On the evolution of Subduction-Transform Edge Propagators (STEPs): consequences for the Calabrian arc

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Introduction

The Subduction-Transform Edge Propagator (STEP) fault is defined as a plate boundary that eventually arises in the wake of the STEP, between the overriding and subducting plates (Baes et al., 2011). At the STEP, mechanical properties control the ease at which lithospheric tearing may occur. Since Govers and Wortel (2005) drew attention to the nature and quantitative implications of STEP faults, it has been the subject of ongoing study and discussion.

In the case of the retreating Calabrian trench system, a STEP is considered to have propagated along the North African margin since the Middle Miocene (Wortel et al., 2009). The location of the present-day STEP near Sicily is still a matter of debate with three options: 1) along the Malta Escarpment (ME) (Govers and Wortel, 2005), 2) along the Etna-Alfeo line at a 150° N strike (Gallais et al., 2013) or 3) along-strike the Ionian fault (Polonia et al. 2011).

The purpose of this work is to predict the propagation direction of STEP faults and to determine the influence of passive margins in steering STEPs, as these represent a strength contrast. For this purpose, we study a series of numerical models inspired by the Mediterranean geodynamics and predict the present-day location of the Calabrian STEP.

Regional setting of the central Mediterranean

In the early-middle Pliocene, slab detachment beneath central Italy was complete (van der Meulen et al., 2000) and the plate contact at the Calabrian trench was bounded on both ends by STEPs. At its western termination, the STEP has changed propagation direction, from ~E-W to ~NW-SE after the Pliocene.

