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The Neogene-Quaternary geodynamic evolution of the central Calabrian Arc: A case study from the western Catanzaro Trough basin

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ABSTRACT

The Catanzaro Trough is a Neogene-Quaternary basin developed in the central Calabrian Arc, between the Serre and the Sila Massifs, and filled by up to 2000 m of continental to marine deposits. It extends from the Sant'Eufemia Basin (SE Tyrrhenian Sea), offshore, to the Catanzaro Basin, onshore. Here, onshore structural data have been integrated with structural features interpreted using marine geophysical data to infer the main tectonic processes that have controlled the geodynamic evolution of the western portion of the Catanzaro Trough, since Upper Miocene to present.

The data show a complex tectonostratigraphic architecture of the basin, which is mainly controlled by the activity of NW–SE and NE–SW trending fault systems. In particular, during late Miocene, the NW-SE oriented faults system was characterized by left lateral kinematics. The same structural regime produces secondary fault systems represented by E-W and NE-SW oriented faults. The ca. E-W lineaments show extensional kinematics, which may have played an important role during the opening of the WNW–ESE paleo-strait; whereas the NE-SW oriented system represents the conjugate faults of the NW-SE oriented structural system, showing a right lateral component of motion. During the Piacenzian-Lower Pleistocene, structural field and geophysical data show a switch from left-lateral to right-lateral kinematics of the NW-SE oriented faults, due to a change of the stress field. This new structural regime influenced the kinematics of the NE-SW faults system, which registered left lateral movement. Since Middle Pleistocene, the study area experienced an extensional phase, WNW-ESE oriented, controlled mainly by NE-SW and, subordinately, N-S oriented normal faults. This type of faulting splits obliquely the western Catanzaro Trough, producing up-faulted and down-faulted blocks, arranged as graben-type system (i.e Lamezia Basin).

The multidisciplinary approach adopted, allowed us to constrain the structural setting of the central Calabria segment. The joined onshore with offshore structural data analysis allowed us to image a more faithful geodynamic evolution of the Calabrian Arc, included in the wider geodynamic framework of the Mediterranean region

Moreover, our results show the close correlation between the NE-SW and N-S normal fault systems and evidence of deformed Quaternary deposits. These findings are relevant to seismic hazard understanding in an area which is historically considered at the highest risk of earthquake and tsunami and where are present important infrastructures and cities.

1. Introduction and aim of the work

Strike-slip fault systems frequently control the opening of sedimentary basins showing a heterogeneous geometry, due to the development of pull-apart and fault wedge basins at fault bends and oversteps. These are transtensional basins *sensu stricto* (Ingersoll and Busby, 1996) characterized by highly geo-structural complexity (Allen et al., 1998), due to local oblique extension with respect to the trends of the main transcurrent faults. Basins formed by transtension are commonly characterized by *en' echelon* arrays of normal faults obliquely oriented to the boundaries of the deformational zone (Allen et al., 1998; Waldrom, 2005; De Paola et al.,

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2006). Transcurrent tectonics is also common in obliquely convergent settings where interplate strain is partitioned into arc-parallel strike-slip zones within the fore-arc, arc or back-arc region (Fitch, 1972; Beck, 1983; Jarrard 1986; Sylvester, 1988; Diament et al., 1992; Hanuš et al., 1996; De Paola et al., 2005; Cunningham and Mann, 2007). Moreover, strike-slip systems, in this geological setting, can rotate and act as elements of accommodation.

The Calabrian Arc (Fig. 1) is considered one of the most interesting subduction systems due to the high level of structural complexity. Since the Tortonian time, strike-slip faults play a relevant role during the evolution of this region, favouring southeastward drifting of the arc and its fragmentation (Ghisetti et al., 1979; Turco et al., 1990; Finetti and Del Ben, 1986; Van Dijk et al., 2000). In this complex tectonic setting, an active extensional regime has produced along the Tyrrhenian side an extensional belt, running for about 370 km of length from the Crati Basin (CR) to the Hyblean Block (Fig. 1). The extensional fault systems are predominantly organized in graben-like structures showing trends spanning from NNE-SSW to NNW-SSE (Monaco and Tortorici 2000; Tortorici et al., 2003; Tansi et al., 2007). This regional fault belt represents the source of several catastrophic earthquakes, indeed, many authors, with different approaches, recognized and analyzed various seismogenic sources (Tortorici et al., 1995; Bordoni and Valensise, 1998; Monaco and Tortorici, 2000; Jacques et al., 2001; Galli and Bosi, 2003; Neri et al., 2004; Galli et al., 2007; Ferranti et al., 2008; Billi et al., 2008; Rovida et al., 2011; Loreto et al., 2013)

The internal structure of sedimentary basins in the central Calabrian Arc is complex with the presence of both longitudinal extensional faults and transversal strike-slip fault systems. In the study area (Fig. 1), the western Catanzaro Trough is bounded by large strike-slip fault zones, crossing the entire emerged Calabrian Arc from the Ionian to the Tyrrhenian Sea (Finetti and Del Ben, 1986; Tansi et al., 2007; Del Ben et al., 2009; Milia et al., 2009).

However, the main controlling factors on the origin of transversal strike-slip zones and extensional faults are not completely understood, and their role in controlling of the geodynamics of this area is still under debate.

