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Seismic potential in Italy from integration and comparison of seismic and geodetic strain rates

Carmelo Angelica [a], Alessandro Bonforte [b,*], Giovanni Distefano [a], Enrico Serpelloni [c], Stefano Gresta [a]

[a] Università degli Studi di Catania, Dipartimento di Scienze Biologiche, Geologiche ed Ambientali, Corso Italia 55, 95129 Catania Italy
[b] Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, Piazza Roma 2, 95123 Catania Italy
[c] Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti, via D. Creti 12, 40128 Bologna Italy

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ABSTRACT

Seismological and geodetic data provide key information about the kinematics and active tectonics of plate margins. Focal solutions enable the determining of the directions in which the current tectonic stress acts when fault rupturing occurs; GPS measurements provide information on the crustal velocity field and on current interseismic strain rates. The comparison of the strain rates resulting from the two datasets provides further insight into how large an area is affected by aseismic deformation, which is a valuable indicator for seismic hazard mitigation and estimation of the seismic potential. In this work, we investigate both seismic and geodetic strain rates and the combined field resulting from the joint inversion of the geodetic and seismic datasets, providing a picture of the overall deformation field and its variation during the last decades. In this way, we try to give an overview of the seismic potential distribution across the Apennines and southern Italy, as a qualitative analysis of space-time variations in the released seismic strain rate, compared to the space-time distribution of the cumulated geodetic strain rate. The results show a variable distribution of the seismic efficiency over Italy. The Southern Apennines shows the greatest seismic potential, highlighting a significantly lower seismicity in the last two decades over an area affected by the highest total strain rates. The Messina Straits and eastern Sicily have a significant seismic potential, together with the Calabrian arc (from the Tindari–Letojanni and central Aeolian islands to the Mt. Pollino area), as a result of seismic gaps with respect to the combined strain rates in the investigated period. This long gap highlights the longer recurrence periods for the strongest earthquakes on this area. The central–northern Apennines and off-shore northern Sicily, show a lower seismic potential than central–southern Apennines, probably due to the more recent seismicity affecting these areas.

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1. Introduction

The collision of the Adriatic Plate with the European continent closed the Tethys in the Mediterranean central region, giving rise to the Alps orogenic chain. Other microplates trapped between the two major ones (African and European) caused the formation of the complex arrangement of European mountain chains generally oriented east–west, while in the Middle East the Arabic Plate collided with Asia (Dewey et al., 1973; Le Pichon et al., 1988).

Over the past 30–35 My the Central and Western Mediterranean tectonics have been controlled by a retreating subduction inside the Africa–Europe convergence zone, with a roll-back and retreat of the subducting slabs (Billi et al., 2011; Dewey et al., 1989; Faccenna et al., 2001).

In the last 8 My, Ionian slab roll-back led to the opening of the Tyrrhenian Sea between the Corsica–Sardinia block and the Italian peninsula, due to the decoupling of the Calabro–Peloritani segment of the orogenic chain from the Corsica–Sardinia block and its migration south-eastwards to its present position. Here it docked 1–0.5 Ma, to become the toe of Italy and the eastern tip of Sicily. It is often assumed that the roll-back and the accompanying back-arc extension continue until today. However, recent GPS observations (Devoti et al., 2011; Hollenstein et al., 2003; Pondrelli et al., 2004) in combination with neotectonic data, show that a tectonic reorganization must have occurred 1–0.5 Ma (Goes et al., 2004). Around 0.5 My ago, the compression between Africa and Europe was transferred from within Sicily to its northern off-shore (Goes et al., 2004).

A complex deformation zone now links the Sicilian backthrust with the Calabrian part of the plate boundary, and further readjustments may still be occurring (Faccenna et al., 2001). This change in plate motions is most likely to be the response to the on-going collision with the irregular African margins in Sicily and Apulia (Goes et al., 2004).

Within this area, Italy is the result of a complex geodynamic evolution and is now characterized by a set of different crustal blocks

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* Corresponding author. Tel.: +39 095 7165800; fax: +39 095 7165826.
E-mail address: alessandro.bonforte@ct.ingv.it (A. Bonforte).

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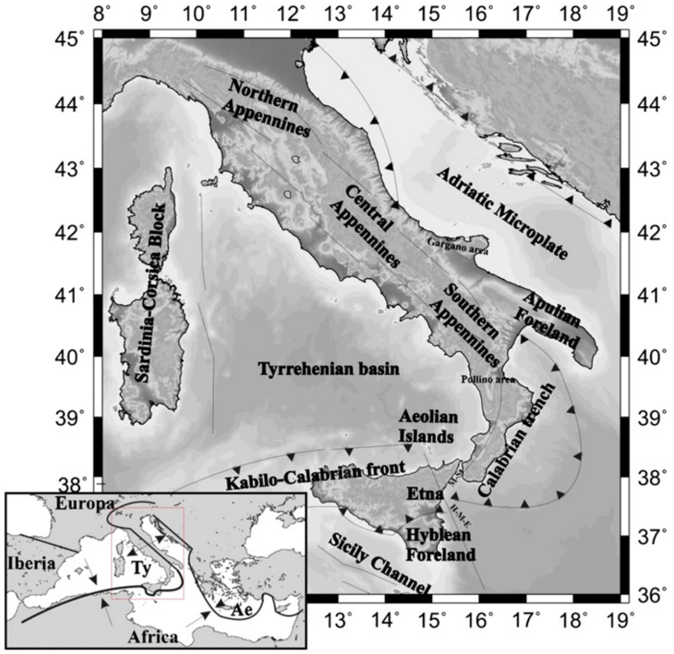

Fig. 1. Structural sketch map of Italy with main tectonic features. HME: Hyblean–Maltese escarpment; MS: Messina Straits.

trapped between the Eurasian and African rigid plates (Fig. 1), whose kinematic and lateral variation in thickness and rheological parameters, make the convergence zone fragmented and irregularly shaped (Grasso, 2001).

