Link between upper and lower plate deformation in the Tyrrhenian domain

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INTRODUCTION

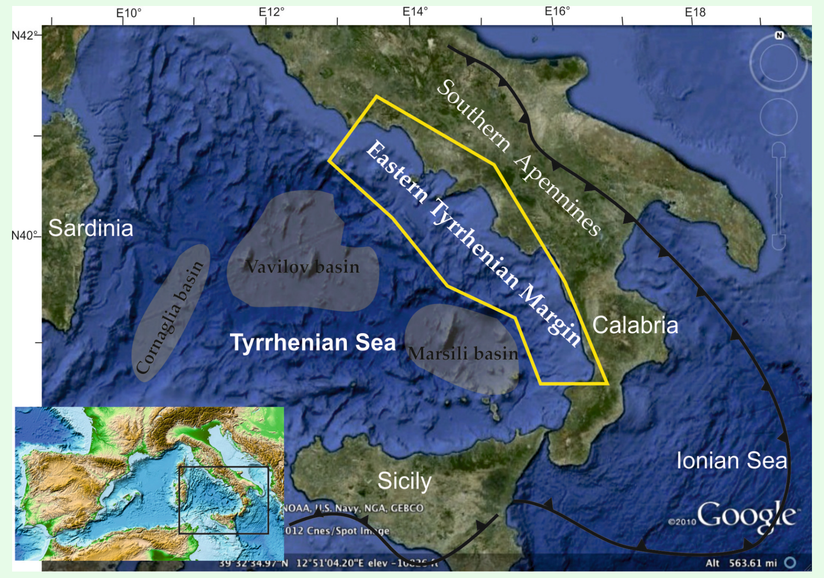
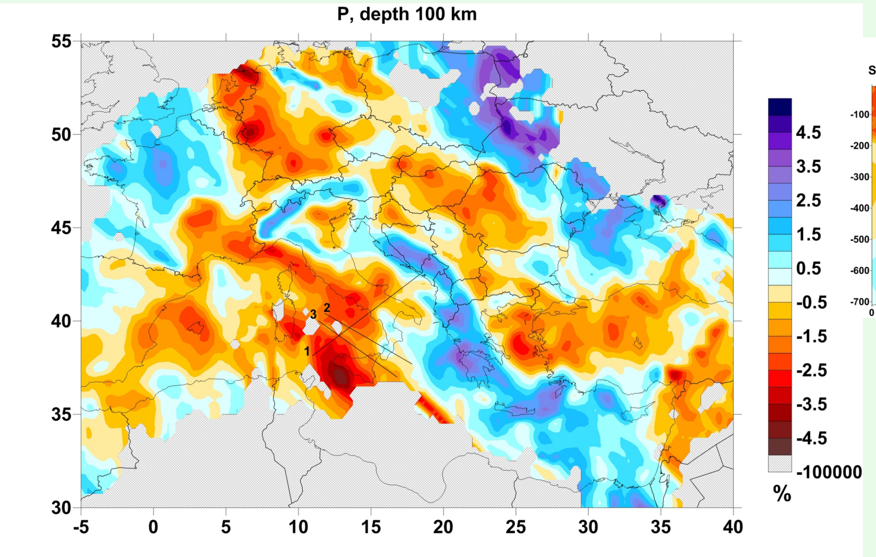


Fig. 1.

The Tyrrhenian Sea is the youngest backarc basin of the Western Mediterranean linked to development of the Ionian subduction zone (Fig 1). The Eastern Tyrrhenian Margin (ETM) is characterized by the opening of the youngest sedimentary basins (Gaeta Bay Basin, Naples Bay Basin, Salerno Bay Basin, and Paola Basin) and fault activity. Studying the tectonic Quaternary evolution of the ETM greatly improves our understanding of the geodynamics of the Central Mediterranean, since it records the mode of extension of a backarc migration toward the continental area and is located in correspondence of the northern boundary of the Ionian subducting plate.

The stratigraphic and tectonic study of the sedimentary basins located on the upper plate provides constraints on the timing and duration of the rifting phases and overall geometry of rift basins that evolve in response to the subducting slab dynamics. Within this frame, the analysis of these sedimentary basins gives fundamental constraints on the reconstruction of the geodynamic evolution and clarifies the relationships between deep and shallow structures in convergent regions.

