# The Gibraltar slab dynamics and its influence on past and present-day Alboran domain deformation: Insights from thermo-mechanical numerical modelling

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## 1. Introduction

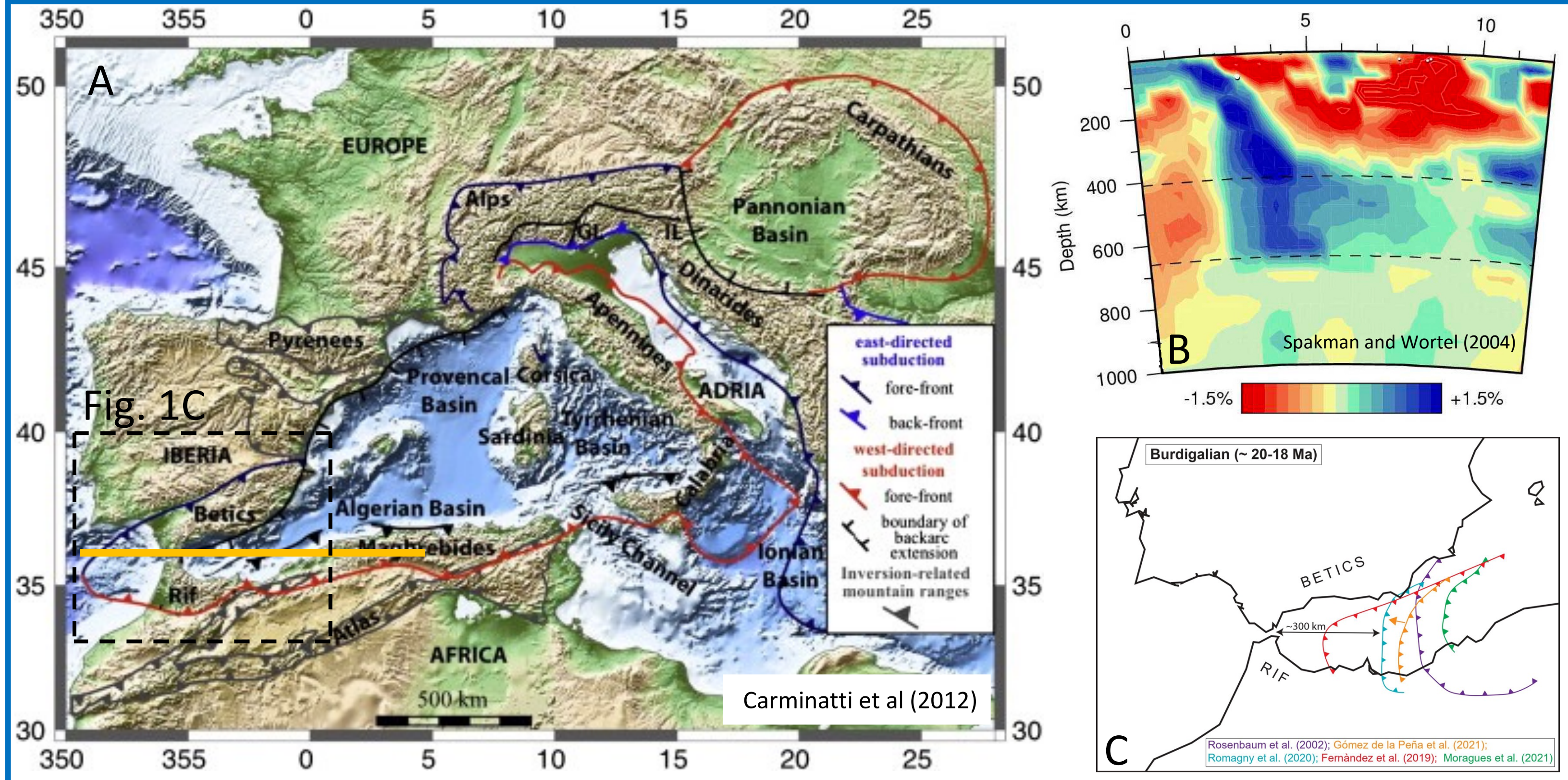


**Figure 1.** (A) Simplified present-day geodynamic scenario of the Central-Western Mediterranean region. Modified after Carminatti et al. (2012). The orange line shows the location of the modelled vertical section in this work. (B) Tomographic cross section (% Vp anomaly) along a similar W-E profile to that of the orange line in Fig. 1A. Taken from Spakman and Wortel (2004). (C) Sketch showing the subduction front at Burdigalian times based on different works (Rosenbaum et al., 2002; Fernàndez et al., 2019; Romagny et al., 2020; Gómez de la Peña et al., 2021; Morages et al., 2021).

