Lateral strength variation in the lithosphere: a key parameter for the localization of intra-plate deformation (T31C-2520)

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1. Introduction and objectives

Lateral variation of strength in the lithosphere is an important factor controlling the localization of intra-plate deformation. Pre-existing heterogeneities can become reactivated in extension as well as in compression, governing the spatial and temporal development of intra-plate deformation.
Analogue models investigating the deformation pattern and topography development of compressional intra-plate settings are presented. The initial scaling conditions are designed to analyse the effects of first order lateral strength variations. The reference lithosphere is characterized by a uniform four-layers brittle-ductile rheological structure. An increase in upper crustal thickness, and thus strength, has been used to approximate a **strong lithospheric section,** representative for an old rift setting. The introduced lateral heterogeneity is striking perpendicular to the compression direction. All experiments have been deformed under normal gravity field. Other investigated parameters have been the strain rate, the thickness of the brittle mantle and the rheology of the viscous upper mantle.

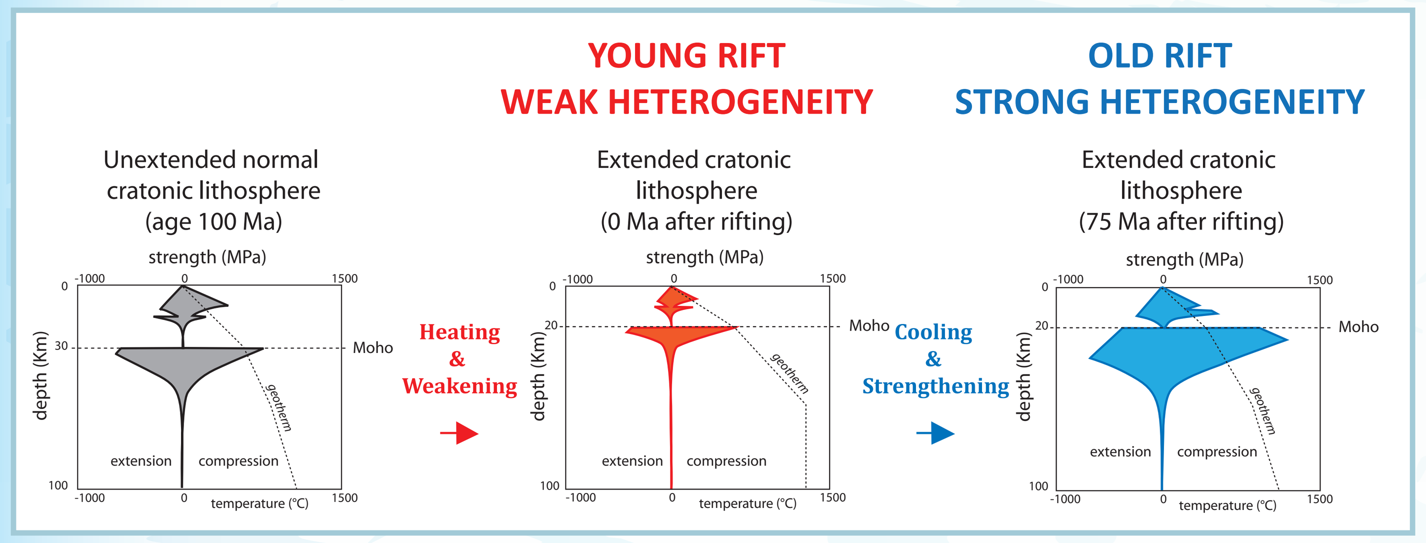

Figure 1: Strength envelopes modified after Ziegler & Cloetingh 2004.