The aim of this work is to describe the Neogene-Quaternary evolution of western Catanzaro Trough, and to discuss the role played by transverse and longitudinal faults during the development of this area. A multidisciplinary approach, combining onshore/offshore geological and geophysical data, has been adopted here to assess the complex structural framework of this key sector, which develops as element of accommodation between northern and southern the Calabrian Arc.

2. Geological setting

2.1. Geodynamic setting of Calabrian Arc-southern Apennine system

The western Catanzaro Trough represents a Neogene-Quaternary sedimentary basin belonging to a well-developed *arc-shaped* structure, the Calabrian Arc (Amodio-Morelli et al., 1976; Tortorici, 1982). The Calabrian Arc is a fragment of Alpine chain connecting the southern Apennines with the Maghrebide belt. The convergence between the Nubia and Eurasia plates (inset in Fig. 1) controlled the NW-subduction and the SE-ward roll-back of the Ionian slab that, in turn, caused rapid SE migration of the Calabrian block (Malinverno and Ryan, 1986; Mantovani et al., 1990; Dewey et al., 1989; Faccenna et al., 2005). The slab roll-back is accompanied by opposite rotations along vertical axis at its northern and southern NW-SE oriented edges (Mattei et al., 2007), the Pollino and Taormina shear zones, respectively (Fig. 1; Ghisetti and Vezzani, 1982; Van Dijk et al., 2000; Langone et al., 2006; Angì et al., 2010). The E- and SE-ward rapid trench migration also caused the fragmentation of the Calabrian Arc into structural highs and longitudinal and transversal sedimentary basins (Ghisetti, 1979; Tansi et al., 2007; Zecchin et al., 2012,2015; Tripodi et al., 2013; Critelli et al., 2013; Muto et al., 2014; Fabbricatore et al., 2014; Longhitano et al., 2014), including the Catanzaro Trough.

During Neogene-Quaternary the Calabrian Arc experienced extensional alternated to contractional or transpressional tectonic phases (Van Dijk et al., 2000; Muto and Perri 2002; Tansi et al., 2007). In particular during Middle-Upper Pleistocene, the tectonic regime in the Calabria region passes from transcurrent to extensional regime (Malinverno and Ryan, 1986; Westaway, 1993; Van Djik and Scheepers, 1995; Van Dijk et al., 2000; Minelli and Faccenna, 2010). The opening of the Tyrrhenian back-arc basin related to the Ionian subduction beneath the Calabrian Arc is characterized by tensional axes perpendicular to the chain. At the present, according to some authors, the Ionian slab has partially or completely undergone detachment (Wortel and Spakman, 1992; Guarnieri et al., 2006; Neri et al., 1996). In response to the Ionian slab detachment, the whole Calabrian Arc undergoes a general tectonic rebound (uplift), at a rate of 0.5–1.2 mm/yr in the last 1–0.7 My, when the propagating tear passes underneath the plate margin segment (Monaco et al., 1996; Wortel and Spakman, 2000).

All these observations suggest that the roll-back in the Tyrrhenian-Calabrian system has either currently stopped or significantly slowed down (D'Agostino and Selvaggi, 2004; Serpelloni et al., 2007, 2010).

2.2. Tectono-stratigraphic features of the Catanzaro Trough

The study area is located in the western Catanzaro Trough, along the Tyrrhenian side of central Calabria, and represents a linkage zone between the northern and southern sectors of the Calabrian Arc (Fig. 1), which experienced different tectonic phases leading to the development of both longitudinal and transversal faults systems (Ghisetti, 1979; Monaco and Tortorici, 2000).

Longitudinal fault systems are represented by highly dipping NE-SW and N-S oriented normal faults, that are part of the Siculo-Calabrian rift zone (Fig. 2; Monaco et al., 1997; Monaco and Tortorici, 2000) and bounding N-S and NE-SW elongated basins extending along the Calabrian Arc until eastern Sicily. The several order marine terraces onland-observed along the Tyrrhenian coast are related with the strong uplift that the Calabrian block experienced during the Quaternary (Westaway, 1993; Miyauchi et al., 1994; Tortorici et al., 2003; Bianca et al., 2011).

Transversal fault systems border the northern and southern edges of the Catanzaro Trough (Fig. 2; Van Dijk et al., 2000; Tansi et al., 2007; Milia et al., 2009). Its northern margin is represented by a regional NW-SE-trending left-lateral strike-slip faults system. These structural lineaments consist of three right-stepping *en' echelon* S-dipping major fault segments. The southern segment is represented by the Lamezia-Catanzaro Fault (Fig. 2; Monaco and Tortorici, 2000; Tansi et al., 2007), recognizable by the evident morphological escarpments with triangular and trapezoidal facets. The southern margin of the basin is bordered partially by the WNW-ESE oriented, NNE-dipping Maida-Stalettì Fault Zone (Fig. 2; Ghisetti, 1979; Monaco and Tortorici, 2000; Langone et al., 2006).

The Catanzaro Trough is filled by Neogene- Quaternary sedimentary succession, (Cianflone and Dominici, 2011; Chiarella et al., 2012; Longhitano et al., 2014). These deposits unconformably overlie igneous-metamorphic units (Fig. 3, Cavazza and Decelles, 1998).

The basement rocks are made of Paleozoic medium to high grade metamorphic rocks intruded by plutonic bodies, belonging to the *Calabride Complex* (*Sila and Castagna Units* in Fig. 3; Ogniben, 1969; Amodio-Morelli et al., 1976; Messina et al., 1991a, 1991b, 1994; Critelli et al., 2011). These tectonic units are, in

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