Evidence for late Alpine tectonics in the Lake Garda area (northern Italy) and seismogenic implications

Giancarlo Scardia[1,†], Andrea Festa[2], Giovanni Monegato[3], Roberta Pini[4], Sergio Rogledi[5], Fabrizio Tremolada[6], and Fabrizio Galadini[7]

[1]*Istituto di Geologia Ambientale e Geoingegneria, CNR, via Salaria km 29.300, I-00016 Monterotondo Scalo (Roma), Italy*
[2]*Dipartimento di Scienze della Terra, Università di Torino, Via Valperga Caluso 35, I-10125 Torino, Italy*
[3]*Istituto di Geoscienze e Georisorse, CNR, via Valperga Caluso 35, I-10123 Torino, Italy*
[4]*Istituto per la Dinamica dei Processi Ambientali, CNR, Piazza della Scienza 1, I-20126 Milano, Italy*
[5]*ENI E&P, via Emilia 1, I-20097 San Donato Milanese, Italy*
[6]*RPS Energy, Goldsworth House, Denton Way, Goldsworth Park, GU213LG Woking, UK*
[7]*Istituto Nazionale di Geofisica e Vulcanologia, via di Vigna Murata 605, I-00143 Roma, Italy*

ABSTRACT

We investigated the recent evolution of the Po Plain–Alps system by integrating subsurface geophysical data from the Po Plain with new stratigraphic and structural observations from the Southern Alps margin. Inversion of structural data and chronology provided by stratigraphic constraints led to the definition of three tectonic events since the Pliocene, namely, the intra-Zanclean, the Gelasian, and the Middle Pleistocene, driven by an axis of maximum compression formerly oriented NE (intra-Zanclean) and then to the NNW (Gelasian and Middle Pleistocene). The associated deformation has been accommodated by two sets of faults consisting of NNE-trending thrust faults, mostly represented in the western sector of Lake Garda, and NW-trending strike-slip faults, observed in the southern and eastern sectors. The interplay between these two sets of faults is interpreted to produce short (<10 km length) thrust ramps activated in left transpression, bounded by longer (30–60 km) transfer faults activated in a right-lateral strike-slip motion. Based on this structural model, we infer moderate seismicity (M_w < 6) associated with the NNE-directed thrusts and stronger earthquakes (also M_w > 6.5) along the NW-trending strike-slip faults. In this framework, the newly defined Nogara fault and the Sant'Ambrogio fault, all pertaining to the NW-trending system, are regarded as potential candidates for the seismogenic source of the January A.D. 1117 event, the most destructive earthquake in the Po Plain.

INTRODUCTION

After a complex succession of deformation phases, the traditional geologic view constrains the end of Alpine tectonics in the Po Plain to the late Messinian (Pieri and Groppi, 1981; Castellarin et al., 1992; Fantoni et al., 2004), with residual activity confined in the eastern Southern Alps (e.g., Castellarin and Cantelli, 2000; Galadini et al., 2005). This view mainly relies on the occurrence of postorogenic Pliocene marine deposits sealing the folded and eroded Mesozoic–Cenozoic Alpine bedrock (Castellarin et al., 1992). However, geomorphologic, seismological, and geodetic evidence (e.g., Desio, 1965; Anderson and Jackson, 1987; D'Agostino et al., 2008; Livio et al., 2009) clearly points to a still ongoing deformation in the Southern Alps and Po Plain, the study of which is the aim of the present work.

Increasing scientific sensibility of the seismic hazard of the Po Plain has led to modern studies based on punctual paleoseismological investigations (Galadini and Galli, 1999; Galadini et al., 2001; Livio et al., 2009). Moving from these studies, our present work aims to depict a new structural model for the Po Plain that accounts for the largely ignored Pliocene–Pleistocene tectonics of the Southern Alps and seismogenic implications at regional scale. A special emphasis is given to the Lake Garda area because of (1) its complexity as an interference area between two different structural styles, (2) the occurrence of deformed Pliocene–Pleistocene deposits, and (3) the occurrence of damaging historical earthquakes (e.g., A.D. 1117, M_w 6.7; A.D. 1222, M_w 5.8; A.D. 1891, M_w 5.9; A.D. 1901, M_w 5.5; Locati et al., 2011; Pessina et al., 2013). We based our study on the integration of subsurface geophysical data with new direct stratigraphic and structural observations, gathered by means of detailed geological survey along the Southern Alps margin. Taking into account that sedimentation (in the Po Plain) or erosion (in the Alps) rates are much higher than the tectonic strain rate (e.g., Livio et al., 2009; Burrato et al., 2012), we focused on Pliocene and Early Pleistocene deposits, where the cumulative deformation is expected to be more evident in the stratigraphic record.

REGIONAL BACKGROUND

The tectonic setting of the Southern Alps has a complex history, including Mesozoic rifting and convergence between the European and Adriatic plates since the Late Cretaceous. Thrusting of the Paleozoic basement and its sedimentary cover during the Miocene represented the final, postcollisional phase of the Alpine orogeny, which resulted in the formation of a fold-and-thrust belt composed of south-verging thrust sheets (e.g., Laubscher, 1985; Picotti et al., 1995).

The Lake Garda area lies between two sectors characterized by different structural styles. To the west, the "Giudicarie belt" consists of NNE-trending, transpressive thrusts and folds (Fig. 1). The eastern sector is characterized by the rigid block of the Lessini Mountains, mainly deformed by the NW-trending, strike-slip Schio-Vicenza fault system. Since the late Messinian, Apennines-related flexural subsidence has involved the southern sector of the Alps, resulting in the southward tilting and burial of the outermost Alpine thrusts (e.g., Fantoni et al., 2004). Southward tilting also involved the former Alpine foreland, producing a regional monocline dipping ~5° toward the Apennines

[†]Current address: Instituto Oceanográfico, Universidade de São Paulo, Praça do Oceanográfico 191, 05508-120 São Paulo, SP, Brazil; scardia@usp.br.

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