Journal of Geodynamics 81 (2014) 17–29

Contents lists available at ScienceDirect

Journal of Geodynamics

journal homepage: http://www.elsevier.com/locate/jog

Early-stage rifting of the Southern Tyrrhenian region: The Calabria–Sardinia breakup

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ARTICLE INFO

Article history:
Received 5 March 2014
Received in revised form 24 June 2014
Accepted 27 June 2014
Available online 7 July 2014

Keywords:
Continental extension
Sequence stratigraphy
Basin analysis
Tyrrhenian Sea
Calabria

ABSTRACT

The Southern Tyrrhenian Sea is an extensional basins linked to the Neogene evolution of the Calabria subduction zone located in the western Mediterranean realm where controversial kinematic and geodynamical models have been proposed. Our study provides a key to unravel timing and mode of extension of the upper plate and the breakup of Calabria from Sardinia. By combining original stratigraphic analysis of wells and seismic profiles off Calabria with a stratigraphic correlation to onshore outcrops, we re-assess the tectonic evolution that controlled the sedimentation and basement deformation of the Southern Tyrrhenian basin during Serravallian–Tortonian times. We document the tectono-stratigraphic evolution of adjacent extensional basins characterized by 3rd order depositional sequences (Ser1, Tor1 and Tor2) and different modes of extension, subsidence and opposite dipping faults. Episodic basin development is recorded by a coarsening-up and fining-up trend of the sedimentary succession and by tectonically enhanced unconformities that reflect three episodes of fault activity. We reconstruct Serravallian–Tortonian paleogeographic maps and propose a block faulting model for the evolution of the Sardinia–Calabria area. Sardinia was disconnected from Calabria through N–S normal faults forming Tyrrhenian extensional basins that formed contemporaneously to the E–W opening of the Algerian basin. Unlike published Serravallian–Tortonian reconstructions of the western Mediterranean realm, our results support a geodynamic model characterized by rapid trench retreat, trench-normal extension in the entire overriding plate and very weak coupling between plates.

1. Introduction and aims

Research on continental passive margins is largely focused on the understanding of rifting processes and mechanisms of lithosphere thinning leading to continental breakup and spreading. Rifting in backarc basins might be different in some points from cratonic rifting, though the mechanism of actual break-up of the continental lithosphere remains similar; the main difference between backarc and cratonic rifting is the presence of a subducting slab in the mantle beneath the backarc basin (Uyeda, 1983; Taylor, 1995). Backarc extensional basin are enigmatic features that have been associated to different mechanisms such as suction at the trench (Shemenda, 1993) or slab-roll back (e.g. Malinverno and Ryan, 1986). Recent geodynamical subduction models suggest that the degree of mechanical coupling between overriding continental plate and subducting oceanic plate plays a fundamental role in the distribution of extension in the overriding plate (Meyer and Schellart, 2013; Schellart and Moresi, 2013). It has been suggested that back-arc rifting initiated with a hot and wet continental lithosphere (Yamasaki and Stephenson, 2011).

The process of lithospheric extension can be characterized by the formation of tilted blocks (e.g. Wernicke and Burchfiel, 1982). These structures exert a fundamental control upon geomorphology and sedimentation patterns producing asymmetric subsidence, tectonic slopes and an emerging footwall area which is the main sediment source for the adjacent basin (Ravnås and Steel, 1998). Active extensional faulting and sedimentation are intimately linked during basin evolution as tectonics controls the creation of the accommodation space, the sediment supply and the ratio variation between subsidence and sedimentation (e.g. White et al., 1986; Muto and Steel, 1997; Milia, 1999). Assuming a variation in the balance between the sediment supply and subsidence rate, the resulting change in the lithological signatures and stacking patterns can reflect variations in the fault-related subsidence rate.