Seismic tomography studies of the central Mediterranean (e.g. Wortel and Spakman, 2000) revealed an extended high-velocity zone, interpreted as the subducting Adriatic and Ionian slab (Fig. 2). The continuity of the Adriatic slab is interrupted in correspondence of the southern Apennines, as observed from the low velocity anomaly located in the uppermost mantle. The existence of a gap in the structure of the subducted slab is interpreted as a slab detachment. Wortel and Spakman (2000) and Govers and Wortel (2005) hypothesized a lateral migration of the slab detachment due to tears formation. These authors suggested that the slab edges correspond to Subduction Transform Edge Propagator (STEP) faults, characterized by a very specific time-space evolution in the upper plate deformation.



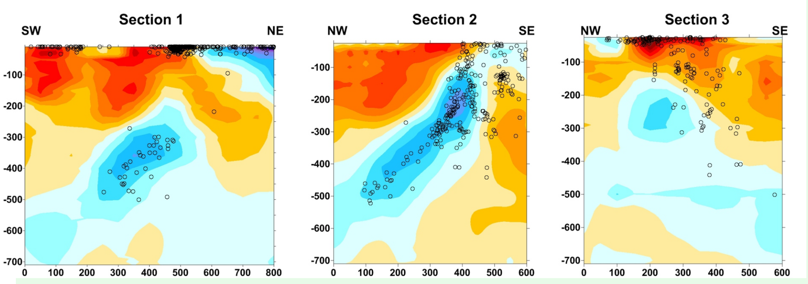


Fig. 2. P-wave velocity anomalies at depth of 100 km and along 3 vertical cross-sections of the seismic tomography model of Koulakov et al.(2009). Black open circles in sections represent the distribution of earthquakes from the USGS catalogue (http://earthquake.usgs.gov/earthquakes/search/) at distances less than 50 km from the cross-sections.

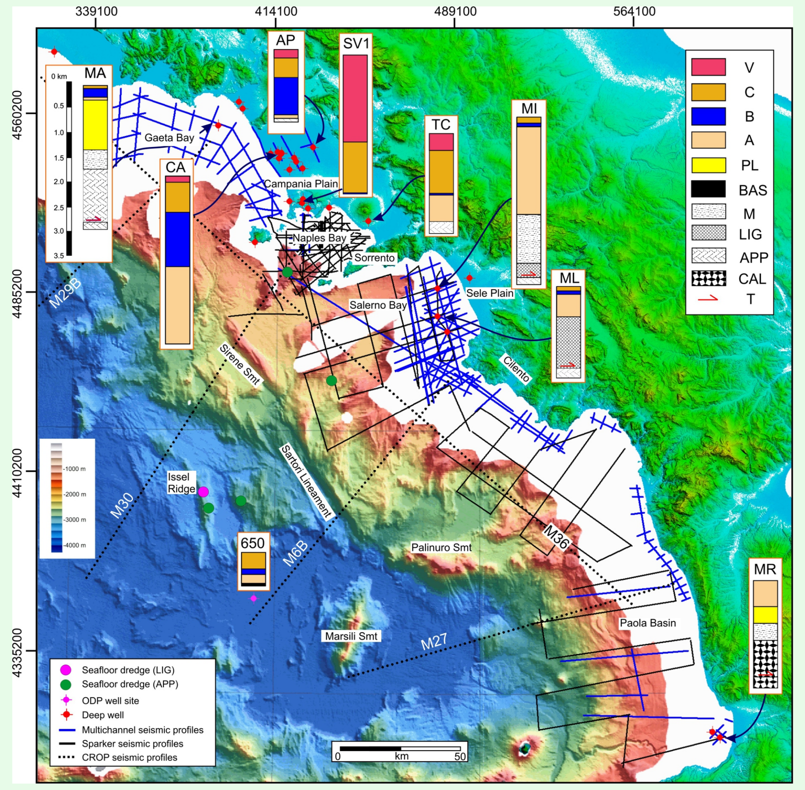


Fig. 3. Index map of seismic grid, stratigraphic successions of deep wells, and seafloor dredges of the eastern Tyrrhenian margin. Multibeam map of the Tyrrhenian Sea from Marani et al. (2004). CAL=Calabride units (Paleozoic), LIG=Liguride units (Cenozoic), APP=Appennine platform unit (Meso-Cenozoic), M=Miocene rocks, PL=Pliocene rocks, BAS=basalts, A=Unit A, B=Unit B, C=Unit C, V=volcanics (Quaternary), T=thrust fault.

