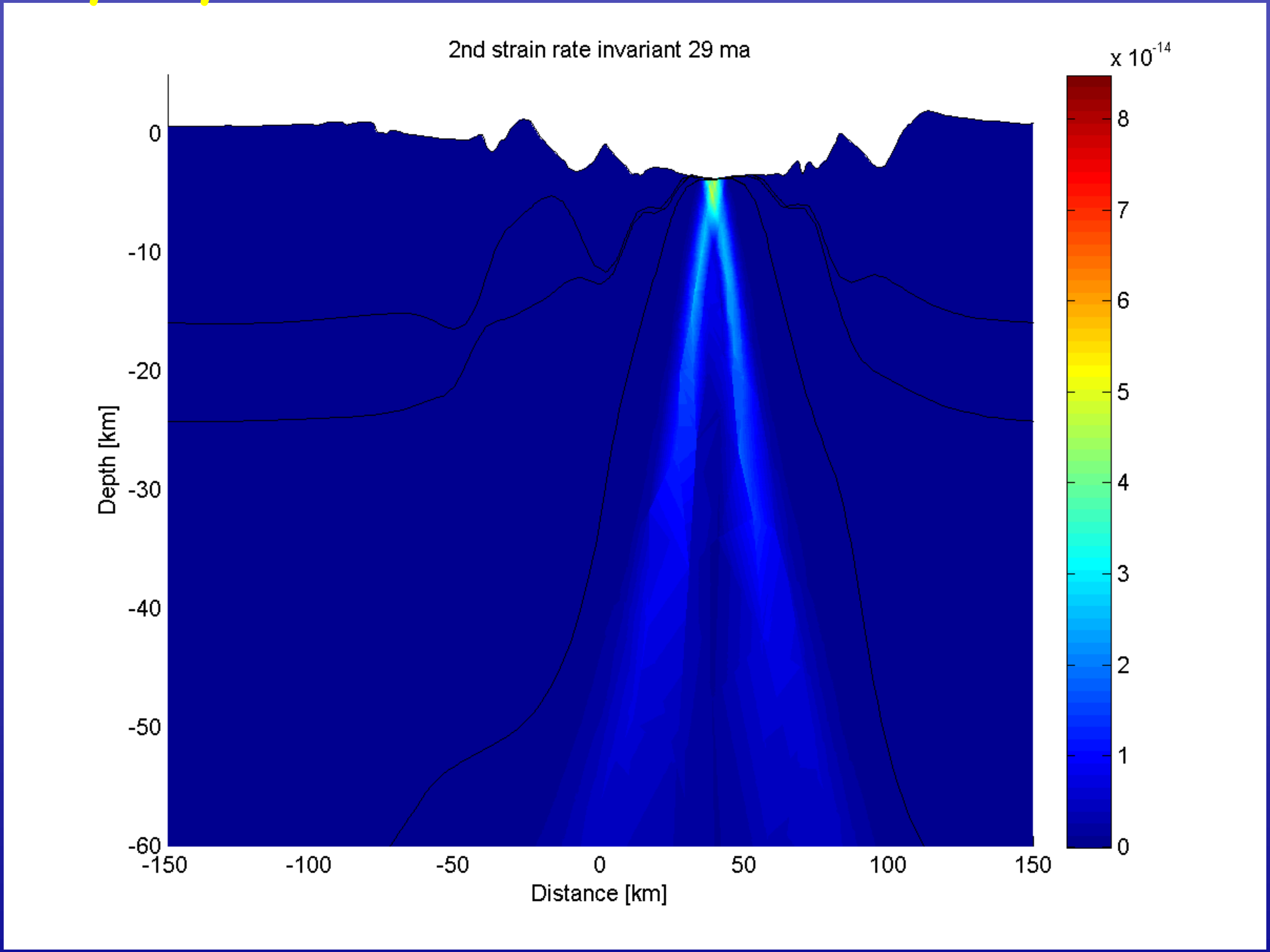


Fully dynamical elasto-viscous models:

- Realistic description of rheological behaviour.
- Accurate estimations of subsidence/uplift
- High ressolution of fault blocks
- Melting, serpentinisation
- Sedimentation/erosion

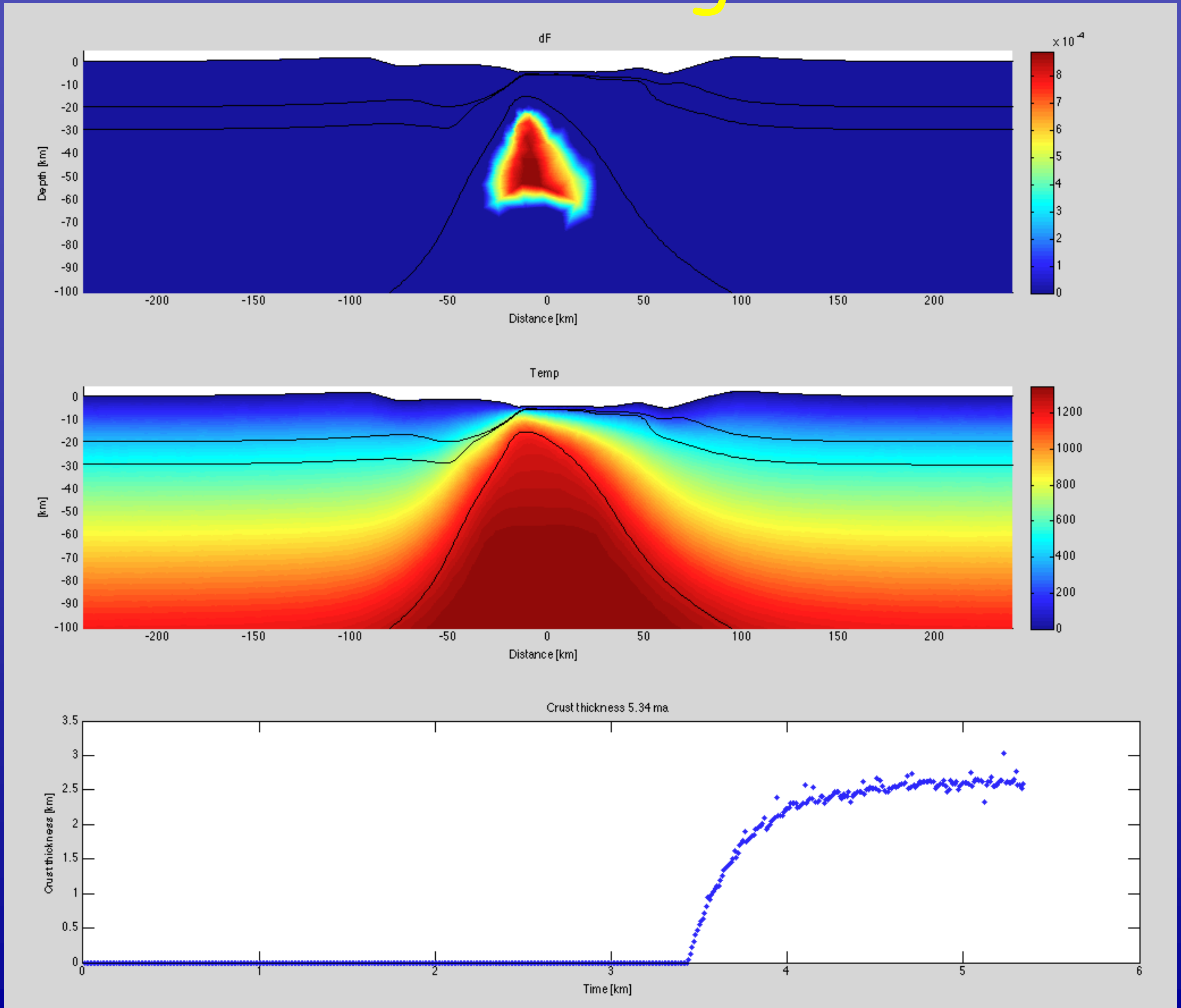
Miguel Andres Martinez

Fully dynamical elasto-viscous models:



Miguel Andres Martinez

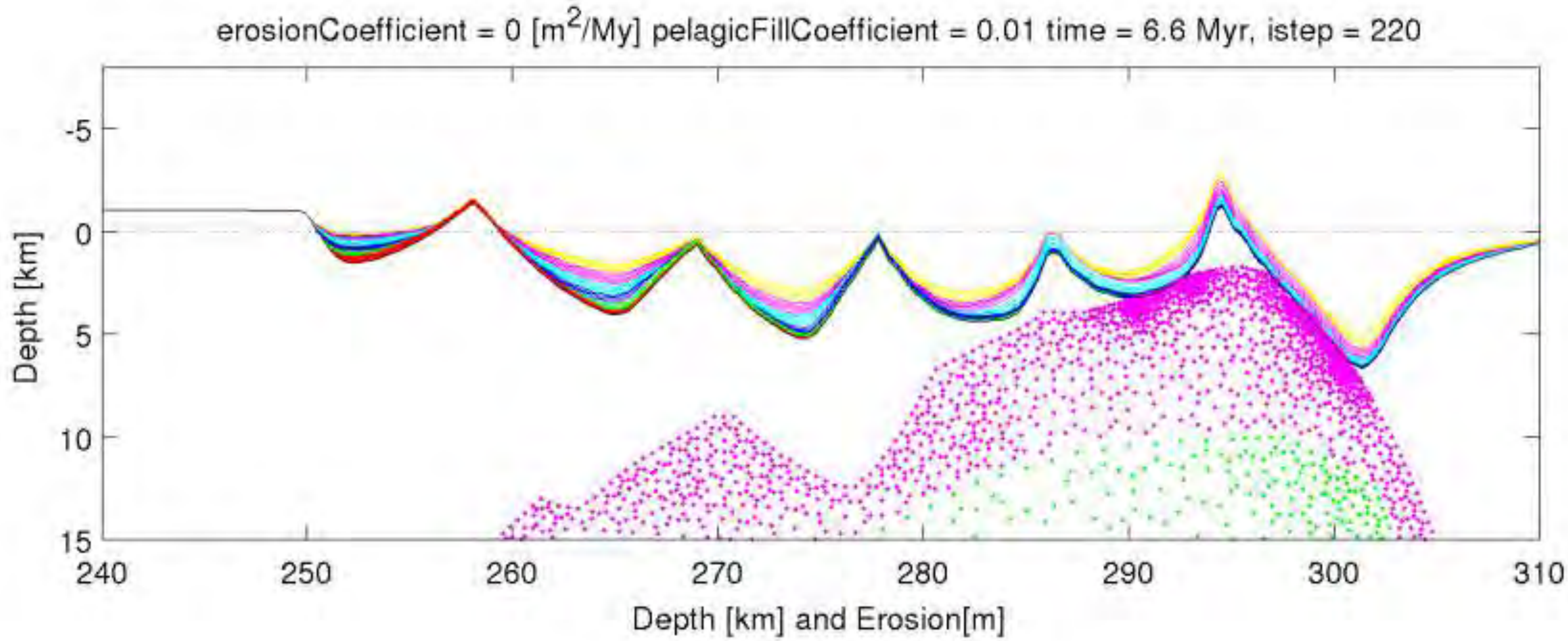
Fully dynamical elasto-viscous models: melting



Sedimentation

- Pelagic sedimentation as a fraction of accommodation space
- Erosion/transport by diffusion equation.
- Additional flexure due to sediment load.
- Flexure due to erosion not yet taken into account!
- Need to apply faulting to sediments!

Sedimentation



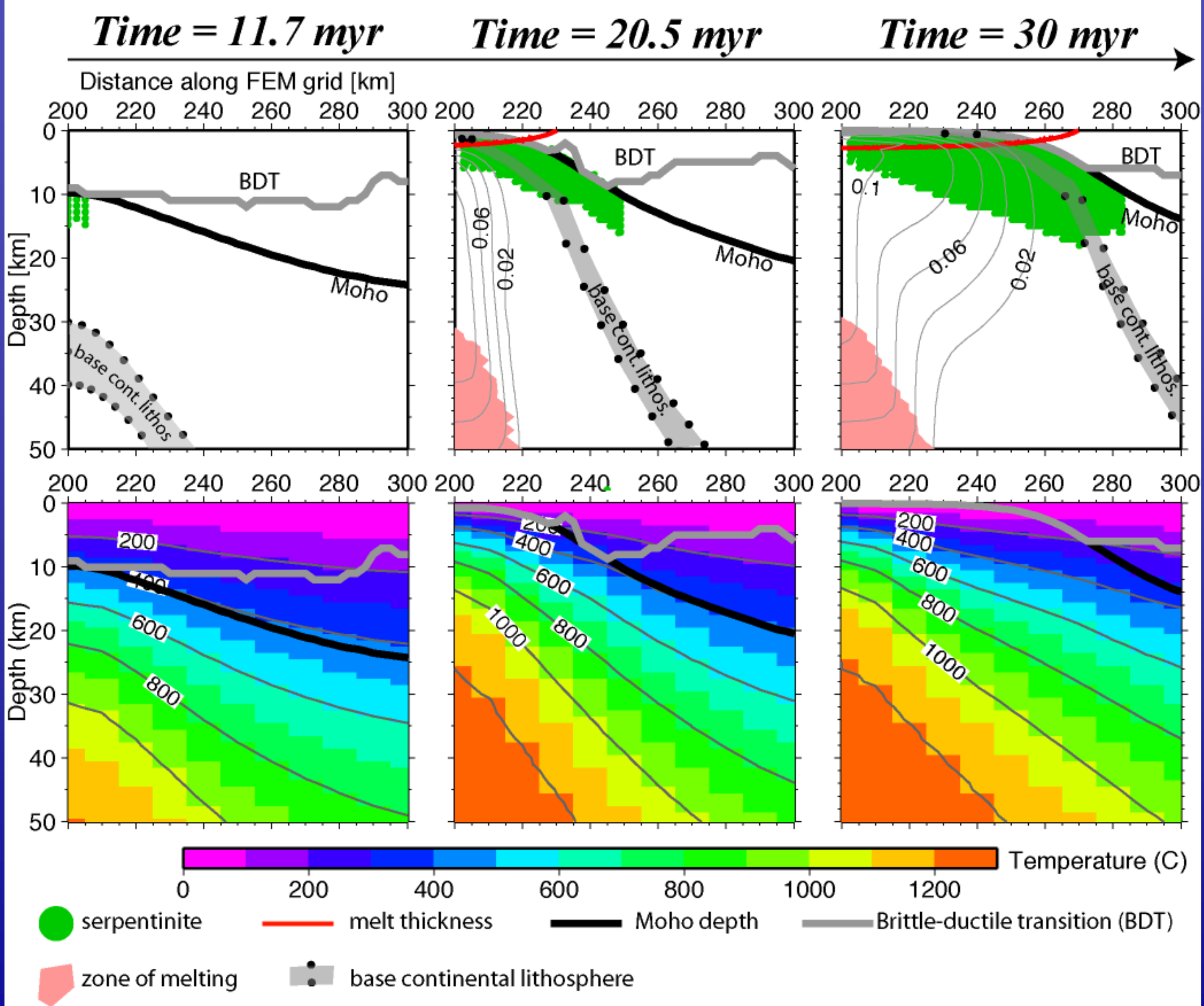
Some Conclusions

- If lower crust strong, fault sequentiality leads to effective crustal thinning and margin asymmetry. Heat flow is asymmetric and migrates oceanwards.

[illegible]

presentation next).

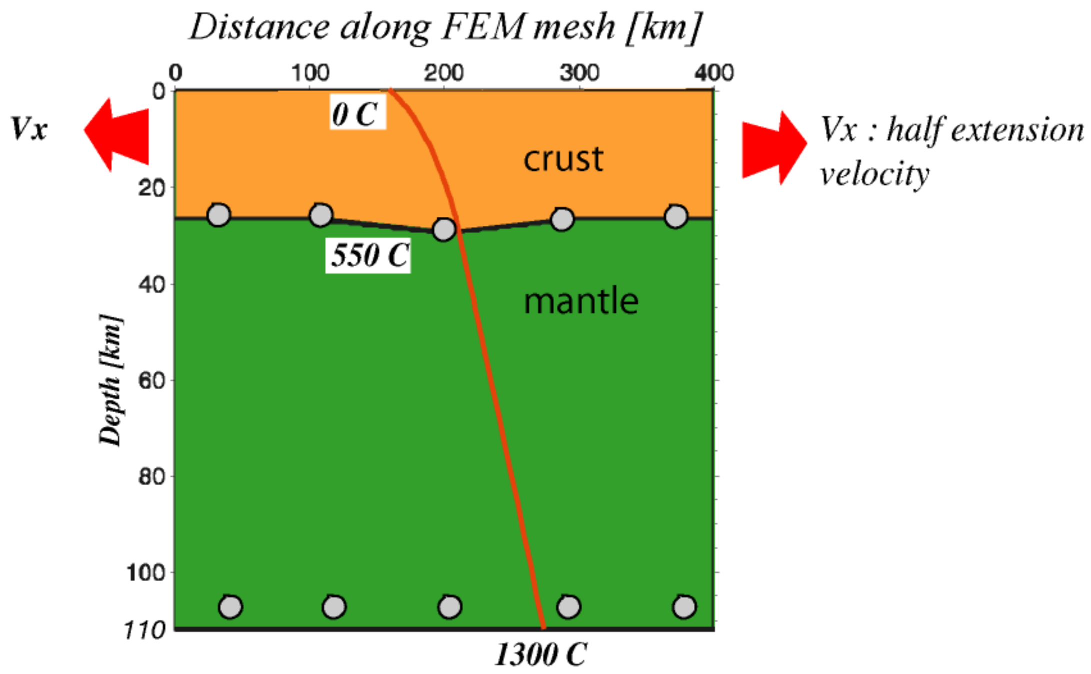
SLOW VELOCITY = 4.2 mm/yr (half extension)
NORMAL MANTLE TEMPERATURE =1300 C

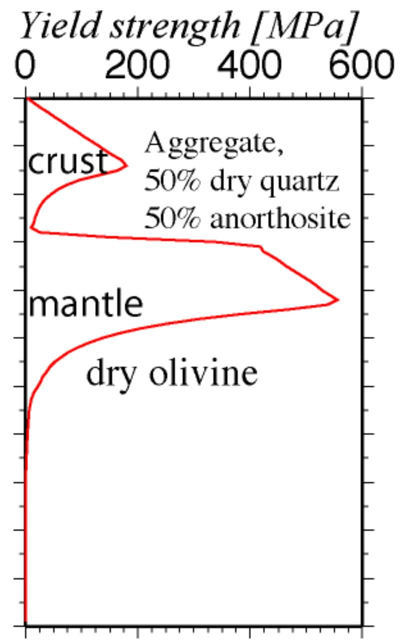


SERPENTINISATION STARTS BEFORE MELTING

Perez-Gussinye et al., EPSL, 2006

INITIAL CONDITIONS AND MODEL SETUP

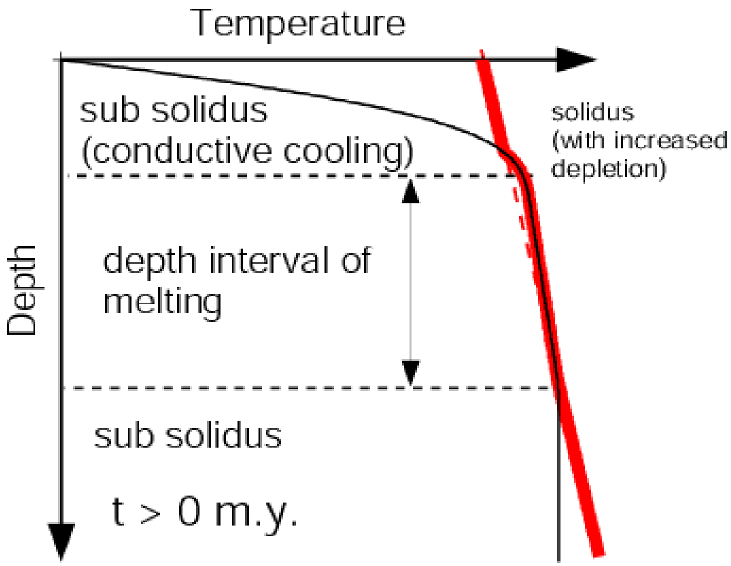


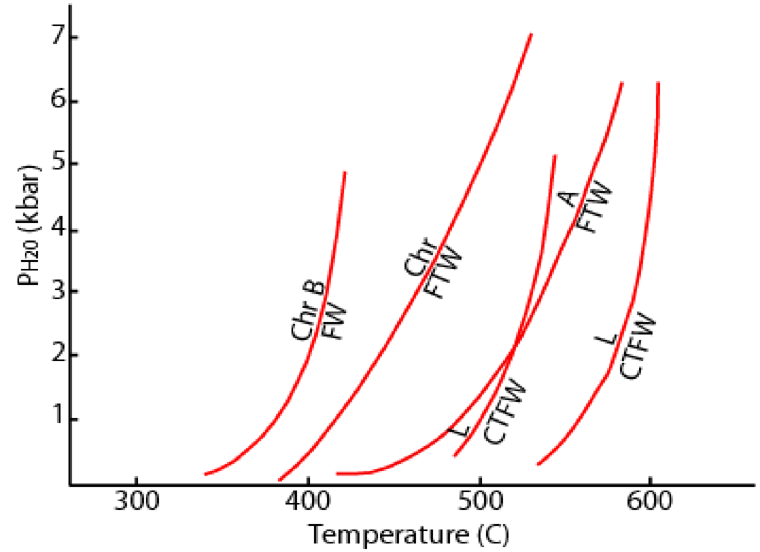


- *Tracer particles follow Moho & base continental lithosphere.*
- *Serpentinization occurs when entire crust becomes brittle due to increased hydrothermal circulation. Tracer particles follow serpentinite.*
- *Decompression melting when geotherm crosses solidus.*
- *At each time step melt produced is focused at rift centre. Subsequently, melt is moved laterally with a velcoity V_x.*