### Research questions

**1. How has slab rollback affected the deformation of the overriding plate (OP) and the crustal and lithospheric structure?**

**2. To which degree is the Gibraltar Arc subduction system presently active?**

- We use a two-dimensional model (cross section given by the orange line in Fig. 1A) to simulate the evolution of the slab over the last 20 Myr and to improve the comprehension of the past and present-day Alboran domain deformation

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## 2. Methodology and model setup

- We use version 2.4.0-pre of the finite-element code ASPECT (Kronbichler et al., 2012; Heister et al., 2017; Bangerth et al., 2021a,b) to solve the conservation equations for mass, momentum and energy. We adopt a composite viscosity given by a combination of diffusion and dislocation creep

- The model setup (Fig. 2) simulates a vertical section at a latitude of about 36°N (orange line in Fig. 1) and emulates the situation of the Gibraltar slab at 20 Ma

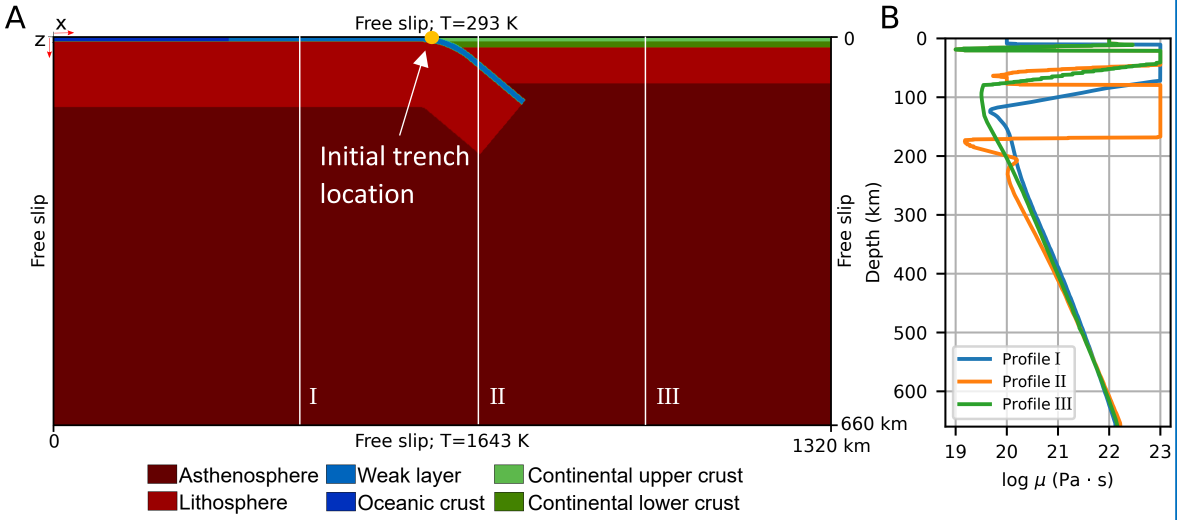


**Figure 2.** (A) Model setup with dimensions and boundary conditions. Each colour represents a different material. The temperature is fixed to 293 K at the top boundary and 1643 K at the bottom boundary. All boundaries are free-slip. White lines show the profiles for which the viscosity is displayed. (B) Viscosity profiles at different distances in the model domain.

