The development of topographic plateaus in an India-Asia-like collision zone using 3D numerical simulations

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INTRODUCTION

● The India-Asia collision zone formed around 50 million years ago, when the Indian continent collided with Eurasia.

● Dynamics not yet understood: the rise of the abnormally thick Tibetan plateau, the deformation at its Eastern and Western syntaxes, the transition from subduction to collision and uplift and the interaction of tectonics and climate.

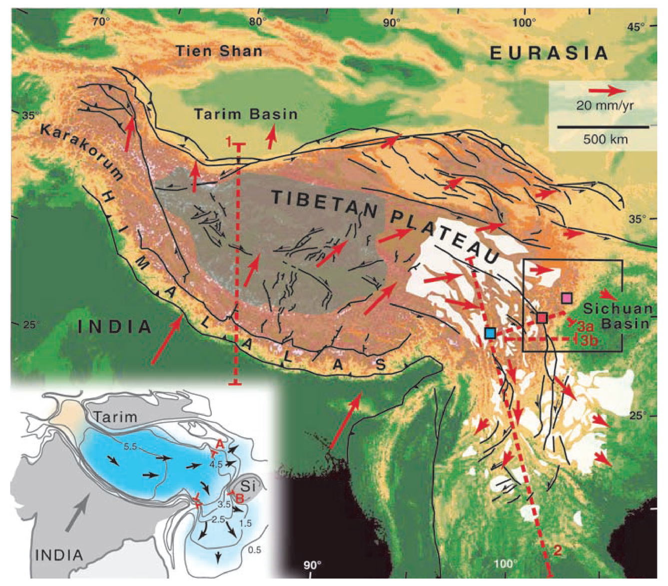


Fig. 1. From Royden et al. (2008). Topography shade map for the Tibetan region. Red arrows indicate generalized GPS measurements.

"Double thickness" problem:

- Wholescale underthrusting (Argand model)
- Distributed homogeneous shortening *(England and Houseman, 1986);*
- Slip-line field model *(Tapponier and Molnar, 1976);*
- Lower crustal flow model *(Royden et al., 2008, Beaumont et al., 2004).*

METHOD

● We use the parallel 3D code LaMEM (**Lithosphere and Mantle Evolution Model**), with a finite difference staggered grid (FDSTAG) solver, viscous rheology and an internal free surface, which allows for the development of topography

● We simulate both free subduction-collision models, and with imposed velocity boundary conditions