DATA AND METHODS

We construct a 3-D model of the Plio-Quaternary basin's substrate of the ETM through the interpolation of close and regularly spaced 2D seismic reflection profiles, integrated and calibrated with borehole data. This study has been carried out using a seismic and borehole dataset and a Geographical Information System (GIS) software (Kingdom, IHS Inc.), which constructs a 3D representation of a geologic volume at depth. The study includes the following steps: a) collection of all the available seismic profiles and boreholes data; b) implementation of a GIS geological data base; c) interpretation of the seismic profiles and calibration of the seismic unit using well-log data; d) construction of 2D and 3D models of the subsurface. A total of 6000 km of seismic lines and data from 25 wells has been collected in the study area (Fig. 3). We use seismic reflection profiles with different resolution and penetration: multichannel seismic profiles, CROP seismic profiles and Sparker data (MEAS). We interpret the seismic data-set using the seismic stratigraphy method: seismic units are groups of seismic reflections, whose parameters (configuration, amplitude, continuity, and frequency) differ from those of adjacent groups. Sedimentary units are delineated on the basis of contact relations and internal and external configurations.

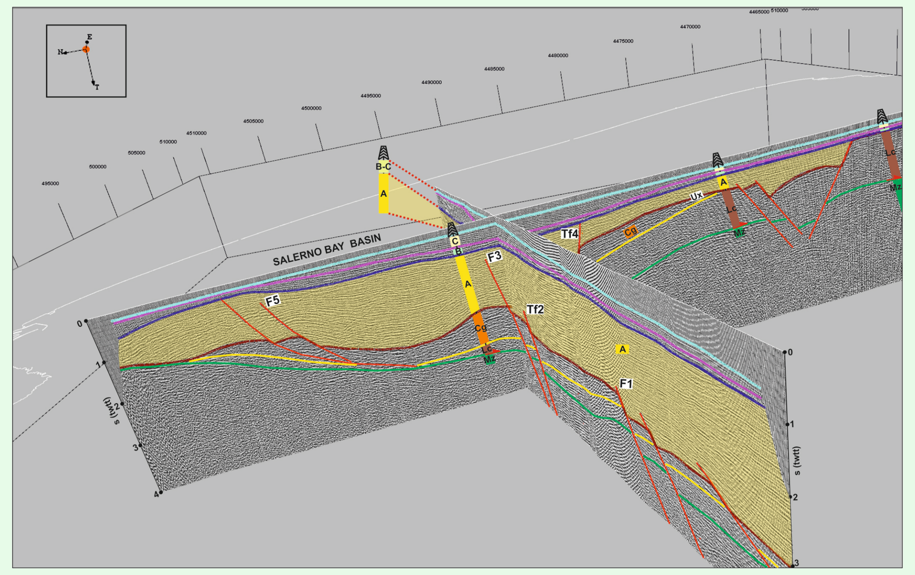


Fig. 4. Interpreted seismic sections calibrated by well logs, showing the stratigraphic infill of the Salerno Bay Basin (units A, B, C), overlying the acoustic substrate (units Cg, Lc and Mz). Normal faults (F1, F3, F5) and transfer faults (Tf2, Tf4) are also shown.