## 3. Results

### Model evolution

- We have a two-phase evolution:
  1. A fast trench retreat phase in which the slab retreats about 300 km westward
  2. A locked trench phase in which the slab is stalled in Gibraltar

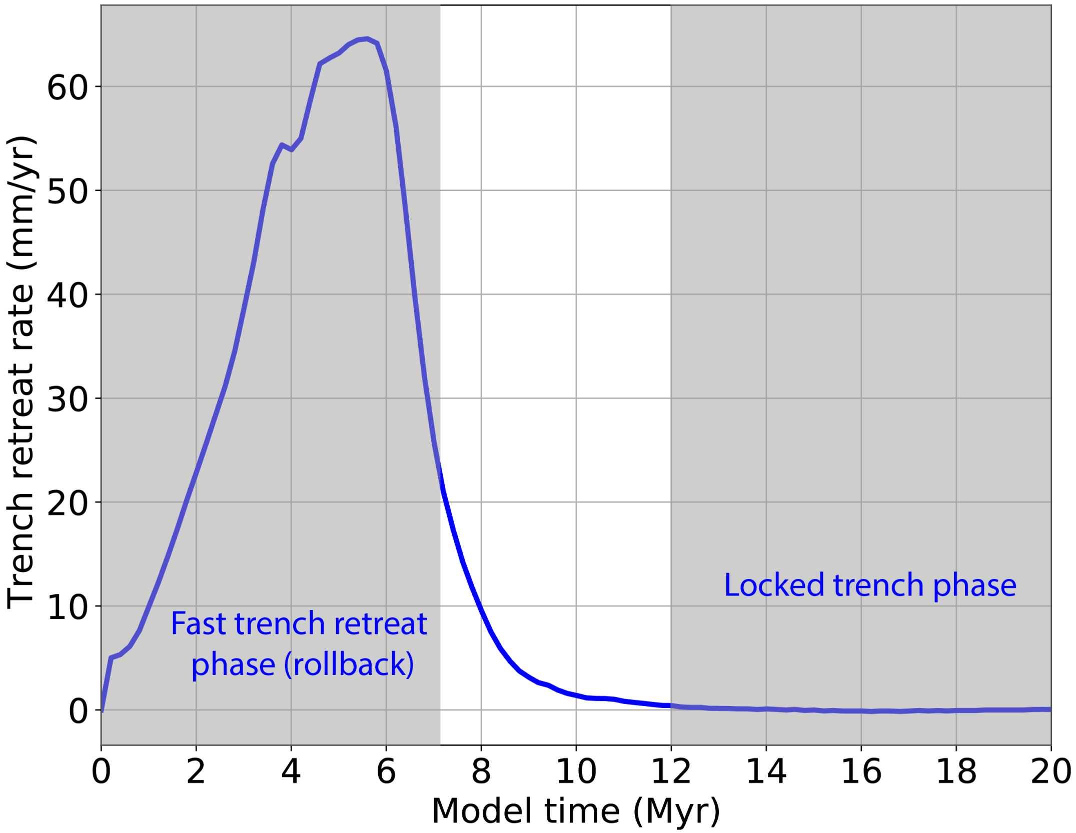


**Figure 3.** Trench retreat rate as a function of time showing the two evolutionary phases of the model.

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# 3. Results

## Model evolution

video

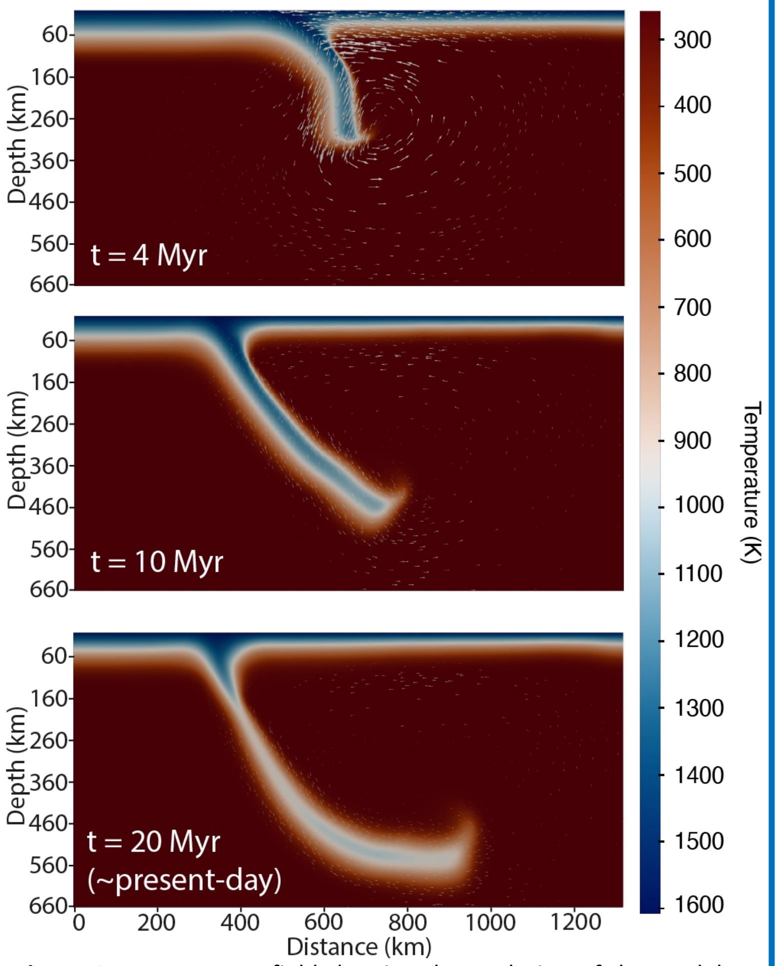


**Figure 4.** Temperature field showing the evolution of the model. Snapshots are shown for 4, 10 and 20 Myr of model evolution. White arrows show the velocity field.

- The slab initially subducts near-vertically and retreats rapidily westward. This process of slab roll-back generates extensional stresses in the entire OP (Fig. 5A)
