Tectonophysics 615–616 (2014) 69–84

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Salt tectonics and crustal tectonics along the Eastern Sardinian margin, Western Tyrrhenian: New insights from the "METYSS 1" cruise

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ARTICLE INFO

Article history:
Received 13 March 2012
Received in revised form 16 December 2013
Accepted 23 December 2013
Available online 29 December 2013

Keywords:
Tyrrhenian Sea
Eastern Sardinian margin
Rifting
Messinian Salinity Crisis
Salt tectonics
Post-rift deformations

ABSTRACT

The Tyrrhenian Sea is usually interpreted to be a Neogene back-arc basin that opened by continental rifting and oceanic spreading caused by the eastward migration of the Apennine subduction system during Miocene and Pliocene times. Rifting of the southern Tyrrhenian Sea started first along the Eastern Sardinian margin during the middle to late Miocene times, including the Messinian. The "METYSS" project aims at better constraining the relationships between crustal tectonics, salt tectonics and sedimentation from Messinian times to present-day. The "METYSS 1" cruise (2009) allowed to acquire about 1200 km of HR seismic-reflection profiles along the Eastern Sardinian margin, Western Tyrrhenian Sea. This data set clearly illustrates that this area has been highly dissected during the rifting stage by N–S trending normal faults delineating ridges and basins, as previously described. The Messinian seismic markers (UU and MU) locally display fan-shaped stratal geometries, but the mechanism responsible for such geometries, salt tectonics or rifting, has yet to be carefully deciphered. We also mapped the spatial distribution of the mobile salt. The highly variable thickness of the small confined salt basins may be related to the initial pre-Messinian basin geometry, to the fact that salt deposition was syn-rift or to salt movement. Southeastward, salt tectonics is vigorous in unconfined basins and appears to have started early during the UU deposition. More surprisingly, our data demonstrate that some of the major faults have been significantly reactivated during the post-rift period, up to late Quaternary time, as shown by bathymetric scarps and associated debris flows. Moreover, some of this post-rift deformation can be evidenced within the Plio-Quaternary sequence by a regional unconformity. The post-Miocene deformation style varies greatly between different areas of the margin, and can also be strongly influenced by the presence or absence of mobile Messinian salt.

1. Introduction

The "METYSS" project is part of an integrated study of the Messinian Salinity Crisis (MSC, Hsü et al., 1973) seismic makers at the scale of the entire Mediterranean basin (Lofi et al., 2008, 2011a,b). These seismic markers were used to establish a new common nomenclature for Messinian sedimentary units and surfaces (Lofi et al., 2008, 2011b). The Western part of the Tyrrhenian Sea (i.e., the Eastern Sardinian margin, Fig. 1) constitutes a major target, first because of the scarcity of recent geophysical data adapted to the Messinian topics, and second because the MSC was coeval with the rifting event, and just before the onset of sea-floor spreading in some parts of the Tyrrhenian Sea (Carminati et al., 2012; Cipollari et al., 1999; Doglioni, 1991; Doglioni et al., 2004; Faccenna et al., 2001, 2004; Helbing et al., 2006; Jolivet et al., 2006; Mantovani et al., 1996, 2009; Rosenbaum et al., 2002; Sartori et al., 2001, 2004). By identifying and characterizing the geometry and distribution of the MSC seismic markers, we can better understand the timing and propagation of the syn-rift deformation in this key area. More precisely, we demonstrate that the MSC seismic markers provide an efficient tool for estimating the rate and timing of deformation processes and especially tilting of fault-bounded blocks in this particular area. We also describe the salt-related structures identified along the Eastern Sardinia margin and new recent post-rifting tectonics in the Plio-Quaternary sequence.