Perez-Gussinye et al., EPSL, 2006

Melting & Serpentinisation





Temperature calculation:

hydrothermal circulation in brittle crust → κ

heat consumed by melting → $-L' dF_m/dt$

heat released by serpentinisation → $H_s dF_s/dt$

radioactive heat production → $H(z)/\rho Cp$

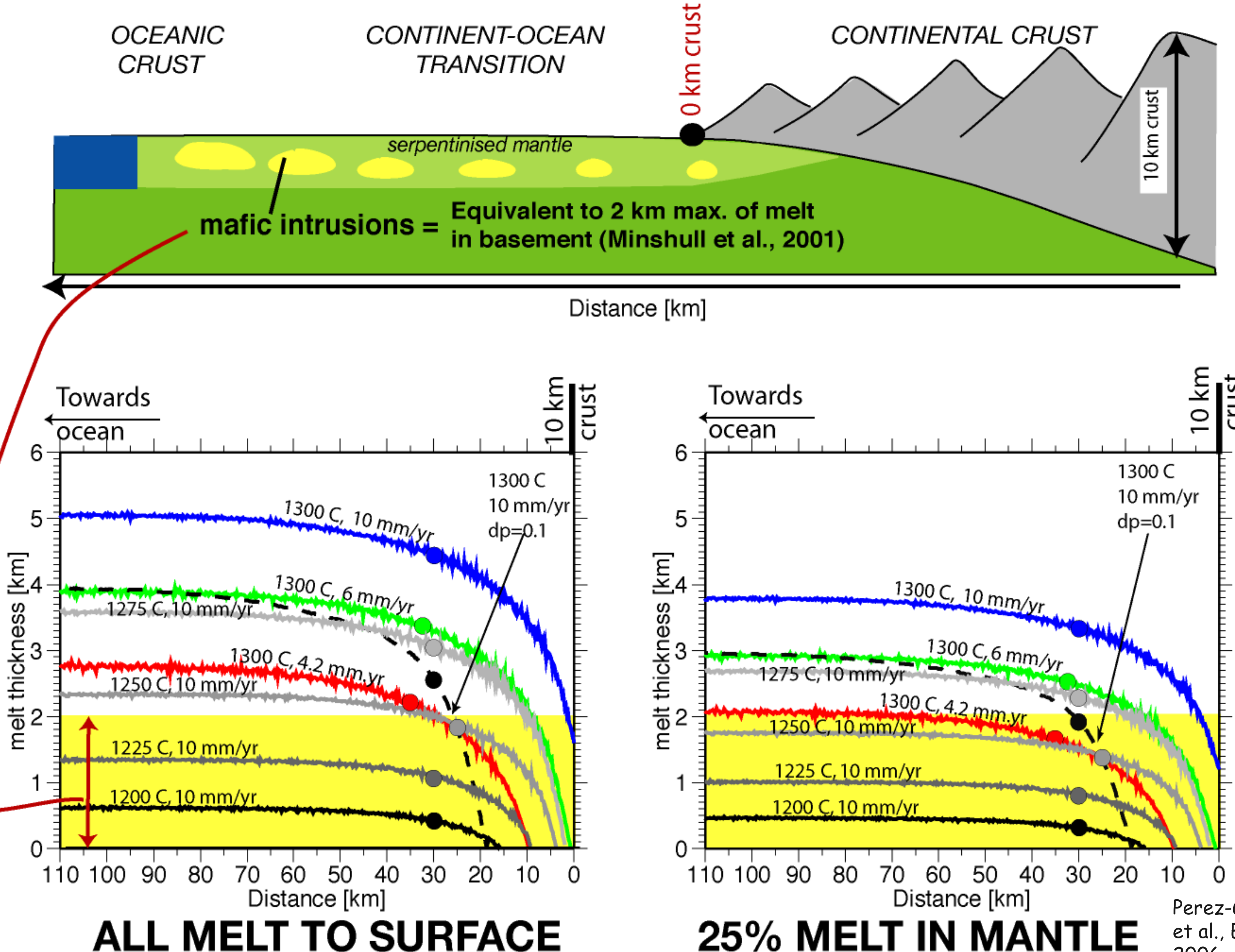
$$dT^c/dt = \kappa\,(d^2T^c/dx^2 + d^2T^c/d^2z) + u_x\, dT^c/dx + uz\, dT^c/dz - L'\, dF_m/dt + H_s\, dF_s/dt + H(z)/\rho Cp$$

dFm/dt is the melt production rate (units in fraction/time) and L' is the latent heat of melting (or heat of fusion), which we convert here into an effective 'superheat' of 600 K (Hess, 1992).

H_s is the heat released when water reacts with olivine to produce serpentinite. This has been converted to an effective heat of serpentinization of 300 K, from the enthalpy of the peridotite-serpentine reaction (e.g. MacDonald and Fyfe, 1984). dF_s/dt is the serpentinite production rate

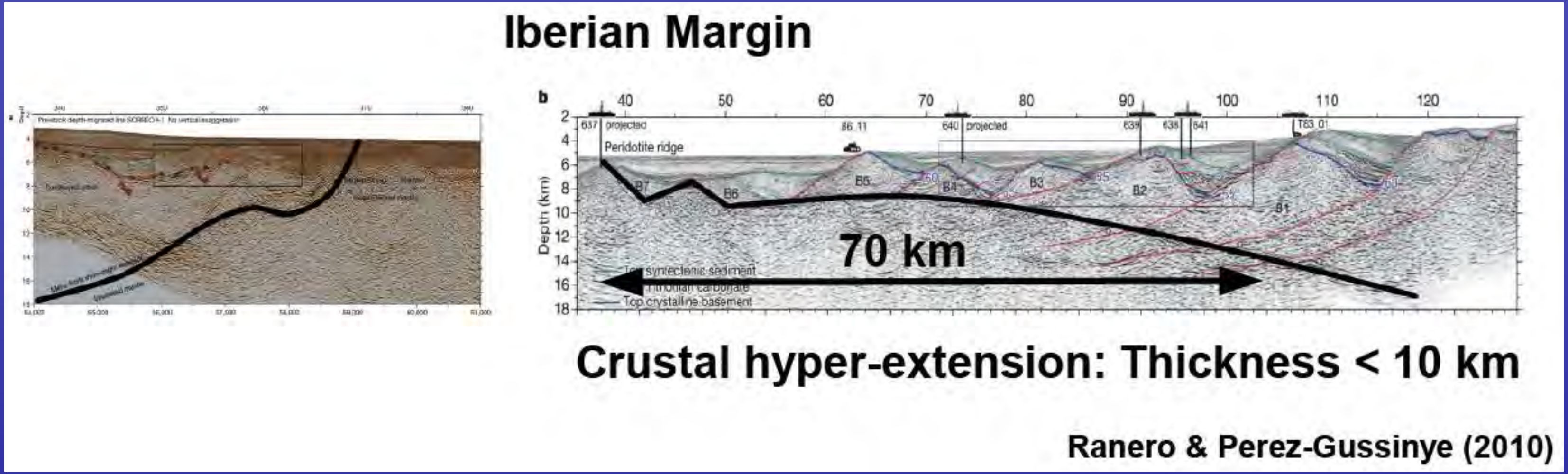
Perez-Gussinye et al., EPSL, 2006

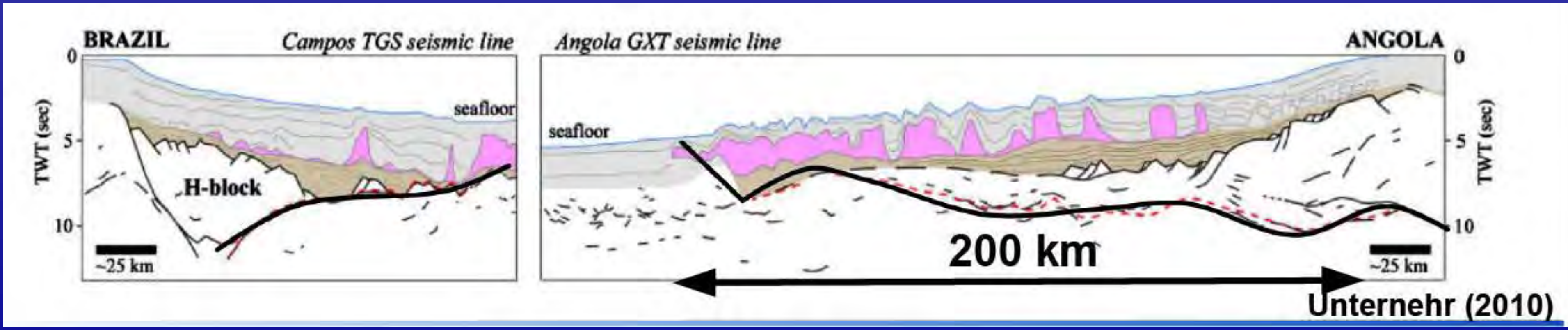
RESULTS



Perez-Gussinye et al., EPSL, 2006

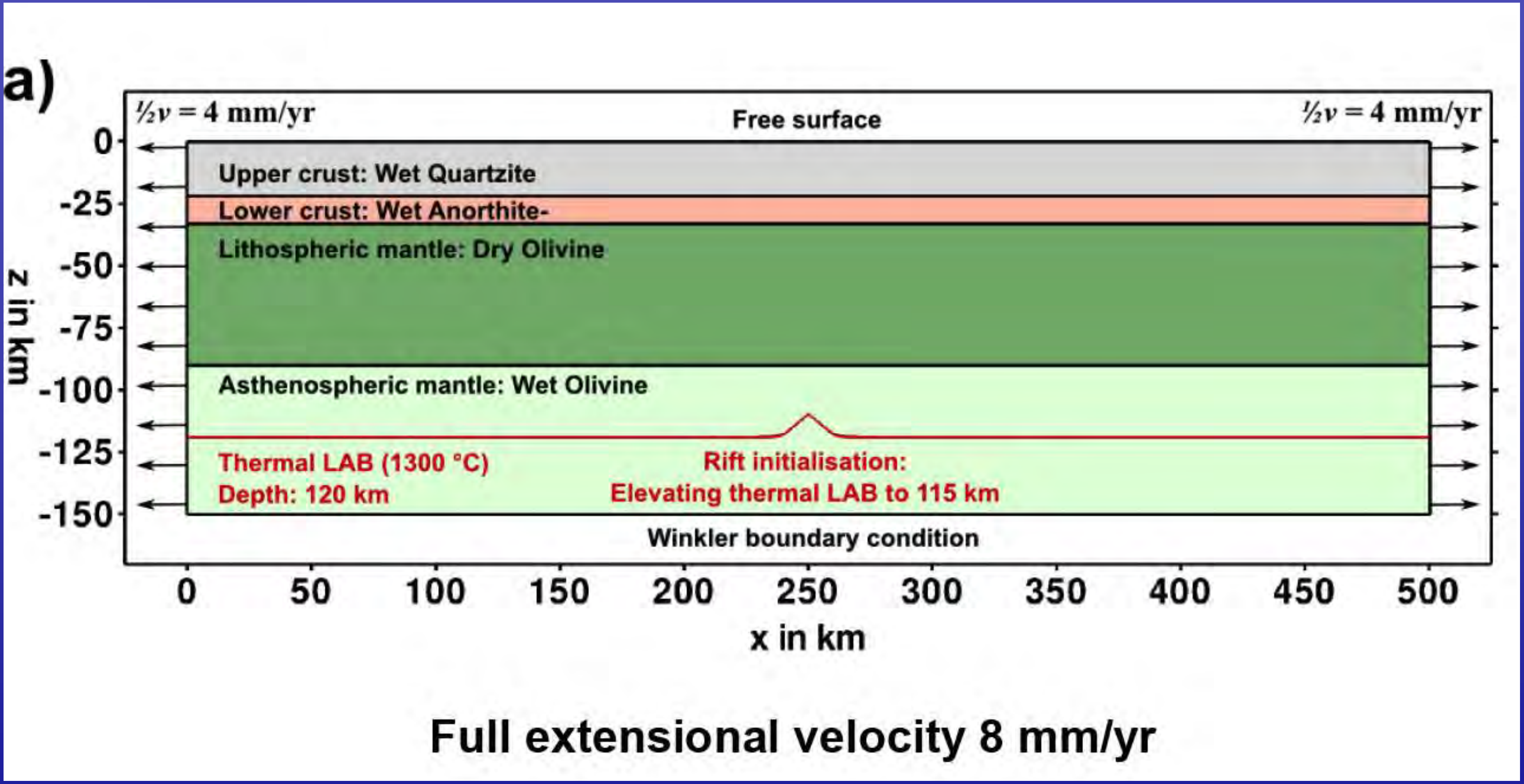
Crustal asymmetry, sequential faulting and dependency on lower crustal rheology and velocity





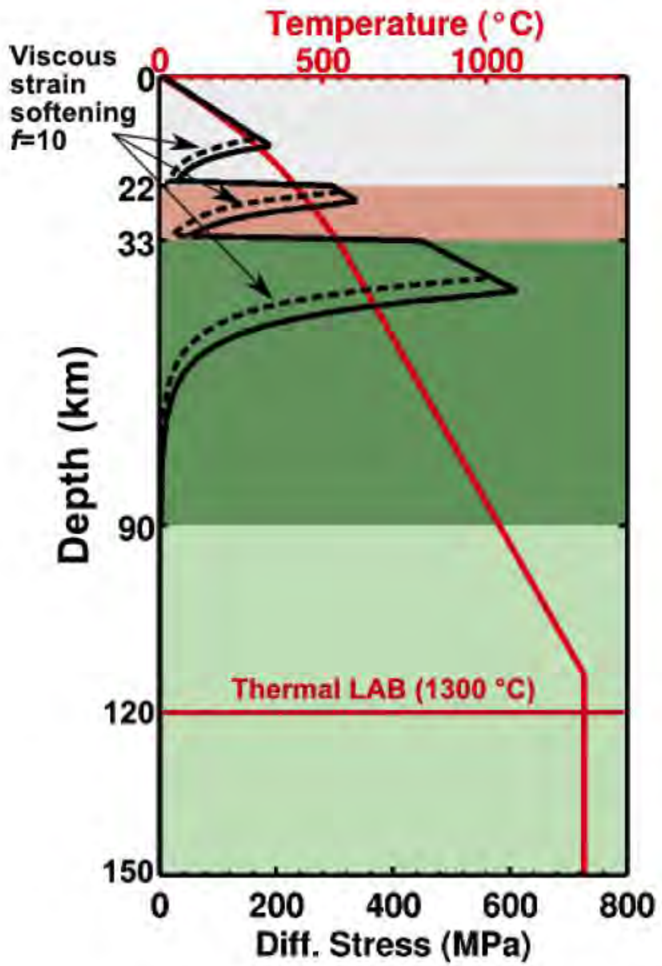
Brune, Heine, Perez-Gussinye and Sobolev, in prep.

Initial configuration



Brune, Heine, Perez-Gussinye and Sobolev, in prep.

Initial configuration



33 km crustal thickness

Mafic lower crust
(agrees with vp velocities of 6.7-6.9 km/s
Iberia/New Foundland & Central South Atlantic)

Initial Moho Temperature 550-600°C
(Müntener et al 2000)

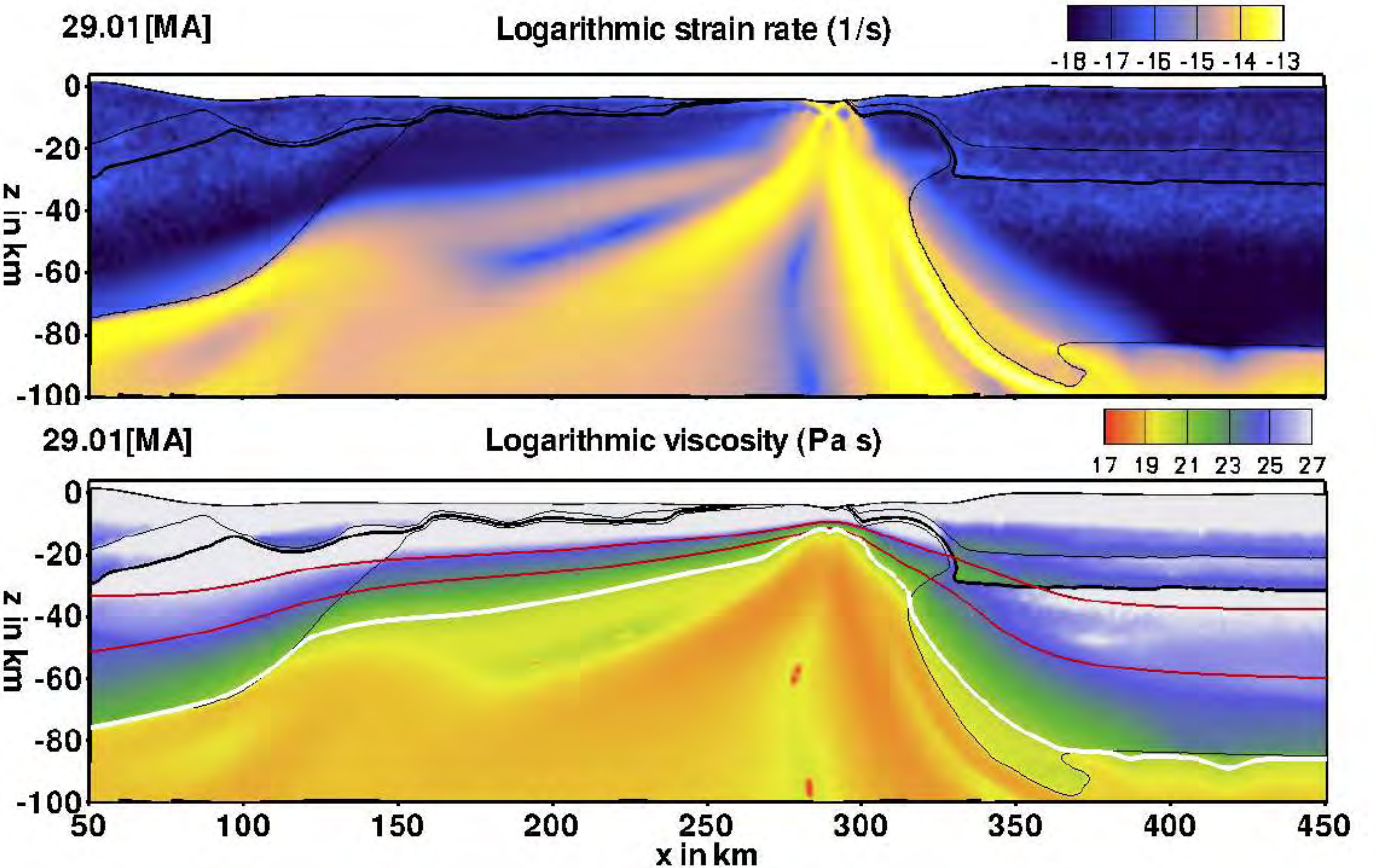
Laboratory-based rheology

Thermal LAB: Mobile belts (Artemieva 2006)