- The rate of slab roll-back starts to decrease after ~8 Myr of model evolution and the slab stagnation in the Gibraltar region occurs at ~10-12 Myr (late Tortonian). Because of this, compresional stresses develop in the OP near the trench (Fig. 5B)
- From that time onwards, there is coexistence of compression near the trench and extension on the fixed side of the OP (Fig. 5B)

video

## Overriding plate deformation

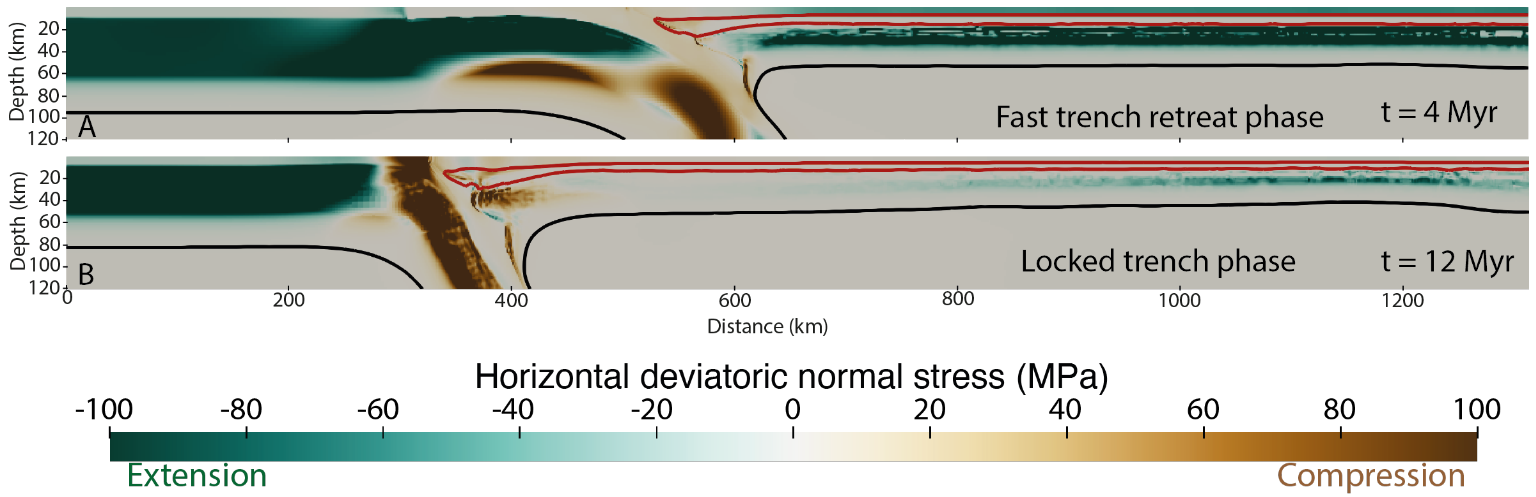


**Figure 5.** Horizontal deviatoric stresses in the subducting and overriding plate after 4 and 12 Myr of model evolution. Positive values (brown) indicate compresional stresses and negative values (green) indicate extensional stresses. Red contours outline the lower crust of the OP. Black lines show the 1400 K isotherms.