Model Setup

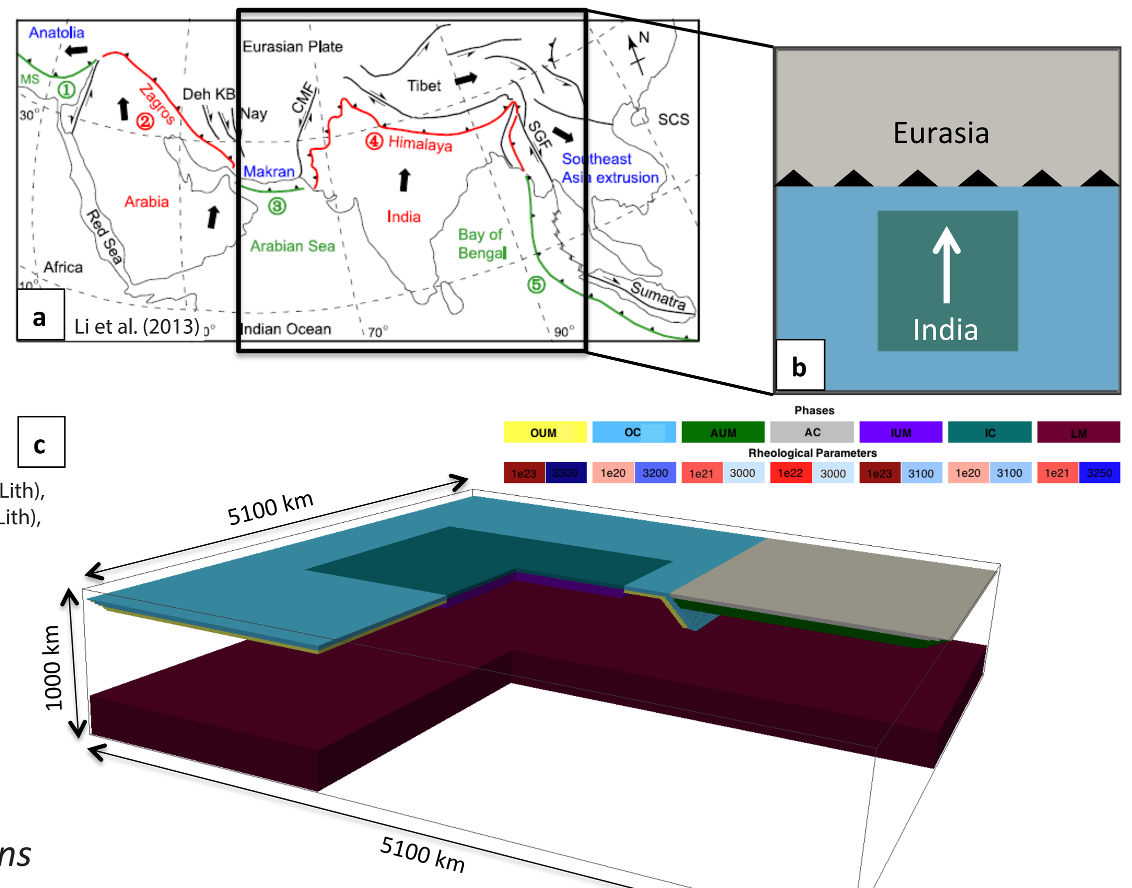


Fig. 2. a-b) Initial model setup was built using a simplified tectonic map of the region.
c) 3D perspective of the model setup.
Domain: 5100 km x 5100 km x 1000 km.
Computational resolution: 170 x 170 x 33 grid cells (3^3 particles/grid cell).
Boundary conditions: Free slip on all boundaries and Sticky Air layer on top.
Stokes Solver: Fully Coupled
Velocity Solver: Hypre + Multigrid (AML)
Phases: OUM - Oceanic Upper Mantle (Lith), OC - Oceanic Crust, AUM - Asian Upper Mantle (Lith), AC - Asian Crust, IUM - Indentor Upper Mantle (Lith), IC - Indentor Crust, LM - Lower Mantle.
The rheological parameters used for the reference model are displayed in the colorbar.
Reference values for the mantle: η = 1e20 Pa.s, ρ = 3200 kg/m³.

External forcing

Pushing is imposed as Dirichlet boundary conditions

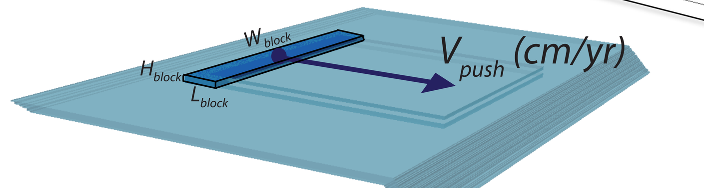


Fig. 3. Schematic of how the pushing BCs are incorporated into the model. The pushing block is defined by its center coordinates: (x_{block}, y_{block}, z_{block}) and by its dimensions: L_{block}, W_{block}, H_{block}. The block moves with constant velocity V_{push}.

ASSUMPTIONS and APPROACH

● The model has 16 free parameters, and to test the basic response of the system to these parameters, it would require 2^16 = 65536 runs.

● We assume that the properties of the lithosphere are the focus of this study, and choose reference values for the mantle.

● We use weak/strong or low/high values for the parameters, because we are interested in understanding the importance of the varied parameters to the system, rather than focus on their true value. See table below for more reference.

● Quinteros et al. (2010) showed that a viscosity contrast of 10 and density contrast of 50 kg/m³ at the transition zone between the upper and lower mantle gives the best results of slab behaviour in numerical models compared to tomography observations.