Plastic strain softening
Viscous strain softening
Shear heating

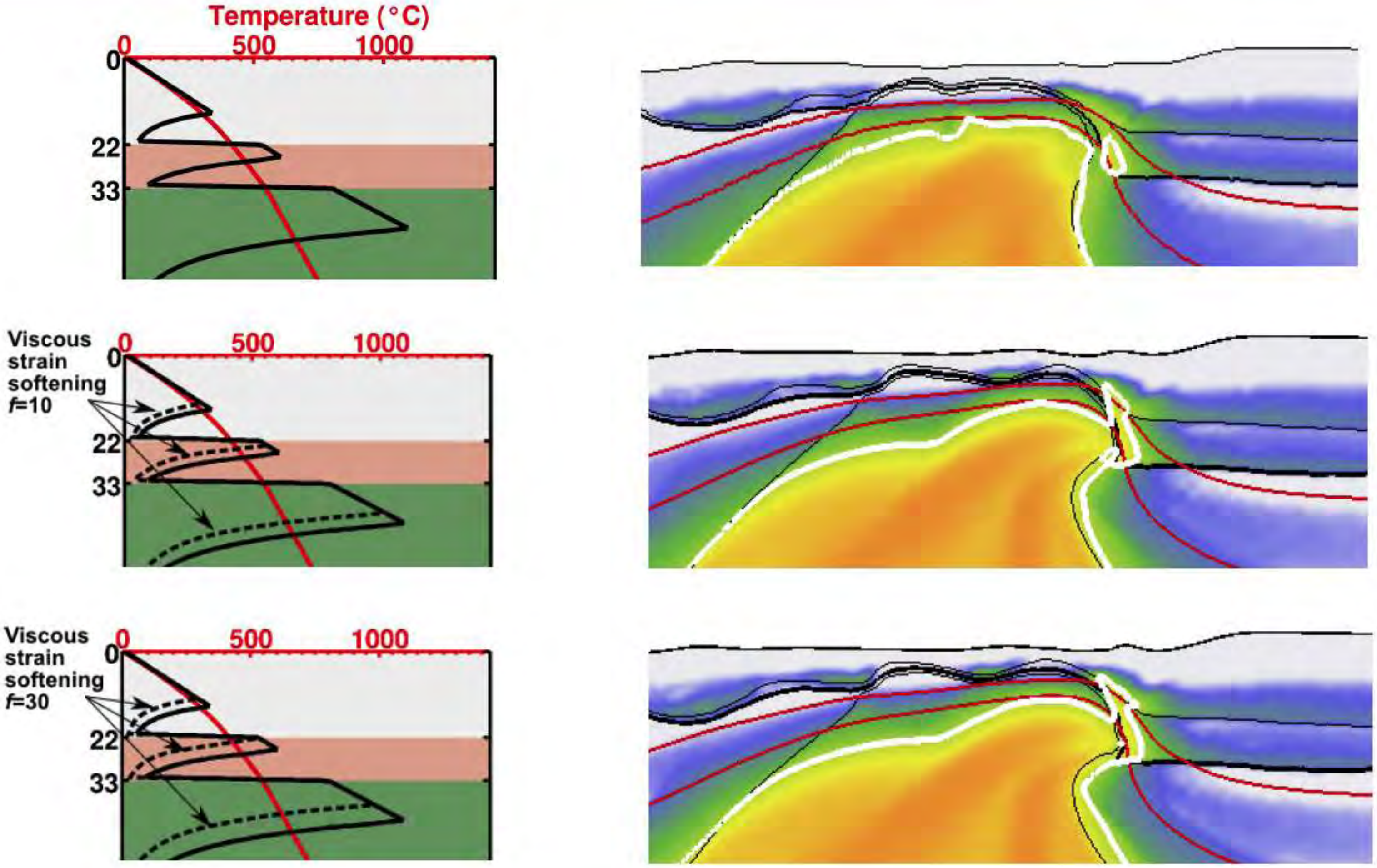
Brune, Heine, Perez-Gussinye and Sobolev, in prep.

Model evolution - strong lower crust

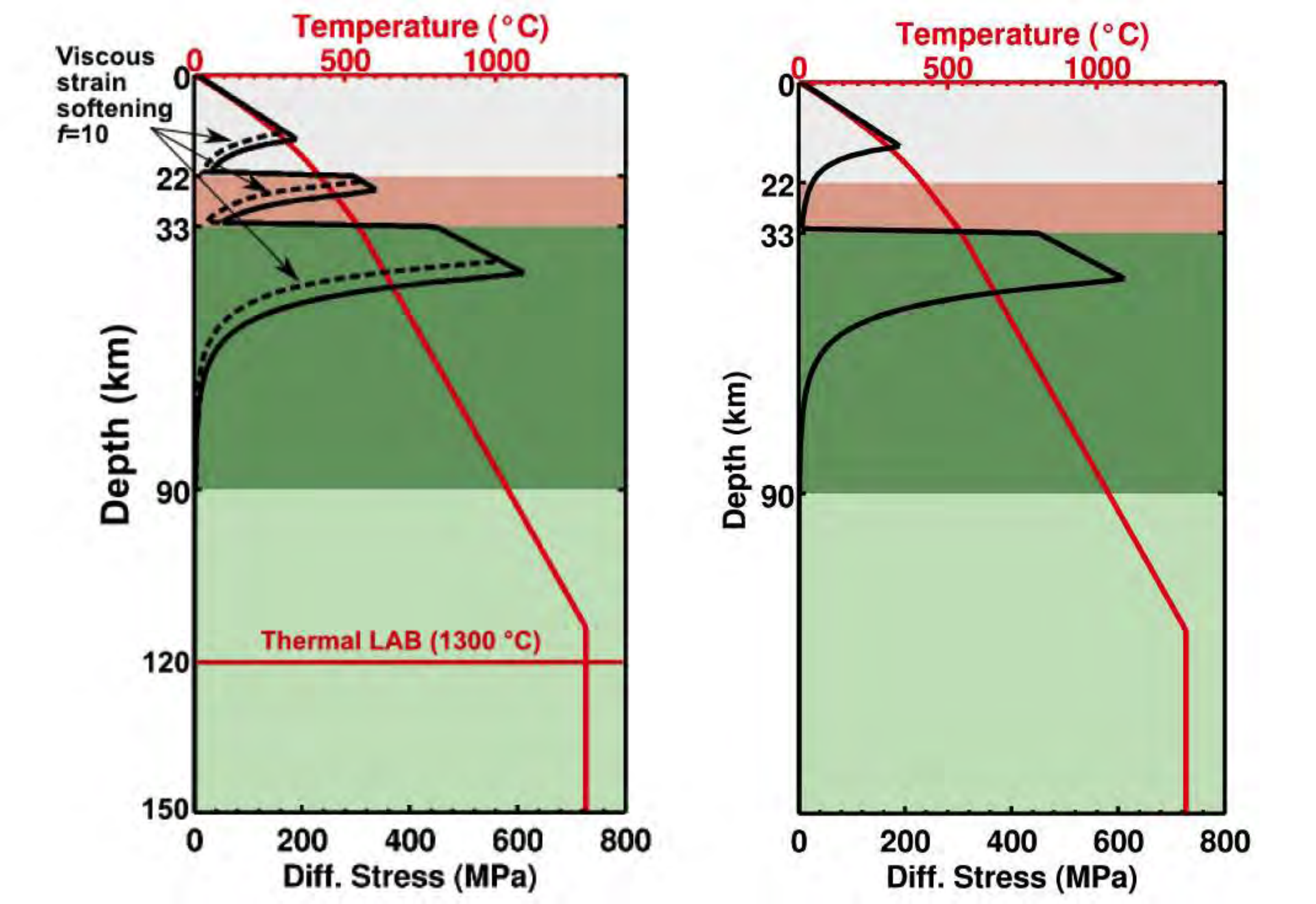


4. Controlling parameters

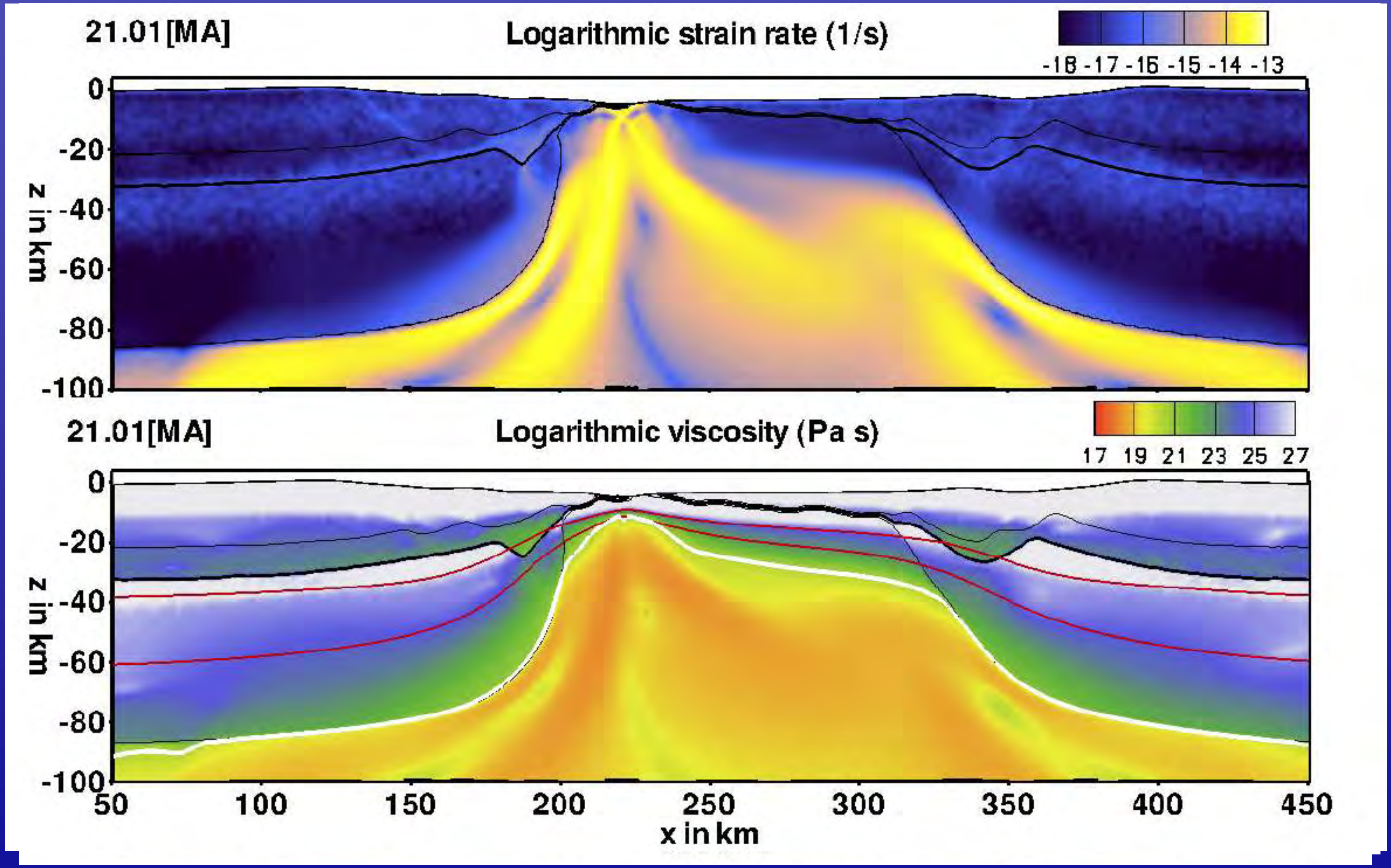
Viscous softening



Lower crustal rheology

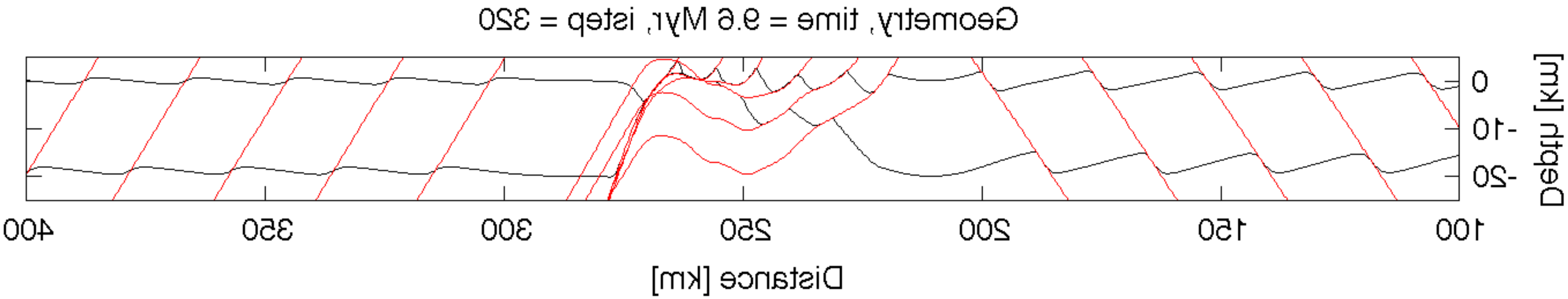


Model evolution - weak lower crust

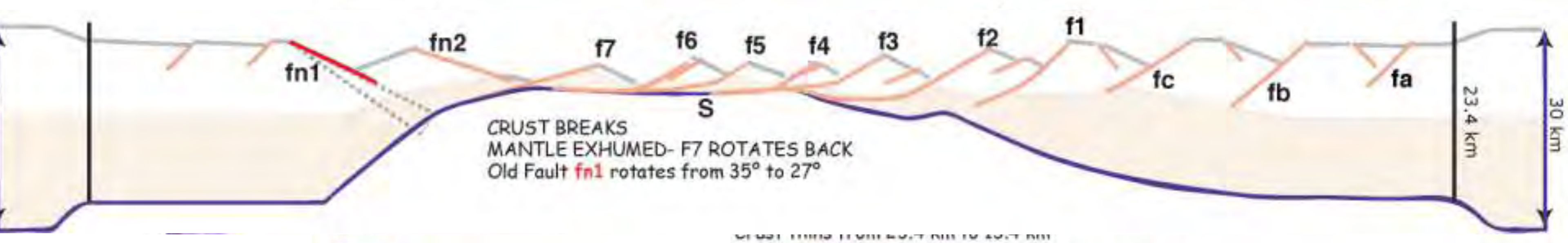


Some Conclusions

- Weak lower crust shows a longer phase of symmetry. Strong lower crust promotes asymmetry earlier in the rift phase.
- Fault sequentiality results from the emergence of a large dominant fault, which breaks the thermal and rheological symmetry of lower crust and mantle. Asymmetry in the thermal structure of lower crust and mantle weaken the area ahead of the previous fault tip, generating a new sequential fault.
- Weak lower crust tends to promote wider margins as phase of symmetry is longer and phase of fault sequentiality is also longer.
- Increasing strain softening or increasing velocity has a similar effect to decreasing lower crustal strength.



Geometry, time = 9.6 Myr, istep = 320
Depth [km]
0
-10
-20
100
150
200
250
300
350
400
Distance [km]



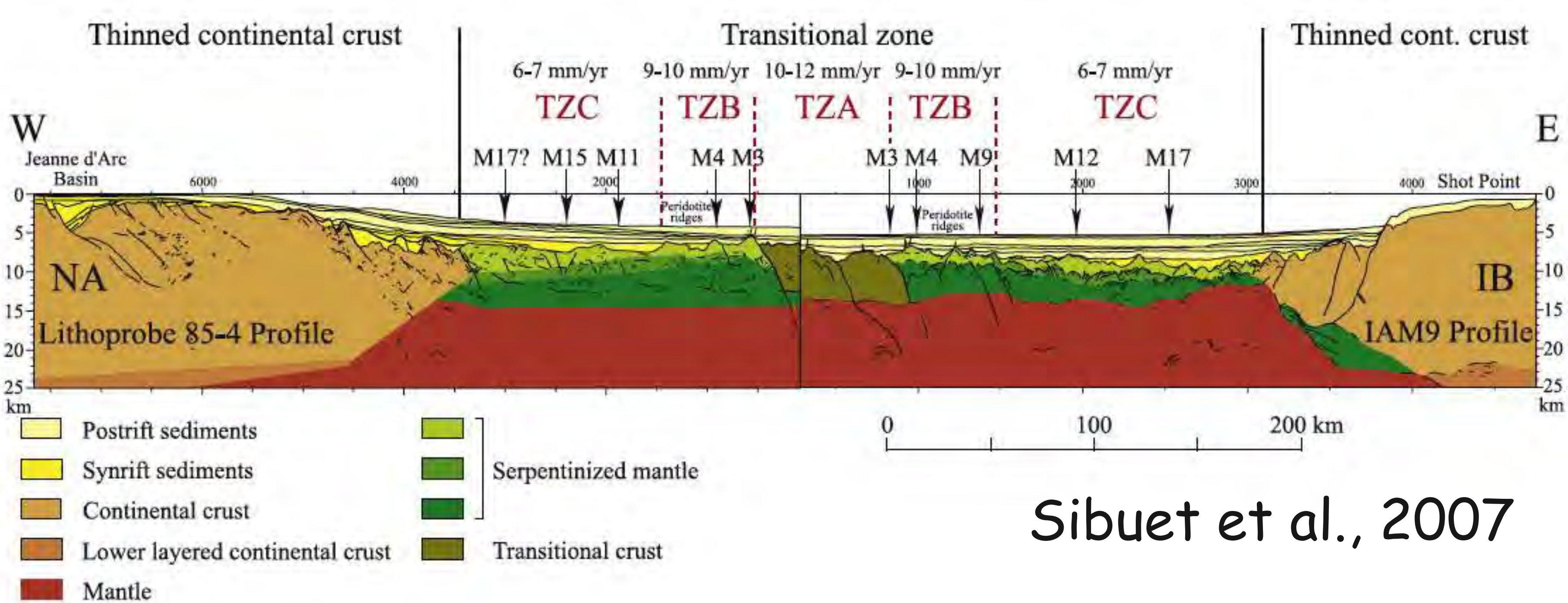
fn1
fn2
f7
f6
f5
f4
f3
f2
f1
fc
fb
fa
S
CRUST BREAKS
MANTLE EXHUMED- F7 ROTATES BACK
Old Fault fn1 rotates from 35° to 27°
23.4 km
30 km

KEY INGREDIENTS FOR MAGMA-POOR MARGIN FORMATION

1- EXTENSION VELOCITY WITHIN ULTRA-SLOW END-MEMBER

2- RATHER COOL INITIAL THERMAL PROFILE

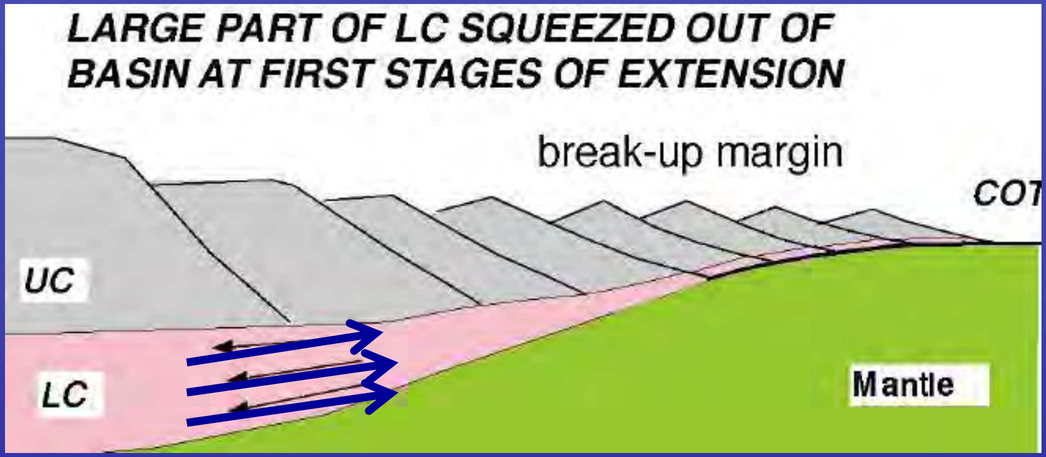
3- LOWER CRUSTAL EMBRITTLEMENT



Sibuet et al., 2007

- Large scale lower crustal flow unlikely at cold non-volcanic margins.

