Strain localization in the crust
the influence of viscoplastic rheology

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Abstract

Orogenic wedges accommodate ongoing convergence and continental collision through various structural styles. Major controls on the structure are exerted by the rheology of the wedge, due to compositional layering and strength contrasts [1,2], thermal gradients[3] and the rates of convergence[2].

Our goals are:

- Assess how crustal thickness and velocity influences orogenic wedges
- Quantifying the difference in structural style

Model setup

- **Underworld** used to solve conservation of mass, momentum & energy[4-5].
- **Crust** – Single crust at 20 (CT20), 25 (CT25) and 30 (CT30) km thick. Better constrain the role of velocity.
- **Convergence velocity** – constant, varied between cases between 1 and 10 cm yr^{-1}.
- **Geotherm** - 25 °C km^{-1} for 10 km, then 12 °C km^{-1} →1300 °C reached at LAB (97.5 km)
- **Rheology** – Viscoplastic (Fig 2). Non-linear dislocation creep encompasses strain-rate, which varies as a function of convergence rate and localization. Plastic strain weakening is also included.
- Total of ~435 km of convergence, in agreement with total convergence from various orogenic wedges[6].
- Insulating top and side walls (no heat flux), open temperature bottom boundary.

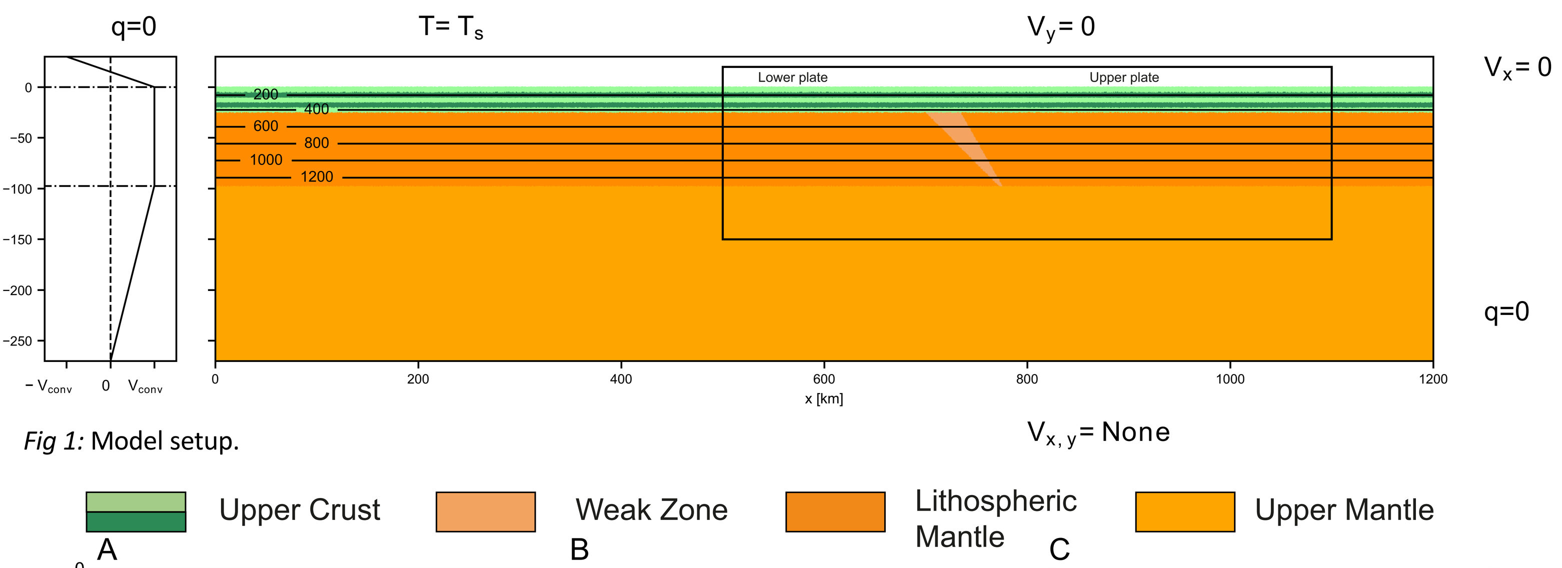

Fig 1: Model setup.