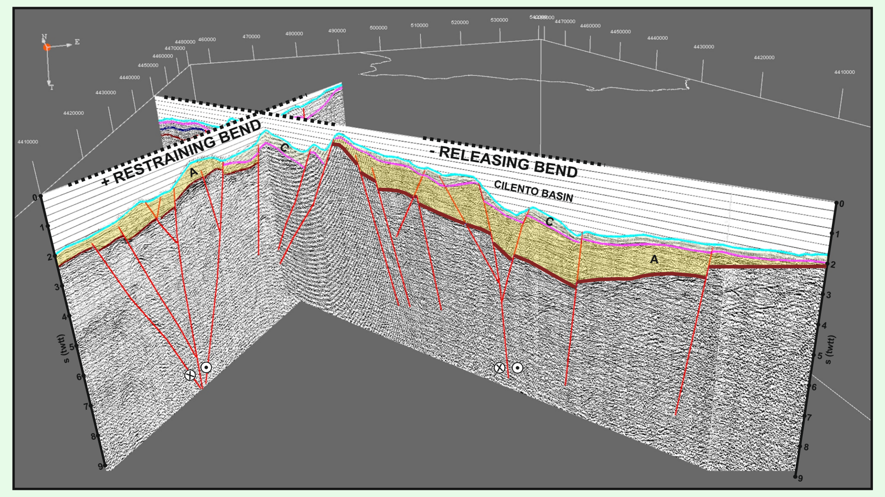


Fig. 5. Interpreted seismic sections CROP showing the whole stratigraphic succession affected by folding and a wide deformation zone, approximately trending E-W. This deformation zone corresponds to a restraining band and a releasing band of a strike-slip fault zone affecting the basement. It is possible to recognize positive structural inversion, characterized by folds and flexural arching, and negative flower structure.