2. Geological setting

2.1. Geodynamics

The Tyrrhenian Sea (Fig. 1) is a Neogene back-arc basin that opened by continental rifting and oceanic spreading related to the eastward

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0040-1951/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.12.015

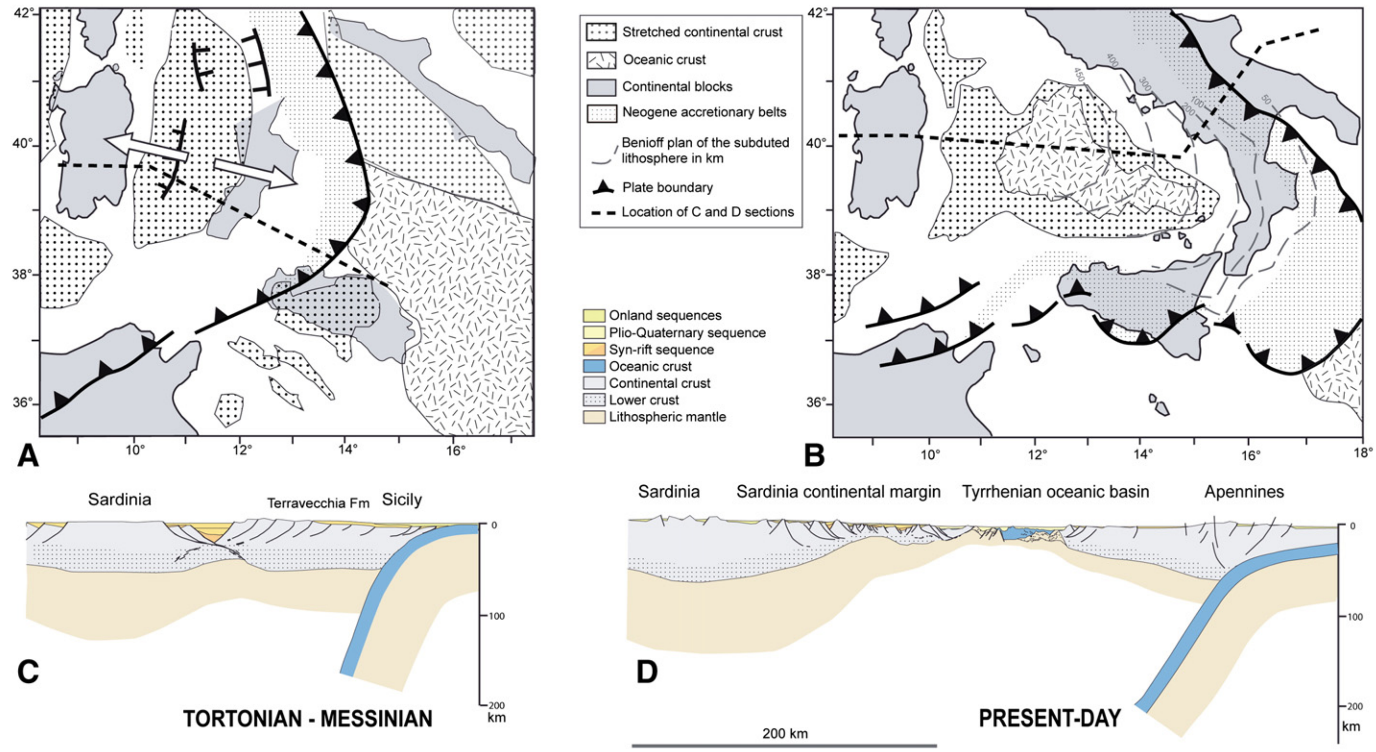

Fig. 1. Geodynamic setting of the Tyrrhenian Sea. A: Geodynamic map reconstruction during Tortonian–Messinian times (6.5–5.3 Ma) (modified from Jolivet et al., 2006). The dotted bold black line shows the location of cross Section C. B: Present-day geodynamic map showing the distribution of the oceanic domains and zones of stretched continental crust (modified from Faccenna et al., 2005; Jolivet et al., 2006). Dotted gray lines represent the depth of the Benioff zone, top of the descending Ionian slab (Sartori et al., 2004). The dotted bold black line shows the location of cross Section D. C. and D: Schematic cross sections, respectively for Tortonian–Messinian and Present-Day times (modified from Jolivet et al., 2006; Sartori et al., 2001, 2004; Spakman and Wortel, 2004).