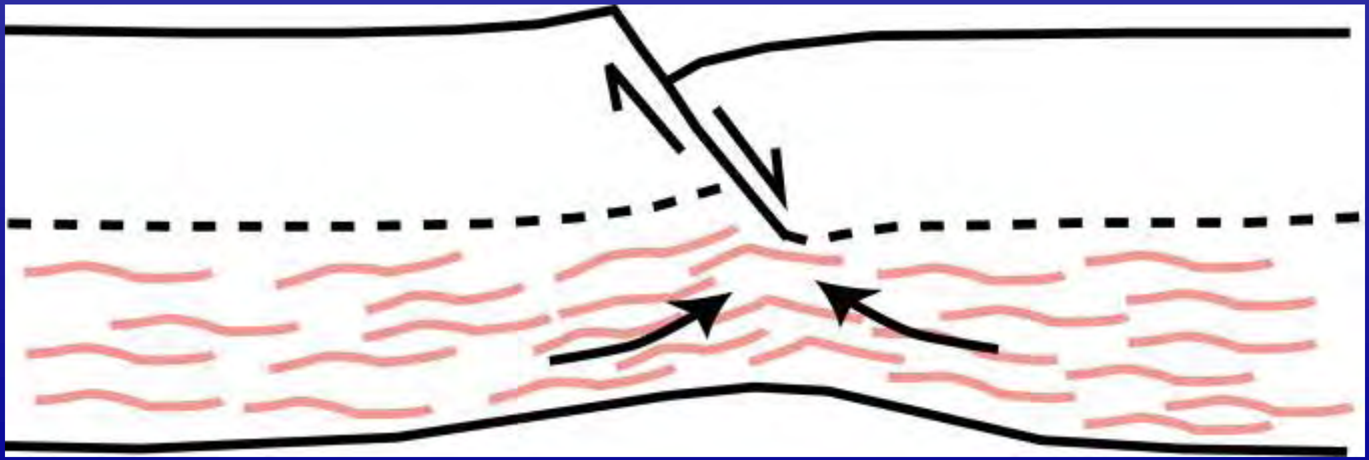
Lower crust flow out of the basin



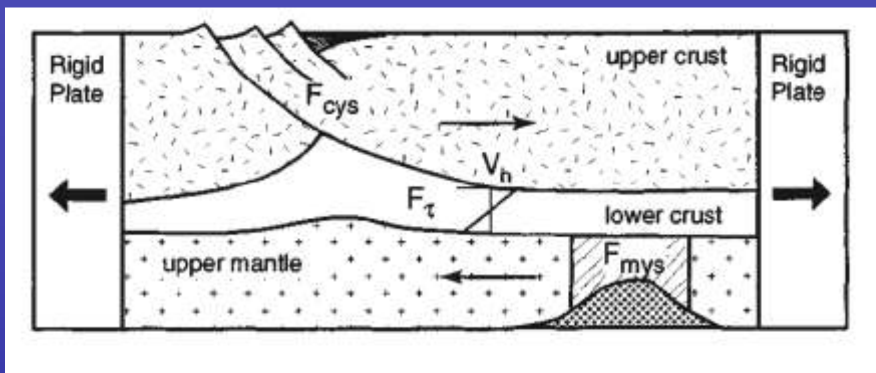
Brun & Beslier, Tectonics, 1995

Driscoll & Karner, JGR, 1998

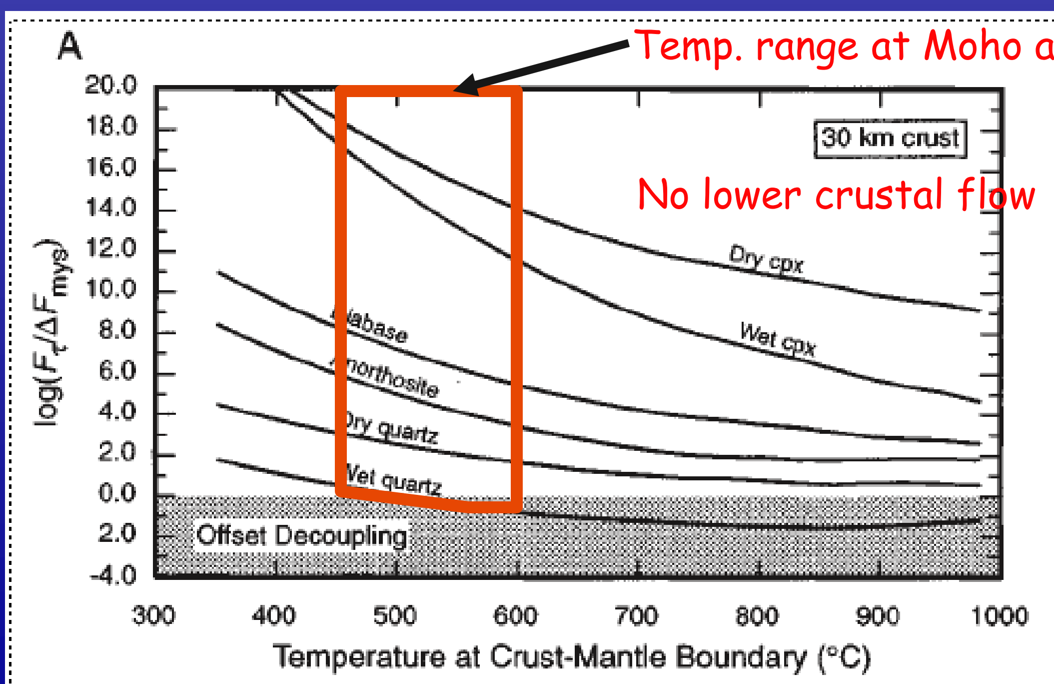
Simultaneous faulting and crustal thinning



Potential for large-scale lower crust flow?



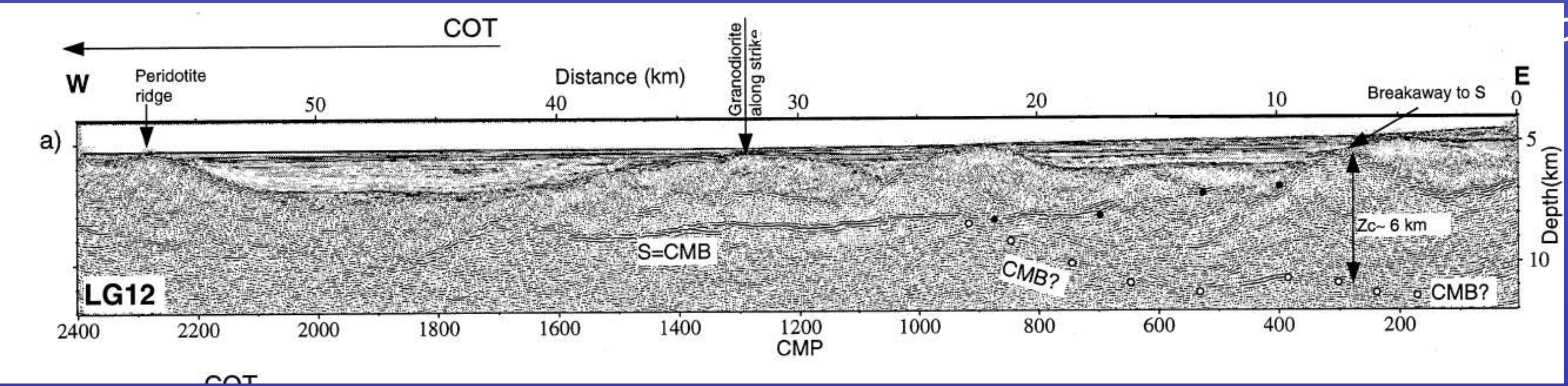
Deformation in upper crust offset from deformation in lower crust and mantle

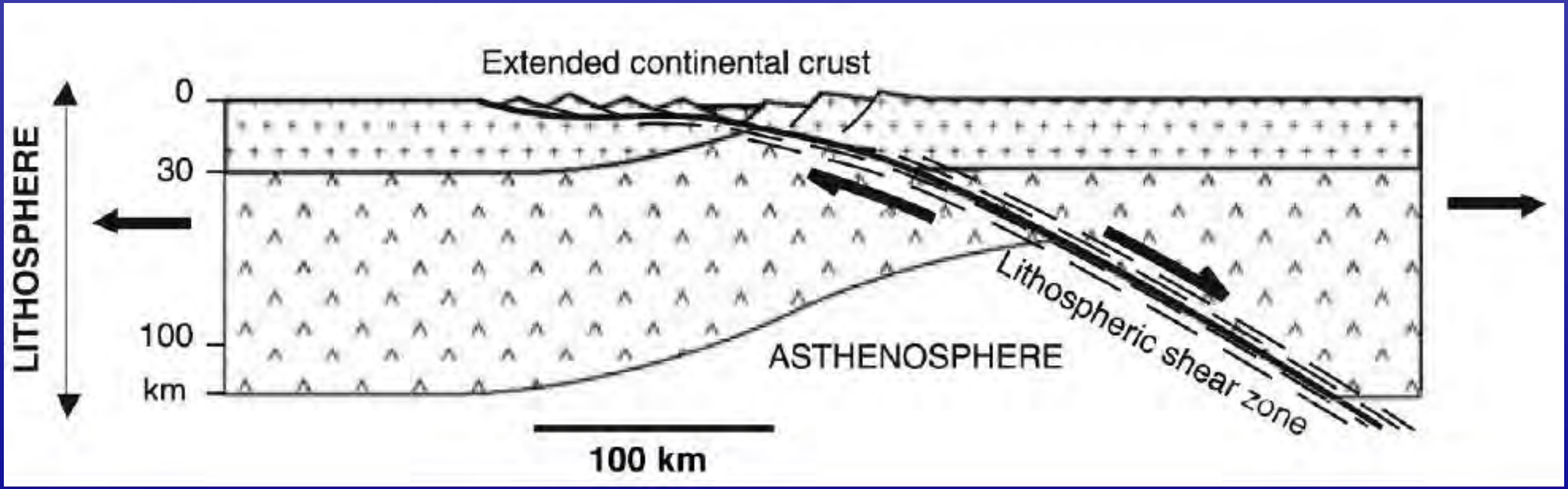


- Large scale lower crustal flow unlikely at cold NVM's (non-volcanic margins).

Hopper & Buck, Geology, 98

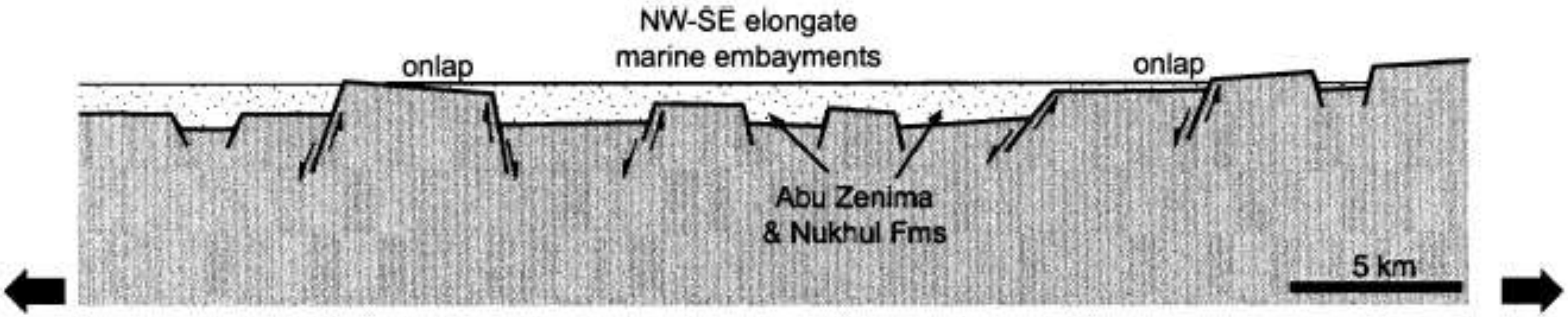
Detachment-like faults are observed when crust is < 6-10 km thick



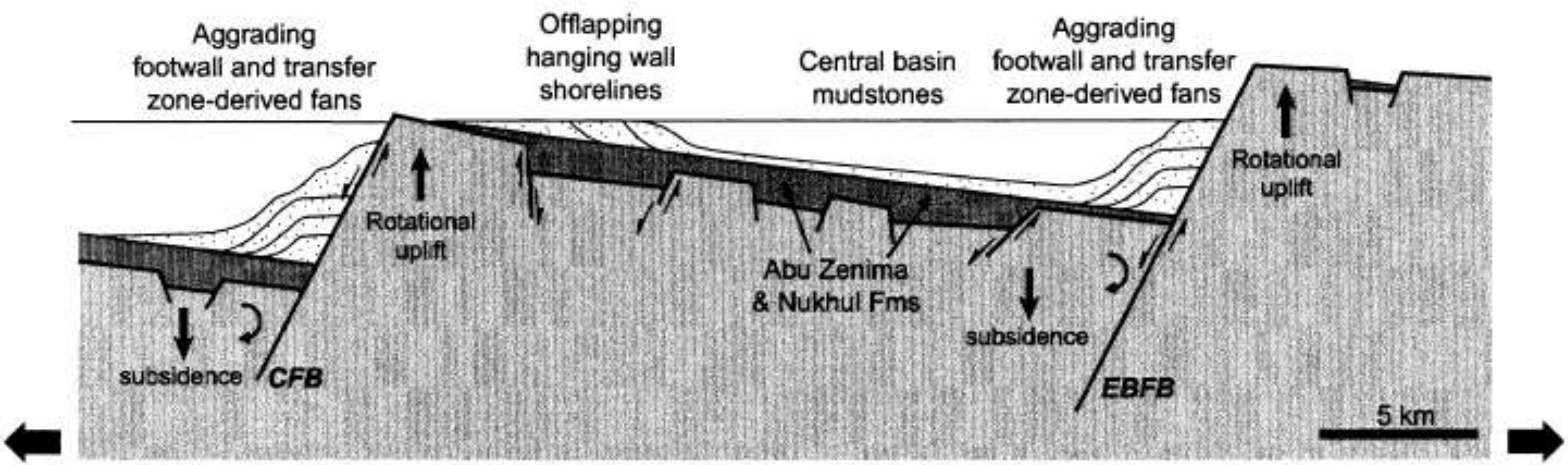


CAN NOT WORK!

Basin stage : Shoulders of rift of Suez



A) - *Rift Initiation stage - Abu Zenima & Nukhul formations - numerous closely spaced faults. Dominance of axial palaeoflow in semi-isolated fluvio-lacustrine to tidally-influenced marine embayments.*



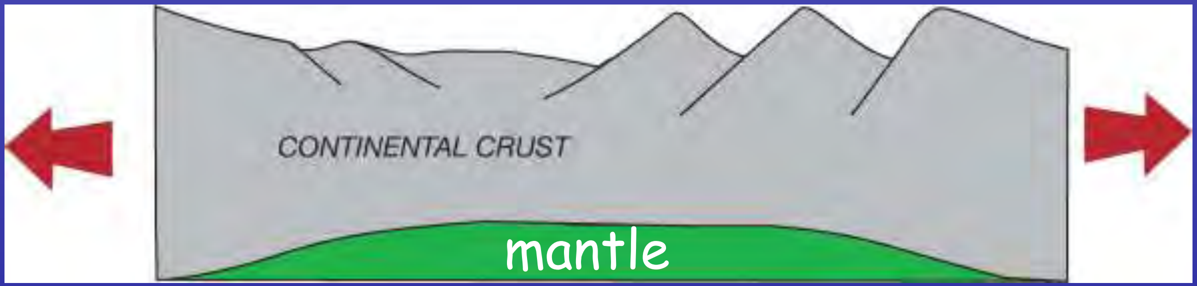
B) - *Rift climax stage - Rudeis & younger formations - regional scale mature fault block topography. Footwall derived fans and hanging wall shorelines. Transverse & axial palaeoflow.*

Sharp et al, Basin Res., 2000

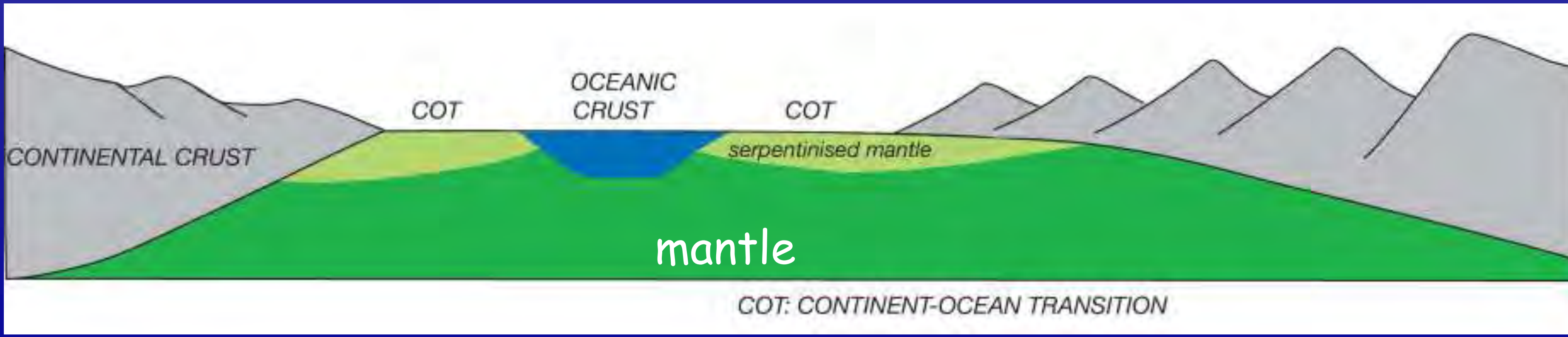
So how do basins and margins really form?

Increasing extension

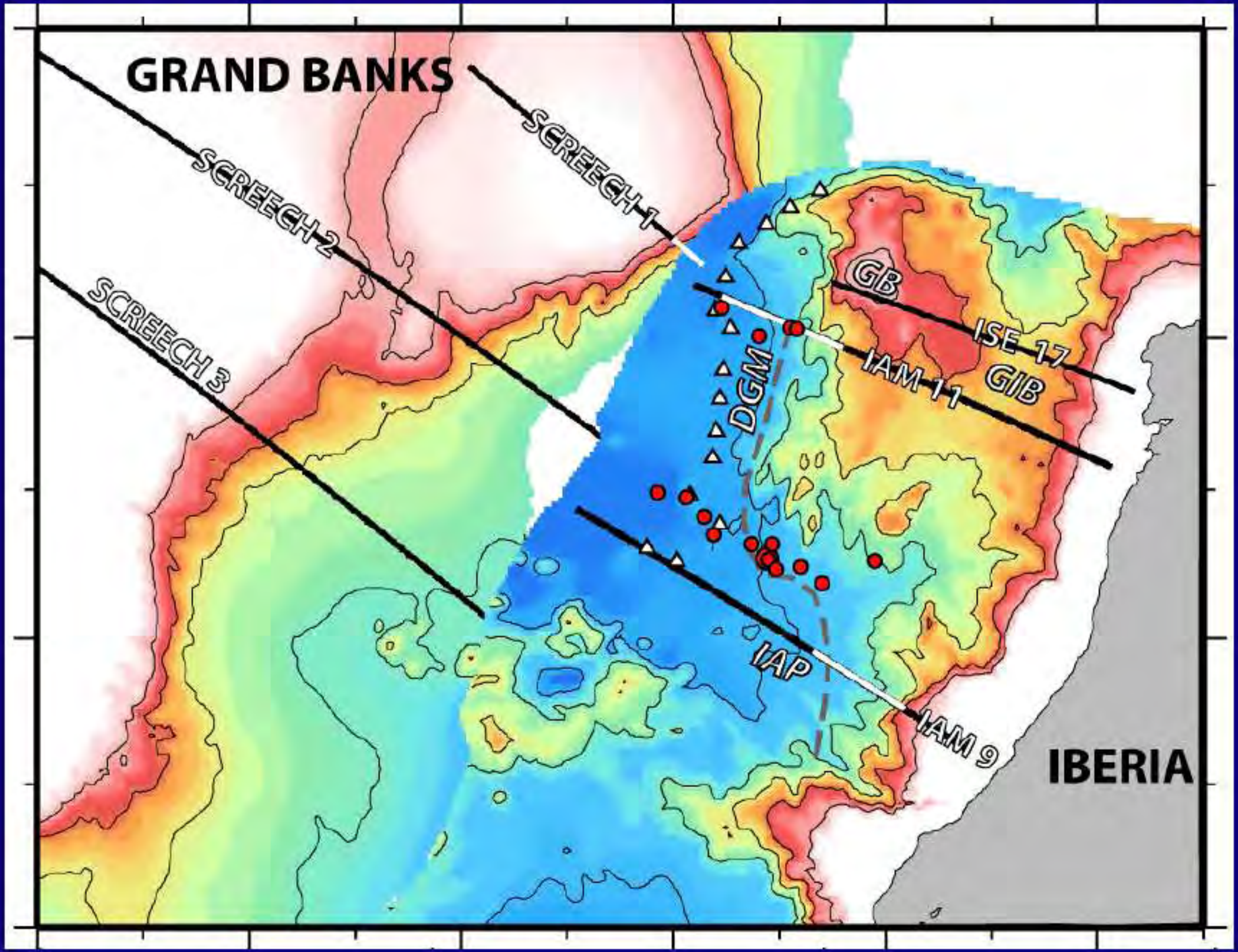
Basin stage



Margin stage



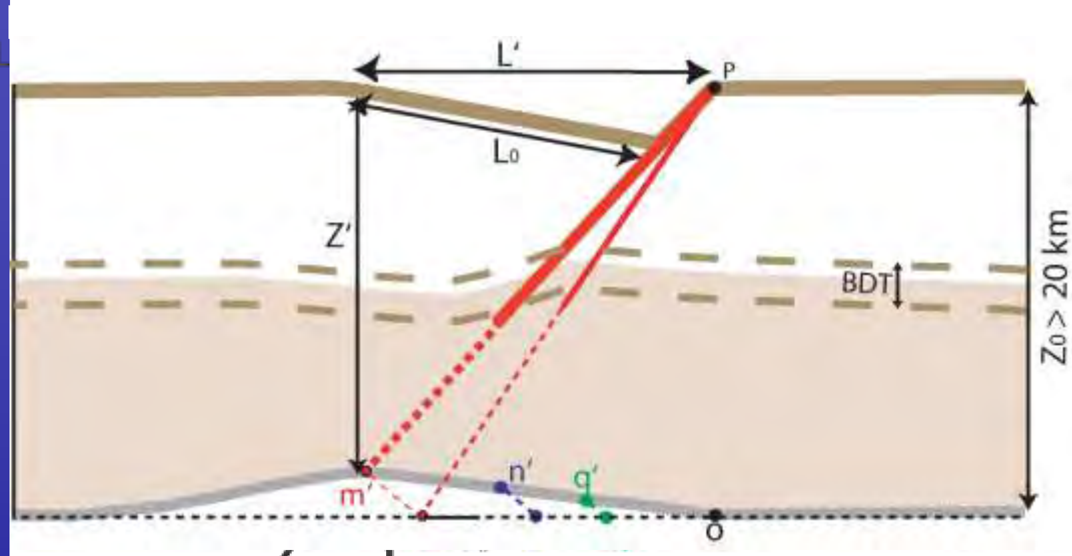
Reconstruction of Iberia-Newfoundland Margins at Anomaly M0