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# 3. Results

## Crustal and Lithospheric structure

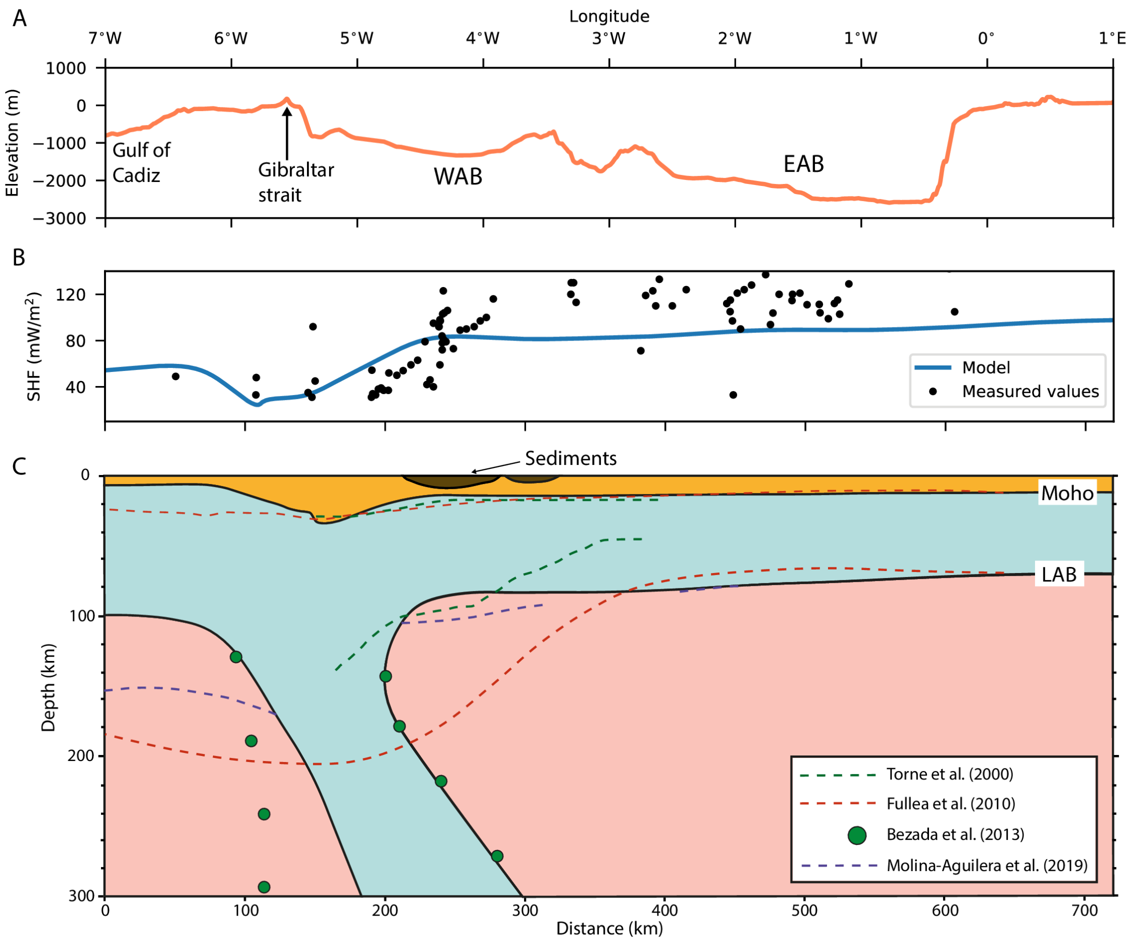


**Figure 6.** (A) Elevation of the area. (B) Surface heat flow derived by our model (line) compared to the measured values (dots). (C) Crustal and lithospheric structure resulting from our model. Dashed lines show the Moho depth and the LAB from previous studies. Green dots show the Gibraltar slab location imaged by Bezada et al. (2013).

