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Opposite verging chains sharing the same foreland: Kinematics and interactions through analogue models (Central Po Plain, Italy)

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ABSTRACT

In this study, we investigate the potential role played by different geological factors on the development of a thrust system. In particular our goal is to analyze how pre-existing compressional structures located in the foreland of a thrust-and-fold belt may affect the kinematics of a thrust system. We studied such circumstances both in a natural case and through analogue models. As a natural case, we selected the Central Po Plain (Italy), where the buried external fronts of the Northern Apennines and Southern Alps are very close to each other. Starting from a regional cross-section representative of this tectonic setting, we reconstructed the post-Messinian development of the Apennines thrust fronts, which includes out-of-sequence thrusting. Then, we modeled this evolution through a set of analogue experiments to evaluate the possible relationships of the out-of-sequence thrusting with the burial of the syntectonic sediments and/or the existence of the outer fronts of an opposite verging chain in its foreland. The comparison between natural case and models highlights that the presence of opposite verging thrust fronts in the foreland of a belt limits the propagation of new thrusts favoring the out-of-sequence reactivation of inner thrusts. An analysis of the study area with respect to adjacent tectonic settings, coupled with analogue models, revealed that syntectonic sedimentation as well has a role in the reactivation of the inner fronts, although secondary. In the Po Plain specific case, this implies that the presence of the buried Southern Alps fronts affects the Northern Apennines kinematics, even if the two fronts did not collide yet.

1. Introduction

The kinematic evolution and structural styles of fold and thrust belts are controlled by a number of factors like structural, tectonic, stratigraphic and petrological parameters that have been long studied (for a review see Poblet and Lisle, 2011). Through times, considerable changes and improvements of the main concepts have been possible, thanks to emerging methods and new techniques progressively provided by different disciplines (structural geology, geophysics, geomorphology, seismology) that led to great research progresses. Nonetheless, many gaps still remain and open issues are far from being solved, in particular those regarding the controlling factors of a fold and thrust belt evolution. Among these, a poorly explored factor is the possible influence of an existing obstacle such as a thrust belt in front of a growing one.

In this study we consider one of the most resounding cases of closely spaced opposite verging thrusts. In Northern Italy, buried under the Po Plain, the N-verging outermost fronts of the Northern Apennines face the S-verging Southern Alps thrust front, located at a distance less than 10 km (Fig. 1).

This work aims at reconstructing the recent kinematics and evolution of the youngest of the two chains, i.e. the Northern Apennines, where the two opposite fronts are at their minimum distance (less than 10 km). The study was carried out in order to (i) understand in detail the evolution of the case study buried structures, which can shed light on the tectonic evolution of Northern Italy, (ii) analyze the recent kinematic and the related seismotectonic implications in an area where two opposite verging chains overthrust the same foreland area (iii) give insights on how such a peculiar setting increases the possibility of out-of-sequence thrust reactivation, and (iv) evaluate through sandbox analogue models if and how much this circumstance was controlled by the presence of the opposite Southern Alps thrust fronts, thus providing some general insights to better understand such a kind of tectonic setting.

These topics are of general interest and are of particular importance in the Emilia arc of folds where different evidences of recent tectonic activity are present (Benedetti et al., 2003; Boccaletti et al., 2011; Burrato et al., 2003, 2012; Maesano et al., 2010; Toscani et al., 2006; Vannoli et al., 2014) and seismogenic sources have been mapped