2. Experimental parameters

GEOMETRICAL and KINEMATICAL PARAMETERS

Experiment	Convergence velocity (cm/h)	Strain rate (s-1)	Bulk shortening (%)	H brittle upper mantle (cm)
Experiment 1	5,0	3,31E-05	20	0,5
Experiment 2	1,0	6,61E-06	20	0,5
Experiment 3	1,0	6,61E-06	20	1,0
Experiment 4	5,0	3,31E-05	20	1,0

Parameters valid for all models
Model length 42 cm
Model width 36 cm
Old rift width 4 cm
h UC (reference lithosphere) 1,0 cm
h UC (old rift) 1,3 cm
h LC (reference lithosphere) 0,5 cm
h LC (old rift) 0,2 cm
h viscous UM 1,3 cm
Gravity 9,81 m/s2

RHEOLOGICAL PARAMETERS

Layer	Material	Experiment	Density ρ (kg m-3)	Coeff. friction μ	Cohesion C (Pa)	Stress exponent n	Material constant A	Effective viscosity η (Pa s)
Brittle upper crust	dry feldspar sand	1 to 4	1300	0.4-0.7	15-35			
Viscous lower crust	silicon 1	1, 2	1400			1,16	1,00E-05	1,06E+05
Viscous lower crust	silicon 1	3, 4	1400			1,16	1,00E-05	8,48E+04
Brittle upper mantle	dry quartz sand	1, 2	1500	0.6	30-70			
Viscous upper mantle	silicon 2	1	1578			1,06	1,00E-05	9,35E+04
Viscous upper mantle	silicon 2	2,3	1578			1,06	1,00E-05	1,02E+05
Viscous upper mantle	silicon 3	4	1550			1,6	7,00E-07	3,37E+05
Lower lithosphere	Na Polytungstate+glycerol	1 to 4	1600					1,2

Assumptions and simplifications

- Simplified rheology of viscous layers: analogue materials are characterized by depth-invariant viscosity.
- Erosion and sedimentation are not included in the experiments.
- Lateral strength variation in the mantle lithosphere are not investigated; lateral changes in bulk lithospheric strength are simulated with variation in the thickness of crustal layers.
- Despite the above simplifications the presented experiments are considered representative for first order deformation and associated topography in presence of a laterally heterogeneous lithosphere under compression.

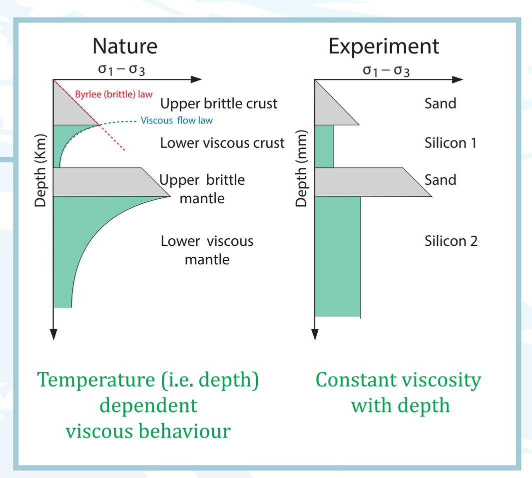

Figure 2: strength profiles for continental lithosphere in nature (left) and in analogue experiments (right).

