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Restraining stepover deformation superimposed on a previous fold-and-thrust-belt: A case study from the Mt. Kumeta–Rocca Busambra ridges (western Sicily, Italy)

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ABSTRACT

The western segment of the Sicilian Apennines (southern Italy) is affected by poly phase deformation characterized by non-coaxial structural associations. In particular, this study is focused on two narrow ~E–W oriented structural and topographic culminations of the fold and thrust belt (Mt. Kumeta and Rocca Busambra ridges), resulting from the exhumation of a deep-seated tectonic unit. A detailed field mapping and meso-structural analysis reveals that since Pliocene time the region was tectonically controlled by the propagation of two major NW–SE oriented right-lateral shear zones and associated structures that often propagated along inherited discontinuities. In particular, the left-stepping geometry and the sense of motion of these regional strike-slip fault systems produced in the overlapping area a wide rhomboidal-shaped contractional region characterized by the occurrence of double-verging ~E–W striking compressive structures. These bound the Mt. Kumeta and Rocca Busambra carbonate ridges, forming a pair of pop-up structures which link the coeval transcurrent boundary faults. Field data show that contractional structures are affected by significant bending along strike that increases close to the major shear zones. Structural rotations around the vertical axis allowed the carbonate ridges to develop a typical sigmoidal shape.

The topographic expression and the internal structural architecture, compared with experimental models describing deformations associated with segmented strike-slip faults, suggest that the analyzed segment of Sicilian fold and thrust belt can be interpreted as a restraining stepover in which crustal shortening, exhumation and vertical axis rotation occurred.

Moreover, field data, compared to the subsurface setting imaged by the analysis of available geophysical data (e.g. gravimetric maps and available/interpreted seismic profiles), reveal that, since Pliocene times, the restraining stepover deformation was transversally superimposed on a pre-existing NE–SW oriented thrust and fold system related to the Miocene Africa–Europe collision.

1. Introduction

Restraining bends or stepovers occur along transform boundaries or in intraplate, intracontinental strike-slip and transpressional settings (e.g. Barka and Kadinsky-Kade, 1988). They mostly develop, from the scale of major mountain ranges to sub-crop-scale examples, along bent strike-slip fault planes (restraining bends) or in contractional sectors between overlapping en-echelon segments (restraining stepovers). In both cases, the involved structures show complex kinematic relationships depending mostly on spatial arrangements and the rate of displacement of the bounding wrench faults (Cunningham and Mann, 2007). Contraction in the overlapping areas generally produces topographic highs related to crustal shortening, uplift and exhumation (Segall and Pollard, 1980; Mann and Gordon, 1996; McClay and Bonora, 2001). Push-up or palm-tree structures usually develop (Harland, 1971; Sanderson and Marchini, 1984; Naylor et al., 1986; Woodcock and Schubert, 1994; Wilcox et al., 1973; Sylvester and Smith, 1976; Harding, 1974; Sylvester, 1988) and consist of a series of anastomosing convex-upward reverse faults which steepen progressively at depth. In addition, three-dimensional strain in overstepping strike-slip settings typically involves vertical-axis rotations (e.g. Jackson and Molnar, 1990). Accordingly, orogenic systems affected by wrench tectonics can provide suitable field examples for understanding the deformation mechanisms associated with the development of segmented strike-slip faults.

As documented by abundant literature, the Sicilian Chain in southern Italy (Fig. 1) experienced a long tectonic history which produced multi-deformed rocks. In particular, many investigators

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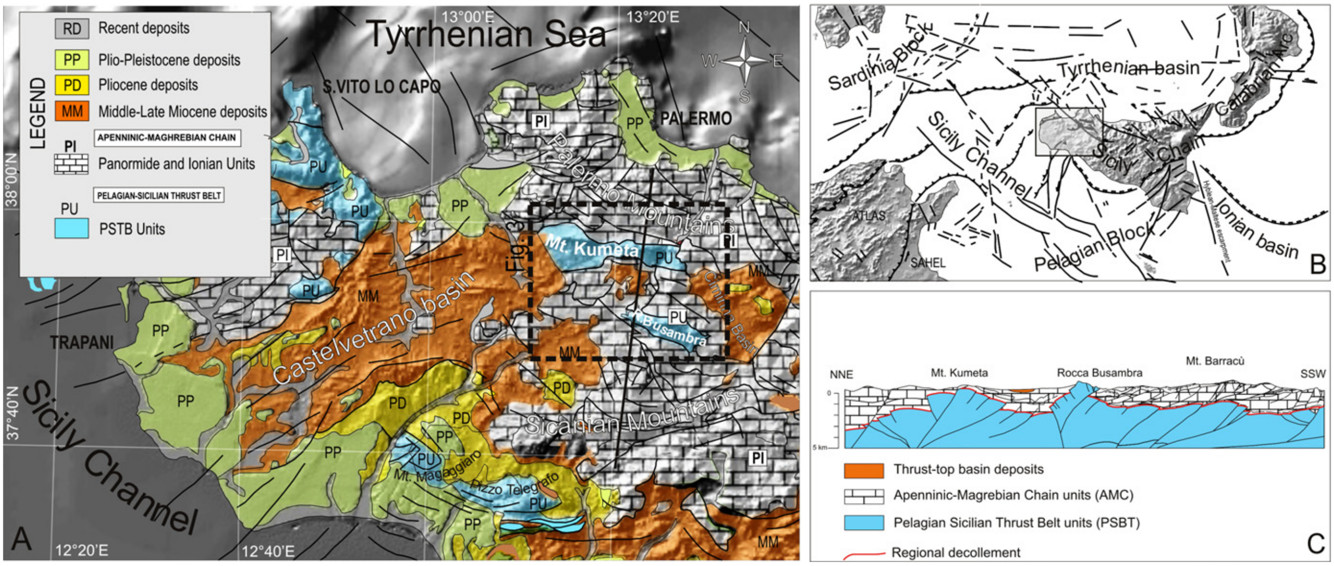