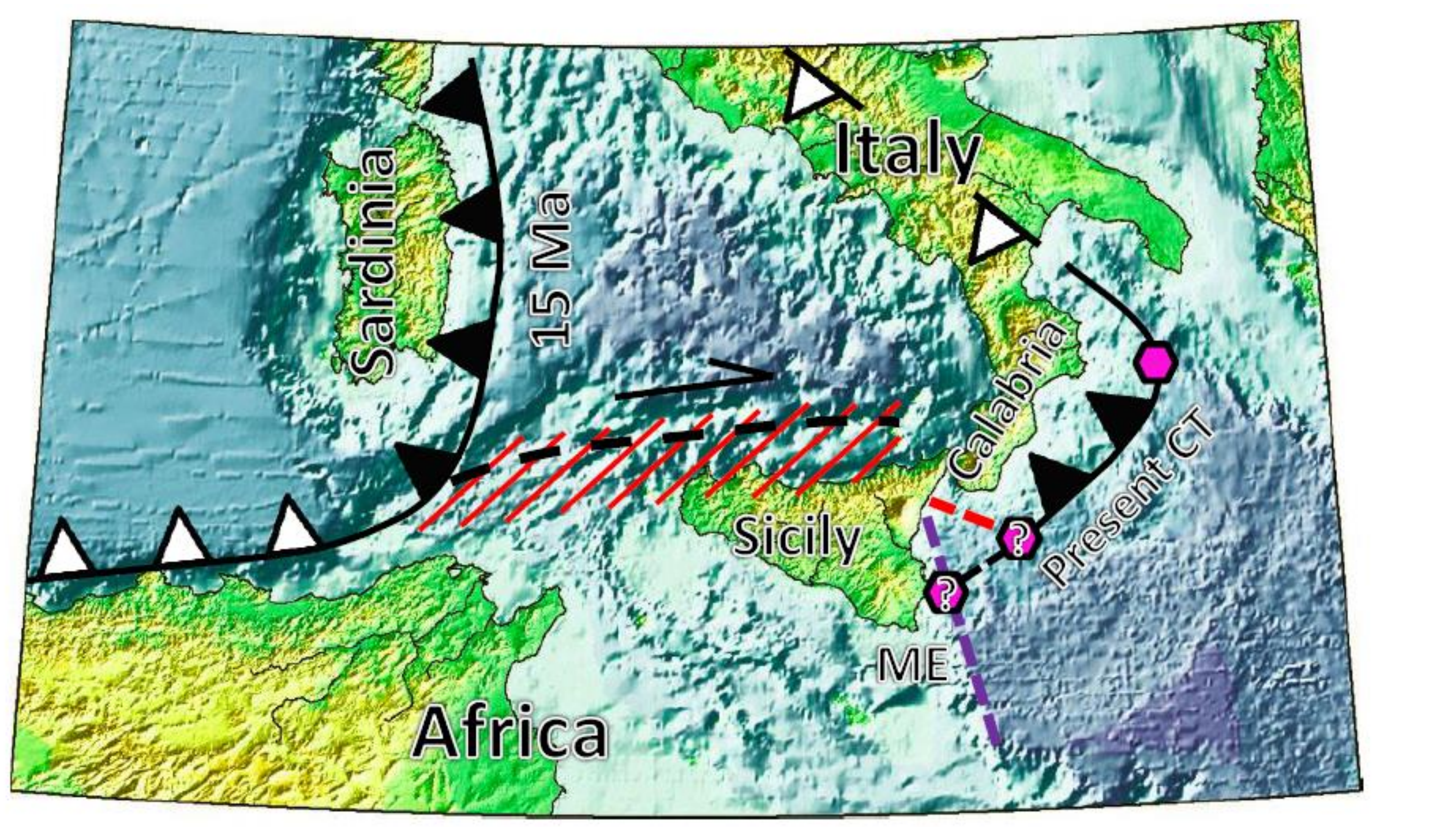


Fig. 1 Regional topographic/bathymetric map with the location of the plate boundary in the western-central Mediterranean in the Langhian (~15 Ma) and at Present. CT = Calabria Trench, ME = Malta Escarpment. White dents indicate slab detachment, black dents indicate continuous slabs. The exact location of the transition from detached towards continuous slab in Southern Italy is uncertain. The STEP fault is shown as a deformation zone, with an overall dextral sense of shear. Pink hexagons indicate the (possible) presence of STEPs. Dashed purple line represents ME, dashed red line represents Ionian fault (Polonia et al. 2011). After Wortel et al. (2009).