Ranero & Perez-Gussinye, Nature, 2011

Model rules: Basin stage

$$\beta_f = L'/L_0 = \sin\delta_0/\sin\delta' = (Z_0/r)/(Z'/r) = Z_0/Z'$$



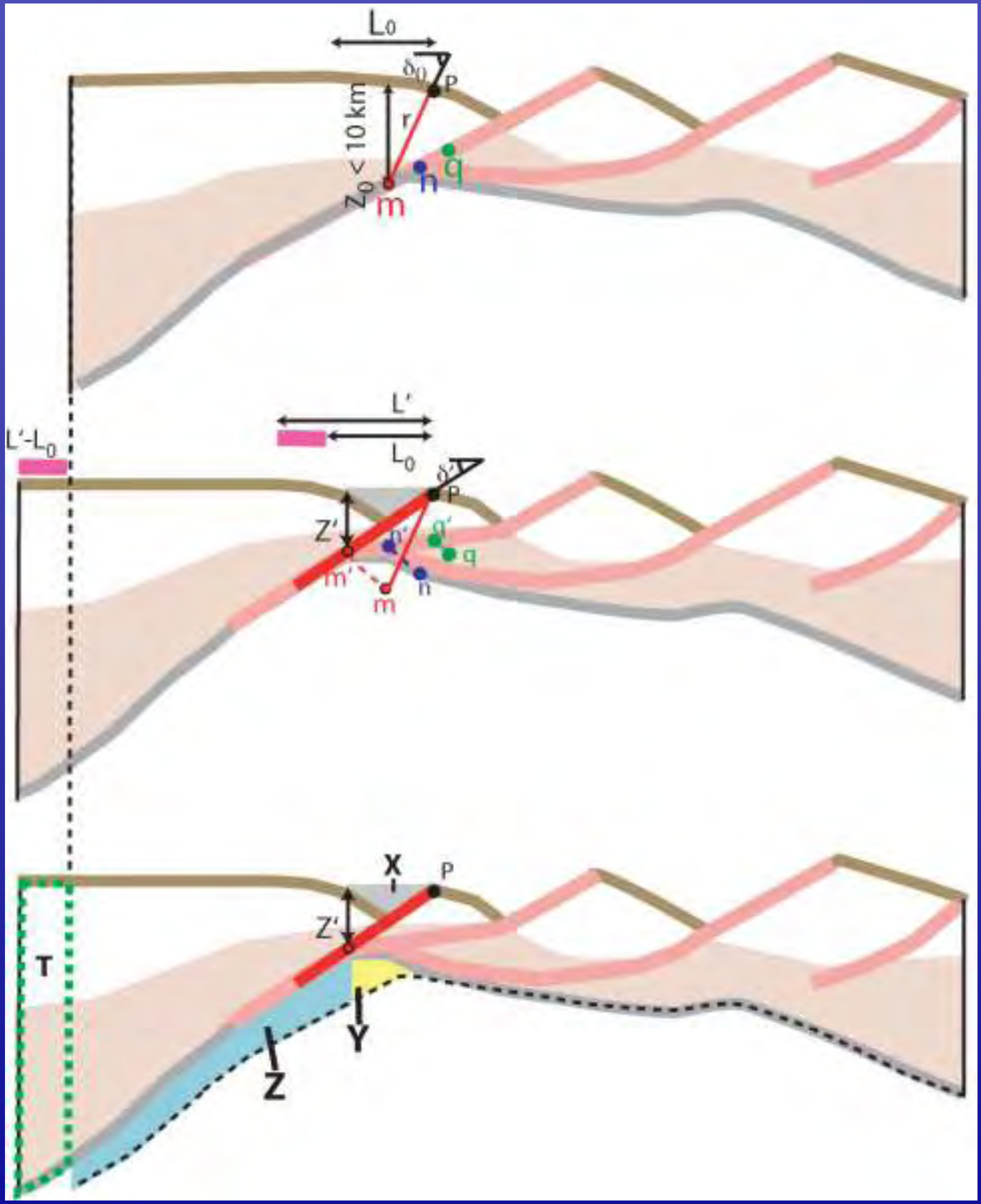
1. Upper crust brittle & lower crust ductile
2. Upper and lower crust extend by the same amount. Lower crust deforms compliant to upper crust.
3. Area conservation: X+Y+Z=T
4. A wide brittle-ductile transition.

Ranero & Perez-Gussinye, Nature, 2011

Model rules

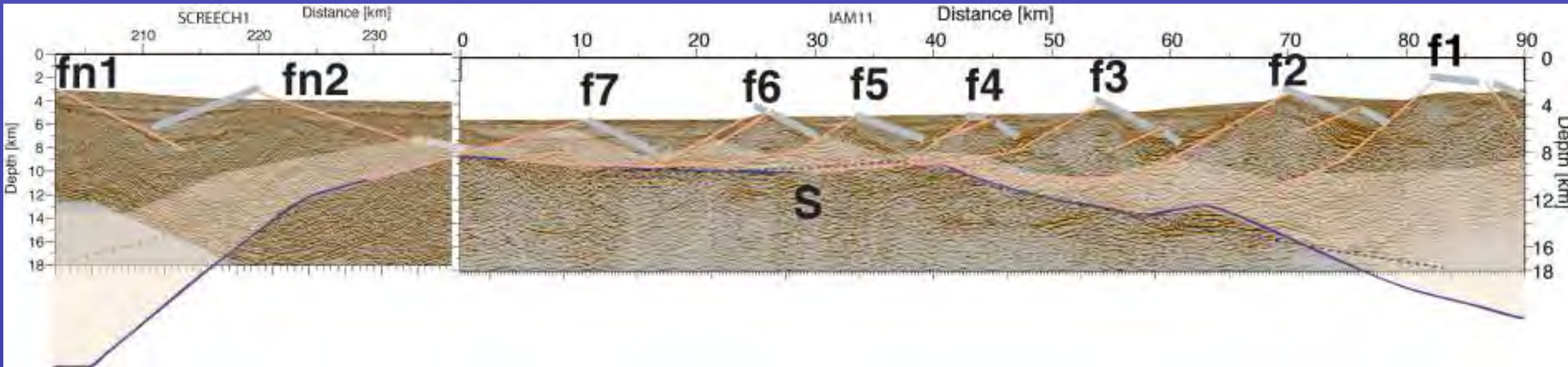
Margin stage:

- Lower crust progressively brittle!!
- Upper and lower crust extend by the same amount. Lower crust deforms compliant to upper crust.
- Area conservation: X+Y+Z=T
- Area conservation leads to back-rotation of previous planar faults.

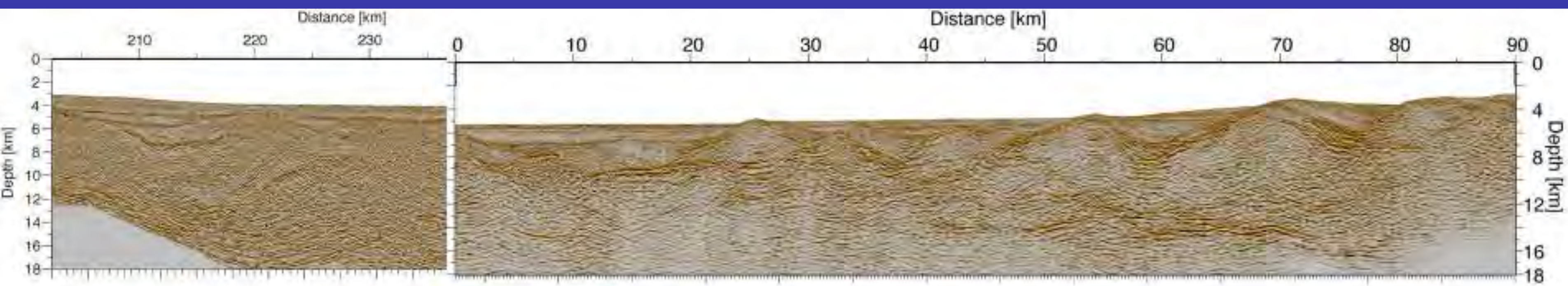


Ranero & Perez-Gussinye, Nature, 2011

Asymmetry and detachment faults?



Newfoundland West Iberia

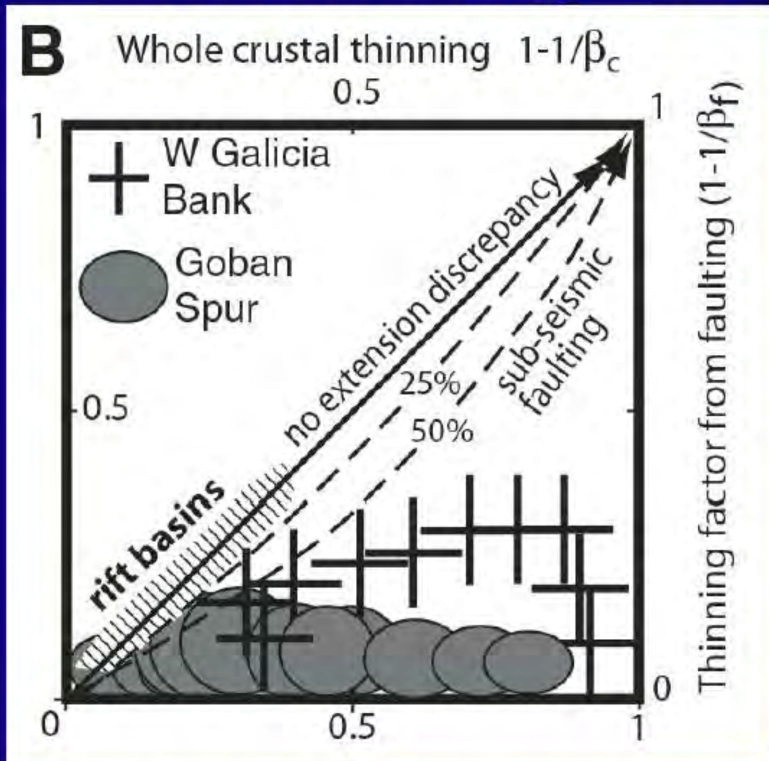


- Detachment fault, S, not active at low angle. It results from an array of sequential normal faults active at ~60°-~30°.
- Asymmetry is the result of the dominant oceanward dip of the sequential fault array.

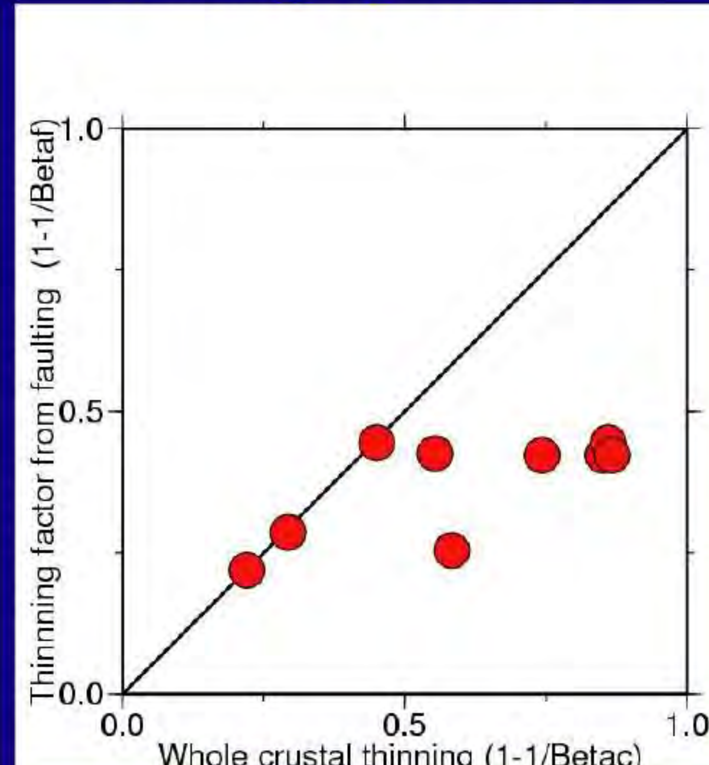
Ranero & Perez-Gussinye, Nature, 2011

Extension Discrepancy?

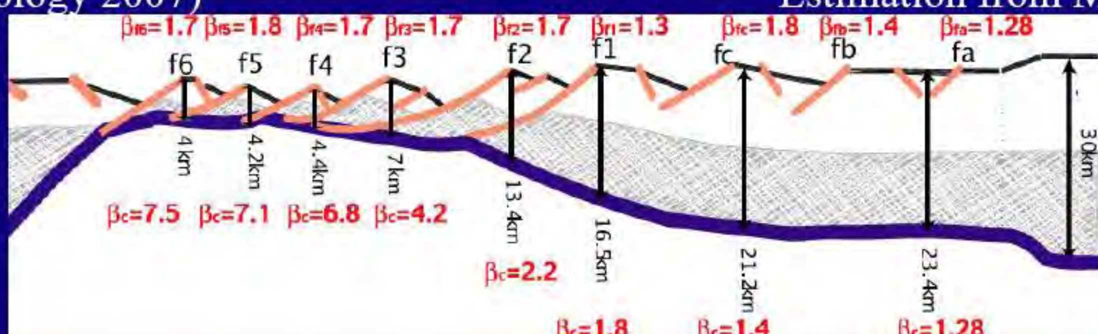
Crustal Thinning Versus Thinning by Faults



Reston (Geology 2007)



Estimation from Model

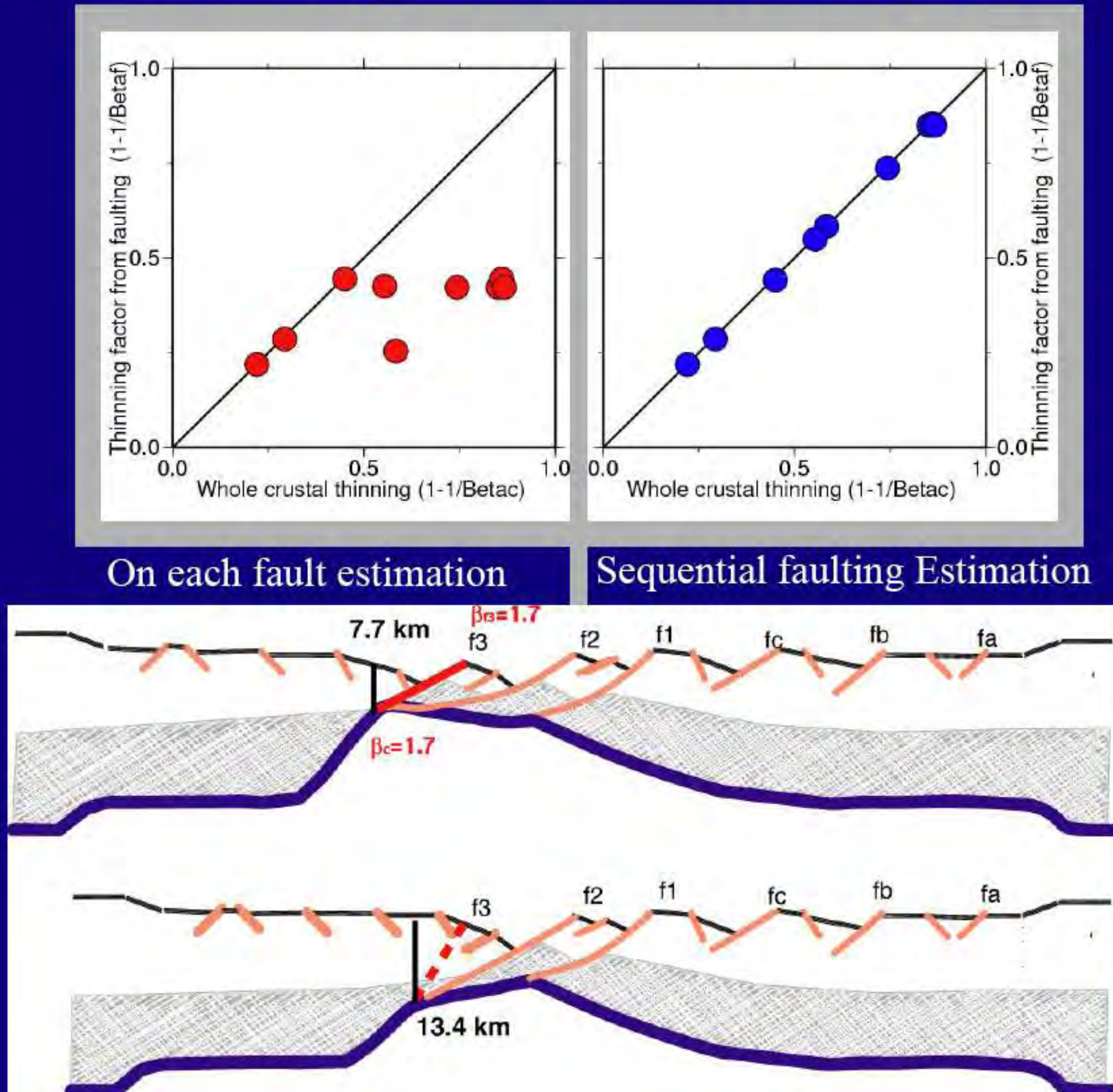


ß estimated for each fault from an originally 30 km thick crust

Ranero & Perez-Gussinye, Nature, 2011

Extension Discrepancy?