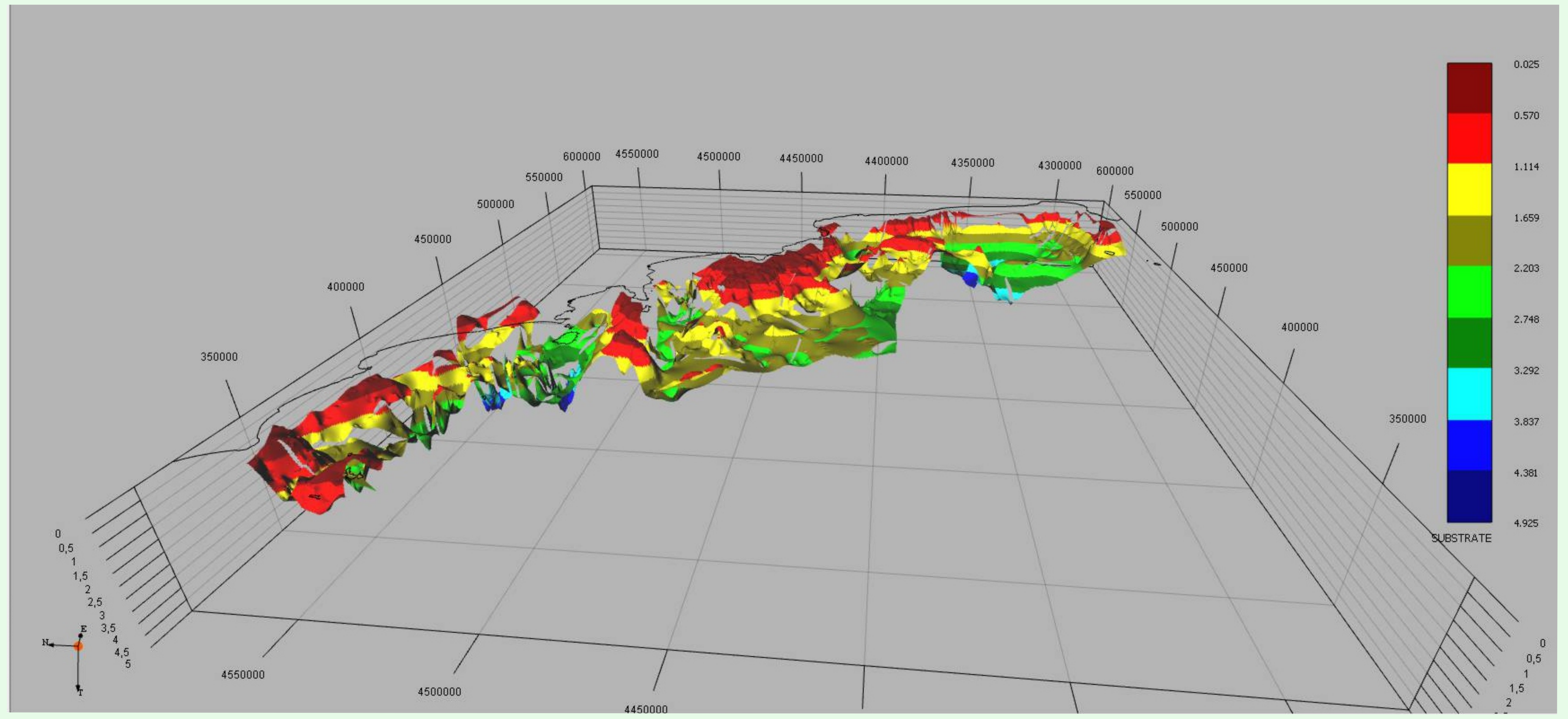


Fig. 6. The 3-D model of the substrate along the ETM reveals a complex architecture due to the occurrence of several fault sets (NW-SE, NE-SW, E-W and NNE-SSW). The substrate presents several structural depressions with associated basins up to 5/6 km-deep.