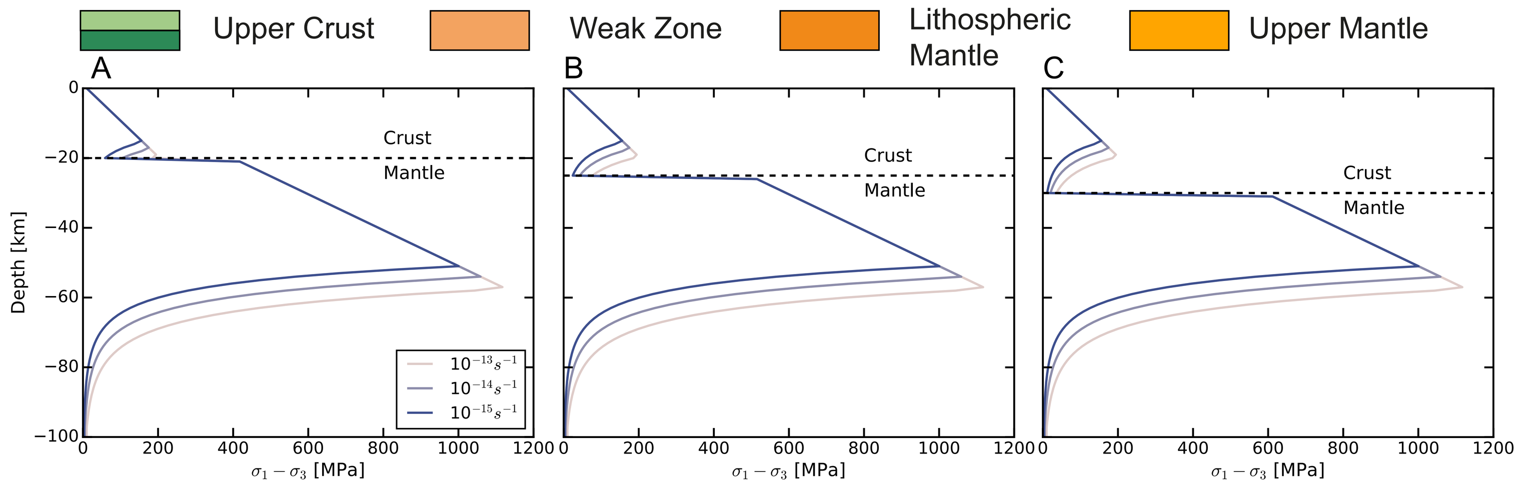

Fig 2: Strength profile for varying strain rates and crustal thicknesses, highlighting the change in depth of the brittle-ductile transition and thickness of ductile lower crust. A) 20 km thick crust (CT20), B) 25 km thick crust (CT25), C) 30 km thick crust (CT30).

