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Positive inversion tectonics in foreland fold-and-thrust belts: A reappraisal of the Umbria–Marche Northern Apennines (Central Italy) by integrating geological and geophysical data

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ABSTRACT

Unraveling the tectonic style in the outer zones of fold-and-thrust belts is generally puzzling because the basement–cover relationships are often hidden in the subsurface as in the outer Northern Apennines of Italy. This study aims to reconstruct the deep setting of the Northern Apennine foreland thrust belt by integrating surface structural–geological and subsurface seismic reflection profile and well data, corroborated by a gravity–magnetic modeling. A remarkable mountain ridge, the Umbria–Marche Apennine Ridge (UMAR), which corresponds to a prominent area of structural and topographic elevation, characterizes the morphology of the Northern Apennines. This mountain ridge is constituted by Meso-Cenozoic carbonates involved in Neogene compressive structures and is surrounded by wide exposures of foredeep deposits. The basement–cover relationships are poorly constrained and both thin- and thick-skinned tectonic styles have been applied. The interpretation of subsurface data allowed recognizing a thick pre-Jurassic sedimentary sequence filling a late Paleozoic(?)–Triassic symmetric fault-bounded extensional basin, lying directly below the UMAR. This deep-rooted basin underwent positive inversion during the Neogene compression and thrust–fold development. The reconstructed thick-skinned inversion tectonic model is consistent with both the modest amount of shortening and the remarkable structural elevation of the UMAR.
The outcomes of this study reveal that prominent mountain ridges occurring in foreland thrust belts are most likely related to the deep-rooted basement-involved positive inversion of pre-existing extensional basins.

1. Introduction

The definition of structural style in fold-and-thrust belt is a main issue in assessing the tectonic setting of orogens (e.g. Butler and Mazzoli, 2006). Commonly, thrust faults affect the basement in the interiors of many chains, whereas in the outer zones (i.e. foreland fold-and-thrust belts) they are usually restricted to the sedimentary cover (Boyer and Elliott, 1982; Butler, 1982; Coward, 1983). The resulting tectonic style is dominated by a combination of thick- and thin-skinned thrusts moving from the hinterland toward the foreland, respectively. In other cases, thrust faults may also involve the basement in the foreland thus generating uplifts (Brown, 1984; Matthews, 1978; Mitra and Mount, 1998; Rogers, 1987) as shown in the Rocky Mountains and in the Andes (e.g. Roure, 2008; Schmidt and Perry, 1988) and the coexistence of thin- and thick-skinned tectonics within the overall fold–thrust belt (e.g. Abascal, 2005; Giambiagi et al., 2008). This compressional basement-involved foreland deformation has been mostly related to the tectonic inversion of pre-existing extensional basins (e.g. Bump, 2003; Kley et al., 1999; Lacombe and Mouthereau, 2002; Marshak et al., 2000; Ziegler et al., 1998).

Both thin- and thick-skinned structural styles have been proposed for the Apennine fold-and-thrust belt, with a simple transition from thick- to thin-skinned tectonics from the inner chain to the foreland (Bally et al., 1986; Barchi et al., 1998; Doglioni, 1991) or with thrust faults involving the basement also in the outer zones of the thrust belt (Finetti et al., 2005; Scisciani and Calamita, 2009; Scisciani et al., 2010), being part of the Pliocene–Quaternary lithospheric neo-chain (Boccaletti et al., 2005). In addition, several studies emphasized the positive reactivation of pre- and syn-orogenic normal faults in the outer Central-Northern Apennines (e.g. Calamita et al., 2009; Coward et al., 1999; Di Domenica et al., 2012; Pace and Calamita, 2014; Pace et al., 2011; Scisciani et al., 2002; Tavarnelli et al., 2004; Tozer et al., 2002). The contrasting structural styles proposed for the Apennine chain mainly derive from the distinctive geological setting of the area, with a basement widely buried underneath a thick sedimentary cover in a broad region of the thrust belt. In the outer zones of the Northern Apennine chain, the UMAR is the most extensive area of high topography

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exhibiting spectacular exposures of exhumed syn-rift and passive margin Meso-Cenozoic carbonate successions involved in Neogene compressive structures.

In this paper, geological and structural data, seismic reflection profile interpretation, and gravimetric–magnetic modeling, were combined with the purpose to reconstruct and shed light on the debated crustal tectonic setting of the UMAR in the Northern Apennines of Italy. The results of this study indicate: i) an abrupt deepening of basement directly underneath the UMAR, ii) strong lateral variations in thickness of the sedimentary cover and iii) reduced displacement of the Neogene thrust system. The interpretation here presented deals with the deep-seated positive inversion of a late Paleozoic(?)–Triassic basin during the Neogene compression.

2. Regional tectonic setting

The Apennine chain extends for 1500 km from the Po Plain to the Calabrian arc and forms the backbone of the Italian Peninsula (Fig. 1). It consists of two main arcs: the Northern Apennine arc and the Southern Apennine arc with different evolution histories, structural styles, rotational patterns, shortening rates, and outcropping structural levels (Boccaletti et al., 2005; Satolli et al., 2014).

The Northern Apennines are a fold-and-thrust belt that developed during the Cenozoic time, following the closure of an eastern branch of the Mesozoic Tethys Ocean (Ligurian Ocean) and the collision of the European (Corsica–Sardinia block) and African (Adria block) continental margins (Carmignani and Kligfield, 1990; Malinverno and Ryan, 1986). The Northern Apennines are composed of an imbricate tectonic stacking of mainly east-verging thrust sheets. The Ligurian units and their sedimentary cover represent the uppermost thrust sheet overlying the deformed units of Adria continental affinity (Tuscan and Umbria–Marche units).