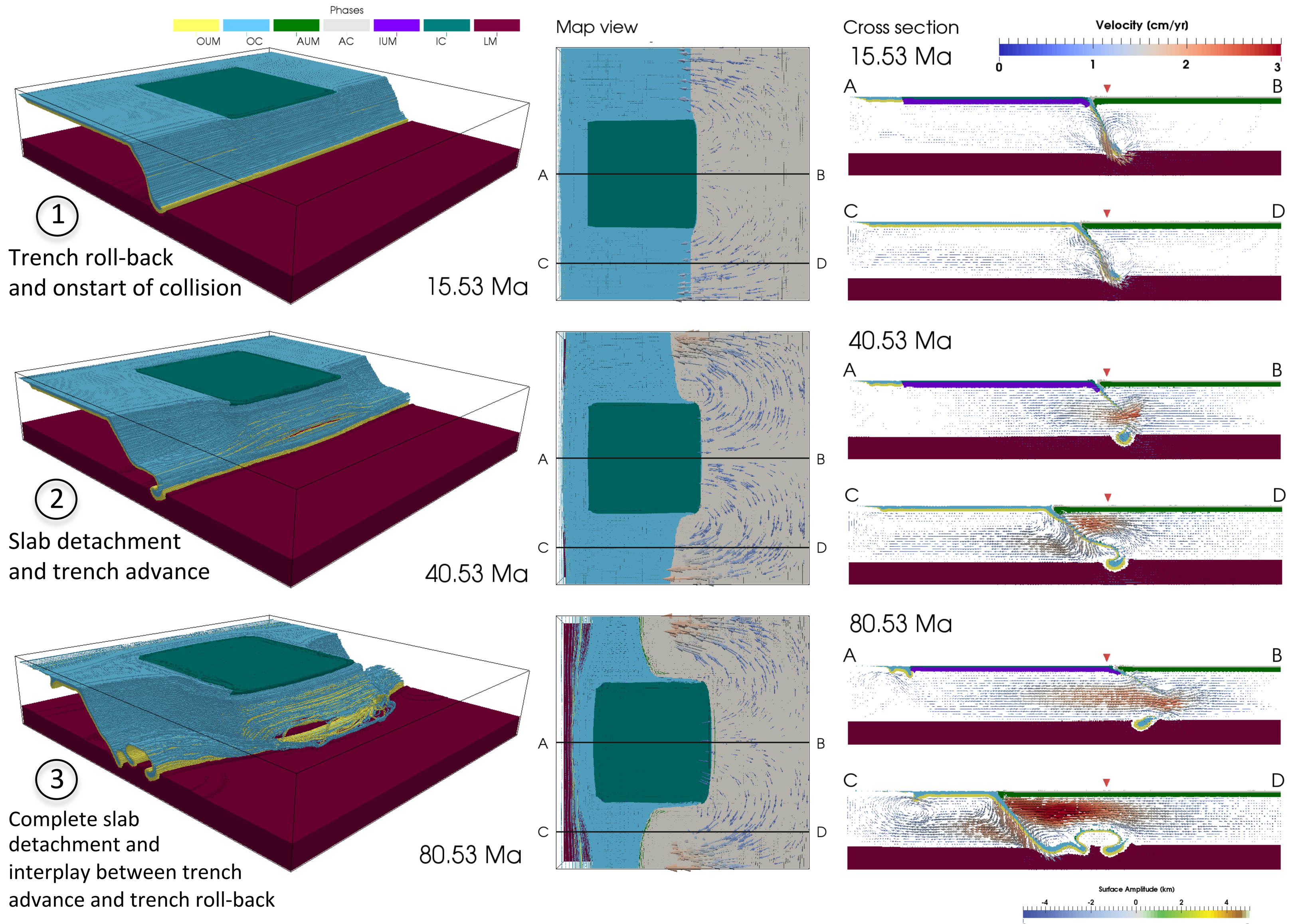
● A viscosity contrast between slab and mantle less than 10^3 Pa.s would result into an unstable, fragmented slab, contrary to what is observed in tomographic studies.

