Strain localization during compression of a laterally heterogeneous lithosphere

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1. Introduction and objectives

First order large scale stress fields, associated with active plate tectonic processes, interact with lateral heterogeneities in the lithosphere and generate strain redistribution. Next to the fact that strength of the continental lithosphere is mainly controlled by its depth dependent rheological structure, continents are often the product of the assemblage of domains that suffered different tectonic processes, resulting in lateral changes in composition and thermal structure.

We present a series of lithospheric scale analogue models designed to investigate strain redistribution in compressional intra-plate settings. The initial scaling conditions are designed to analyse the effects resulting from the presence of a stronger rheological heterogeneity embedded in a weaker lithosphere. The reference lithosphere is characterized by a uniform four-layers brittle-ductile rheological structure, representative of low geothermal gradient conditions. The experiments consist of three domains with different mechanical properties: two external blocks sharing the same lithospheric stratification and one narrow central block where an increase in upper crustal thickness, and thus strength, has been used to approximate a **strong lithospheric domain**. Strength increase in the lowermost part of the crust can be related to compositional variation as for example mafic intrusions in rift settings. Among the investigated parameters, convergence velocity and thickness of the brittle upper mantle are varied, both playing an important role in the crust-mantle coupling. Furthermore, we examined different orientations of the vertical rheological boundaries with respect to the convergence direction, since reactivated lithosphere heterogeneities are often observed to strike oblique with respect to the main horizontal stress field.