Crustal Thinning Versus Thinning by Faults



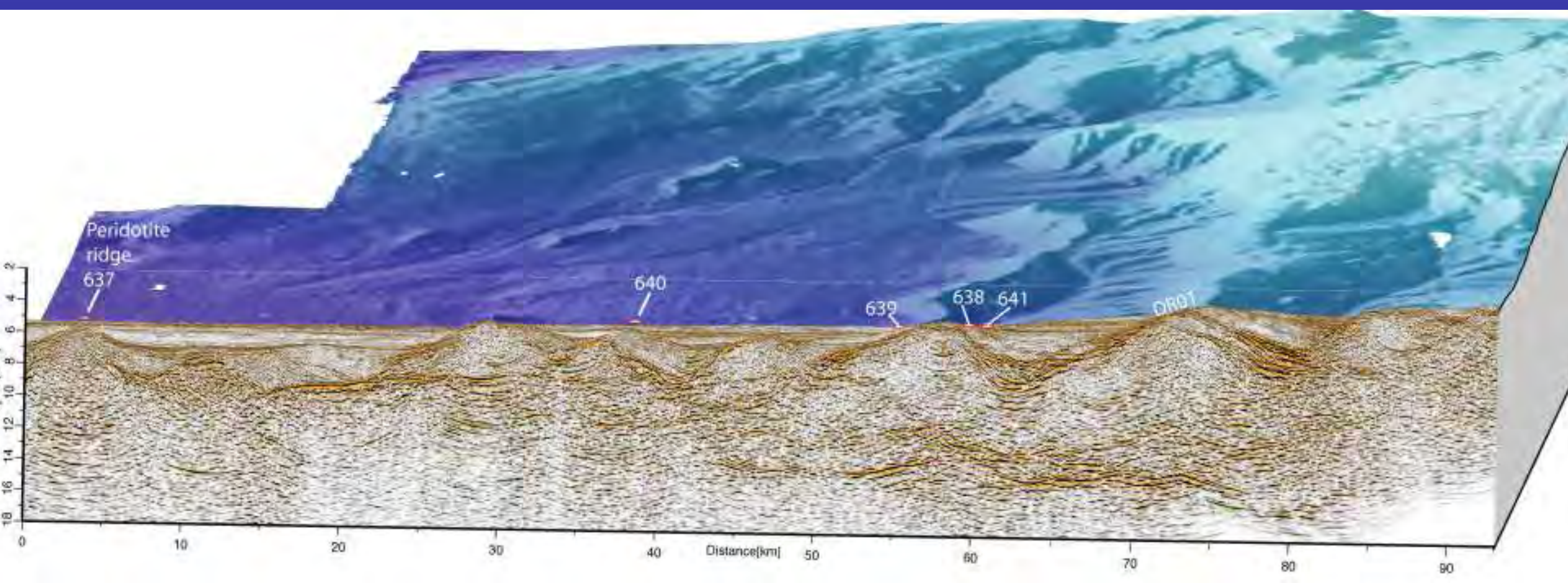
ß estimated for each fault taking into account that crust in a block is the result of thinning by several faults.

Ranero & Perez-Gussinye, Nature, 2010

Progress

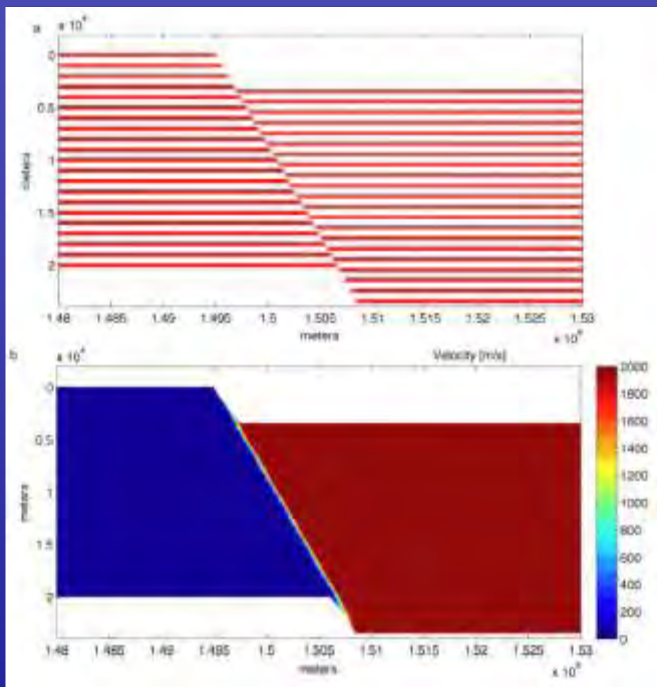
- Built the kinematic model for description of faults.
- Building a kinematic/dynamic model for self-consistent description of faulting, lower crustal flow, heat flow and subsidence prediction.
- Progress on interpretation and process oriented gravity modelling for estimation of subsidence and callibration against numerical model.

Understanding tectonic structure, heat-flow, subsidence and sedimentation patterns at magma-poor margins

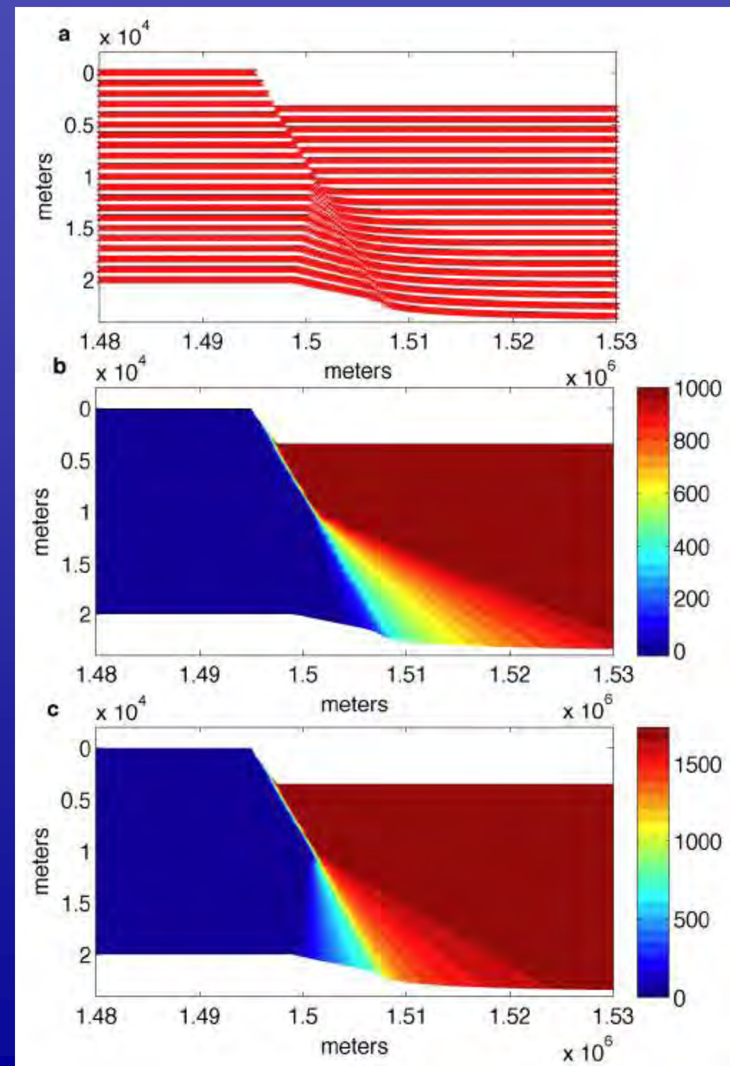


Kinematic model
Deformation: brittle & ductile layers

Brittle

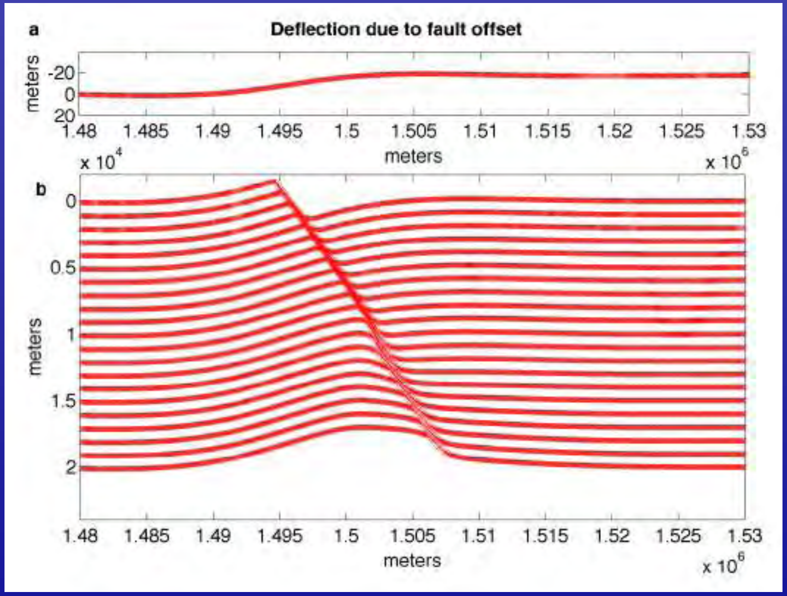


Ductile

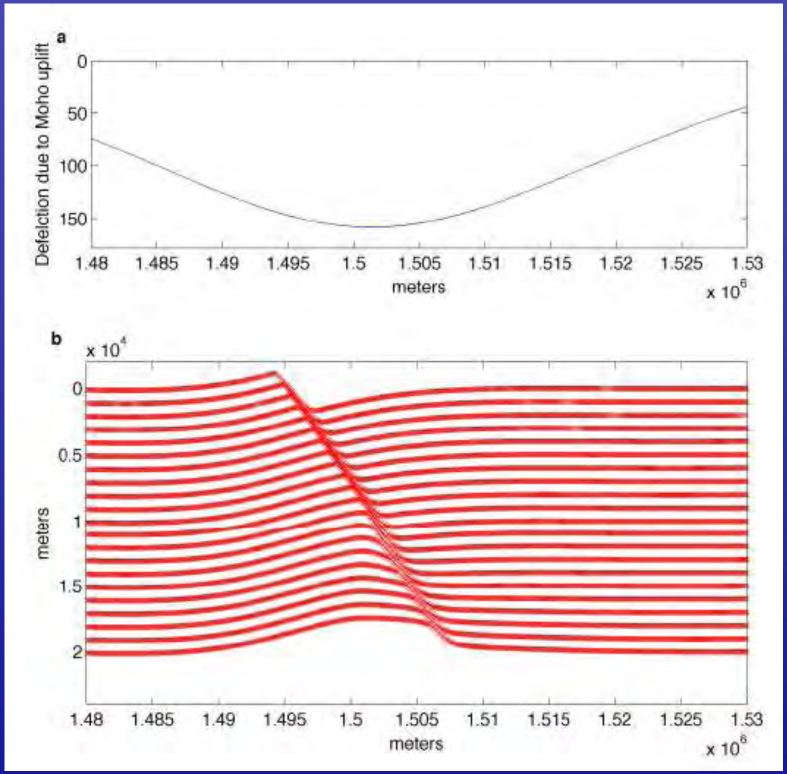


Deformation: Flexure

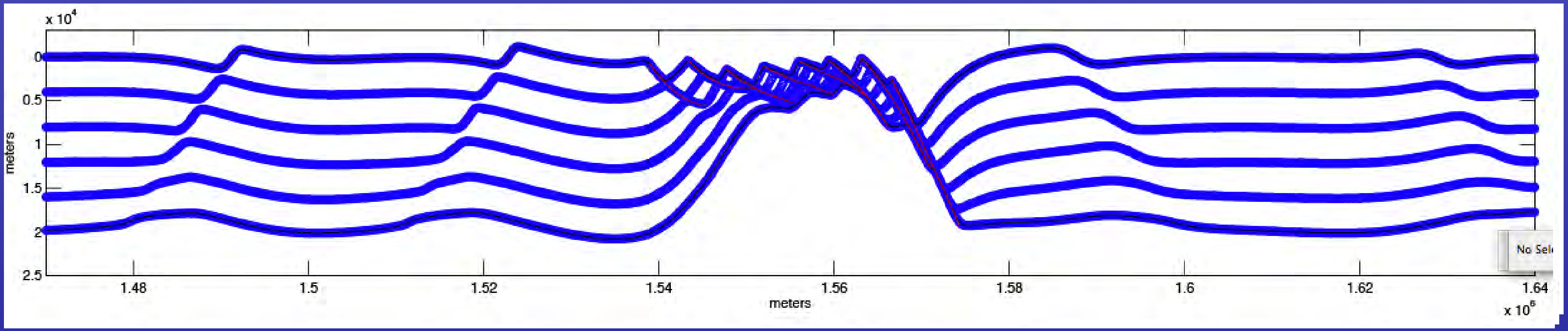
Flexure due to fault offset



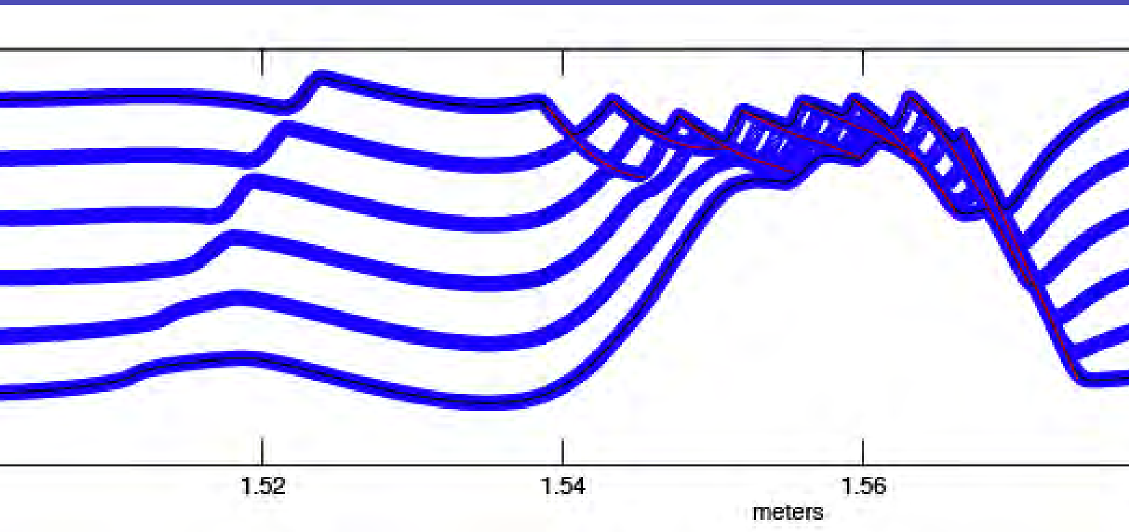
Flexure due to Moho uplift

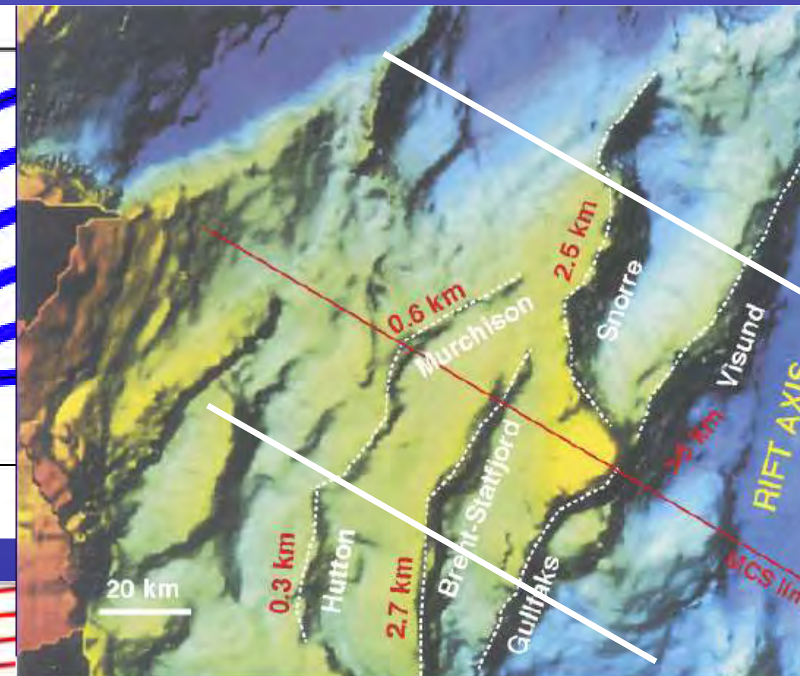


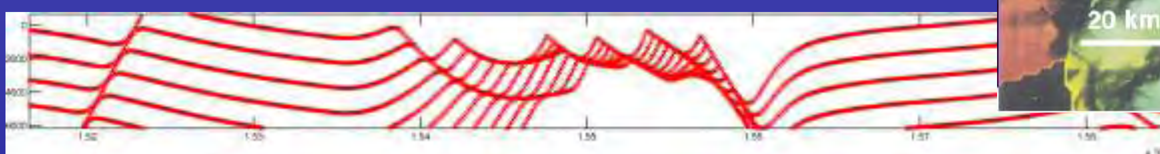
Kinematic model evolution

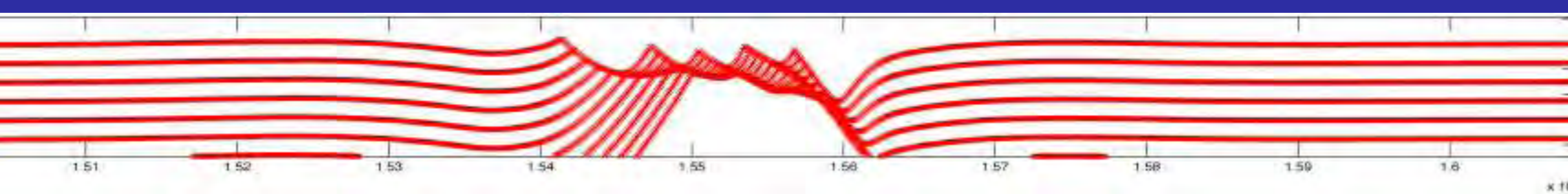


Change in 'detachment' geometry in 3D

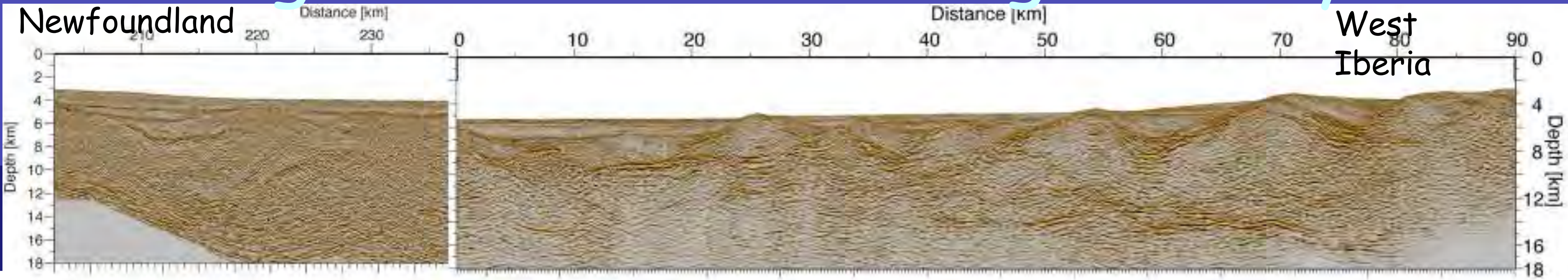


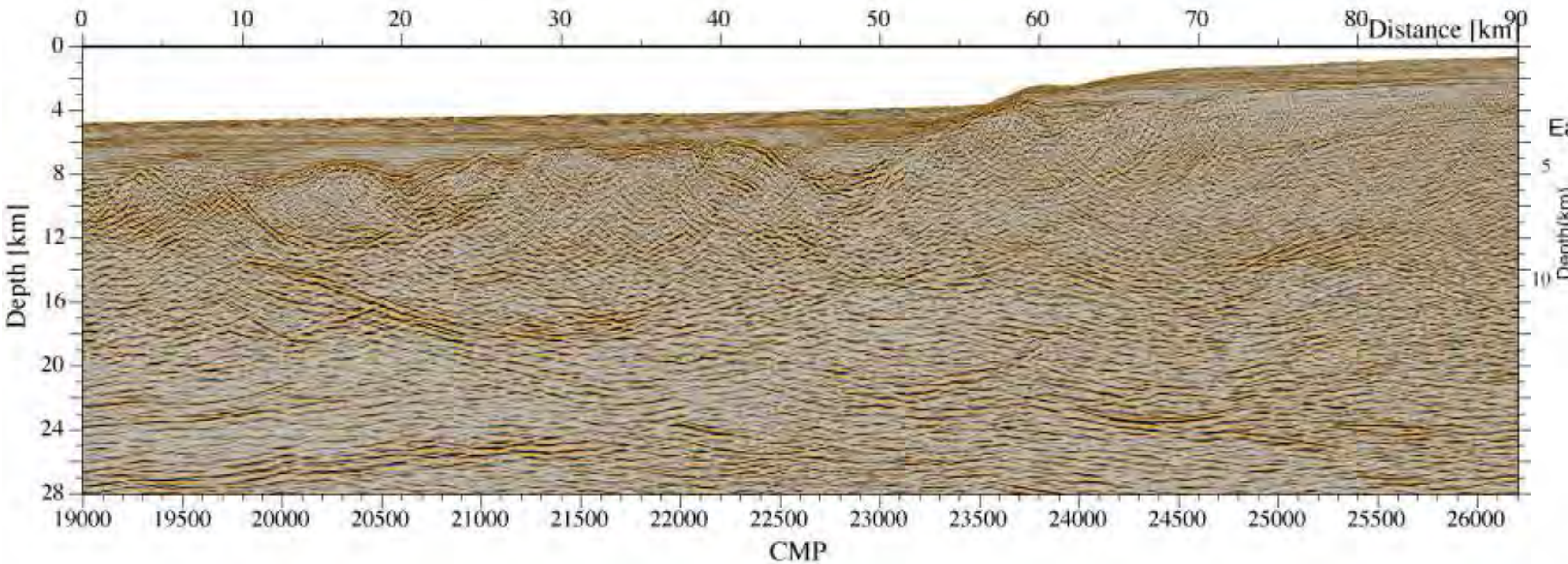


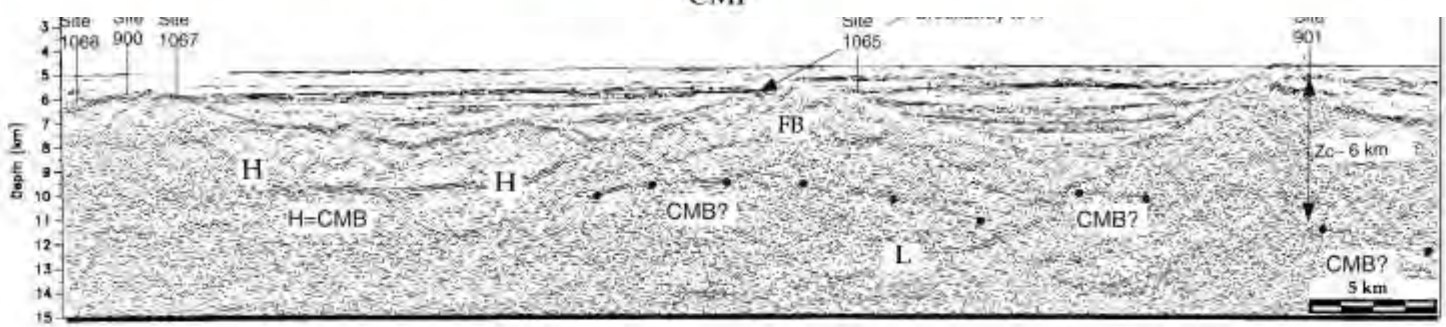




Change in ‘detachment’ geometry in 3D







Progress since August

- More realistic ductile deformation field for lower crust and mantle lithosphere.
- Estimation of temperature field and subsidence.

