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Three-dimensional seismo-tectonics in the Po Valley basin, Northern Italy

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ABSTRACT

The Po Valley (Northern Italy) is a composite foreland–foredeep basin caught in between the Southern Alps and Northern Apennine mountain belts.
By integrating the 3D structural model of the region with the public earthquake dataset, the seismo-tectonics of the basin is shown at different scales of observation.
The three-dimensional geo-volume is used to review the seismicity around the region and validate the structure–earthquake association for such a complex tectonic framework.
Despite the overall uncertainty due to the original data distribution-quality as well as the crustal scale model dimension, the direct correlation between structures and seismicity a) confirms the Po Valley region as an active tectonic system and b) allows the whole structural architecture to be revised by a unique three-dimensional perspective and approach.
This study also indicates that 3D methodology is a powerful tool for better understanding of highly complex seismo-tectonic situations at both regional and local scales.

1. Introduction

Italy is an active tectonic province within the Mediterranean geodynamic puzzle. In the region, the major structural units and the related crustal scale geological boundaries are clearly revealed by the current stress field and the important seismicity (e.g. Carminati & Doglioni, 2012; Di Bucci & Angeloni, 2013 and reference therein). Through geological time, both pre-Alpine (Mesozoic and pre-Mesozoic) and Alpine (mainly Cenozoic) tectonics have interacted to create the current structural and stratigraphic setting (Elter and Pertusati, 1973; Laubscher, 1996; Castellarin, 2001; Castellarin and Cantelli, 2010; Cuffaro et al., 2010; Mosca et al., 2010; Carminati and Doglioni, 2012 and reference therein). As a result, the Po Valley (Fig. 1) represents the north-westernmost buried sector of the Apulian indenter (or Adria plate: Channell et al., 1979, Dewey et al., 1973, Dercourt et al., 1986), the foreland/foredeep domain to the Alpine and Northern Apenninic belts and, ultimately, one of the major hydrocarbon provinces of continental Europe.

Historical and instrumental earthquakes across the Italian peninsula are recorded, collected and reviewed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV; National Institute for Geophysics and Volcanology). The derived catalogues are constantly updated at each new seismic event and both initial and (re)processed data are available to the public, on the institution's website (http://www.ingv.it/it/).

While earthquakes happen continuously all through the country, the northern part of Italy is characterized by patchy hypocentre occurrence with highly concentrated clusters (Fig. 2a). Magnitude (*local*) of the reported earthquakes across the region is between 0 and 7 while depth of the events is between 0–70 km. Focal mechanisms from the available literature (Fig. 2b) indicate mainly north–south active shortening with thrust-related and strike–slip structures, these being supported by regional stress, thrust–slip rates, GPS-derived maps and geomorphological criteria (Burrato et al., 2003; Montone et al., 2004; Maesano et al., 2010, 2011; Rovida et al., 2011; Burrato et al, 2012; Carminati & Doglioni, 2012; Michetti et al., 2012; Di Bucci & Angeloni, 2013; Maesano et al., 2013, 2014; and all references therein).

Three-dimensional modelling is an important tool to tackle highly complex geological structures. Although such technique has become a standard procedure especially for oil and gas exploration (Mitra and

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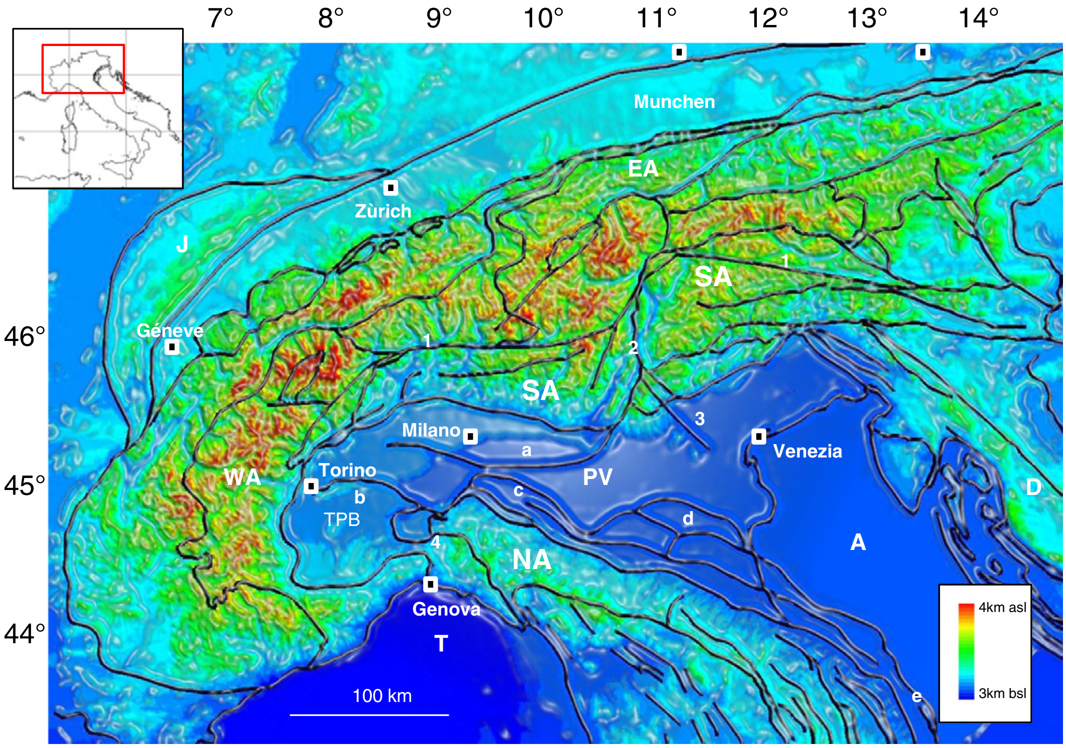