Deformation styles – plastic to viscous wedges

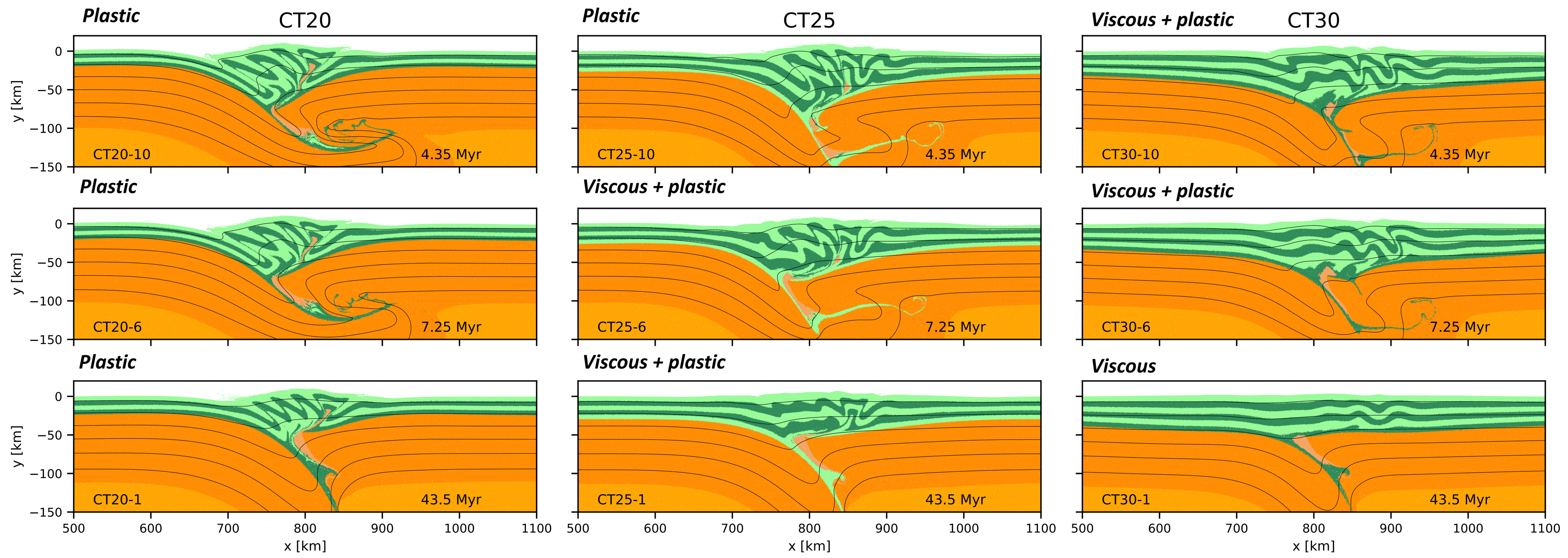

Fig 3: Deformation styles after ~435 km of convergence, highlighting plastic, viscoplastic and viscous wedges. **Plastic wedges** are characterized by strain localization (faults) throughout the crust to the rheological boundary at the bottom of the crust, creating significant crustal thickening. Viscous wedges are characterized by no strain localization and grow laterally, not vertically. **Viscoplastic** wedges are intermediate, showing strain localization in the upper crust (plastic) and strain rate processes occurring in the lower crust (viscous)

Wedge characterization after 435 km of convergence

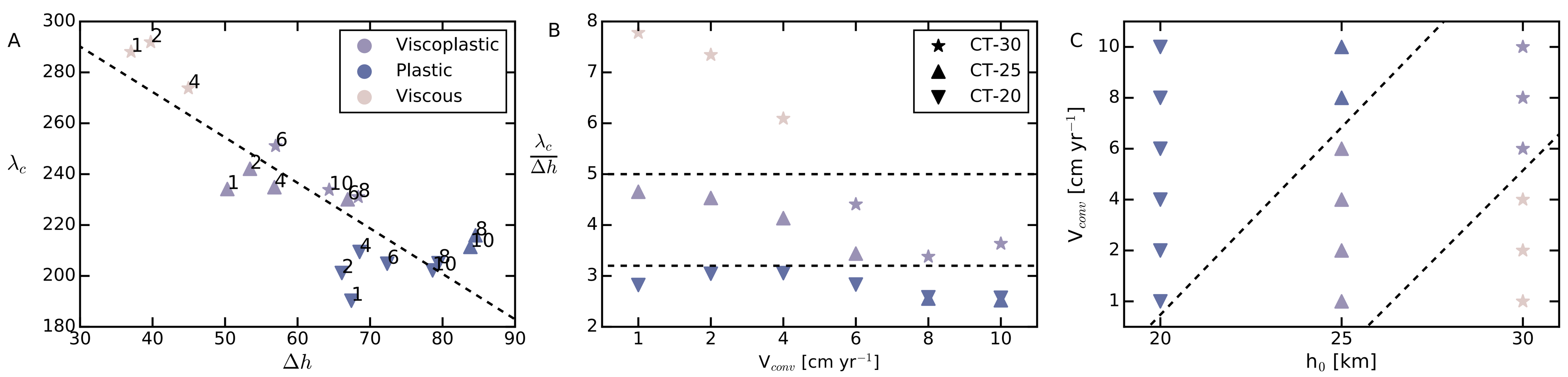

Fig 4: Wedge characterization based on length (λ_c) and change in thickness (Δh), with three distinct groups in fig 4A. Fig 4B portrays the ratio ($\frac{\lambda_c}{\Delta h}$) based on the convergence velocity (V_{conv}). With $\frac{\lambda_c}{\Delta h}$ decreasing with decreasing thickness with an initial crustal thickness of 25 km and above. CT20 has a low $\frac{\lambda_c}{\Delta h}$ independent of velocity due to the plastic rheology being strain rate (velocity) independent. C) portrays the characterization of the wedges based on the initial crustal thickness (h_0) and convergence velocity (V_{conv}).