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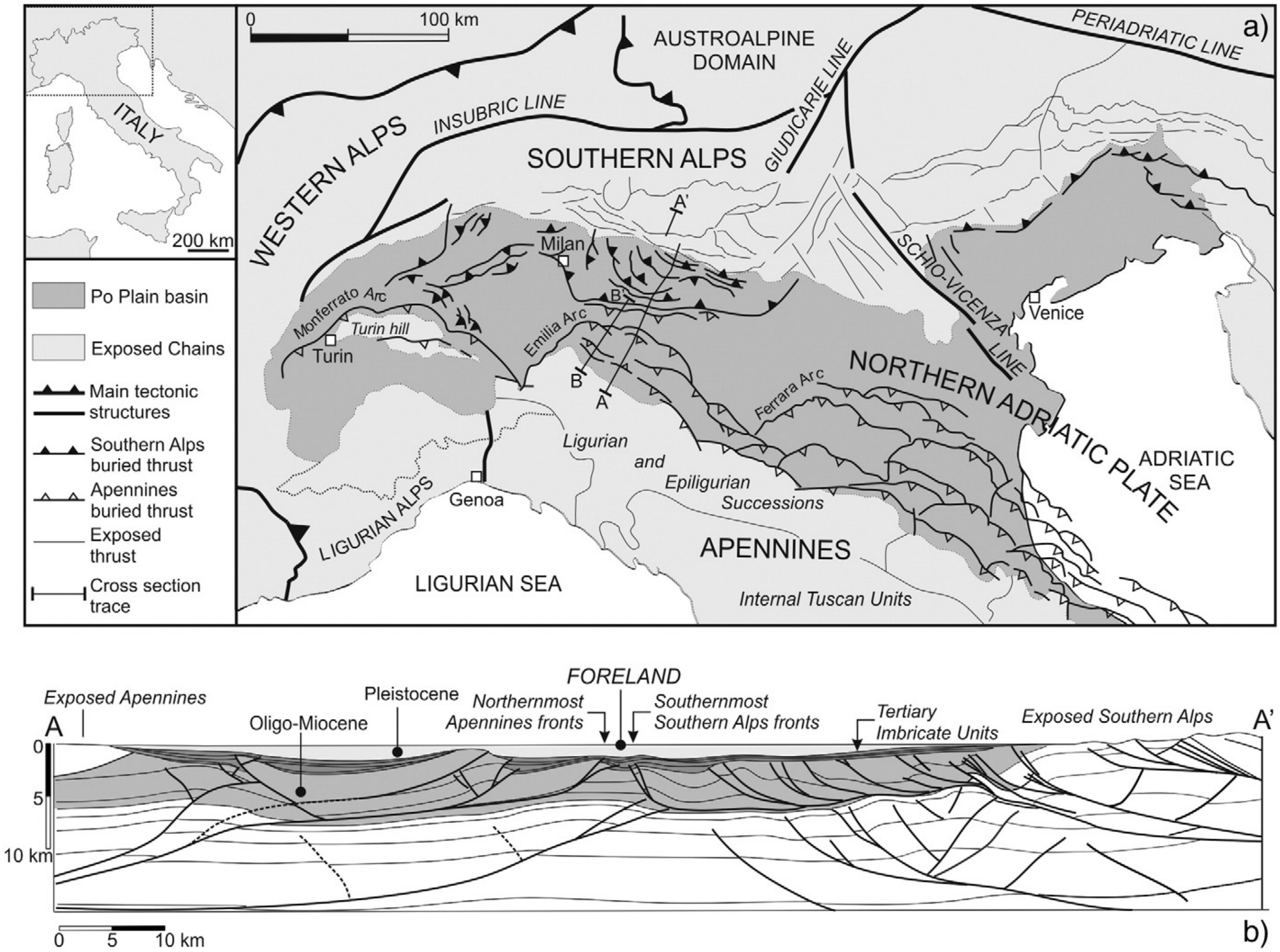

Fig. 1. (a) Map of the study area (after Castellarin et al., 2006 and Fantoni et al., 2004). (b) Cross-section (trace A–A′) redrawn after Fantoni et al. (2004). The second section trace (B–B′) refers to the cross-section of Fig. 2.

(Basili et al., 2008; DISS Working Group, 2010). The study area has moderate to low seismicity, but high exposure, being the Po Plain one of the most densely populated and productive areas in Europe. This has been dramatically demonstrated in recent times (May 2012), when two different mainshocks caused 26 casualties and more than 16,000 people in need of assistance (Dolce and Di Bucci, 2014).

2. Geological setting

The geodynamic evolution of Alps and Apennines belts is the result of the interaction between Eurasia and Africa plates. In this area, the part of Africa plate involved in the collision with Eurasia is commonly known as the African promontory or Adria microplate (Dercourt et al., 1986). The convergence created a complex indentation between the Northern Alps metamorphic belt and the Insubric domain, active since the Cretaceous up to the present (Carminati and Doglioni, 2012; Coward et al., 1989; Dal Piaz et al., 2003; Dewey et al., 1989). This process led to: (i) the development of the Southern Alps, a SSW-verging chain, active from the Late Cretaceous to the Late Miocene as retro-belt side of the Alpine collisional system; (ii) the growth of the Northern Apennines, a NNE-verging belt, which underwent its main compressive tectonic activity from the Early Eocene onward (Boccaletti et al., 1990; Cibin et al., 2004; Di Giulio et al., 2013); and (iii) the formation of the Neogene Po Plain foreland basin, interposed between the two opposite verging chains, representing both the retro-side Alpine foreland basin and the pro-side Apennines foreland basin.

2.1. The Northern Apennines

The Northern Apennines are a fold-and-thrust belt characterized by NNE convexity and shortening direction (Fig. 1a). They include (i) the frontal and outermost structural belt, buried under the alluvial sediments of the Po Plain and the marine sediments of the Northern Adriatic Sea, deformed by thrust propagation from Messinian, and (ii) the exposed chain that, in turn, may be separated into an outer and an inner region. The outer region, is located to the NE of the belt watershed and is mainly characterized by active compressional structures; conversely, the inner belt, SW of the watershed, is currently affected by extensional tectonics (Bennett et al., 2012; Bertotti et al., 1997; Castellarin, 2001; Picotti and Pazzaglia, 2008).

In detail, the thrust front of the Northern Apennines, buried under the Po Plain, shows three main structural arcs (Fig. 1a): (i) Monferrato, in the western part of the Po Plain, mostly deformed since Messinian to Pleistocene; (ii) Emilia, in the central part, which started to develop in the Messinian reaching a maximum activity during the middle–late Pliocene; (iii) Ferrara, located in the eastern part of the Po Plain, active since late Pliocene.

All arcs display strong asymmetry with a shorter western limbs and longer, smoother eastern ones (Cassano et al., 1986; Castellarin and Vai,