Mediterranean model description and setup

Model setup (fig. 2) corresponding to the Early-Middle Pliocene (van der Meulen et al. 2000), where the trench is oriented according to the observed iso-depth contours (Selvaggi and Chiarabba, 1995).

A strength contrast is implemented through a viscosity contrast across the passive margin (P.M.).

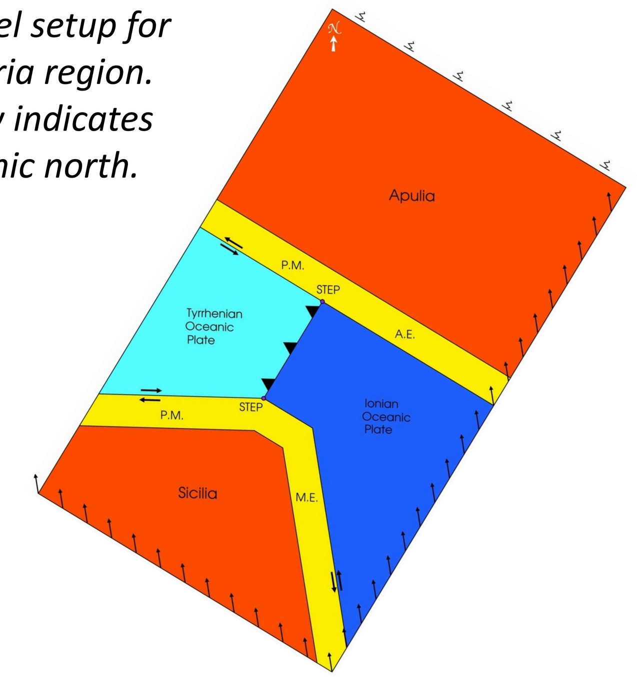
Both STEP faults and Malta Escarpment (M.E.) are considered low-friction, vertical faults modelled through the slippery node technique.