2. Analogue experiments: set-up

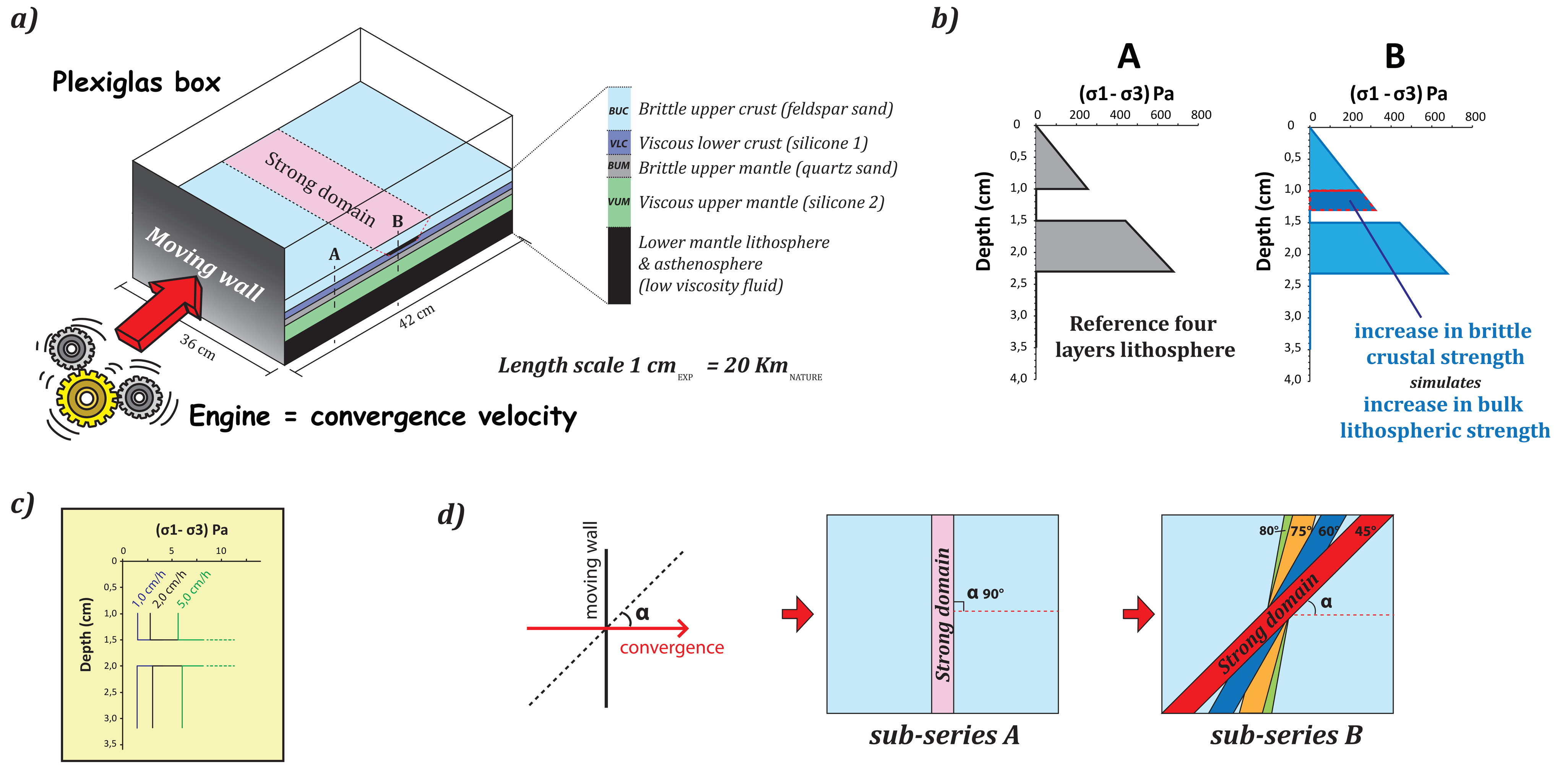


Figure 1: a) Sketch of the experimental set-up; b) representative strength profiles calculated for a convergence rate of 1 cm/h, describing the very initial deformation stage; c)effect of different convergent velocities on crust-mantle coupling; d) geometry of the experiments (top-view).