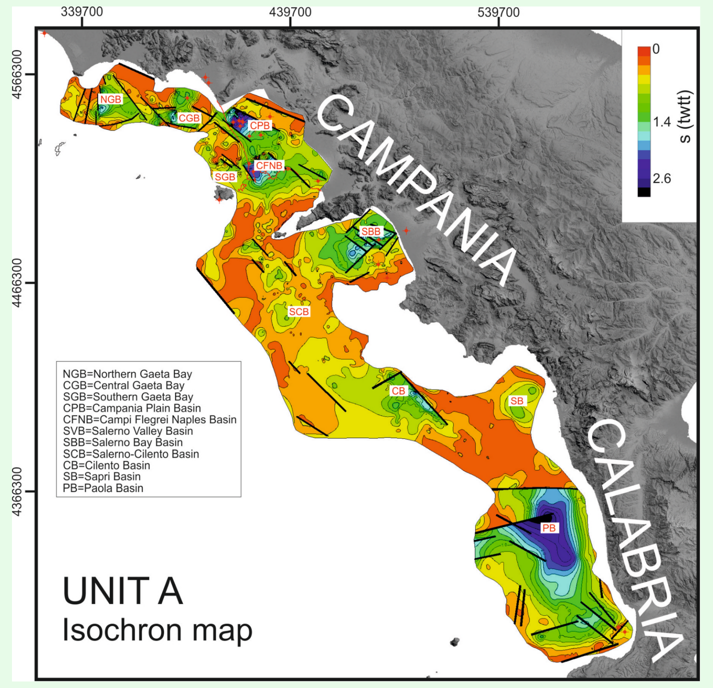


Fig. 7

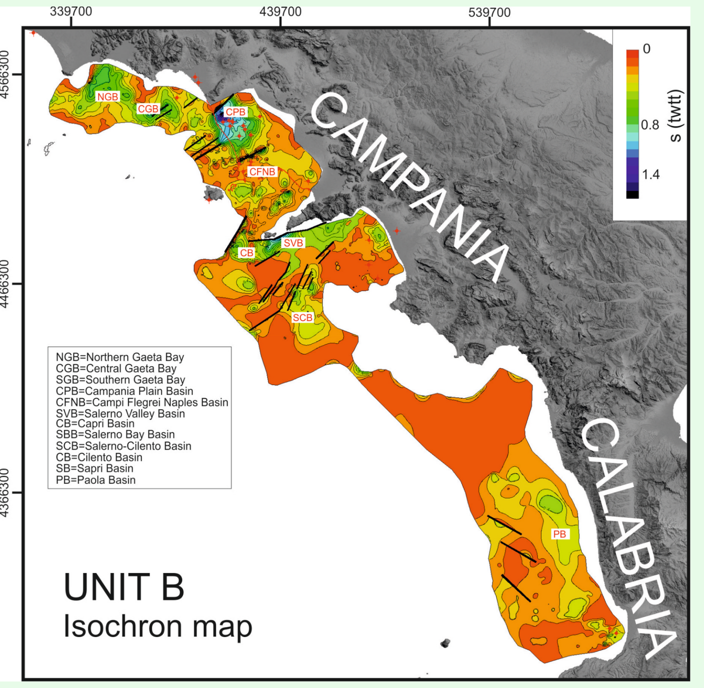


Fig. 8

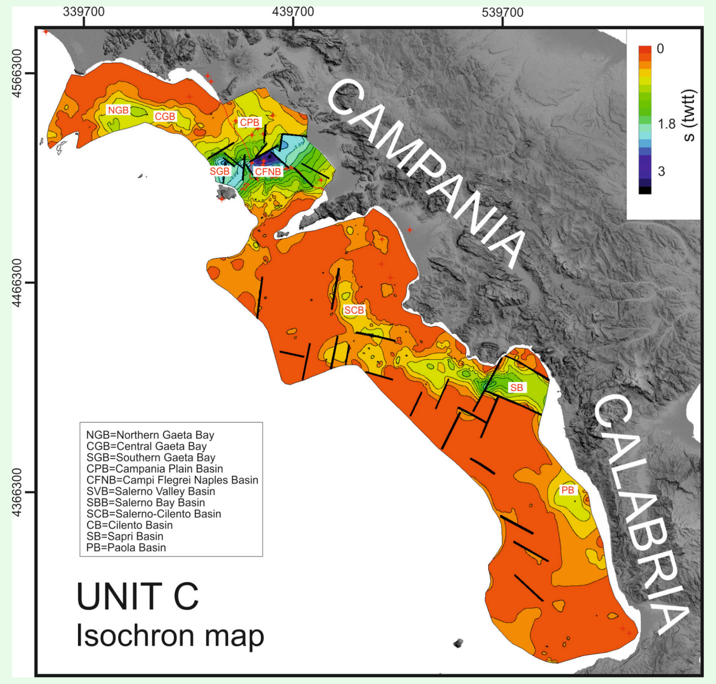


Fig. 9

RESULTS

We map the pre-Quaternary substrate and three stratigraphic units (A, B, C) of the basin infills for 350 km along the ETM, to establish a coherent chronostratigraphic framework across the sedimentary basins and build a 3D model of the study area.

The recognition of the syn-kinematic strata in the basin infill and analysis of the interplay between stratigraphic horizon and faulting enabled us to assign an age to fault activity in the Eastern Tyrrhenian Sea. We divide the fault structures into three groups (Fig. 10) according their age: Lower Pleistocene structures, Early Middle Pleistocene structures, Late Middle Pleistocene-Present structures.

The interpretation of the seismic data reveals a complex fault pattern along the ETM due to a poliphased tectonic evolution. The 2-D and 3-D models of stratigraphic surfaces, faults and isochron maps of the stratigraphic units reveal that the major faults bounding the basins correspond to normal faults and strike-slip transfer faults (Figs. 4-9). The process of lithospheric extension within the Eastern Tyrrhenian Sea produced tilted blocks/half grabens (sensu Wernicke and Burchfiel, 1982). We also recognize in the ETM positive inversion structures (Fig. 5), documented by the changes of structural relief from previous lows (indicated by thick deposits) to highs (indicated by flexural arching or uplift).

UPPER PLATE QUATERNARY EVOLUTION

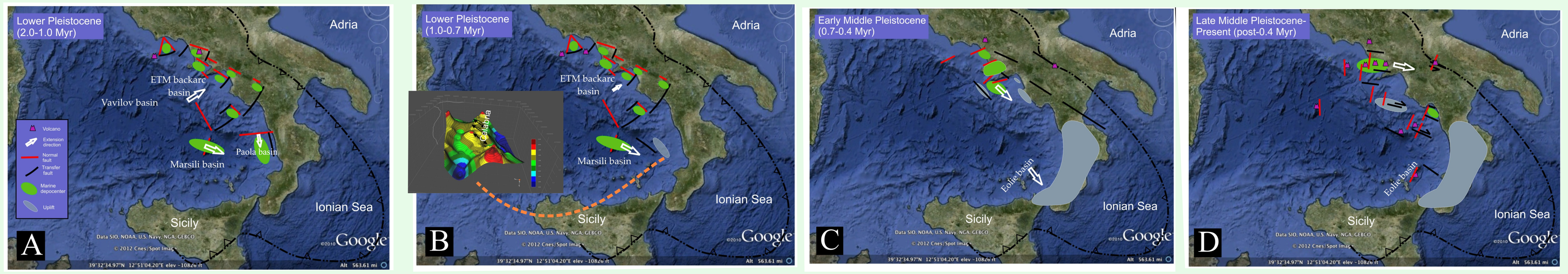


Fig. 10. Kinematics of the Tyrrhenian backarc basin during Quaternary, modified from Milia et al. (2013).