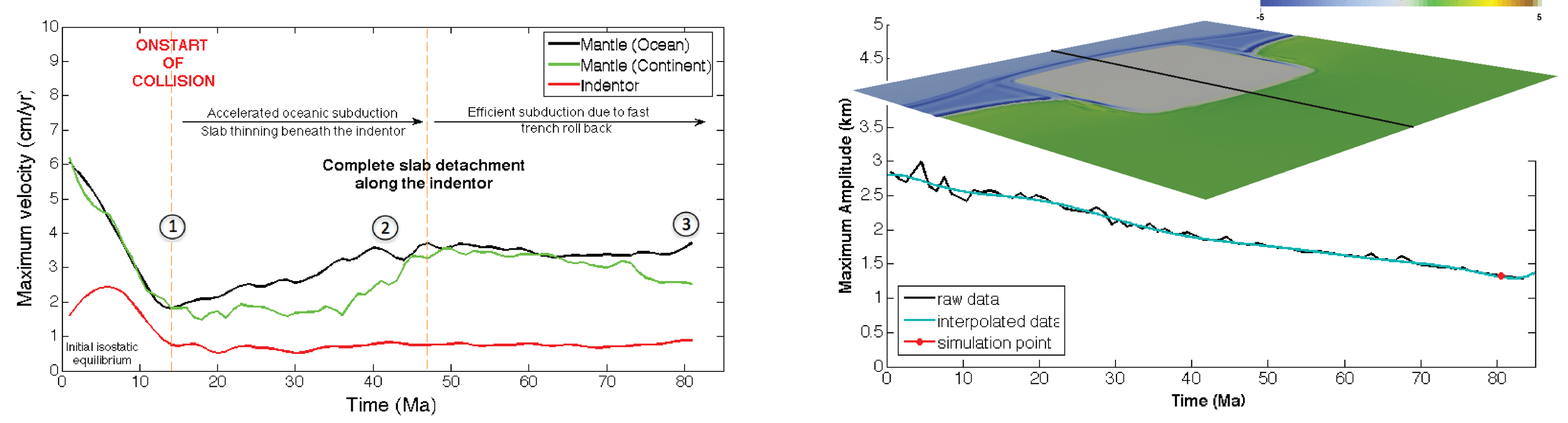
	Case 1		Case 2		Case 3		Case 4
Factor	Slab pull		Continental indentor		Upper plate		External forcing
No. of runs	16		48		72		68
Parameters	η_{AUM}	1e21-1e22 Pa.s	η_{IUM}	1e22-1e23 Pa.s	η_{AUM}	1e21-1e23 Pa.s	pushing BC
	η_{AC}	1e21-1e22 Pa.s	η_{IC}	1e20-1e21 Pa.s	η_{AC}	1e21-1e23 Pa.s	strong blocks
	ρ_{OC}	3100-3200 kg/m³	ρ_{IUM}	3100-3200 kg/m³	ρ_{AUM}	3000-3100 kg/m³	pushing BC +
	ρ_{AUM},ρ_{AC}	3000-3100 kg/m³	ρ_{IC}	3000-3100 kg/m³	ρ_{AC}	3000-3100 kg/m³	strong blocks

Table 1. Summary of cases and parameters varied.

RESULTS

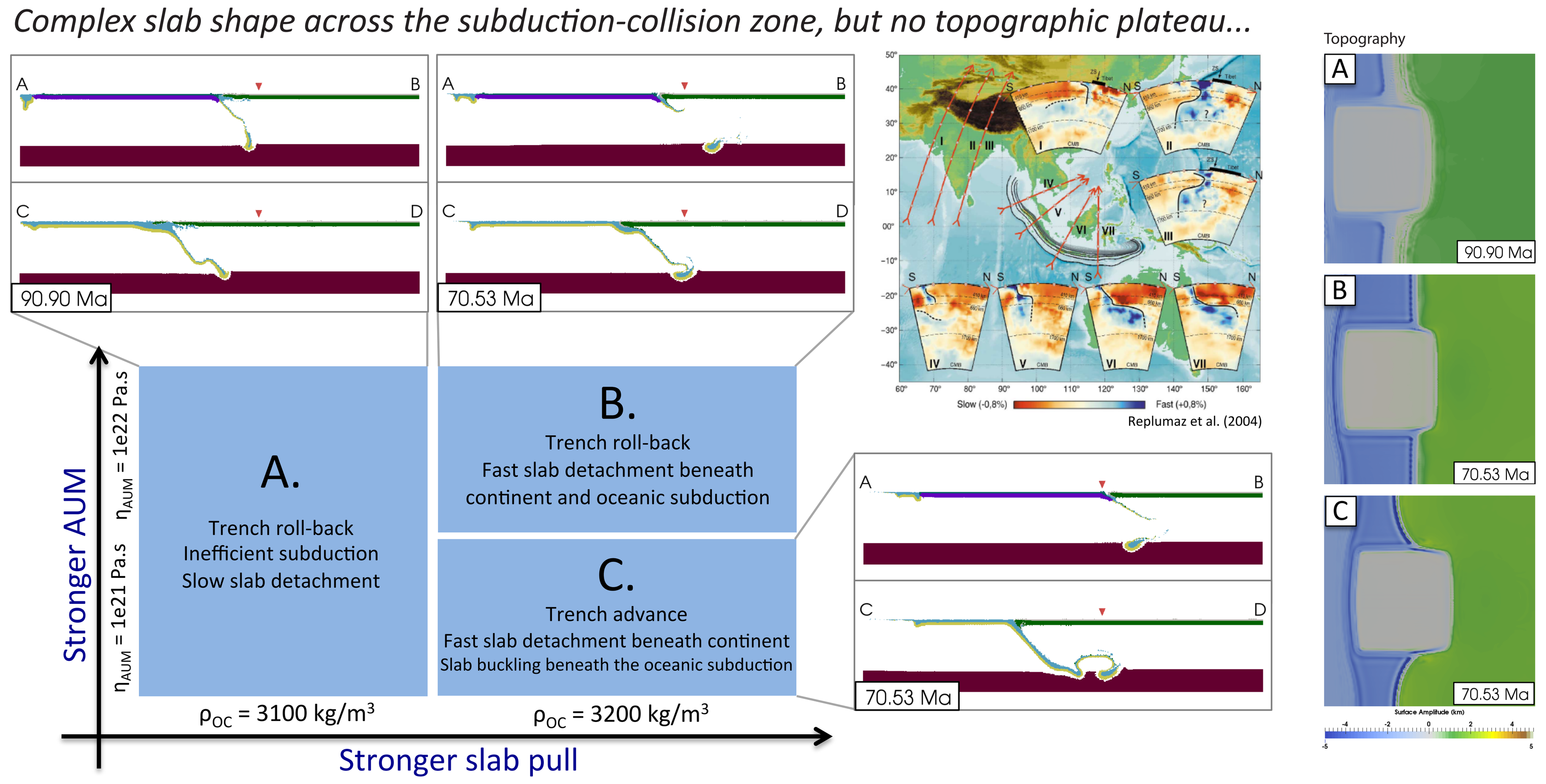
Reference Model - evolution and general aspects