3. Analogue experiments: set-up

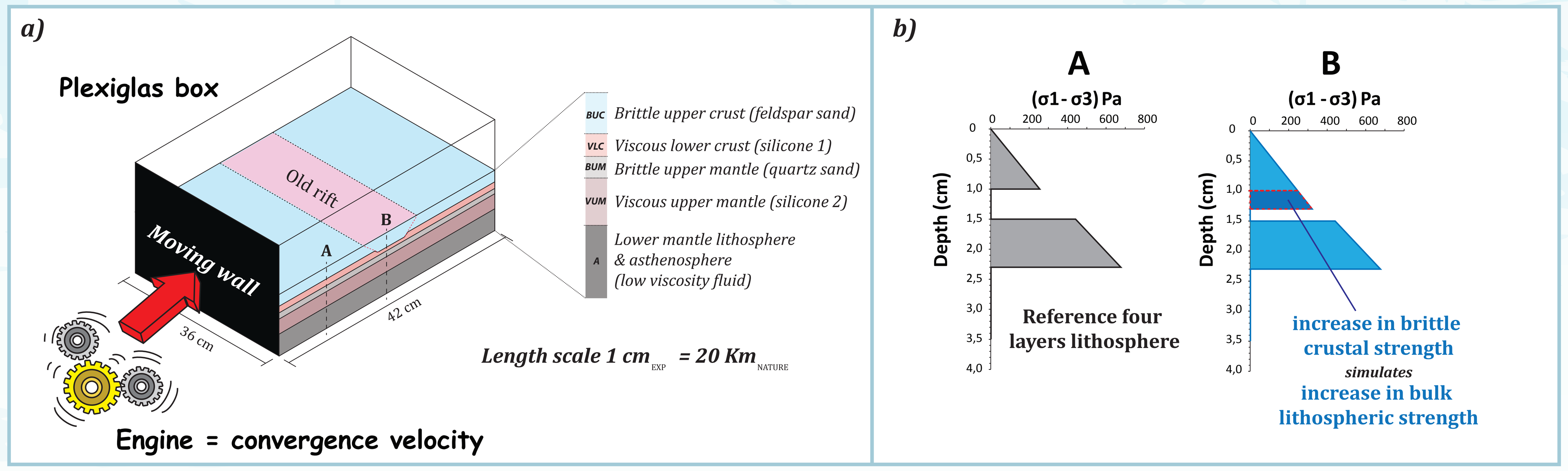

Figure 3: a) Sketch of the experimental set-up; b) representative strength profiles calculated for a convergence rate of 1 cm/h, describing the very initial deformation stage.

