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Investigating slab edge kinematics through seismological data: The northern boundary of the Ionian subduction system (south Italy)

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ABSTRACT

An integrated analysis of seismotomography models, earthquake spatial distribution and focal mechanism solutions has been performed in the still poorly constrained region marking the northern boundary of the Ionian subducting slab (south Italy). In this area, research findings related to the continuous-vs detached-slab transition are diffused on a wide sector running from central Calabria to the southern Apennines tip and different locations of a subduction-transform edge propagator (STEP) have also been proposed in the recent literature. We present seismic data and analyses aimed to investigate the location of the northern edge of the in-depth continuous slab and the present-day kinematics of the concerned boundary region by also focusing on the possible clues of STEP fault activity. We used both standard linearized and non-linear probabilistic methods to locate, in a recently developed shallow-to-intermediate 3D velocity model, the seismicity that occurred between 1997 and 2012 at the Ionian slab northern boundary. Earthquake kinematics have also been investigated by integrating high-quality focal mechanisms selected from the literature with 70 waveform inversion solutions obtained in the present study.

The results allow to identify in central Calabria the northern edge of the in-depth continuous slab and just north of it a ca. 100 km-wide deformation zone reflecting lateral STEP migration in the slab edge area. The migration likely indicates an alternation of tear propagation along a slab edge and slab break-off progressively reducing the lateral extension of the subduction zone. In this framework, the recent seismicity seems also to suggest the possible location of an incipient shallow slab break-off beneath central Calabria.

1. Introduction

Slab edge kinematics has been a primary topic of interest in the most recent literature concerning retreating subduction systems (see among others, Burkett and Billen, 2010; Clark et al., 2008; Duarte et al., 2013; Ely and Sandiford, 2010; Faccenda and Capitanio, 2013; Faccenna et al., 2014; Hale et al., 2010; Meighan et al., 2013b; Ruiz-Constán et al., 2011; Schellart et al., 2007, 2011; van Hunen and Allen, 2011; Wortel et al., 2009). In this framework, special efforts have been particularly devoted both to evaluate geophysical constraints in the slab edge area (see e.g., seismic deformation and anisotropy, GPS velocity fields, paleomagnetic data) and to quantitative modelling (through numerical and experimental simulations) the subduction system dynamics. Slab break-off or tearing may generally occur during a rollback process producing segmentations that differently mark the slab edge dynamics. Break-off or detachment usually refers to the rupturing of a subducting lithosphere while slab tearing is commonly used to describe a propagating tear in the subducting lithosphere that can be either vertical or horizontal (Rosenbaum et al., 2008). The progressive detachment of a retreating litospheric slab may lead to the generation of a vertical slab tear (also defined as subduction-transform edge propagator or STEP fault; Govers and Wortel, 2005) that laterally decouples the in-depth continuous subducting lithosphere from the already detached one in a scissor type of fashion. Propagation of vertical tears usually occurs at the edges of retreating subduction zones (e.g. at the continental to oceanic lithospheric transition) and/or when the rates of trench retreat change along strike (Govers and Wortel, 2005; Hale et al., 2010; Rosenbaum et al., 2008). Quantitative modelling highlighted, in particular, that at the slab edges the subduction system dynamics is strongly influenced by several factors mainly related to mantle flow dynamics, slab width and geometry

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and tear resistance at slab edges (Hale et al., 2010; Schellart et al., 2007, 2011). According to the numerical simulations by Govers and Wortel (2005) at the slab edge the subduction system may evolve (i) through a STEP fault propagation in a direction parallel to the same STEP orientation (similarly to the tearing of a sheet of paper) or, alternatively, (ii) through a slab break-off along an inclined plane cutting the slab itself if the resistance to STEP propagation is larger than the resistance to slab break-off. On this regards, Martin (2007) also suggested that if the subduction zone is progressively choked by further slab break-off, the STEP fault may migrate laterally towards the new edge of the continuous slab, producing at the slab edge an enlarged deformation zone where about sub-parallel systems reflecting the STEP lateral migration will accommodate strike-slip kinematics and block rotations induced by the rollback process.

In the present study we use earthquakes occurred in the Calabrian Arc region (Fig. 1) to investigate the kinematic processes occurring at the northern edge of the Ionian subducting slab. The Calabrian Arc region appears to be the only site of residual subduction rollback in the framework of a larger scale subduction process that has involved the western Mediterranean in the last tens of millions years (Fig. 1a). This is also one of the few sites (about a dozen all around the world) proposed as good candidates to study the STEP-wise evolution (Wortel et al., 2009). Several efforts have been made to investigate both the overall characterization of the residual rollback process and the existence, and eventually location, of STEP fault zones in the Calabrian Arc region (see e.g., D'Agostino et al., 2011; Faccenna et al., 2011; Orecchio et al., 2014; Polonia et al., 2011, 2012; Rosenbaum et al., 2008; Speranza et al., 2011; Wortel et al., 2009). A main feature highlighted by several authors (see e.g., Baccheschi et al., 2007; Giacomuzzi et al., 2012; Govers and Wortel, 2005; Neri et al., 2012) is the high uncertainty characterizing the northern edge of the Ionian slab: here the research findings related to the transition between continuous- and detached-slab are diffused over a wide area running from central Calabria to the southern Apennines (see also Fig. 1b).

