Journal of Geodynamics 86 (2015) 42–60

Contents lists available at ScienceDirect

Journal of Geodynamics

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

Tectono-stratigraphic signature of a rapid multistage subsiding rift basin in the Tyrrhenian-Apennine hinge zone (Italy): A possible interaction of upper plate with subducting slab

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ARTICLE INFO

Article history:
Received 11 November 2014
Received in revised form 11 February 2015
Accepted 25 February 2015
Available online 3 March 2015

Keywords:
Continental rifting
Sequence stratigraphy
Basin analysis
Tyrrhenian Sea

ABSTRACT

The Campania Plain is a rapidly subsiding Quaternary basin that formed on the eastern margin of the Tyrrhenian Sea in association with the younger phase of Tyrrhenian rifting. It is located in the hinge area between the Apennines fold-thrust belt and the Tyrrhenian extensional backarc basin. By combining original stratigraphic analyses of well logs and seismic profiles we built a basin subsidence curve, mapped the fault pattern of the Campania Plain and analyzed the impact of the block faulting on the sedimentology and stratigraphic architecture of the basin fill. Well data indicate that the Quaternary succession consists of offshore, shoreface and coal-bearing coastal plain deposits arranged to form thick aggradational and retrogradational units. The sequence stratigraphy interpretation of well logs permitted us to recognize thirteen depositional sequences and the stratigraphic signatures of the rift stages. The study area corresponds to a sediment overfilled/balanced infill basin type that resulted from superposition of several rifting events characterized by high rates of basin subsidence.

Taking into account the geological data of the adjacent areas, we propose a Pliocene-Quaternary rifting evolution of the upper Tyrrhenian plate consisting of four episodes. Two peculiar features of the Tyrrhenian rifting are a skip of the extensional axial zone eastwards leaving the previous zone of high strain localization (Vavilov basin), followed by a dramatic change (90°) of the direction of extension. Because these Tyrrhenian features cannot be accounted for by the current rifting models we hypothesized a link between the evolution of upper plate and subducting slab. The proposed geodynamic scenario is characterized by a progressive rupture of the subducting plate and formation of extensional basins in the upper plate.

1. Introduction and aims

In the classical literature, the stratigraphic signature of the rift basin has been defined in term of a succession characterized by early-, syn-, climax and post-rift deposits (e.g. Ravnås and Steel, 1998 and bibliography therein). These rift stages have been related to changes of the rate of subsidence (e.g. Sclater et al., 1980). However recent papers document that the evolution of a rift is more complex, resulting in the superposition of rift basins that grow in different structural conditions (e.g. Whitmarsh et al., 2001; Lavier and Manatschal, 2006) and characterized by a change in the direction of extension (e.g. Walker et al., 2011; Milia et al., 2013). Within this frame the stratigraphic succession of a rift basin is the product of a complex interplay between tectonics and sedimentation that is not yet completely understood.

The tectonic evolution of a rifted margin has a profound effect on the structural style and tectonic subsidence events of rift basins. Ideas on synrift sediment architecture have evolved from studies of rift basins (e.g. Leeder and Gawthorpe, 1987; Prosser, 1993; Gawthorpe et al., 1994; Friedman and Burbank, 1995; Milia, 1999). Structurally controlled accommodation results from the effects of background subsidence and from slip on basin-bounding faults.

Assuming a variation in the balance between sediment supply and subsidence rate, change in the lithological signatures and stacking patterns can reflect variation in fault related subsidence rates. Clay-prone intervals in syn-tectonic successions are known to represent periods of rapid differential subsidence (Steel, 1988), whereas in shelf areas the intervals of coarse facies with a progradational stacking pattern relate to periods of relative tectonic quiescence and minimal accommodation creation (e.g. Blair, 1987;

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http://dx.doi.org/10.1016/j.jog.2015.02.005
0264-3707/

Milia, 1999). During a rift phase the stratigraphy appears to be controlled mainly by sediment supply in relation to the creation of an accommodation space. The accommodation space changes in time and space according to fault-related subsidence, background subsidence, eustacy and sediment supply (linked to bathymetry, source area size, lithology) (e.g. Wilgus et al., 1988; Milia et al., 2006). Sequence stratigraphy focuses on analysing the change in facies and the geometric character of strata together with the identification of key surfaces so as to determine the chronologic order of the basin filling.