At the bottom of the Sicily and Ionian domains, Europe-Africa convergence velocity is imposed (3 mm/yr).

At the trench, slab pull tractions are pulling the Ionian basin towards the Tyrrhenian basin, while a trench suction force is pulling the overriding Tyrrhenian basin towards the Ionian basin (slab pull determined as in fig. 3).

Solve the mechanical equilibrium equations using GTecton software with plane stress approximation

Fig. 2 Model setup for the Calabria region. The arrow indicates geographic north.



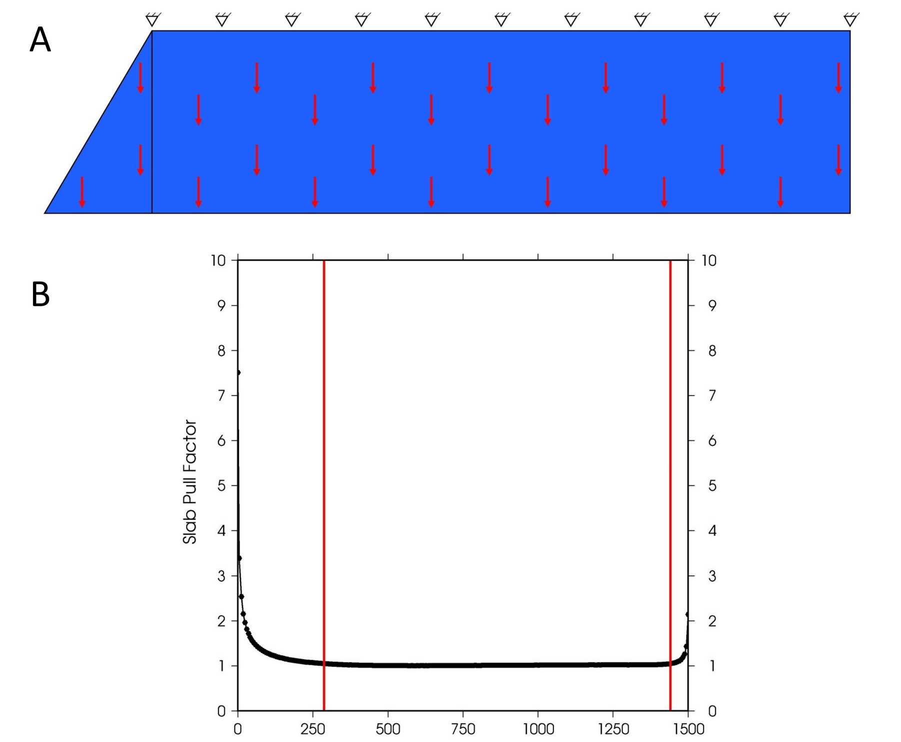
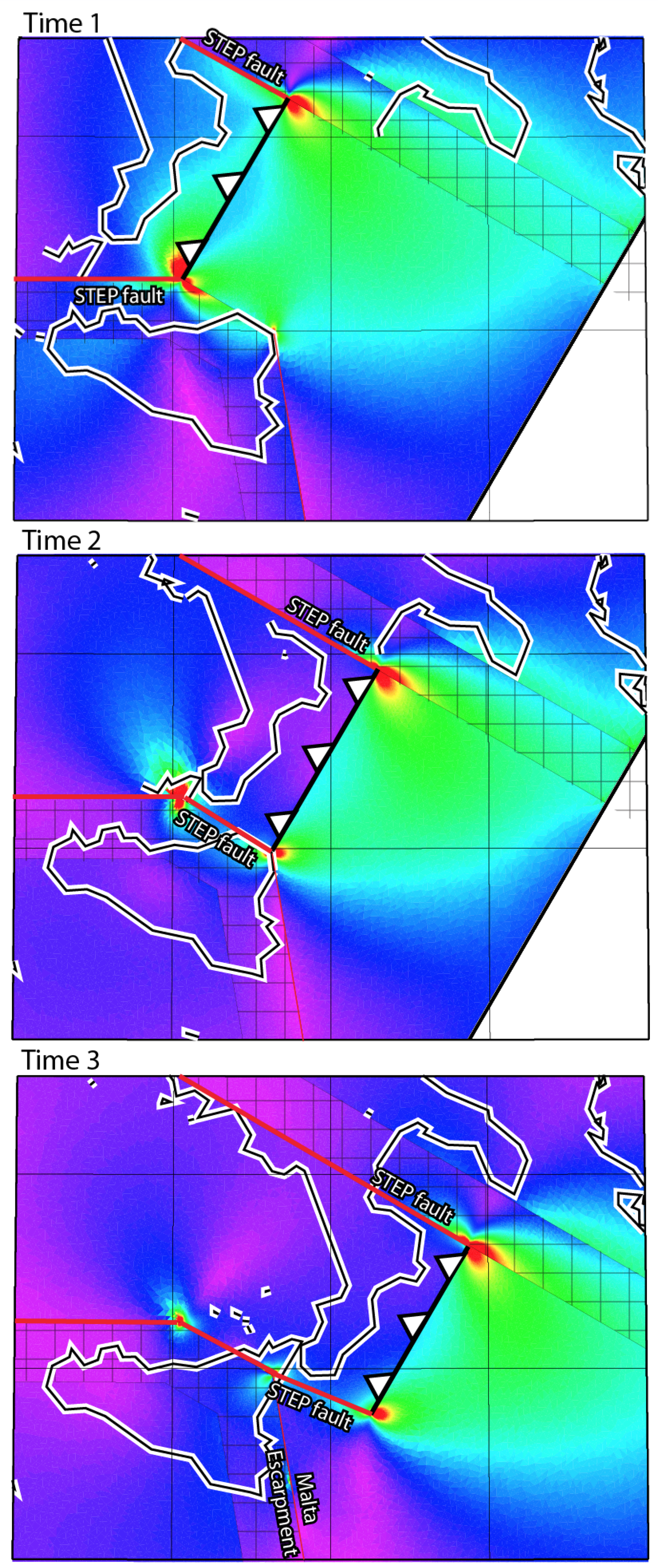