Italian seismicity (http://csi.rm.ingv.it/) can be considered as superficial, since the hypocenters are concentrated at depths of less than 50 km except in the area beneath the Calabrian arc, and is affected also by a deeper seismicity that reveals the presence of a subduction zone along a NW-dipping Benioff plane (Chiarabba et al., 2005).

Italy has been affected by several destructive earthquakes that caused considerable loss of life and damage to human settlements. These events may strike infrastructures and urban settlements, much larger today than in the past, with a significant risk to the inhabitants and/or integrity of infrastructures. Knowledge on the seismic history of Italy is limited to the period after the first millennium while, for more ancient times, there is no reliable information. After the first millennium, this history is marked by many earthquakes, of which the largest occurred in the Apennines, in Calabria and Eastern Sicily (Boschi et al., 1995, 1997, http://emidius.mi.ingv.it/CPTI/home.html).

In this work, we modeled detailed seismic and geodetic strain rates field for Italy, allowing an improved interpretation of the current tectonics. Integration of the recent GPS information with seismicity data enables defining the deformation styles of the study region in detail; furthermore, we calculated the seismic efficiency distribution (i.e., seismic/geodetic strain rate ratio; Masson et al., 2005) over the entire area and also investigated its variation during the last decade. In this way, we can detect the most “potentially seismic” areas over the Apennines, by performing an analysis of space-time variations in the released seismic strain rate, compared to the space distribution of the cumulated geodetic strain rate.

2. Seismic potential

Traditionally, seismic potential, namely the capacity of an area to generate earthquakes, is estimated from seismicity catalogs (Jenny et al., 2006). Using this approach, the southern Apennines, Calabrian arc, the Messina Straits and southeastern Sicily have all been identified as high seismic hazard regions (e.g., Brancato et al., 2009; Slejko et al., 1998, 1999). Also the northern Apennines and western Sicily (Belice valley) are classified as areas with significant seismic hazard.

Seismic moment rate is proportional to seismic strain rates, thus allowing a comparison with other types of strain rate data (Jenny et al., 2006). It has been shown that instrumental seismicity catalogs, which are usually much shorter for Italy than the largest-event recurrence times, generally underestimate long-term average seismic moment rates (Jenny et al., 2004; Ward, 1998). This implies that Italy's instrumental seismic catalog most likely provides a lower limit for long-term average seismic strain rates, and for seismic potential estimations.

In this study, we use the information from geodetic data to calculate tectonic strain rates with the aim of improving seismic potential estimates for Italy. Assuming that tectonic loading (thus the slow overall deformation) is stationary in time, long-term average seismic strain rate release cannot exceed tectonic loading rates; conversely, it can be significantly lower, if part of the deformation occurs as aseismic creep or if elastic energy has not yet been released.

Seismic moment release estimates by Westaway (1992) (from macroseismic intensities of historical earthquakes) are comparable to geodetically measured strain rates in the Apennines (Hunstad et al., 2003), indicating that the deformation there has been entirely released by seismic activity. However Pondrelli (1999), using regional moment tensors, found that seismicity accounts for only about 30% of the total deformation inferred from VLBI data, along the Apennines, and for about 30% in Calabria and 10% in Sicily. Only in the Sicily Channel, the estimated ratios reach a higher value (79%). Ward (1998) calculated similar low percentages by his comparison of seismic and VLBI strain rates. He attributed these low ratios to the short catalog length, compared to the long seismic cycle in this slowly deforming region. The rate comparison performed by Boschi et al. (1995) yields a very low 20-year probability of $M \geq 6$ crustal seismic event in most of Italy, except in northern and southeastern Sicily, where probabilities reach 65% along the northeastern coast.

These previous studies are significantly hampered by the sparse distribution of geodetic data. Here, we provide more detailed strain rate fields for the Apennines and Sicily, allowing an improved interpretation of the current active crustal deformation. In addition, by GPS and seismicity data combination we can provide a detailed distribution of the overall deformation styles over the region, and we can also calculate the seismic efficiency distribution (as the ratio between seismically released and cumulated geodetic deformation) over the entire area, investigating also its variation during the last decades. In this way, we try to provide a picture of the seismic potential distribution over the Apennines and Sicily, as a qualitative analysis of space-time variation of the released seismic strain rate, compared to the space-time distribution of the cumulated geodetic strain rate.

3. Data sources

3.1. GPS data

In 1987, the first GPS survey across the Messina Straits was performed with single frequency receivers, over the terrestrial network of Caputo et al. (1981). The same network, with some additional TyrGeoNet stations (Anzidei et al., 2001), was re-occupied with dual frequency GPS receivers in 1994, partially in 2002 and 2004, and most recently in 2008 (Margheriti and Messina, 1908–2008 Team, 2008).

Following the December 13th 1990 earthquake in south-eastern Sicily, a first GPS network was installed around the epicentral area and surveyed in 1991. The former GPS network was later extended and currently consists of 50 stations. In 1998 and 2000, two GPS surveys were carried out on 26 stations of the northern half of the network (Bonforte et al., 2002), and the same network was resurveyed more recently in 2006, and was also improving its geometry and logistics.

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