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Seismogenic sources in the Adriatic Domain

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A B S T R A C T

We present an overview of the seismogenic source model of the Adriatic domain included in the latest version of the DISS database (http://diss.rm.ingv.it/diss/) and in the European SHARE database (http://diss.rm.ingv.it/SHARE/). The model consists of Composite and Individual Seismogenic Sources located inside and along the margins of the Adria plate. In order to locate and parameterize the sources, we integrated a wide set of geological, geophysical, seismological and geodynamic data, either available from published literature or resulting from our own field work, seismic profile interpretations and numerical modelling studies. We grouped the sources into five regions based on geometrical and kinematic homogeneity criteria. Seismogenic sources of the Central Western Adriatic, North-Eastern Adriatic, Eastern Adriatic and Central Adriatic regions belong to the Northern Apennines, External Dinarides and offshore domains, respectively. They are characterized by NW–SE strike, reverse to oblique kinematics and shallow crustal seismogenic depth. Seismogenic sources of the Southern Western Adriatic region instead are E–W striking, dextral strike-slip faults, cutting both the upper and lower crust. The fastest moving seismogenic sources are the most southern thrusts of the Eastern Adriatic and the strike-slip sources of the Southern Western Adriatic, while the seismogenic sources of the Central Adriatic exhibit the lowest slip rates. Estimates of maximum magnitude are generally in good agreement with the historical and instrumental earthquake records, except for the North-Eastern Adriatic region, where seismogenic sources exhibit a potential for large earthquakes even though no strong events have been reported or registered. All sources included in the database are fully geometrically and kinematically parameterized and can be incorportaed in seismic hazard calculations and earthquake or tsunami scenario simulations.

1. Introduction

The Adriatic Sea has long been considered a relatively undeformed crustal block and foreland area of the Apennines and External Dinarides thrust belts (e.g. Channell et al., 1979; Anderson and Jackson, 1987). Most of the largest earthquakes are distributed along the coasts and inland, while the seismic record for the offshore is less complete. Available geological data from standard active fault mapping cover the inland and coastal portions of some of the islands, but almost no data were reported for most of the offshore until recently (Grandić et al., 2007; Fantoni and Franciosi, 2010). As new seismic profiles and borehole data were made available by hydrocarbon exploration, the attention shifted also towards the offshore areas. Such new data revealed a complex structural setting including inherited and reactivated normal faults, horst and graben geometries, NW–SE trending anticlines and evaporite bodies and active thrusts deforming Plio-Quaternary units. Moderate size earthquake sequences of the past few decades confirm the seismogenic activity of the faults in the Adriatic domain and at the same time call for a re-evaluation of the seismic potential in the entire region.

The outer thrusts of the Apennines and External Dinarides propagated into the Adriatic from the coastal areas towards the offshore, resulting in complex pattern of NW–SE trending anticlines, thrust faults and backthrusts and involving Late Pleistocene deposits. The two thrust fronts currently confront each other (Scrocca, 2006; Ivančic et al., 2006), a configuration that is somehow reminiscent of the proximity of Southern Alpine and Apennines fronts in the subsurface of the central Po Plain. In the southern Adriatic, morpho-bathimetry and seismic analyses (Ridente et al., 2008a; Di Bucci et al., 2009; Fracassi et al., 2012) revealed the presence of at least one major E–W, dextral, strike-slip fault stretching from the Gargano Promontory into the offshore.

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The southern eastern Adriatic is undergoing shortening and thrusting, but the external thrusts are less advanced than in the central Adriatic and generally follow the coastline.

Seismicity in the Adriatic domain is ditributed both along the Adria plate margine and its interior (Renner and Slejko, 1994; Herak et al., 2005; Ivančic et al., 2006; Rovida et al., 2011) and shows prevailing compressional focal mechanisms (Renner and Slejko, 1994; Herak et al., 1995; Pondrelli et al., 2006, 2011). The strongest earthquakes are reported to have occured along or close to the coastlines of the southern part of the Adriatic domain, while $M \geq 5.5$ earthquakes are typical for the entire region (Shebalin et al., 1974; Herak et al., 1995; Markušić et al., 1998; Herak et al., 2005; Papazachos et al., 2009; Thessaloniki Macroseismic earthquake catalogue, 2010; Rovida et al., 2011).

We aimed at building a seismogenic model of the Adriatic domain that could both improve the current understanding of the active tectonics and help assessing the local seismogenic potential. Our study was designed to integrate available data and recent advancements on the structural and seismological characteristics of the Adriatic domain into a homogenized and possibly uniform seismogenic source model. The Adriatic domain is not an easy area to characterize from the active tectonics point of view because most of the relevant geological and structural features are concealed by a thick recent sedimentary cover and by the sea. As a consequence, parameterization of the seismogenic sources is mostly based on geophysical subsurface data, covering only a small portion of the domain and often presenting contrasting interpretations. The fact that the Adriatic domain is shared among different countries inevitably implies a diverse level of geologic exploration and data availability. The model presented here attempts to overcome these limitations by 1) integrating all available data, 2) building on similarities between adjacent areas and 3) following common criteria for source characterization.