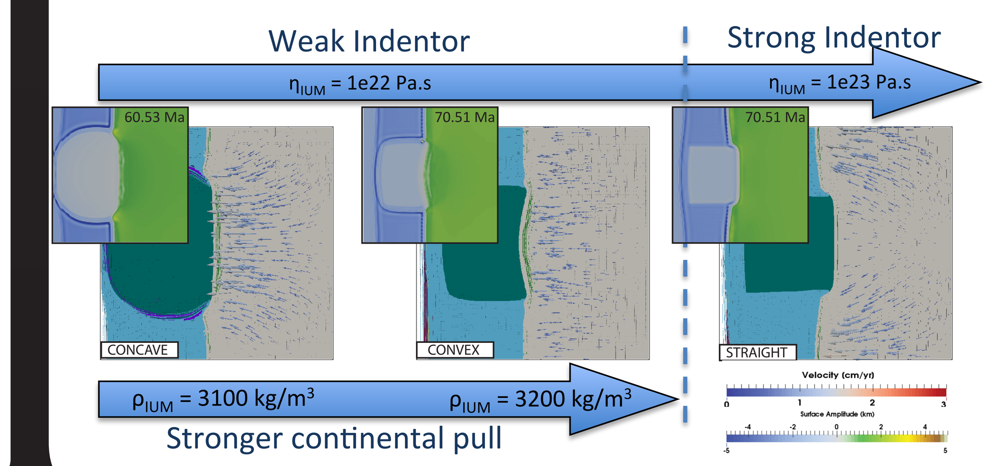


Case 1 - Slab pull and dynamics of the slab

Complex slab shape across the subduction-collision zone, but no topographic plateau...



Case 2 - Deformable continental indentor and curvature



● A **weak indentor** allows for the development of a curvature of the collision front, while a **strong indentor** is too stiff to deform.

● **Convex curvature** is obtained for all cases of a weak and heavy indentor, while **concave curvature** is obtained for all cases of weak and light indentor.

● However, the **surface horizontal velocity field** for the weak indentor case is the opposite of what we observe in the India-Asia collision zone.

● The properties of the continental indentor have little effect on the **topography** of the upper plate, with the highest amplitudes obtained for runs with a stronger indentor.