Strain localization in crust over time

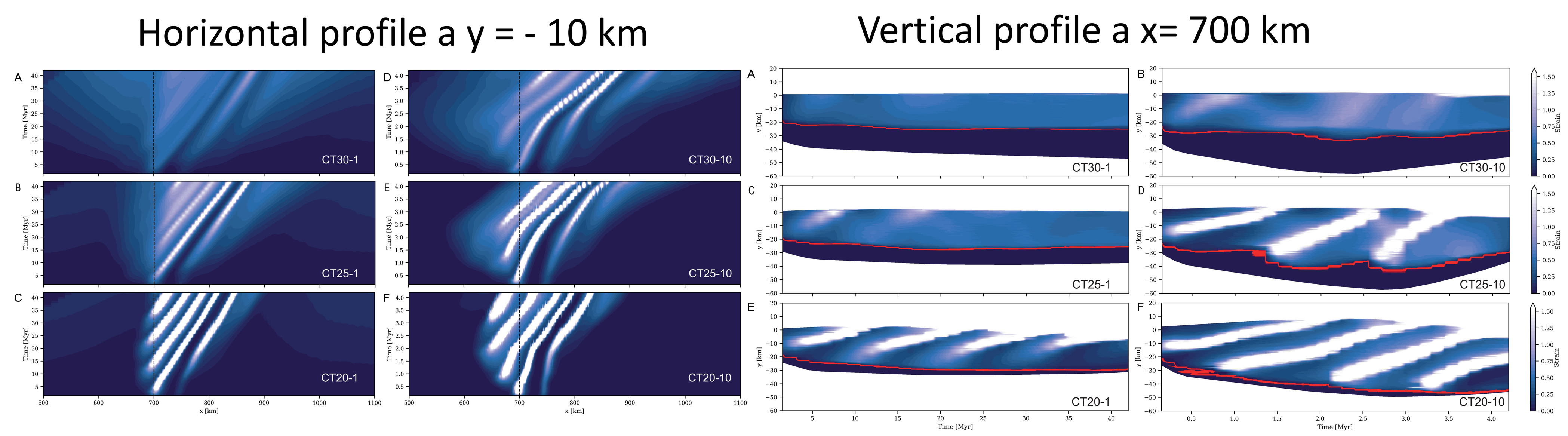

Fig 5: Strain localization in the crust, with a horizontal profile y = -10 km (left) and a vertical profile at x = 700 km (right) for varying velocity and crustal thickness, with the red contour highlighting the depth of the brittle-ductile transition. With increasing influence of viscous rheology, the amount of strain localization in the crust decreases, with the BD depth also decreasing.

References

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Key points

Viscous wedge:

- Favored when ***low convergence velocity*** and ***high Moho T***.
- Convergence is ***accommodated laterally*** (figs 3 & 4).
- No strain localization in the crust (plastic), instead ***dominated by strain rate (viscous) deformation*** (fig. 5).
- Results in a ***wide and thin wedge*** (fig. 4).

Plastic wedge:

- Occurs at ***low Moho T***.
- Resulting deformation style is ***independent of velocity*** (CT20).
- Convergence is mainly ***accommodated vertically*** (figs 3 & 4).
- ***Strain localization (plastic deformation) dominates***, with strain rate (viscous) deformation negligible (fig. 5).
- results in a ***thick and narrow wedge*** (fig. 4).

Viscoplastic wedge:

- Intermediate Moho T (low velocity = mainly viscous features (CT25-1), high = mainly plastic features (CT25-10).
- Combination of the plastic and viscous wedges, ***strain localization in the upper crust,*** *and* ***viscous deformation in the lower crust*** (fig. 5).

Conclusions & future work

- **Strain localization and shear zone development dependent on the thickness of the viscous lower crust (fig. 5).**
- The **viscous layer thickness** is a product of the **crustal rheology, geotherm** and **convergence velocity**, that influence strain rates, as these are all components of the non-linear dislocation creep rheology.
- Plastic, viscoplastic and viscous wedges accommodate convergence differently. This can be seen by the aspect ratio ($\frac{\lambda_c}{\Delta h}$).
- **Plastic** – grows in mainly in thickness (low $\frac{\lambda_c}{\Delta h}$)
- **Viscoplastic** – grows in both thickness and lengthens (intermediate $\frac{\lambda_c}{\Delta h}$).
- **Viscous** – predominantly lengths (high $\frac{\lambda_c}{\Delta h}$).

Future work:

- Assess how you accommodate ~2700 km with varying velocity over time (the Himalayas)[7,8].
- The 3D evolution of orogenic margins, with insights into escape tectonics & lower crust channel flow (viscous lower crust?).

@CloseToTheWedge

Underworld

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