The Western Mediterranean is characterized by the opening of several backarc basins formed within the zone of convergence between the Africa and Eurasian plates during the migration of the Calabria subduction zone (Boccaletti and Guazzone, 1972; Cherchi

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http://dx.doi.org/10.1016/j.jog.2014.06.001
0264-3707/

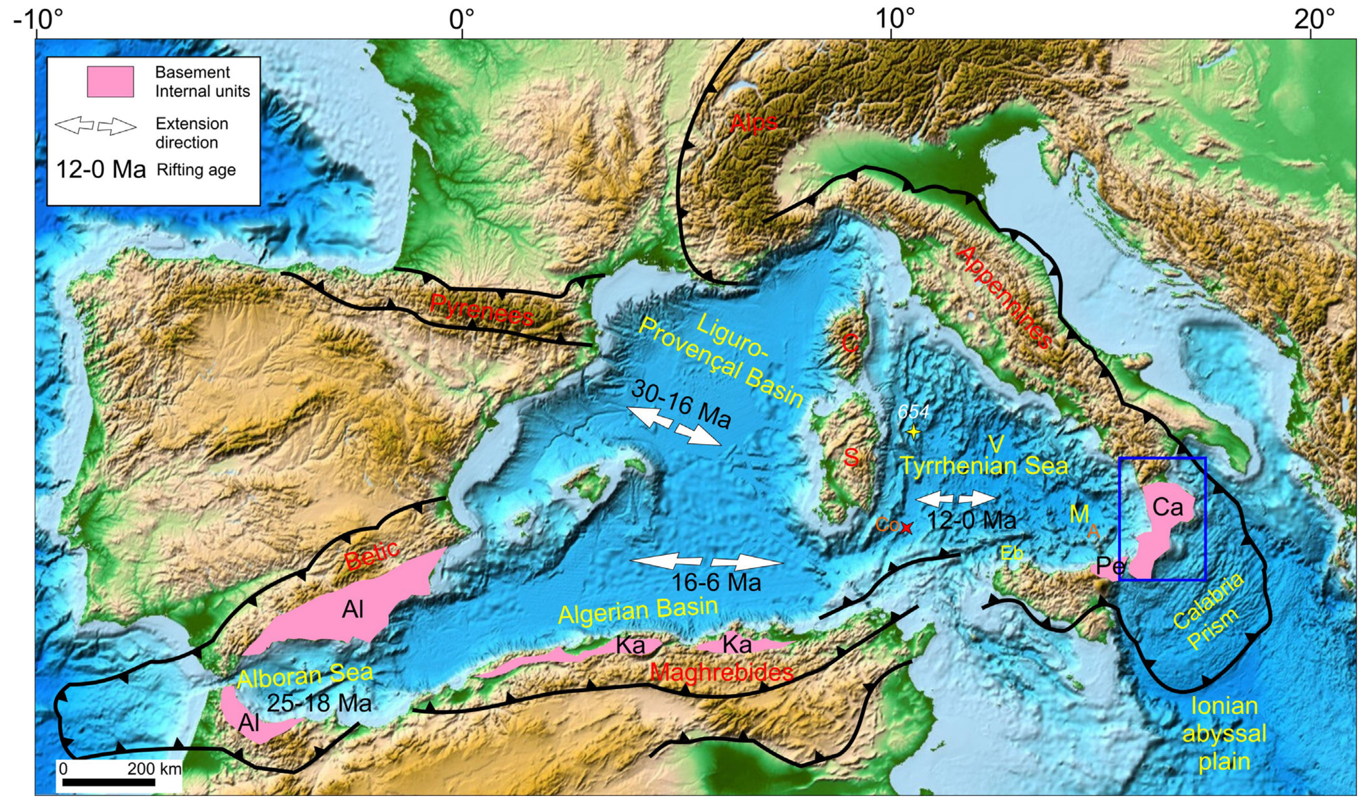

Fig. 1. Tectonic map of Western Mediterranean region. Bathymetry and topography are from ETOPO1 min Global relief (http://www.ngd.noaa.gov). Main tectonic features are from Bigi et al. (1992), Frizon de Lamotte et al. (2000), Mauffret et al. (2004), Michard et al. (2006), Faccenna et al. (2007), Handy et al. (2010), Capozzi et al. (2012), Jarsve and Pedley (2012). The blue rectangle marks the location of the area shown in Fig. 2. Al = Alboran, Ka = Kabilia, Pe = Peloritani, Ca = Calabria, C = Corsica, S = Sardinia, 654 = 654 ODP well, Co = Cornacia volcano (subduction-related, Serravallian), M = Marsili Basin, V = Vavilov Basin, Eb = Erice Basin, A = Aeolian Islands. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

and Montadert, 1982; Patacca et al., 1990; Doglioni et al., 1997; Faccenna et al., 1997; Carminati et al., 1998; Guerrera et al., 2005; Schettino and Turco, 2006; Roure et al., 2012; Catalano et al., 2013; van Hinsbergen et al., 2014).

The Southern Tyrrhenian Sea (Fig. 1) is one of these backarc basins developed until upper Miocene time in response to an eastward rollback of the subducting slab that favored upper plate lithospheric thinning (Malinverno and Ryan, 1986; Patacca and Scandone, 1989; Faccenna et al., 2007). Several workers proposed that the Tyrrhenian extension (e.g. Patacca et al., 1990; Sartori, 1990; Spadini et al., 1995; Rosenbaum and Lister, 2004) started during late Miocene (10 Ma) on the Sardinia Margin and migrated eastwards to the Vavilov basin (5.5 Ma) and then to the Marsili basin (1.8 Ma). The Southern Tyrrhenian Sea passes westward to the Algerian basin (Fig. 1) that opened in a EW direction during the middle to late Miocene as the result of backarc extension (Mauffret et al., 2004; van Hinsbergen et al., 2014).