Fig. 1. (A) Schematic geological map of western Sicily (after Finetti et al., 2005) framed in the central Mediterranean region (B) and simplified regional cross-section (after Lentini et al., 2006) through Mt. Kumeta–Rocca Busambra culminations (C) showing the structural relationship between the Apenninic-Maghrebian Chain (AMC) and the Pelagian Sicilian Thrust Belt (PSTB). Dashed rectangle represents the study area.

in the past decades (e.g. Ghisetti and Vezzani, 1984; Finetti et al., 1996, 2005; Guarnieri, 2004; Lentini et al., 2006; Giunta et al., 2009; Barreca et al., 2010a,b) have pointed out the role of wrench tectonics in the Plio-Quaternary geodynamics of the Sicilian Apennines and its Tyrrhenian margin. Although there are different interpretations on mode, role and timing of deformation, the development of shear zones along the Sicilian Chain is in good agreement with Africa–Europe convergence dynamics. Indeed, the articulated setting of the involved crustal blocks and the obliquity of the convergence process produced progressive indentation and spreading of the orogenic system.

The present-day crustal setting of the Sicilian Chain has been recently elucidated by geophysical exploration of the Central Mediterranean (Finetti et al., 2005). Regional seismic sections highlight that along the Tyrrhenian coast of northern Sicily collisional and subduction processes took place contemporaneously. The subduction beneath the Calabrian Arc (Malinverno and Ryan, 1986) and collision to the west resulted in the development of lithospheric discontinuities (transfer faults), at the plate boundary or along the orogenic hinge. These accommodate the differential advancement of the orogenic system towards unconstrained regions characterized by oceanic crust such as the Ionian sector (Fig. 1B). This regional deformation process took place in the Sicilian Chain with the nucleation of dextral ∼NW–SE trending transcurrent faults (Finetti et al., 1996; Lentini et al., 2002) known as Southern Tyrrhenian System (Lentini et al., 1996). Detailed field studies (e.g. Guarnieri, 2004; Avellone et al., 2010; Barreca et al., 2010a,b) and regional ones (e.g. Ghisetti and Vezzani, 1984; Oldow et al., 1990; Giunta et al., 2000; Catalano et al., 2000) have shown that most of these structural elements are characterized by transpressive kinematics and that they produced a series of associated structures during their propagation (e.g. uplift and block rotation, Guarnieri, 2004).

In this paper we present a structural study performed in the western segment of the Sicilian fold and thrust belt where a segment of the E–W oriented mountain range has been strongly uplifted and rotated within a complex strike-slip fault system. The main goal of this work is to provide field evidence for restraining stepover deformation patterns (as a natural example for comparison with analogue models) and thus to understand the role of en-echelon segmented strike slip-faults in the post-collisional structural evolution of the Sicilian Chain.

We focus our study on the spatial arrangement and kinematics of the main transcurrent and contractional structures occurring in the study area by detailed fieldwork (see also Barreca and Maesano, 2010) and extensive meso-structural analysis. The study was supported by 1:10,000 scale aerial photograph interpretation and by the elaboration of a 3D topographic digital elevation model of the area. Moreover, we analyzed available seismic lines using a depth-conversion algorithm (Move 2010® MVE Ltd) and gravity data in order to reconstruct the deep structural architecture of the region and to estimate the offset along the main contractional structures.

2. Regional setting

From a regional point of view, western Sicily (Fig. 1A) represents a part of the south-verging foreland-ward migrating Sicilian Chain, a contractional belt lying between two extensional domains, the Tyrrhenian Basin to the north and the stretched Sicily Channel region to the south (Fig. 1B). The structural architecture of this region has been depicted by deep seismic profiles (Catalano et al., 1998, 2000, 2010a,b; Finetti et al., 2005) that highlighted the occurrence of two superimposed thrust wedges separated by a regional décollement (Fig. 1C). The upper one (named Apenninic-Maghrebian Chain, see Lentini et al., 2006) is composed of a thin fold and thrust system that includes several thrust sheets. The lower one (named Pelagian Sicilian Thrust Belt, see Finetti, 2004; Finetti et al., 2005) consists of a younger ∼10 km thick thrust duplex (Catalano et al., 2000) that involves carbonate sequences of an ancient foreland domain.

The Apenninic-Maghrebian Chain (AMC) is made up of a pile of thrust sheets derived from the late Oligocene – middle Miocene deformation of the oceanic realm of the Neotethys (i.e. Alpine and Ionian Tethys, see Finetti et al., 2005) and of the African continental paleomargin (Bianchi et al., 1987; Ben-Avraham et al., 1990; Roure et al., 1990; Catalano et al., 2000; Tortorici et al., 2001; Finetti et al., 2005). The regional sole thrust lies upon a deeper thrust-involved foreland domain, the Pelagian Sicilian Thrust Belt (PSTB) that includes mainly carbonate rocks comparable with those outcropping in the Pelagian Block (Fig. 1B).

The occurrence of a deep thrust system along the Sicilian Chain was inferred from field data (Lentini et al., 1994, 1996) and was imaged by seismic lines both in western (Catalano et al., 1998, 2000;