Fig. 1. Digital topography and tectonic framework (modified from Nicolich, 2010) around the Po Valley region. (PV) Po Valley; (SA) Southern Alps; (NA) Northern Apennines; (WA) Western Alps; (EA) Eastern Alps; (D) Dinarides; (J) Jura Mountains; (A) Adriatic; (T) Tyrrenhian; (1) Insubric Line; (2) Giudicarie Line; (3) Schio–Vicenza Line; (4) Sestri–Voltaggio–Villavernia Lines; (a–e) buried thrust fronts: a = Milano Thrust Front; b = Monferrato Thrust Front; c = Emilian Thrust Front; d = Ferrara–Romagna Thrust Front; e = Ancona Thrust Front. TPB = Tertiary Piedmont Basin. Latitude and Longitude values are North and East of Greenwich. Grid in the inset map is 500 km.

Leslie, 2003; Turrini and Rennison, 2004; Dischinger and Mitra, 2006; Mitra et al., 2005, 2007; Valcarce et al., 2006; Turrini et al., 2009; Lindsay et al., 2012; Vouillamoz et al., 2012; Shao et al., 2012 and reference therein), groundwater aquifer studies (Berg et al., 2004 and references therein) and ore deposit analysis (Han et al., 2011, and references therein), the application of 3D models to seismo-tectonic studies is rare (e.g. Bechtold et al., 2009; Burrato et al., 2014; Carena et al., 2002; Maesano et al., 2014). Hence, schematic cross-sections or simple map-view projections constitute the classic tools for the analysis of structures-versus-earthquakes associations.

As follow-up to the recent Po Valley 3D model (Turrini et al., 2014), this study aims to illustrate and discuss the structures and the seismicity of the region from crustal to local scale.

Noteworthy, given the range of uncertainty in both the 3D model and the original earthquake dataset, this study does not aim to offer a quantitative seismological analysis about the selected structural domains. Conversely, the final 3D geo-volume may represent a powerful tool in the unravelling of the basin seismo-tectonic complexity.

2. Regional framework of the Po Valley

2.1. Structures, stratigraphy & exploration

Structures across the Po Valley region mainly refer to the external domains of the Southern Alps and the Northern Apennines and intervening foreland, this latter being a major obstacle to the propagation of large and buried tectonic arcs (Pieri and Groppi, 1981; Castellarin and Vai, 1982; Bartolini et al., 1996; Cassano et al., 1986; Castellarin et al., 1986; Ricci Lucchi, 1986; Perotti, 1991; Perotti and Vercesi, 1991; Bertotti et al., 1997; Argnani and Ricci Lucchi, 2001; Carminati and Doglioni, 2012; Ahmad et al., 2014; Toscani et al., 2014; Turrini et al., 2014, and reference therein). Provided the well results and the outcrops around the region, the Po Valley sedimentary successions are defined by Mesozoic carbonates, clastic Cenozoic deposits and a crystalline basement essentially composed of Hercynian metamorphic rocks. The final tectonic features evolved from late Triassic–early Jurassic extension to late Cretaceous–Cenozoic compression, this providing inversion of the pre-existing extensional structures and shortening across both the foreland and the surrounding orogenic belts (Bertotti et al., 1993; Fantoni et al., 2004; Jadoul et al., 1992). During such a deformation history, sedimentation of the carbonates kept pace with the overall tectonics so that shelf, marginal and basin type deposits developed as part of the northern Africa derived Adria micro-plate. Triassic–early Jurassic rift-related structures were locally inverted by Cretaceous contraction with reactivation of some of the existing N–S and E–W trending normal faults (Dal Piaz et al., 2004; Ravaglia et al., 2006; Schmid et al., 2004). Onset of the foreland flexure at the front of the western Southern Alps is suggested by the deposition of Oligocene turbidites (Gonfolite basin; Gelati and Gnaccolini, 1982; Castellarin and Vai, 1986; Roure et al., 1989, 1990). Finally, in Miocene and Pliocene times, the basin became the foreland of the Alps and the Apennine belts and the Mesozoic rocks were deeply buried beneath the Palaeogene–Neogene clastics and the associated foredeep wedges (Fantoni et al., 2004; Trumpy, 1973).

Since the end of the 20th century a number of hydrocarbon fields have been discovered and developed inside the Po Valley basin (Pieri, 1984). Among others, the Villafortuna–Trecate field, 30 km west of Milano, has been the most successful so far as it produced 240 MMbbls from a Triassic carbonate reservoir, 5000 m below the mean sea level. By the acquisition of modern 2D/3D seismic surveys and the drilling of deep wells (green dots in Fig. 2a), the oil business strongly contributed to the understanding of the basin tectonics, sedimentology and geochemistry (Bello and Fantoni, 2002; Bongiorni, 1987; Casero et al. 1990; Cassano et al., 1986; Errico et al, 1980; Fantoni et al., 2004; Lindquist, 1999; Mattavelli and Margarucci, 1992; Mattavelli and Novelli, 1987; Nardon et al., 1991; Pieri, 1984; Pieri and Groppi, 1981).