Despite the broad agreement on the geodynamic framework for the Tyrrhenian Sea, there are still some geological subjects of debate among the scientific community: (1) the geodynamic process responsible for the opening of the Southern Tyrrhenian Sea and Calabria basins (mantle diapirism, rollback, poloidal and toroidal mantle flows); (2) the origin of the N–S extensional faults displacing the Calabrian nappe stack (forearc or backarc extension?); (3) the age and tectono-stratigraphic evolution of the first stage of rifting that led to the Calabria–Sardinia break up; (4) the Serravallian–Tortonian paleogeographic position of the Calabrian terrane relative to Sardinia; (5) the style (symmetrical or asymmetrical) of the Tyrrhenian rifting; (6) the relationship between Tyrrhenian and Algerian backarc extension.

The Calabria–Sardinia breakup and the early-stage Tyrrhenian rifting constitutes a fine example of the evolution of a upper plate extensional domain where the hypotheses until now formulated (e.g. meaning and kinematics of extensional structures and timing of deformation) remain poorly constrained. In this paper new findings on the stratigraphic architecture of Serravallian–Tortonian extensional basins overlying the Calabrian nappe stack are presented. The points we address are: (1) clarification of the chronostratigraphy of the oldest basin affecting the Calabria and Sardinia Margin and timing of sedimentation and deformation, (2) describe the 3D architecture of the basins in the Calabria–Sardinia region; (3) shed light on the issues regarding the style and distribution of extensional deformation, (4) examine kinematic and geodynamic implications. In order to achieve these goals we made a sequence stratigraphy interpretation of seismic and borehole data offshore Calabria; we also built a regional correlation between Serravallian–Tortonian subbasins located offshore and onshore Calabria. An accurate basin analysis has permitted to place the various geodynamic processes and mechanisms in a geological time-frame, combining them with a new structural model of the early-stage Southern Tyrrhenian rifting and with considerations concerning the potential driving mechanisms of the overriding plate's extension.

2. Geological and geodynamical setting

Based on tomographic images, seismological data, the petrology of volcanic rocks and analog models, several authors reconstructed a complex geometry of the subducting slab in the Western