3. Results: sub-series A, α 90°

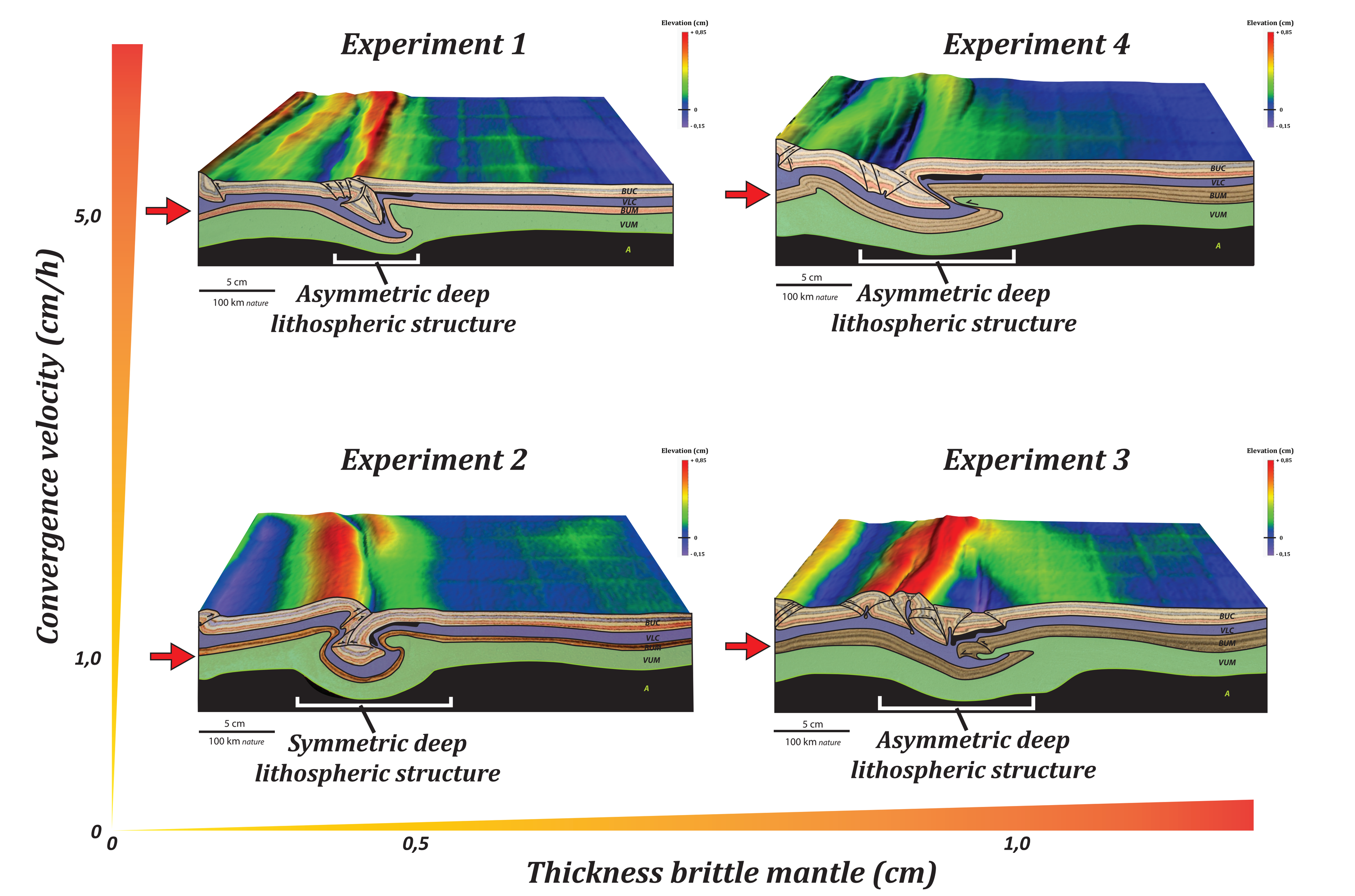
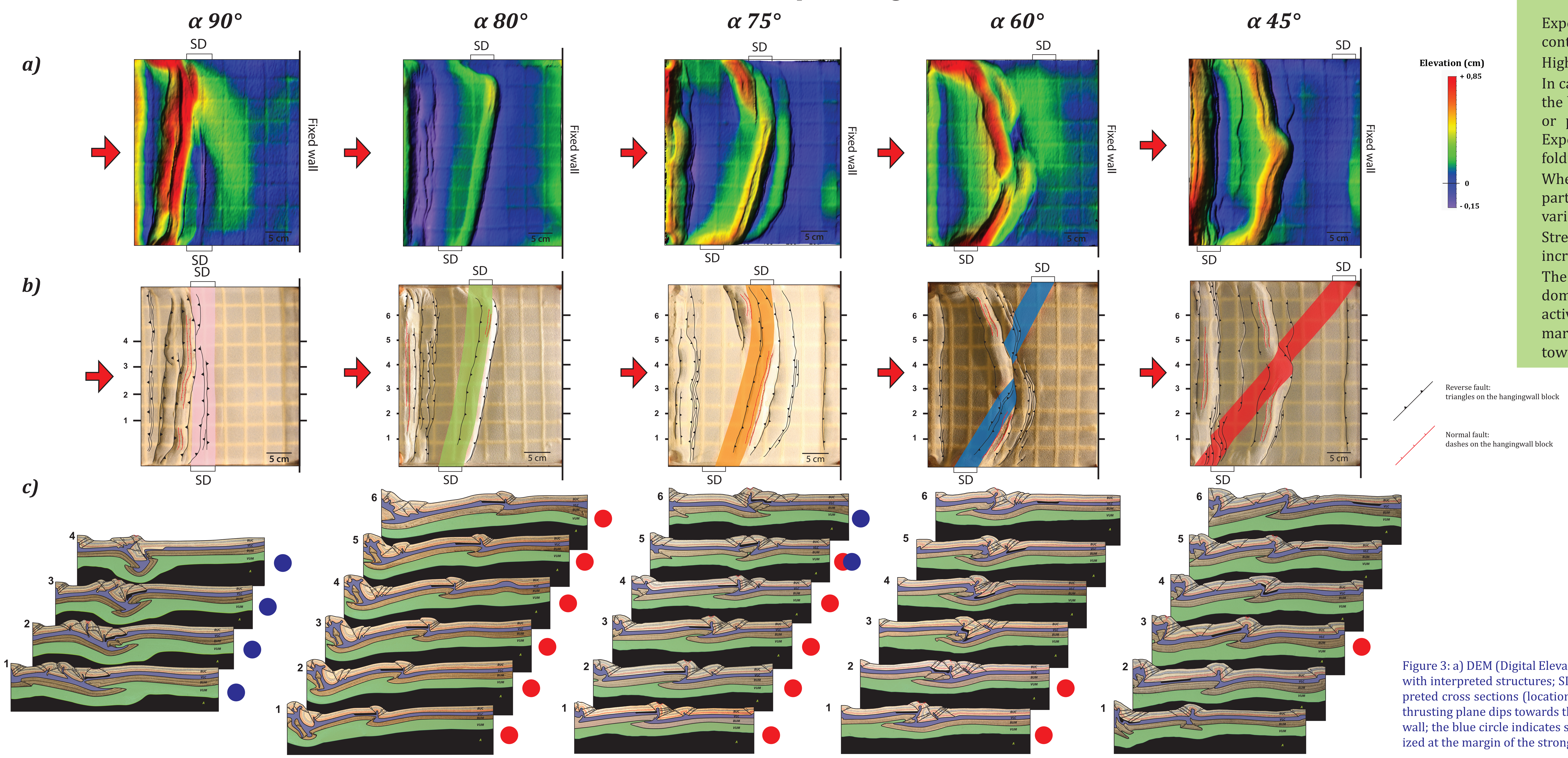


Figure 2: Experimental results for sub-series A. Representative cross sections and DEM(Digital Elevation Models) of the experiments' surface at 20% bulk shortening.