Fig. 3 Model A) setup and example of B) slab pull transmission along-strike a trench (in km).



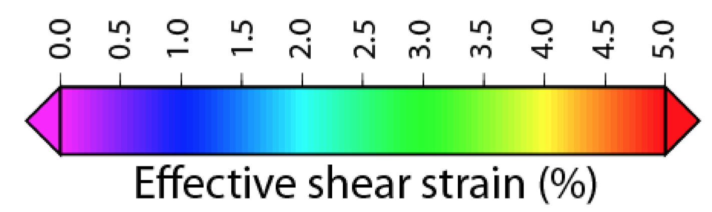


Fig. 4 Effective strain results in the area surrounding the trench and STEPs. Time 1 corresponds to the Early-Middle Pliocene (van der Meulen et al., 2000), Time 3 to the present-day setting. Time 2 is an intermediate stage in rollback evolution. Black and white triangles indicate the end of the Ionian plate contact, which does not correspond to the surface cutting fault. The Calabrio-Peluritan block is traced on the overriding plate. Red lines indicate the STEP-faults, cross-hatched regions are passive margins.

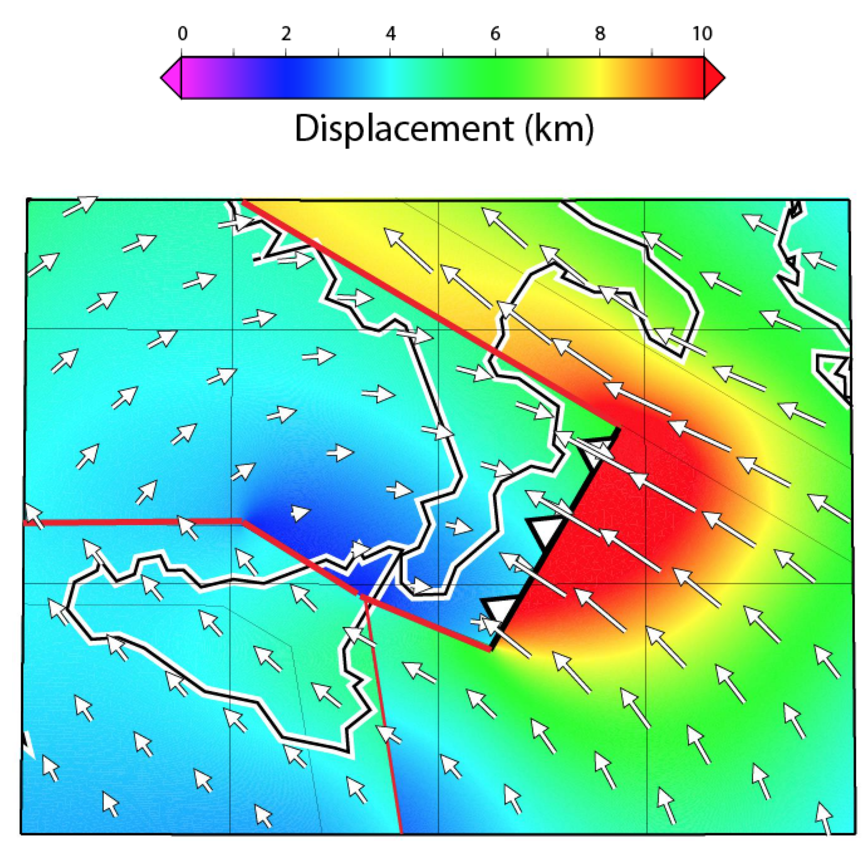


Fig. 5 Total displacement field at Time 3. Arrows indicate velocity field. Modelled velocities are with respect to stable Europe, largest arrow corresponds with a velocity of nearly 1,0 cm/yr. Thick red lines highlight STEP faults, thin red line the Malta Escarpment. Dents show subduction direction.

Mediterranean model results

At Time 1, strain localizes ahead of both (active) STEPs along the passive margin-ocean interface: the Calabrian STEP is guided towards the ESE along the edge of Sicily.

At Time 2, the Calabrian STEP reached the northern termination of the Malta Escarpment. The pattern of strain localization indicates that the STEP will propagate to the ESE into the Ionian basin.

In the present-day situation of Time 3, the STEP has propagated further into the Ionian basin towards the present-day subduction contact. Dextral slip rate along the Malta Escarpment is <2 mm/yr. In the non-subducting part of the Ionian domain and the passive margins, compressive stresses are observed.

Comparison with field data

Polonia et al. (2011) show that the Calabrian accretionary wedge is segmented along-strike the trench into two distinct lobes. The eastern lobe shows higher shortening rates and more complex deformation patterns when compared to the western lobe.

The amount of convergence in the models is largest across the trench, corresponding to the eastern lobe of the accretionary wedge. In the non-subducting part of the model, the horizontal velocity gradient is smaller and more variable in direction This part corresponds to the western lobe of the accretionary wedge.

The small amount of slip along the Malta Escarpment may be enough to explain observed seismicity

Observed compressive stresses along the passive margins may explain seismicity associated with onset of subduction and inversion tectonics.

Conclusions

Through our models, we predict the location of the present-day Sicilian STEP in the Ionian basin, along-strike the Ionian fault. With the critical taper theory in mind, the two separate lobes of the accretionary wedge can be understood through a contrast in the basement velocities. The western lobe of the accretionary wedge can then be considered to have resulted from the propagation of the STEP, as an edge effect.

References

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