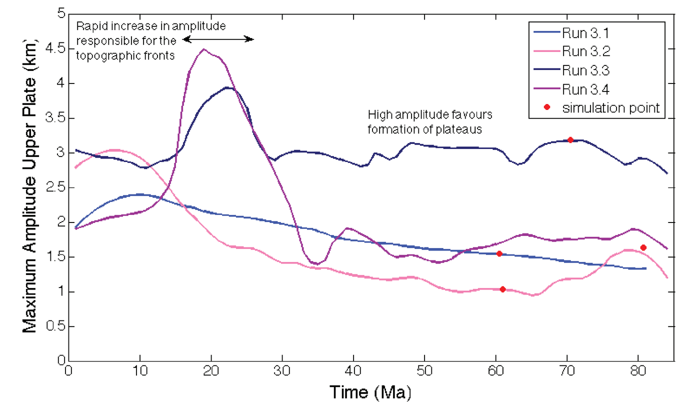
Case 3 - Upper plate and development of topographic plateaus

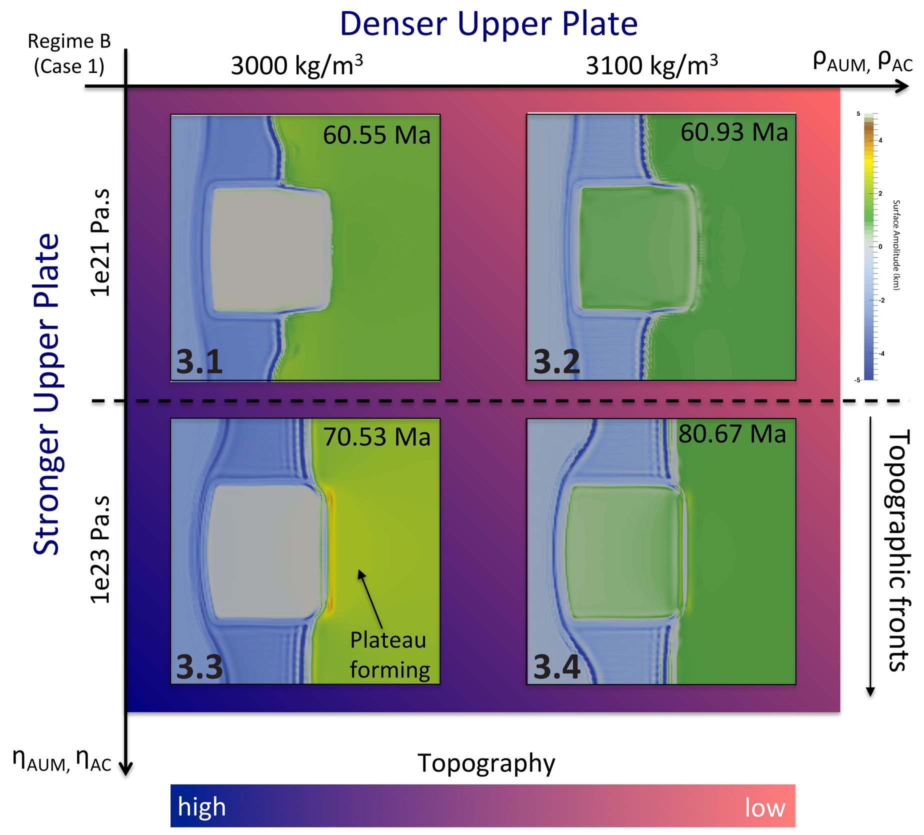
● The way slab dynamics is affected by upper plate parameters is shown in Case 1.

● Topography is strongly influenced by these parameters.

● A **topographic front** forms when the upper plate is strong, as a result of rapid accumulation of gravitational potential energy (GPE) locally.

● A **high topographic plateau** forms when the upper plate is strong and light, able to store GPE for a longer time.