migration of the Apennine subduction system from middle Miocene to Pliocene times (Gueguen et al., 1998; Jolivet and Faccenna, 2000; Jolivet et al., 2006). Rifting and back-arc opening of the Tyrrhenian Sea followed the opening of the Liguro–Provençal basin that occurred during Oligocene to Burdigalian times (rifting from 30 to 21.5 Ma, spreading from 21.5 to 15 Ma, Gattacceca et al., 2007; Pasquale et al., 1995). The whole process of rifting and spreading in the Western and Central Mediterranean basins, from the late Oligocene to Present-day, is considered to be linked to the progressive retreat of subducting African slab during convergence between Africa and Europe (Carminati et al., 2012; Doglioni, 1991; Doglioni et al., 2004; Faccenna et al., 2007; Jolivet and Faccenna, 2000; Jolivet et al., 1998, 2006; Malinverno and Ryan, 1986).

Rifting of the southern Tyrrhenian Sea occurred during Serravallian–Tortonian and Messinian times, starting possibly as early as the Langhian, and was followed by sea-floor spreading in a few small deep basins from c. 5 Ma to present-day (Carminati et al., 2012; Doglioni et al., 2004; Faccenna et al., 2007; Finetti, 2005; Kastens et al., 1988; Mascle and Réhault, 1990; Sartori et al., 2001, 2004; Scrocca et al., 2003; Spadini and Podladchikov, 1996). Along the Eastern Sardinian margin, Tortonian *p.p.* to Pliocene *p.p.* series are considered to be syn-rift sediments (Sartori et al., 2001, 2004). Because the Messinian Salinity Crisis took place during the rifting time, the Eastern Sardinian Margin is thus a key area to document the relationships between the evaporitic deposits of the MSC and the tectonic activity associated with the rifting process.

Recent deformation is generally considered to be very weak or absent along the Eastern Sardinian margin. Study of late Pleistocene marine terraces onshore shows little recent uplift, c. +0.04 mm/yr, restricted to Orosei area (Ferranti et al., 2006). Vertical movements within that area, which probably are not related to tectonic activity, have been attributed to a flexural response to the development of Plio-Quaternary volcanic bodies (Ferranti et al., 2006; Mariani et al., 2009). Present-day seismic activity appears to be scarce and only a few significant earthquakes ($M_w \geq 3.5$, depth ≤ 50 km) have occurred recently in the northern part of the Eastern Sardinian margin (Angelone et al., 2005; Nocquet, 2012; Pondrelli et al., 2004). The Regional Centroid Moment Tensor (RCMT) focal mechanisms correspond to reverse faulting, revealing a surprising compressional stress regime in that area (Fig. 2, D'Agostino et al., 2008; Nocquet, 2012; Pondrelli et al., 2006).

2.2. Tectonic framework

Tectonic features in the study area are largely dominated by normal faulting inherited from the rifting stage (Carrara, 2002; Finetti, 2005; Finetti et al., 2005; Sartori et al., 2001, 2004; Scrocca et al., 2003; Thommeret, 1990). The main structures are N–S trending normal faults bounding tilted blocks (Fig. 2). The East-Sardinia Basin, corresponding to the upper margin, comprises both east and west-dipping faults associated with a system of grabens and horsts such as the Baronie Ridge or the Quirra Seamount (Vai and Martini, 2001), a structural pattern already described in the Northern Tyrrhenian Basin (Finetti, 2005; Pascucci et al., 1999). Conversely, the Cornaglia Terrace and the deep Tyrrhenian basin mainly display east-dipping normal faults. East of Orosei Gulf, some oblique lineaments, i.e., East–west to WNW–ESE (Sartori et al., 2001, 2004; Vai and Martini, 2001), have been interpreted as a wide transfer zone (Orosei Canyon Line/OCL, Carmignani et al., 1992; Sartori et al., 2001). This trend separates two domains that have different structural histories. According to Sartori et al. (2001), the basin located North of OCL experienced discontinuous and severe rifting during Tortonian to Pliocene times, while rifting in the basin located South of OCL was continuous albeit less intense during the same time. Another major transverse structure, separating the Northern Tyrrhenian Basin from the Southern Tyrrhenian Basin (Fig. 2), is also described in previous works and named the 41° parallel lineament (Carmignani et al., 2004; Sartori, 1990; Spadini and Wezel, 1994), or the Circeo fault (Mauffret et al., 1999).