↓

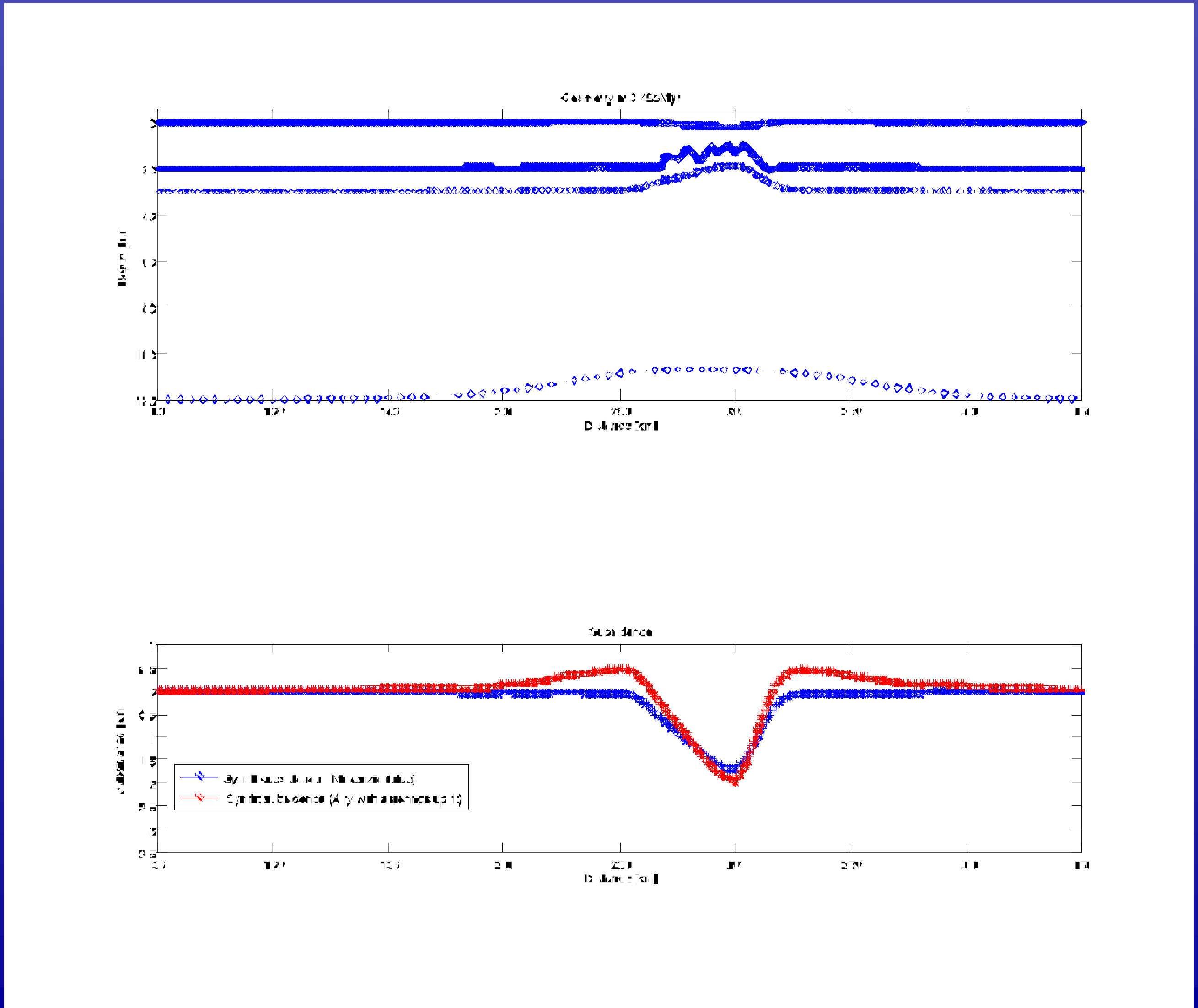
Kinematic model for upper crustal faulting with a dynamic model for lower crust and mantle deformation

Progress since November

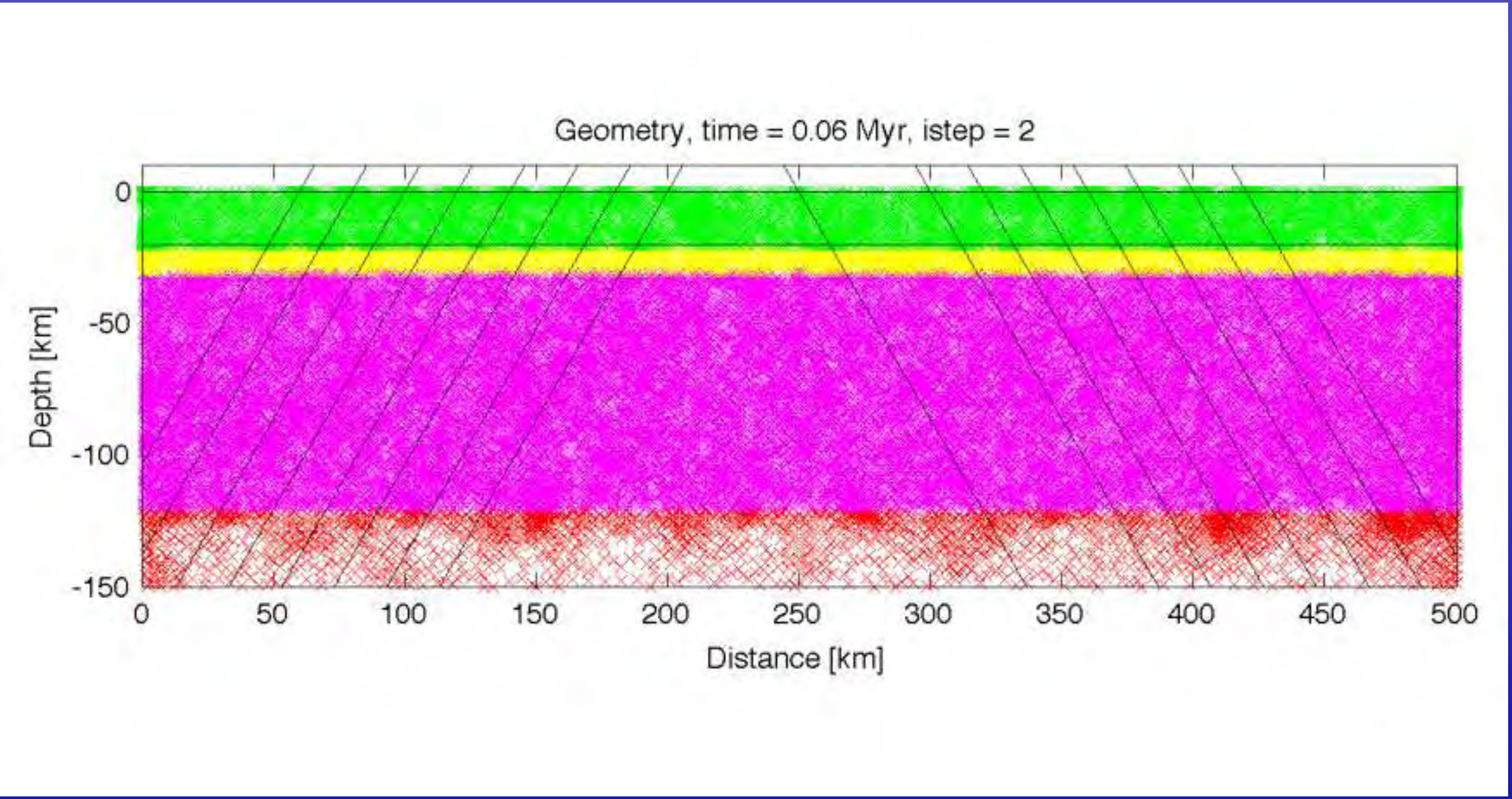
- Solved problems: Boundary conditions, remeshing for very high extension factors.
- Included non-newtonian viscosities.
- Obtained a more realistic description of subsidence
- Implemented first phase of sedimentation modelling.

Subsidence

Flexure due to fault offset given by kinematic model.
Flexure due to Moho thinning as given by dynamic model
Flexure due to asthenospheric uplift as given by dynamic model



High extension velocity 8 mm/yr strong lower crustal rheology



Effective thinning of crust due to sequential faulting and symmetric temperature field

To do in kinematic + dynamic model

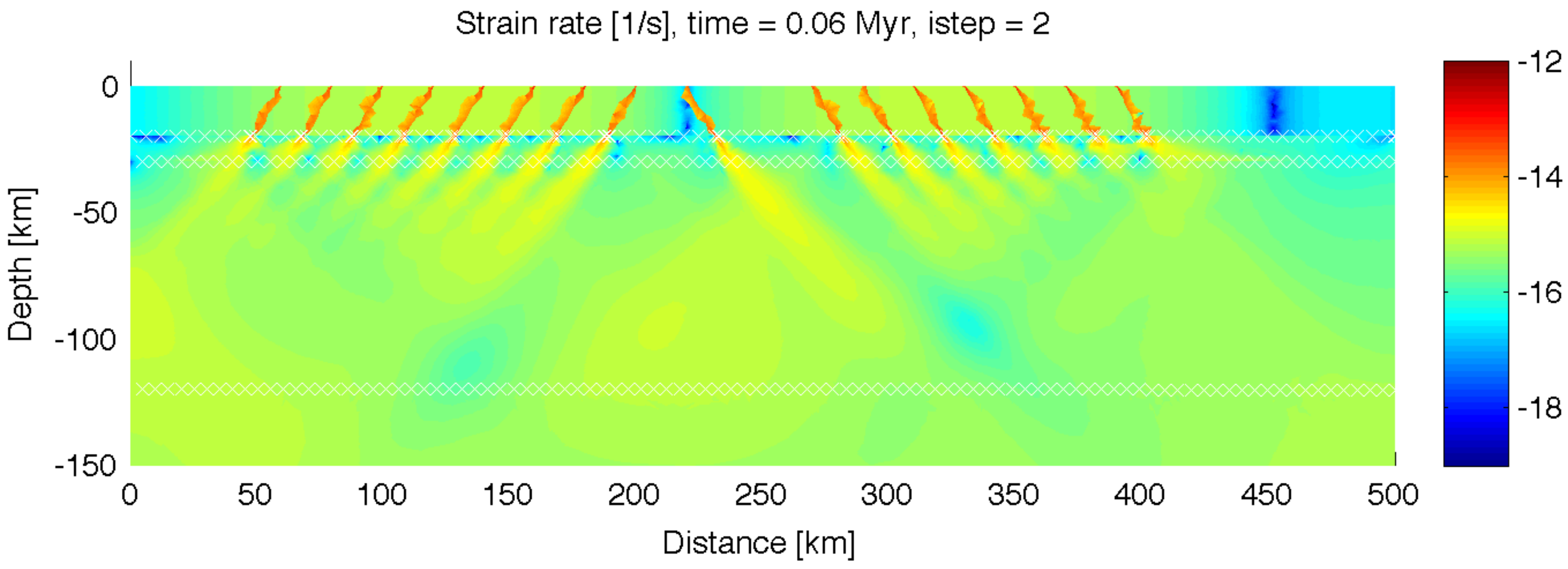
- Introduce more up-to-date constants, e.g. activation energies etc for rheologies.

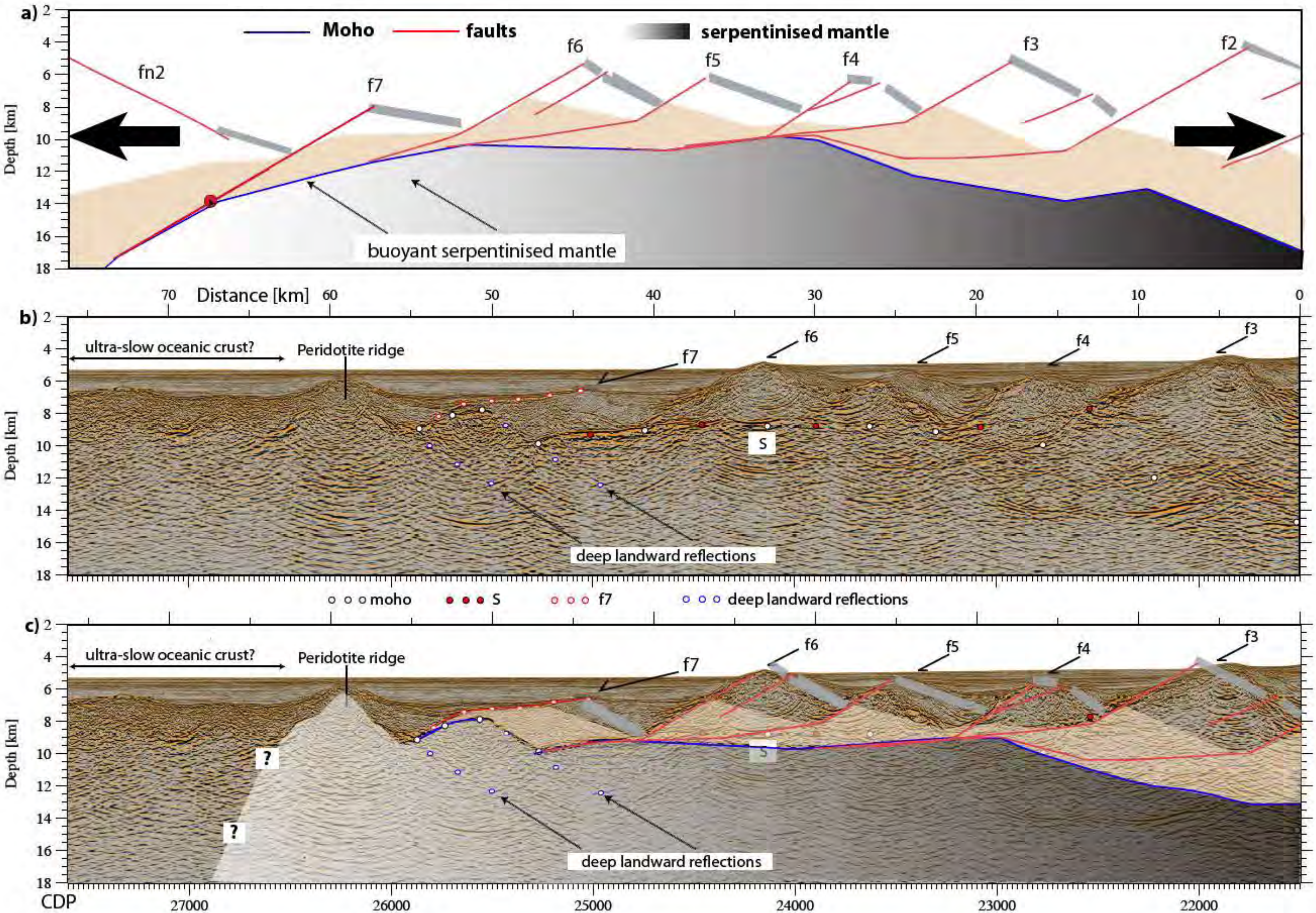
- Further analyse effect of velocity.

Future work:

- Fault sediment packages (Couple sediment to kinematic grid doing faulting).
- Introduce flexural rebound for erosion.
- Analyze best way to produce syn-rift wedges.
- Compare with estimations of subidence in West Iberia (Tiago's work).

Slow extension velocity 4 mm/yr strong lower crustal rheology





a)
Moho
faults
serpentinised mantle
fn2
f7
f6
f5
f4
f3
f2
buoyant serpentinised mantle
Depth [km]
Distance [km]
b)
ultra-slow oceanic crust?
Peridotite ridge
S
deep landward reflections
moho
S
f7
deep landward reflections
c)
?
CDP

A NEW CONCEPTUAL MODEL

Motivation:

1- Lower crust is too cold to flow long distances at the start of rifting.

2- Lower crust is brittle during the last stages of rifting.

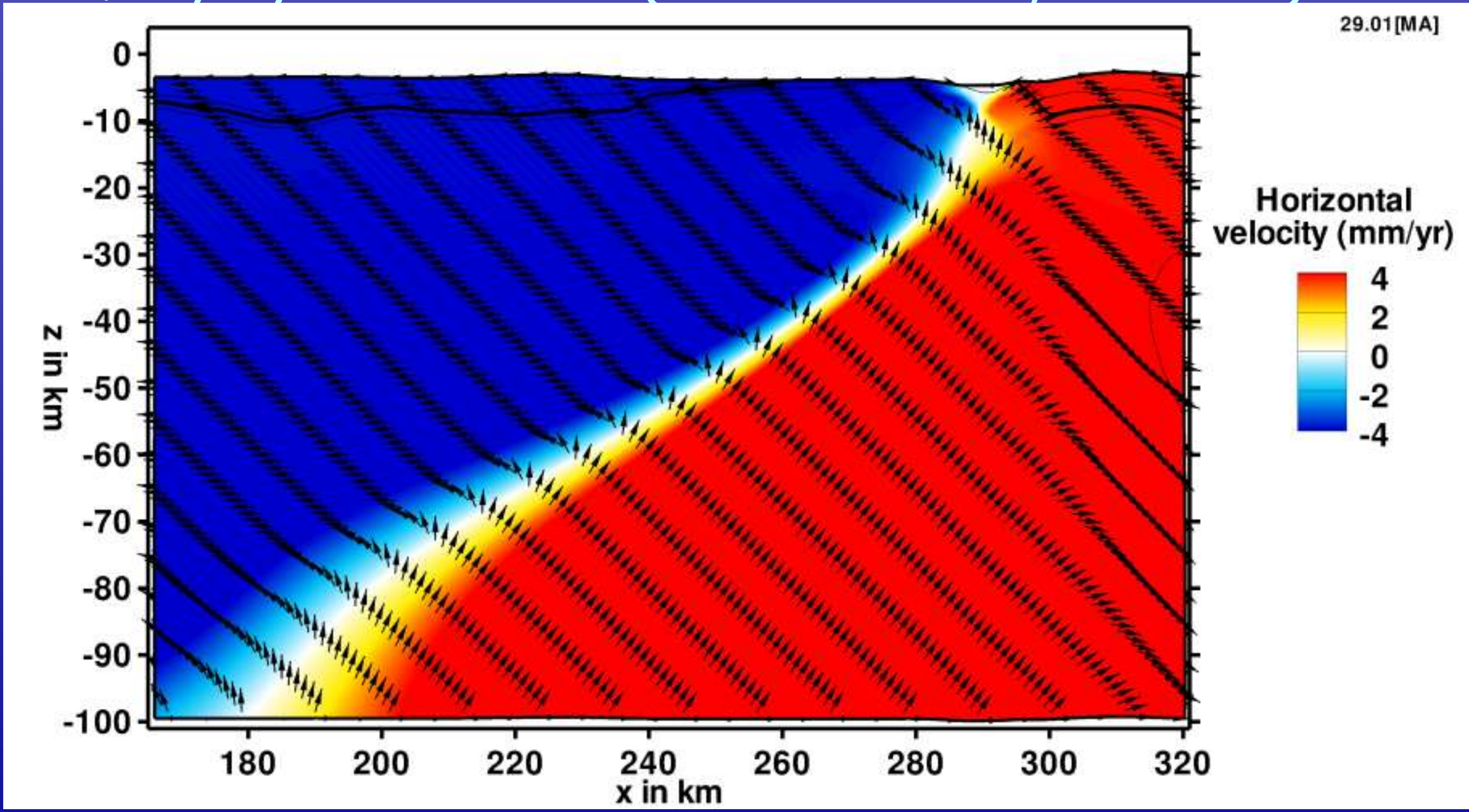
3- Larger faults at margins have well-defined pre-rift and synrift strata.