During the Lower Pleistocene extensional tectonics affected the entire ETM and the western flank of the Apennines, creating several basins (Fig. 10a): NW-SE normal fault formed along the ETM (offshore and onshore). NE-trending and E-W normal faults developed, in the Marsili and Paola basins, respectively. These three contemporaneous extension directions follow Martin's double-saloon-door model (2006): the Campania margin and Marsili basin approximately match with the two arc-parallel rifts and the Paola basin with the rift orthogonal to the subduction zone. During this stage rapid counterclockwise rotations affected the hanging wall of the active thrust sheets along the outer front of the Apennines (Mattei et al., 2004).

In the late Lower Pleistocene (1.0-0.7 Ma; Fig. 10b) there was a change in the structural pattern: extensional faults continued their activity in the Campania Margin, Marsili basin, and western flank of the Apennines, while en echelon folds, linked to a NW-SE left-lateral transfer zone, formed in the Paola basin (the inset shows the 3D model of the 1.0 Myr surface). The activity of this transfer zone could be related to a higher speed of the Marsili basin opening compared to that of the ETM.

In the Early Middle Pleistocene an abrupt change of direction of extension (from NE-SW to NW-SE) in the ETM occurred (Fig. 10c). This change can be linked to the change of direction of the tectonic transport (from NE to SE) of the southern Apennines thrust belt (Patacca et al., 1990). The extensional basins related to this stage correspond to underfilled half grabens of the Campania margin. During that time, NW-SE left lateral strike slip faults in the Apennines (Catalano et al., 2004; Schiattarella et al., 2005) and NW-SE transfer zones in the ETM were active. These transfer zones were affected by uplifts and inversion structures.

In the Late Middle Pleistocene to Present extensional basins and transfer zone formed (Fig. 10d). Intense volcanism and eastwards migration of the extension was recorded in the Northern Campania Margin. NNE-trending normal faults developed in the ETM and Apennines and this extensional pattern is coherent with the migration of the Calabrian accretionary prism toward E-SE. During this tectonic stage, a NW-SE transfer zone, featuring restraining and releasing bends, formed at the southwest border of the ETM.

LINK BETWEEN UPPER AND LOWER PLATE DEFORMATION

The deformation features of the upper plate in correspondance of the ETM are not consistent with the current rifting models. We hypothesize a link between the evolution of upper plate and subducting slab. The proposed geodynamic scenario (Fig. 11) is characterized by the formation of extensional basins in the upper plate and onset and development of a STEP (Subduction-Transform-Edge-Propagator) fault along the northern margin of the Ionian slab.

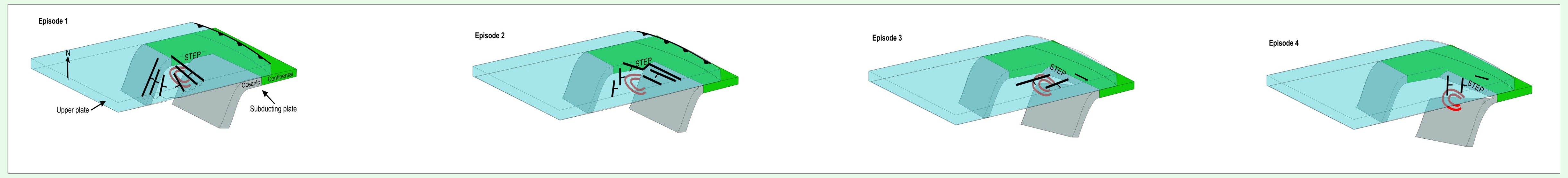


Fig. 11. Sketch showing the hypothetical plate configuration, the rifting structuresand the pattern of toroidal mantle flow (red lines) in the ETM over the last 2 Ma, modified from Milia and Torrente (2015).

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