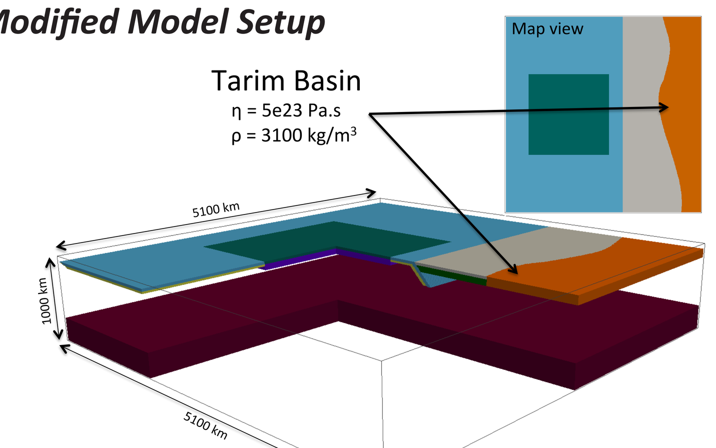


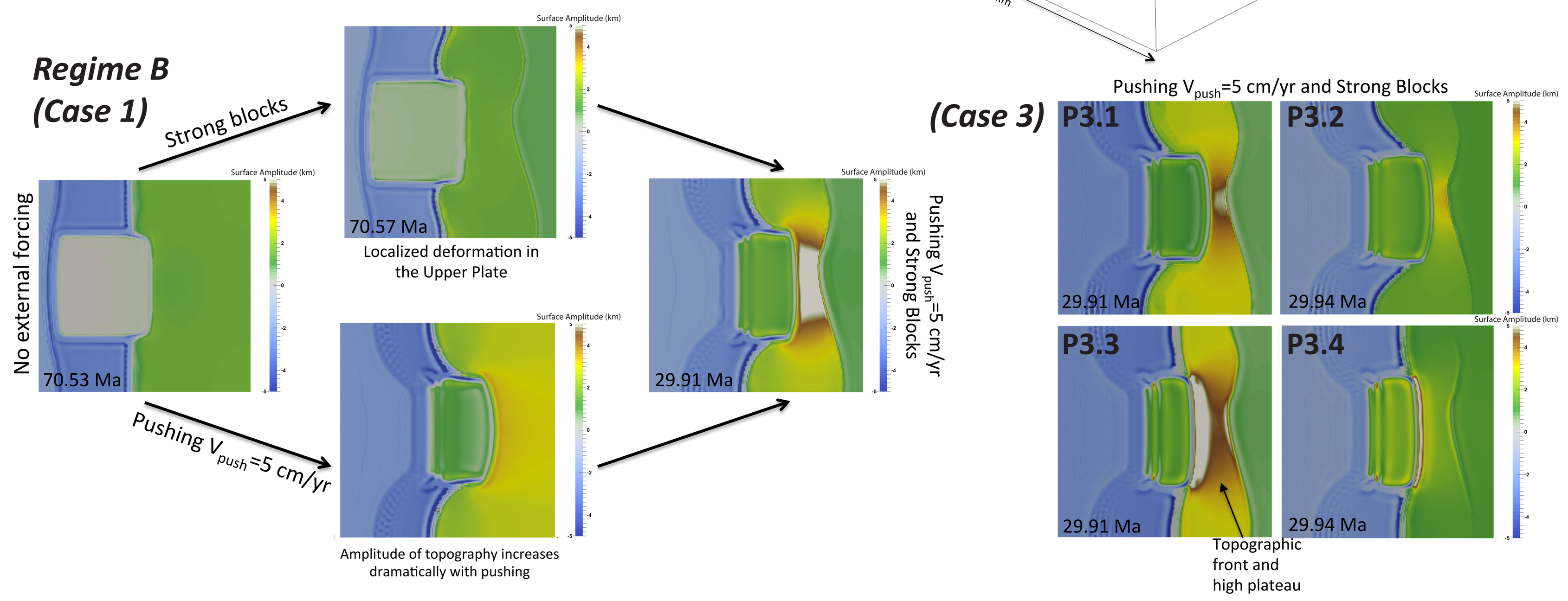
Case 4 - External forcing

1. Ridge Push
- simulate far field forces (referred here as "pushing")
(Chemenda et al., 2000, Li et al., 2008)

2. Presence of strong blocks
- such as the Tarim Basin N of Tibetan Plateau
(Neil and Houseman, 1997)

Modified Model Setup





CONCLUSIONS

● *More than 200 numerical simulations and factors such as slab pull, deformable continental indentor, upper plate and external forcing have been perfomed here.*

● *Dynamics of subduction-collision 3D models is very complex with distinct behaviours beneath the continental collision and oceanic subduction at the sides.*

● *External pushing and the presence of strong blocks such as the Tarim Basin are necessary to create both high topographic fronts (Himalayas) and plateaus (Tibetan Plateau). Upper plate material properties also give a signature to the topographic amplitude.*

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