In the hinterland of the Northern Apennines, an unmetamorphosed succession (Tuscan Nappe) is emplaced over a metamorphic sequence (Massa–Apuane Units) composed of Permian to Oligocene metasediments, unconformably resting onto a Palaeozoic basement (Kligfield, 1979). The Apuane metamorphic core complex, originated as a tectonic stack, progressively deformed as a duplex during Oligocene–Miocene (Carmignani and Kligfield, 1990). In the foreland, the exhumation of the deformed Adria margin has been less strong and the thrust–fold belt is mostly buried underneath Neogene siliciclastic foredeep sediments, unless in the UMAR. Within the Apennine foreland, the UMAR represents a curve-shaped mountain ridge that extends for about 450 km exhibiting a prominent topography (more than 2000 m a.s.l.) with respect to the adjacent foothills. The UMAR is mainly constituted by Mesozoic–Paleogene pelagic carbonate sediments deformed by Neogene folds and thrusts.

The UMAR has been classically interpreted as a thin-skinned thrust belt, with imbrication of sedimentary units detached along the Triassic evaporites, over an undeformed and buried crystalline basement (Bally et al., 1986; Ghisetti and Vezzani, 1997; Hill and Hayward, 1988). This tectonic style has been applied to the whole Apennine chain and combined with high-resolution stratigraphy of piggy-back and foredeep basins (Cipollari and Cosentino, 1992; Patacca et al., 1991) implying large amounts of orogenic contraction and anomalous

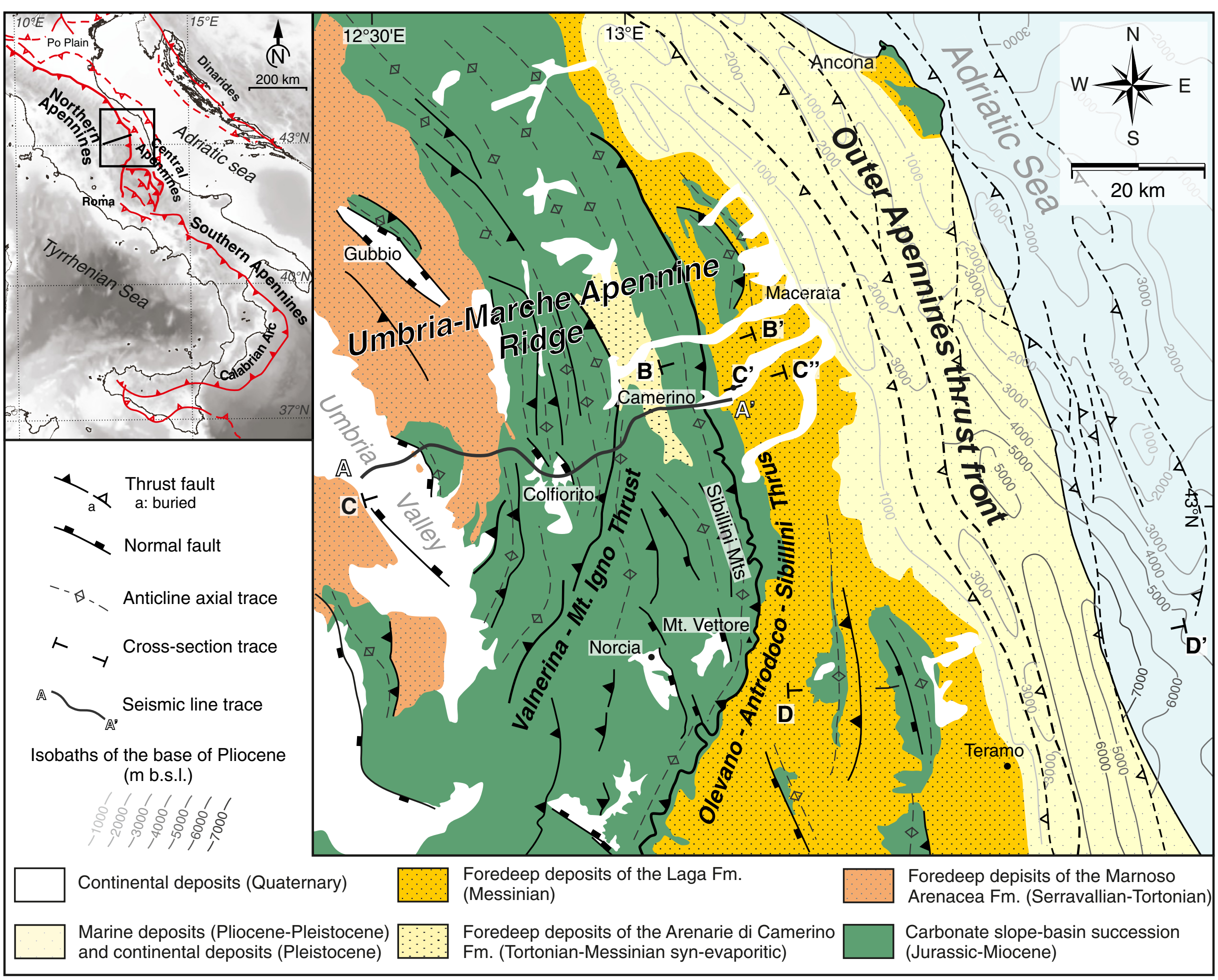

Fig. 1. Structural sketch map of the southern sector of the Northern Apennines (modified from Bigi et al., 1992) transected by the arc-shaped Umbria–Marche Apennine Ridge (UMAR), upper left inset for location.