Backarc basins are rift basins characterized by an underlying subducting slab in the mantle (Uyeda, 1983; Taylor, 1995). Backarc extensional basins are enigmatic features that have been associated with different mechanisms such as suction at the trench (Shemenda, 1993) or slab-roll back (e.g. Dewey, 1980; Malinverno and Ryan, 1986). The mode of extension and the stratigraphic signature of backarc basins are to a large extent controlled by the interaction of the upper plate with the subducting slab (Cloetingh et al., 2013 and bibliography therein). Besides geodynamic models show that the mode of extension of the overriding plate is influenced by its rheological stratification and potential energy (e.g. Schellart and Lister, 2005).

The Tyrrhenian Sea rifting has been interpreted as an extensional backarc basin linked to the Neogene evolution of the Calabria subduction zone (Fig. 1A). Many authors (e.g. Faccenna et al., 1996; Sartori, 2003; Doglioni et al., 2004; Rosenbaum and Lister, 2004) maintain that the extension in the Tyrrhenian Sea migrated from northwest to southeast (from Sardinia margin, to Vavilov Basin to Marsili Basin; Fig. 1A). They underestimated the role of the extensional tectonics that affected the eastern margin of the Tyrrhenian Sea during the Quaternary when very thick sedimentary basins formed (Ippolito et al., 1973; Mariani and Prato, 1988; Brancaccio et al., 1991; Milia and Torrente, 1997, 1999, 2011; Milia et al., 2003, 2006, 2013).

The Campania Plain is a very deep sedimentary basin located in a key area: the hinge between the Apennines fold-thrust belt (boundary between the Northern and Southern Apennine) and the Tyrrhenian Sea margin (Fig. 1a). The results of sedimentologic and paleontologic studies of the deep wells drilled in the Campania Plain were published by Ippolito et al. (1973). Even if the stratigraphic and structural framework of the Gaeta and Naples bays located offshore the Campania Plain was described by Milia and Torrente (1999), Milia (1999) and Milia et al. (2013), the geological relationships between these basins and the adjacent Campania Plain, a coherent evolution from the Vavilov basin to the Apennines, and the geodynamic implications are still poorly known.

In this study we use seismic profiles and well data from the Campania Plain. Our purpose is manifold: (1) to characterize the structural style and tectonic evolution of a hinge zone rift basin; (2) to describe the sedimentologic and stratigraphic architecture of a Quaternary rapidly aggrading, coastal plain to open marine syn rift succession; (3) to investigate the extensional evolution of the hinge zone between fold-and-thrust belt and related back-arc basin; (4) to propose a driving mechanism for this rapidly subsiding basin.

2. Geological setting

The Tyrrhenian Sea (Fig. 1a) is a land-locked extensional basin that developed during the Serravallian to Quaternary and formed at the rear of the Neogene Apennine thrust belt (e.g. Kastens and Mascle, 1990; Patacca et al., 1990; Milia and Torrente, 2014). Its back-arc evolution has been mainly attributed to the roll-back toward the south-east of the subducting Ionian plate (e.g. Malinverno and Ryan, 1986; Faccenna et al., 1996; Cavinato and De Celles, 1999; Rosenbaum and Lister, 2004). The Tyrrhenian Sea is characterized by two sectors with different extension values (Fig. 1a): a northern Tyrrhenian sector, consisting of thinned continental crust (20–25 km) and lithosphere (50–60 km); a southern Tyrrhenian sector with a very thin continental crust (25 to less than 10 km) and lithosphere (30–50 km) (Panza and Calcagnile, 1979/1980; Nicolich, 1981; Panza, 1984). The Southern Tyrrhenian Sea corresponds to a middle Miocene–Quaternary polyphase rift, with several fault trends, that started during an initial stage (10 Ma) on the Sardinia Margin and then migrated eastwards to the Vavilov basin (5.5 Ma) and the Marsili basin (1.8 Ma) (e.g. Alvarez et al., 1974; Sartori, 1990, 2003; Spadini et al., 1995; Rosenbaum and Lister, 2004). The opening of the Vavilov and Marsili basins produced a high value of stretching in the Southern Tyrrhenian Sea and a crustal thickness that thinned to less than 10 km (Panza, 1984; Nicolich, 2001). Indeed the Vavilov basin displays a Lower Pliocene detachment fault that was responsible for the exhumation of mantle rocks underlying extensional allochthonous blocks made up of Alpine rocks (Kastens et al., 1987; Mascle and Rehault, 1990; Milia et al., 2013).