On these grounds, we contribute to the ongoing debate by seismically investigating the location of the northern slab edge and the present-day kinematics of the concerned boundary region also focusing on the possible clues of STEP fault activity. Therefore we focused on the whole sector where the northern slab edge and the concerned STEP fault zone seem to be located (i.e., from central Calabria to the southern Apennines tip) by performing high-quality earthquake location and moment tensor computation. We have located the seismicity of the last 15 years by using a 3D velocity model (Neri et al., 2012) and both linearized and non-linear earthquake location algorithms (Evans et al., 1994; Presti et al., 2004). Then, the use of the Cut And Paste (Zhao and Helmberger, 1994; Zhu and Helmberger, 1996) waveform inversion method has allowed us to estimate 70 new focal mechanisms that, integrated with available ones of comparable quality, have furnished a dataset of 132 solutions relative to the period 1977–2012. Finally, hypocenters and waveform inversion focal mechanisms have been

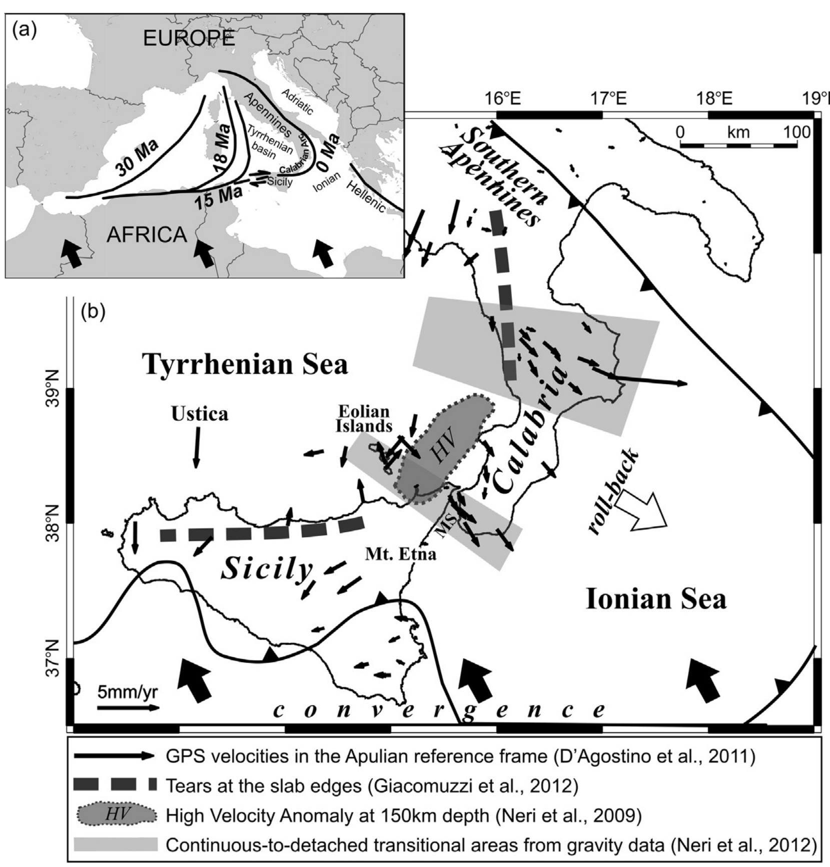

Fig. 1. (a) Map of the Mediterranean region with the western Mediterranean plate boundary evolution in the last 30 Myrs (redrawn from Wortel and Spakman, 2000). The space-time evolution of the boundary marks the process of rollback of the subducting lithosphere and the related trench retreat until the present-day location near the Ionian shoreline of Calabria. Black arrows indicate the present motion of Africa relative to Europe (Nocquet, 2012; Nocquet and Calais, 2004). (b) Present-day location of the trench zone of the NW-ward subducting slab in the Calabrian Arc region. The GPS velocity field in the Apulia-fixed reference frame (data from D'Agostino et al., 2011) shows a slow residual rollback (SE-ward velocity of ca. 2 mm/yrs) in the Calabria area. The dashed lines in northern Sicily and northern Calabria indicate the slab tears at the edges of the Calabrian Arc as identified by Giacomuzzi et al. (2012); the dark grey area "HV" is the high P-wave velocity anomaly ($\Delta Vp \geq 2\%$) found at 150 km depth by Neri et al. (2009) showing the only sector where the Ionian slab appears to be still in-depth continuous; light grey boxes depict the areas where gravity data show the signatures of transition from continuous to detached subduction mode (Neri et al., 2012). MS stands for Messina Straits.