- Our model reproduces the overall pattern of an eastward increase of the surface heat flow in the WAB (from ~40 $mW/m^2$ to from ~100 $mW/m^2$) and a fairly constant heat flow in the EAB (Fig. 6B)
- The crustal and lithospheric structure resulting from our model is roughly in agreement with previous works. We obtain a steep thinning of the crust from the Gibraltar Arc (~35 km) towards the WAB (~15 km) (Fig. 6C)
- The main crustal and lithospheric deformation occurred during the Miocene and there has been only moderate deformation since ~8 Ma
- Slab pull and mantle flow interacting with the lithosphere are first-order drivers of crustal behaviour, although other features such as the NW-SE relative plate convergence may also play a role

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# 3. Results

## Alboran domain deformation driven by slab rollback

- The extension is generated by the increase of the horizontal mantle flow at the base of the OP in the trench direction (Fig 7A)
- The compression near the trench is a result of a change in the style of the mantle flow (Fig. 7B), which drags the OP into the trench at a faster rate than the trench retreats, causing compressional stresses

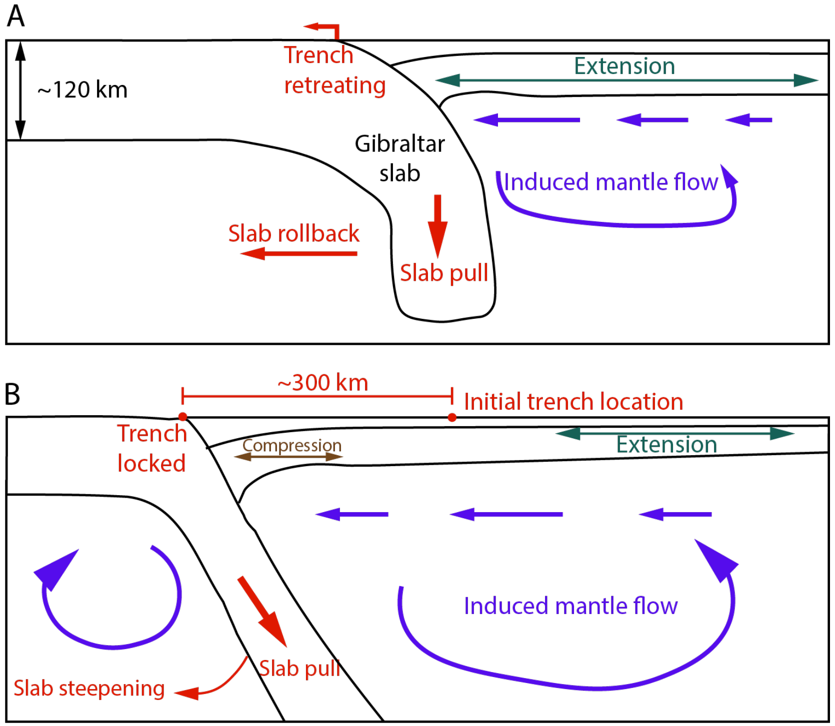


**Figure 7.** Cartoon showing the two stages of the OP deformation and the main processes involved. (A) Extension of the entire OP during the phase of fast slab rollback. The extensional stresses are generated by the increase of the horizontal mantle flow at the base of the OP in the trench direction. (B) Coexistence of compression and extension in the OP when the slab rollback has ceased. Compression near the trench occurs because the mantle flow drives the OP towards the SP at a faster rate than trench retreats.

For any ideas or suggestions, please do not hesitate to contact me

# 4. Take-home messages

- The cessation of slab rollback at Miocene times (~8 Ma) produced a change in the induced mantle flow beneath the OP that resulted in compresional stresses near the trench and extension to the east of the Alboran domain
- Although the trench retreating may have stopped, the deep sinking of the slab still generates induced mantle flow that produces a basal shear traction in the direction of the slab, as suggested by Neres et al. (2016)
- The slab pull and the slab-induced mantle flow are first-order drivers of crustal behaviour. We find that there has been only moderate deformation since ~8 Ma

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**Acknowledgements:** This work was funded by Spanish national projects PID2019-109608GB-I00/AEI/10.13039/501100011033 and the Andalusian regional project A-RNM-421-UGR18. We thank the Computational Infrastructure for Geodynamics (geodynamics.org) which is funded by the National Science Foundation under award EAR-0949446 and EAR-1550901 for supporting the development of ASPECT.



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