4. Results: sub-series B, oblique strong domain



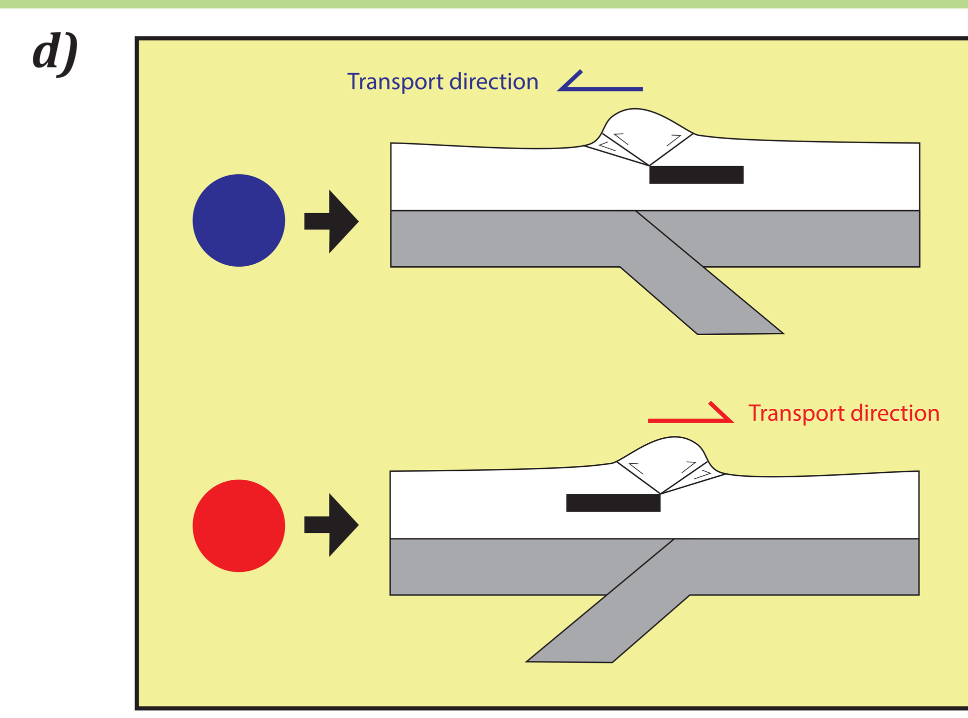


Figure 3: a) DEM (Digital Elevation Models) at 20% bulk shortening; SD: strong domain; b) top-view pictures at 20% bulk shortening with interpreted structures; SD: strong domain; the colored area indicates the approximate location of the strong domain; c) interpreted cross sections (location is indicated in the top-view pictures in b); the red circle indicates sections where the main underthrusting plane dips towards the moving wall and a thrusts belt is localized at the margin of the strong domain facing the fixed back wall; the blue circle indicates sections where the main underthrusting plane dips towards the fixed back and a thrusts belt is localized at the margin of the strong domain facing the moving wall (see also Figure 3d).

5. Summary and Conclusions

Experimental outcomes indicate that the presence of a strong lithospheric domain controls localization of deformation at the vertical rheological boundaries.

High relief build-up is associated with strain localization.

In case of a strong domain perpendicular to the convergence direction (sub-series A) 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 folding (Experiment 2).

When the strong domain strikes oblique to the convergence direction, deformation is partially localized along the vertical rheological boundaries, due to along-strike variation in distance from the moving wall.

Strength variation at depth leads to a curvature in the thrust systems, particularly for increasing obliquity of the strong domain (α 60° and α 45°).

The dip direction of the main underthrusting plane depends on which of the strong domain margins is localizing deformation: when the margin facing the moving wall is activated the main underthrusting plane dips towards the fixed back wall; when the margin facing the fixed back wall is activated the main underthrusting plane dips towards the moving wall.

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