Our seismogenic source model consists of 38 Composite (CSS) and 23 Individual Seismogenic Sources (ISS) located inside and along the Adriatic domain margins, all of them structurally belonging to the external areas of the Central and Northern Apennines, the eastern Southern Alps, and the External Dinarides thrust belts. The geometrical and kinematical definition of each source is the outcome of integrated geological, geophysical, seismological, and geodynamic studies. These sources are included in the most recent version of the DISS database (http://diss.rm.ingv.it/diss/), a regional compilation originally covering the Italian territory (Valensise and Pantosti, 2001; Basili et al., 2008), and in the European SHARE database (http://www.share-eu.org/), an extension of DISS to the Euro-Mediterranean regions (Basili et al., 2010). The reader may refer to Basili et al. (2009) for a more detailed decription on how the seismogenic source model was built. The fully parameterized seismogenic sources may serve as input data for various geodynamic and seismological applications, including regional probabilistic seismic hazard assessment (e.g. Meletti et al., 2008), large-scale geodynamic modelling (e.g. Barba et al., 2008; Cuffaro et al., 2010), studies on earthquake probabilities (e.g. Akinci et al., 2009, 2010), tsunami scenarios (e.g. Lorito et al., 2008; Tiberti et al., 2008), and strong-motion prediction models (e.g. Calderoni et al., 2012; Zonno et al., 2012).

2. Geological framework

The Adriatic Sea is a semi-closed basin of Meso-Cenozoic continental origin (e.g. Suess, 1883; Canavari, 1885; for a review see also Piccardi et al., 2011) surrounded by the Apennines and External Dinarides – Albanides thrust belts, having opposing vergence and defining its western and eastern margins, respectively, and by the S-verging Southern Alps to the north. Based on seismicity distribution and GPS measurements, the Adriatic domain has been interpreted either as a single microplate (Anderson, 1987; McKenzie, 1972), as the combination of two microplates joined along the Mid-Adriatic Ridge (e.g. Oldow et al., 2002; Scisciani and Calamita, 2009), or as two microplates connected roughly along the Gargano promontory-Dubrovnik alignement (e.g. Westaway, 1990; D'Agostino et al., 2008). Within this complex structural setting, the main factors causing and controlling the evolution of the circum-Adriatic region are 1) the subduction of the Adria plate below the Apennines and its east directed slab rollback (Doglioni et al., 1999; Wortel and Spakman, 2000); 2) the south-dipping slab of the European plate below the Southern Alps (Lippitsch et al., 2003); 3) the east-directed Adriatic slab under the External Dinarides (Piromallo and Morelli, 2003); 4) N–NE directed indentation of Adria into the Southern Alps and the External Diarides. A high velocity crustal body connected to the indentation of Adria is recognized by various investigators beneath the Southern Alps and External Dinarides. structural units (Brückl et al., 2007; Šumanovac et al., 2009). A common characteristic of all bounding thrust belts is their orogenic transport towards Adria (e.g. Dewey et al., 1973; Dercourt et al., 1986). The Adriatic domain shows a northeast to north directed motion with respect to Eurasia (Babbucci et al., 2004; Battaglia et al., 2004; Grenerczy et al., 2005; D'Agostino et al., 2008; Devoti et al., 2008) and a higher lithospheric strength compared to its surroundings (Tesauro et al., 2009; Carafa and Barba, 2011). Geophysical and seismological investigation within Adria itself revealed the differences in the lithosphere structure between the northern and southern parts (Venisti et al., 2004).

The Eastern Southern Alps are the eastern portion of the late Cretaceous-Quaternary S-verging back-thrust belt of the Alpine chain, bounded to the north by the Insubric-Periadriatic line (Doglioni and Bosellini, 1987; Castellarin and Cantelli, 2000). The outer thrust front is composed by NE–SW to E–W trending faults and folds emerging along the mountain front or buried below the Quaternary foredeep and continental sediments of the Veneto-Friuli plain (Galadini et al., 2005), which were used to define the Neogene-Quaternary timing of activity of these structures (Caputo et al., 2010). To the east the Southalpine thrusts interact with the NW–SE trending, dextral strike-slip faults of the Idrija fault system in the Slovenia border region (Bajc et al., 2001; Burrato et al., 2008; Kastelic et al., 2008).

The convergence along the eastern Adria margin since Late Jurassic first resulted in the formation of the Internal Dinarides (Tari, 2002). Thrusting gradually propagated westwards, as recorded by the migration of foredeep basin sequences in Late Cretaceous–Early Paleogene (Tari, 2002; Korbar, 2009), forming the External Dinaric thrust belt. The oldest thrusting activity associated with the External Dinarides in western Slovenia was recorded by Early Eocene foredeep flysch deposits (Drobne and Pavlovec, 1991). The onset of thrusting and related foredeep flysch deposition becomes younger southeastwards along the External Dinaric belt, and westwards in the offshore direction (Tari, 2002). Through Oligocene–Miocene times the foredeep basins progressively occupied the Adriatic offshore (Tari-Kovačić, 1998; Tari-Kovačić et al., 1998). Active faults in the External Dinarides are mostly NW–SE oriented, NE-dipping thrusts (Ivančic et al., 2006).

The outermost front of the NE-dipping External Dinarides lies adjacent to the SW dipping Northern Apennines outermost thrust front (Scrocca, 2006) in the middle of the Adriatic Sea. Different terms are used in the literature to refer to this region: Middle Adriatic Ridge (e.g. Finetti, 1982; Scisciani and Calamita, 2009), Adriatic Ridge (e.g. Scrocca, 2006) for its more central-western part, Central Adriatic Deformation Belt (e.g. Argnani and Gamberi, 1995), and Mid Adriatic Basin (e.g. Fantoni and Franciosi, 2010). The region