The Eastern Tyrrhenian margin (Fig. 1a and Fig. 2) consists of many half-graben basins (e.g. Paola Basin, Salerno Bay, Naples Bay, Campania Plain, Gaeta Bay, Pontina Plain) that commonly have a width of 10–30 km, are filled with thousands of meters of clastic sediments and are characterized by aggrading and prograding infill. The extensional tectonics on the margin started during the Pliocene and displaced the Apennine fold-and-thrust belt (Zitellini et al., 1984; Mostardini and Merlini, 1986). The stratigraphic architecture of several peri-Tyrrhenian basins (offshore Tuscany, Gaeta Bay, Naples Bay, Paola Basin) reveals that their depositional sequences are arranged into transgressive-regressive cycles (Zitellini et al., 1984; Marani et al., 1987; Milia, 1999, 2010; Milia et al., 2003, 2009, 2013; Milia and Torrente, 2003; Ridente et al., 2012; Iannace et al., 2013; Torrente and Milia, 2013).

The fault pattern of the Eastern Tyrrhenian margin is characterized by high-angle structures trending E–W, NE–SW, NW–SE and N–S (Fig. 2). The Pontina Plain is a 15–20 km wide and 40 km long coastal plain, located in southern Latium, enclosed between the Tyrrhenian coast and the Circeo Promontory toward W and SW and the Apennine mountains (Lepini and Ausoni Mts) to the NE (Fig. 2). This structural depression is controlled by SW-dipping regional normal faults and filled by several hundred meters of Pliocene-Quaternary clastic deposits (Mostardini and Merlini, 1988). The stratigraphic analysis of the Pontina Plain in outcrop and subsurface reveals that the oldest age of the basin fills is Lower Pliocene (Lombardi, 1968; Malatesta and Zarlenga, 1986; Bellotti et al., 1997). The Campania Plain is 70 km-long and 30 km wide and corresponds to the largest coastal plain of the Eastern Tyrrhenian margin (Fig. 2). It is enclosed by the Tyrrhenian coast toward SW and the Apennine mountains to the NW (Mt. Massico), NE (Caserta and Sarno Mts) and SE (Sorrento Peninsula). Unlike the Pontina Plain, the Campania Plain features Quaternary tectonic evolution controlled by both NE-SW and NW-SE faults and thicker basin fill (>3.3 km) with very high subsidence rates (Ippolito et al., 1973; Rosi and Sbrana, 1987; Mariani and Prato, 1988; Mostardini and Merlini, 1988; Milia and Torrente, 1997, 2011). The study of the sedimentological characteristics and the microfauna associations of the Campania Plain succession (Ippolito et al., 1973) showed that these sediments are marine intercalated with sediments of a brackish environment and with sedimentation environments varying from lagoon, to delta plain, to pro-delta.

Besides structural, stratigraphic and palaeogeographical analyses document (Milia and Torrente, 2011) rates of subsidence of up to 4.9 mm/a over the past 154 ka at Campi Flegrei (southern Campania Plain).

The complex fault pattern of the Eastern Tyrrhenian margin is the product of three extensional events. During the Pliocene–Early