4- Detachment-like faults only imaged when the crust is very thin > 6 km. Can therefore not explain larger-scale asymmetry.

Progress

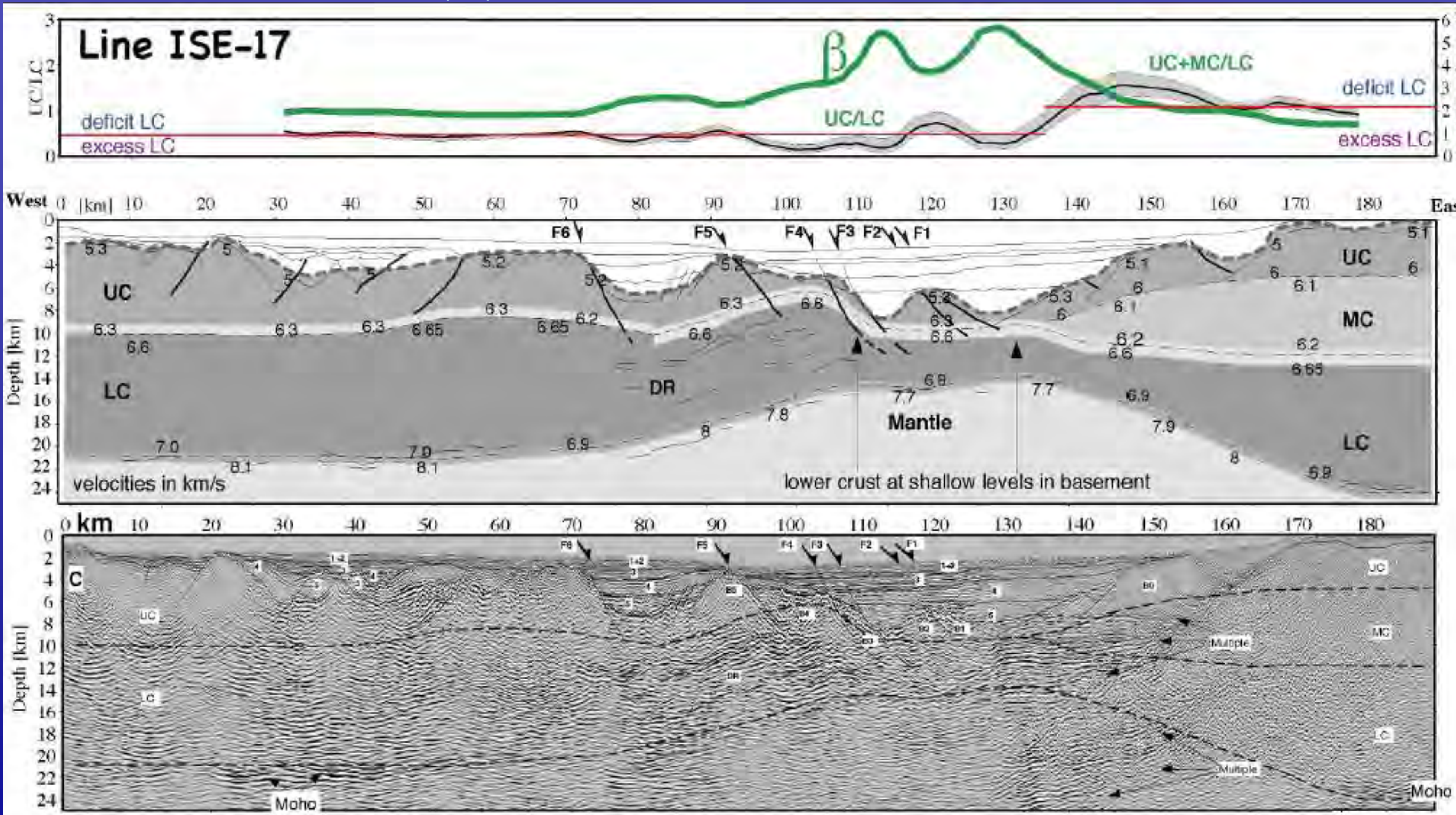
- Built the kinematic model for description of faults.
- Built a kinematic/dynamic model for self-consistent description of faulting, lower crustal flow, heat flow and subsidence prediction.
- Building the sedimentation geometries produced by model.
- Progress on interpretation and process oriented gravity modelling for estimation of subsidence and callibration against numerical model.

Slow extension velocity 4 mm/yr, strong mafic granulite lower crust fully dynamic model (Sascha Brune, Potsdam)



Brune, Heine, Perez-Gussinye, Sobolev, in prep.

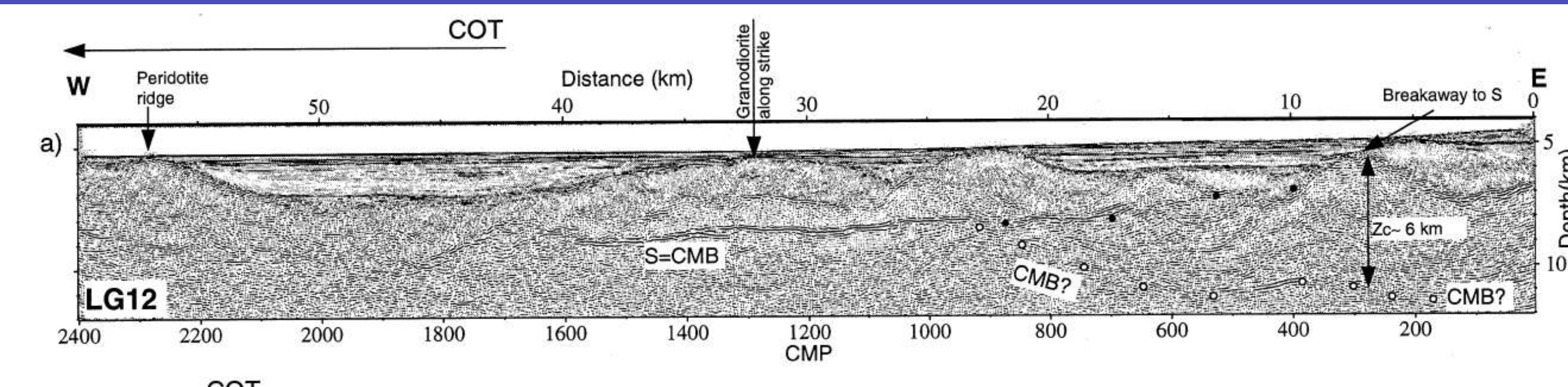
No large-scale differential thinning of upper and lower crust

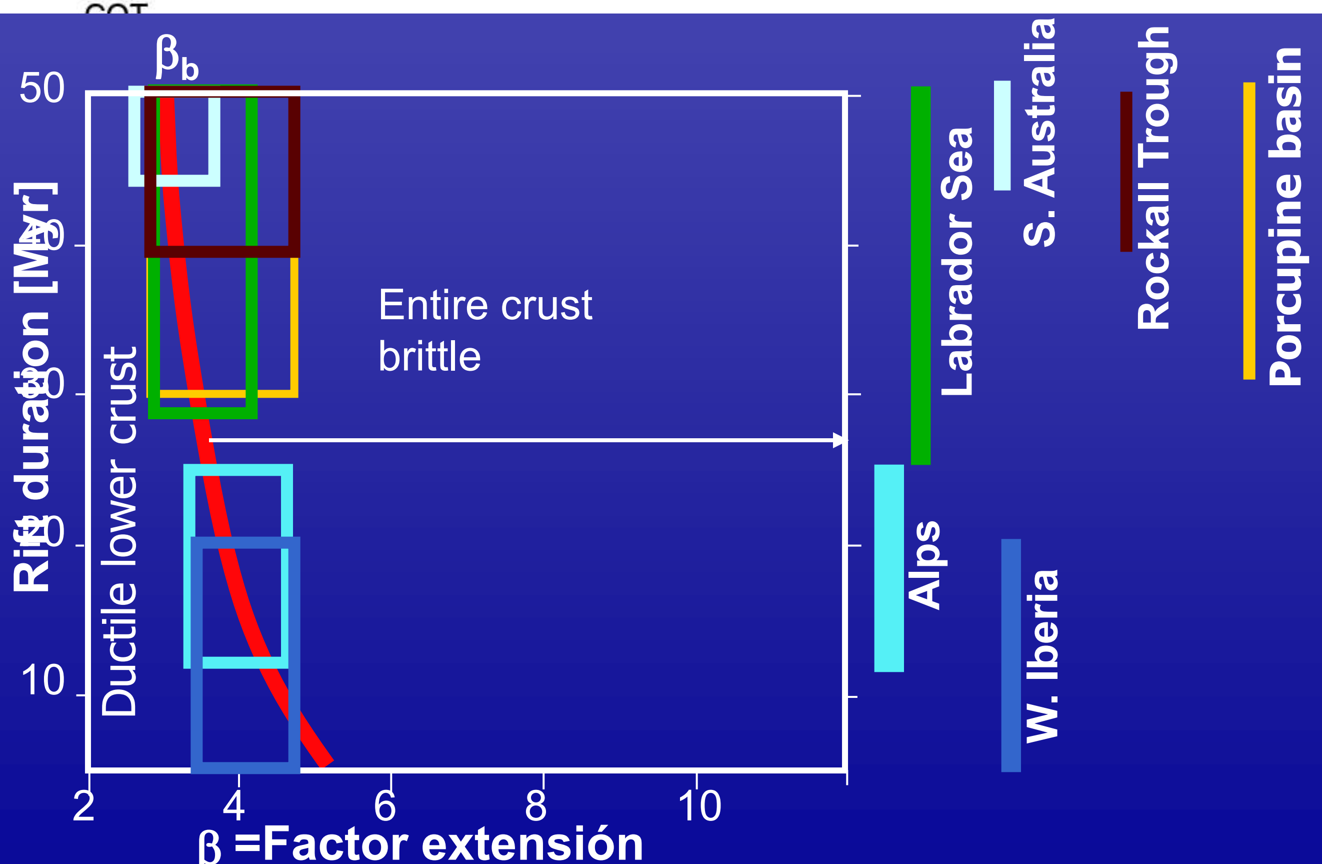


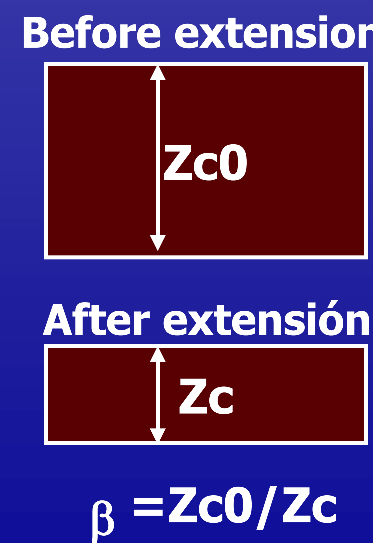
Galicia Interior Basin

Perez-Gussinye et al., JGR, 2003

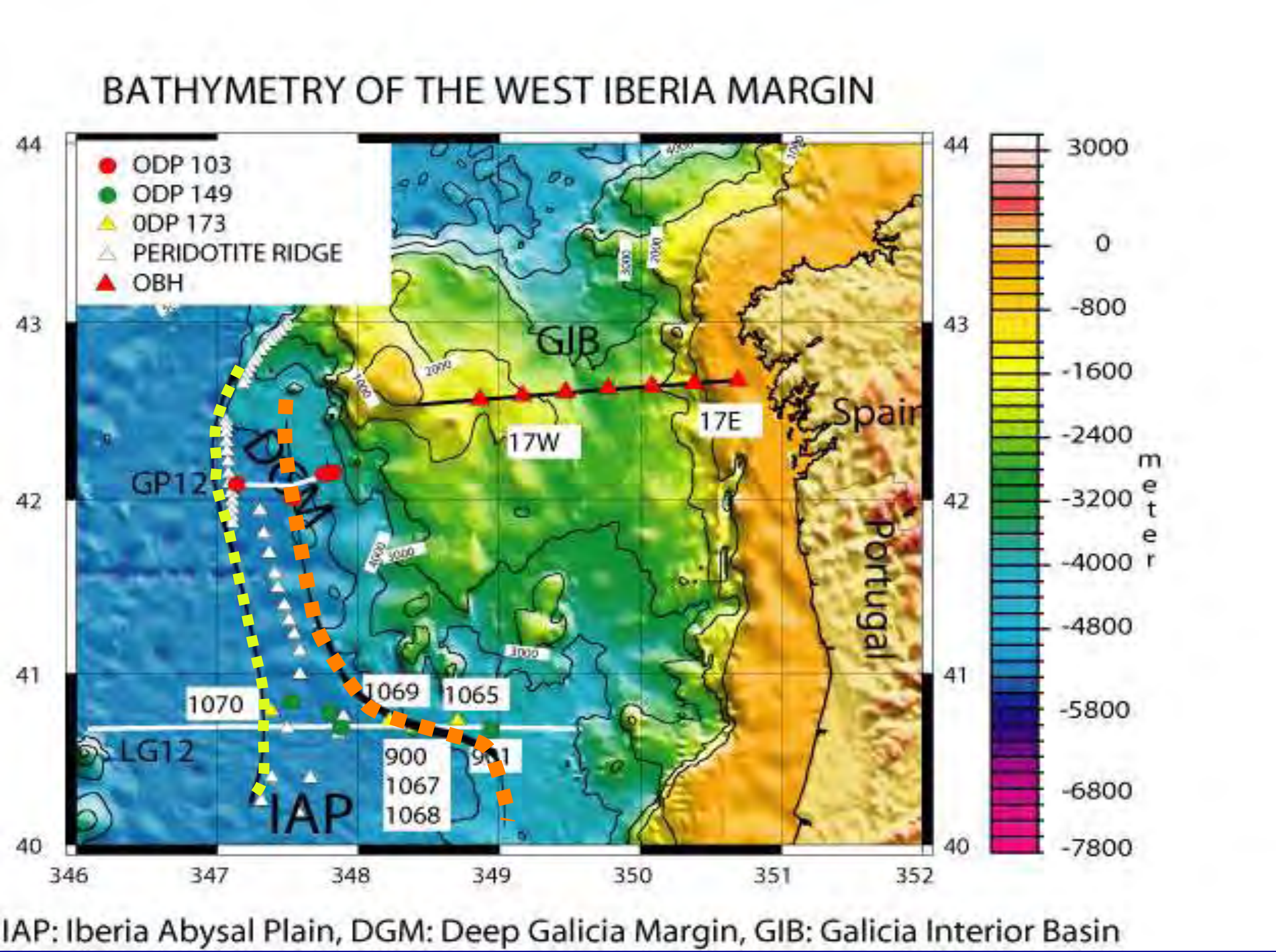
Lower crustal embrittlement at NVRMs, when?







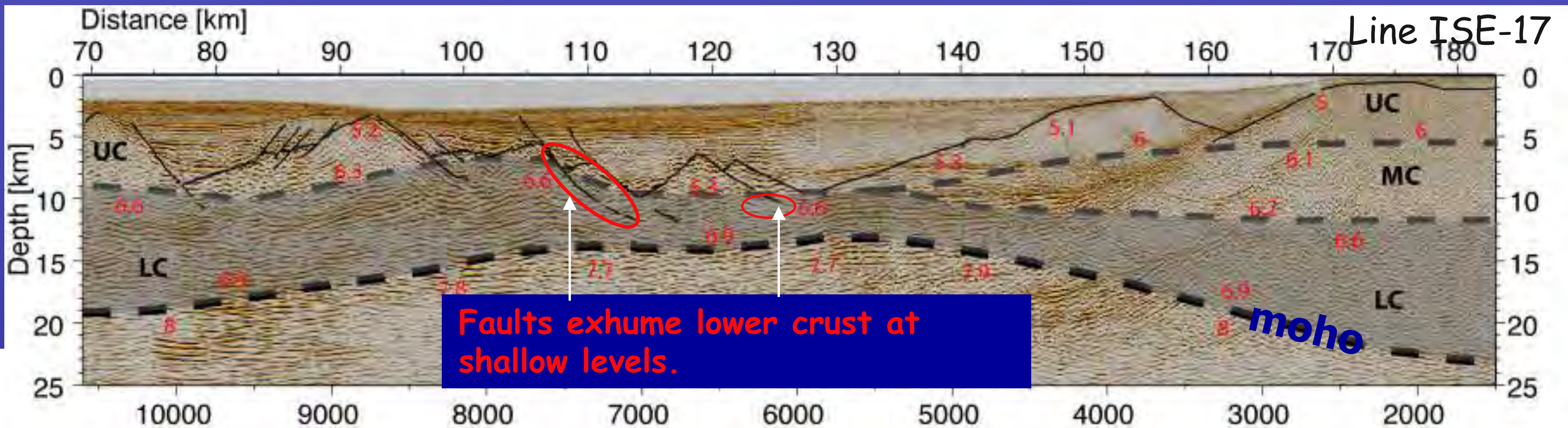
Evidence for lower crustal embrittlement: The Galicia Interior basin



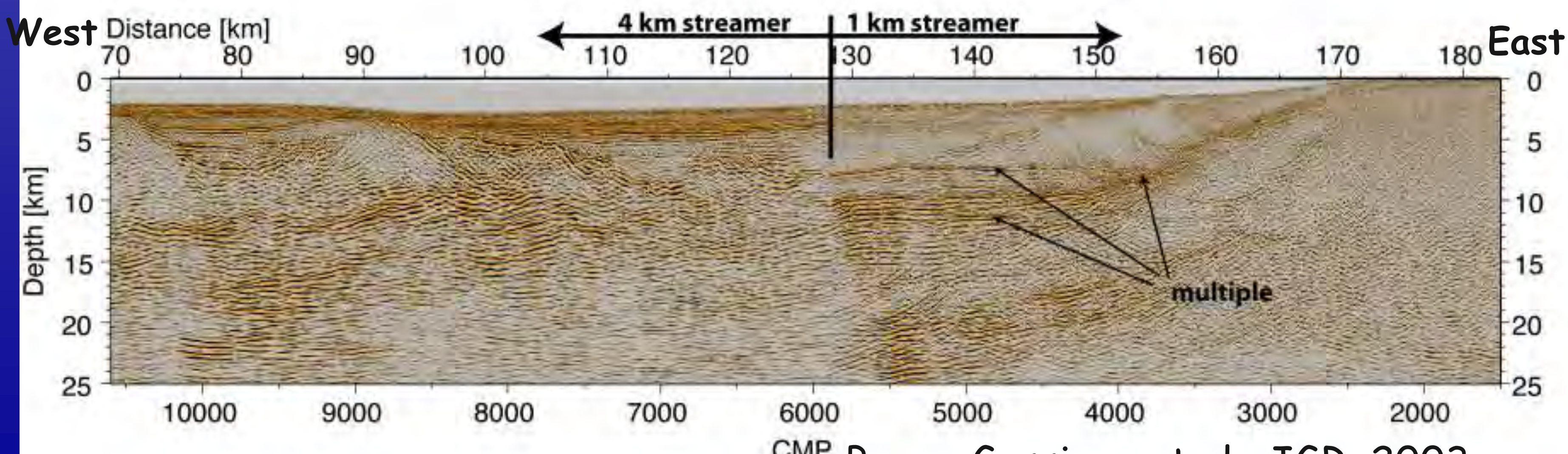
Perez-Gussinye et al., JGR, 2003.

Exhumation of deep lower crustal rocks along "normal" normal faults

Galicia Interior Basin



Pre-stack depth migration, interpretation & wide-angle seismic velocities



Perez-Gussinye et al., JGR, 2003

Model evolution