4. Results: intra-plate deformation in presence of a strong lithospheric section

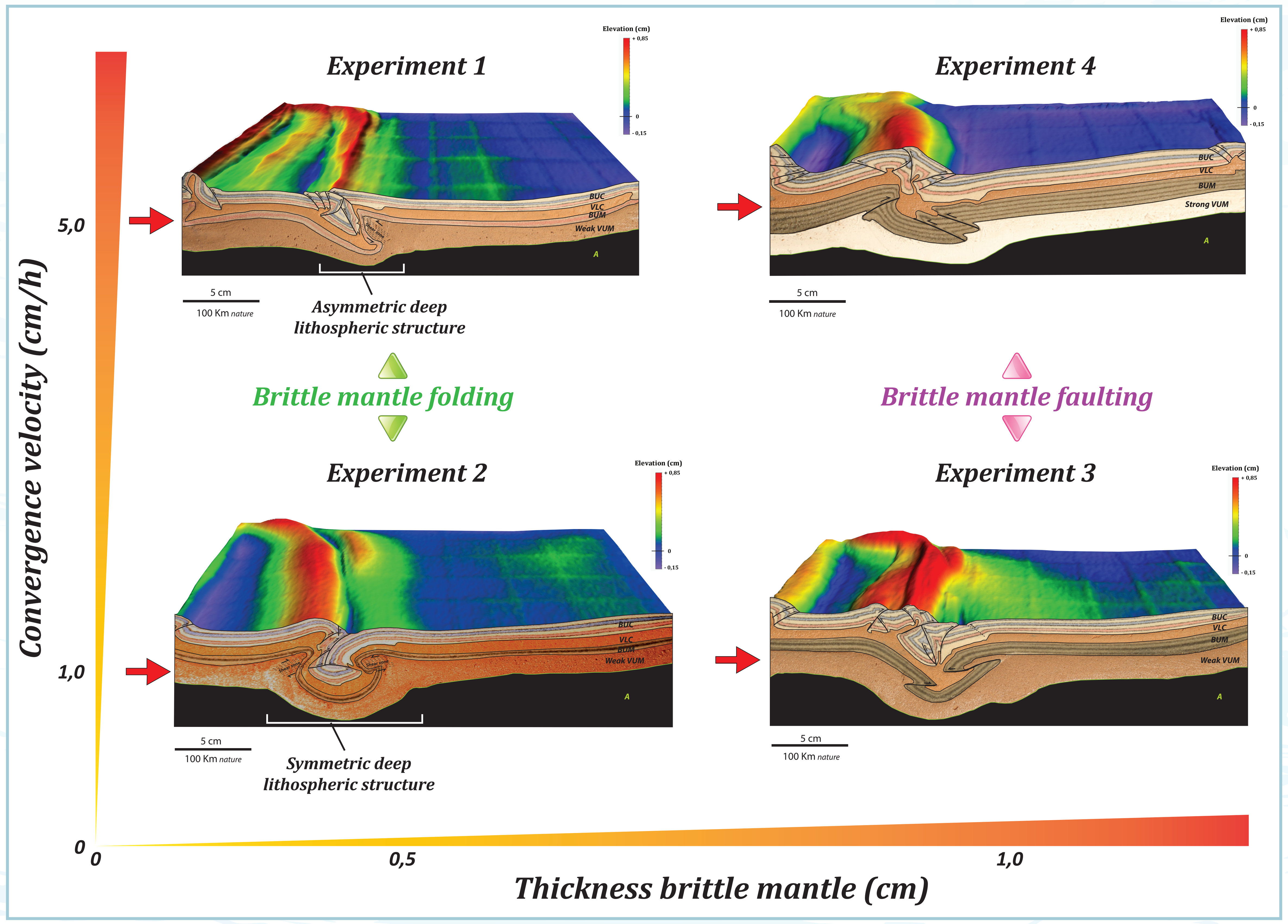

Figure 4: representative cross sections and DEM (Digital Elevation Model) of the experiments' surface at 20% BS (bulk shortening).

5. Comparison with previous experiments: intra-plate deformation with a pre-existing weak lithospheric section

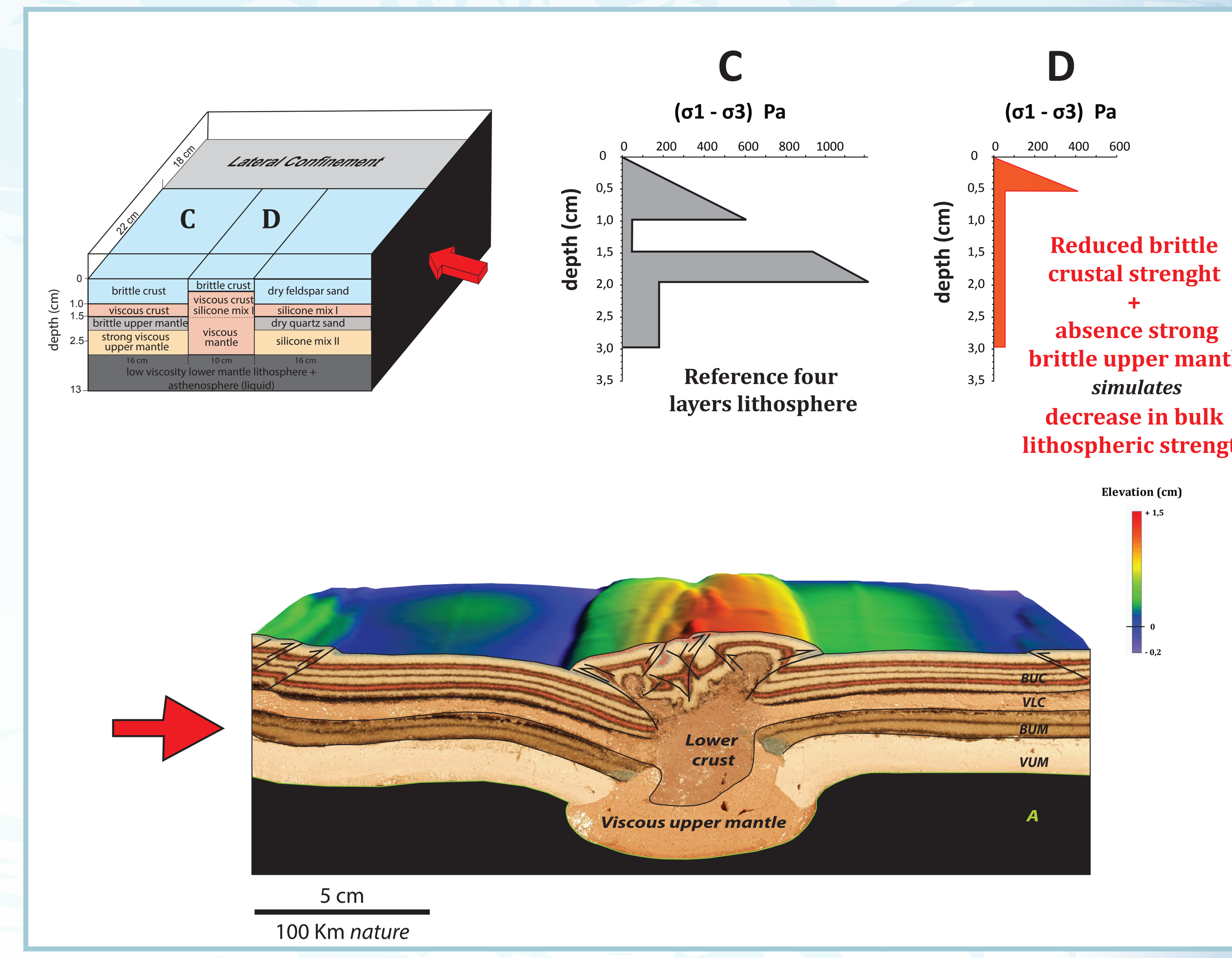

Figure 5: intra-plate deformation with a pre-existing weak zone. Modified after Willingshofer et al., 2005.

6. Summary and Conclusions

In presence of a mechanically stronger old rift subject to compressional stresses deformation localizes along the basin margin facing the compression direction.

Strain rate governs the geometry of the deep lithospheric structure. An increase in convergence velocity results in a progressive increase in aymmetry of the lithospheric root underlying the pop-down.

The brittle-ductile ratio in the lithospheric mantle determines the absence (low B/D) or presence (high B/D) of faults in the upper brittle mantle (Experiment 2, Experiment 3). For a low B/D ratio deformation in the mantle is accommodated by shear zones (Experiment 2).

Underthrusting along the margin of the old rift is the main deformation mechanism in case of low strength brittle mantle and high convergence velocity (Experiment 1).

Folding and formation of a mountain root are the main deformation mechanisms in case of low strength brittle mantle and low convergence velocity (Experiment 2).

A weak viscous upper mantle allow the development of a major pop-down prismatic structure in the upper crust; a strong viscous upper mantle prevents the formation of a pop-down basin in the crust and underthrusting along the basin margin (Experiment 4).

In presence of a mechanically weaker young rift subject to compressional stresses deformation starts along the rift margins and remains localized inside the weak plate leading to the development of pronounced topography, which is compensated by a lithospheric root (Willingshofer et al., 2005; Figure 5).

References

Willingshofer E., Sokoutis D. & Burg J.P., 2005 - Lithospheric scale analogue modelling of collision zones invoking a pre-existing weak zone. In " Deformation Mechanisms, Rheology and Tectonics: from Minerals to the Lithosphere" (Eds. Gapais D., Brun J.P. & Cobbold P.R.). Geological Society, London, Special Publications 243, 277-294

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Aknowledgments: The research project was funded by the European Union FP& Maire Curie ITN "Topomod", contract n. 264517