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Fast geodetic strain-rates in eastern Sicily (southern Italy): New insights into block tectonics and seismic potential in the area of the great 1693 earthquake

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ABSTRACT

Along the ∼500 km long Sicily–Calabria segment of the Nubia–Eurasia plate boundary GPS data highlight a complex, and debated, kinematic pattern. We focus on eastern Sicily, where the style of crustal deformation rapidly changes in the space of few tens of kilometers. In southeastern Sicily, struck by the 1693 $M_W \sim 7.4$ earthquake, GPS measurements highlight a steep velocity gradient, with ∼2.4 mm/yr of ∼N–S shortening in ∼10 km, changing to broader extension (∼3 mm/yr in ∼60 km) in northern Sicily and shortening in the southern Tyrrhenian Sea. GPS data and kinematic elastic block models highlight a complex fragmentation of the Sicilian domain into three tectonic blocks, which move independently from Nubia, describing an overall clockwise rotation of this crustal domain with respect to Eurasia. Shortening in southeastern Sicily is associated with a system of high-angle reverse faults resulting from tectonic inversion of extensional faults at the northern tip of the Hyblean plateau. Extension in northern Sicily occurs on a broader deformation belt, developed on the former Kumeta–Alcantara line, extending west of Mount Etna toward the southwestern Tyrrhenian Sea, accommodating the faster rotation of the northeastern Sicily block with respect to central Sicily. Although the seismic potential of inland faults is not negligible, our results strengthen the hypothesis that the Malta escarpment is the likely source of the large 1693 earthquake and tsunami. The observed kinematics appears only subordinately driven by the Nubia–Eurasia convergence and the dynamics of the Mediterranean subduction system is likely playing a major role in governing block motions and active tectonics in Sicily.

1. Introduction

Sicily and Calabria lay at the boundary between the converging Nubian and Eurasian plates, in a sector recognized as a key area for understanding the geodynamics of the Mediterranean. The study area is among the most seismically active regions of the Mediterranean and has been the locus of the strongest historical earthquakes in Italy (Fig. 1). The kinematics of the complex mosaic of microplates that characterizes the central Mediterranean is of great interest in the scientific debate. Here, we use measurements of crustal deformation by GPS to provide quantitative constraints on both microplate motions and strain accumulation at active faults. The large-scale kinematics of the study region has been discussed in several papers (e.g., D'Agostino et al., 2011; Serpelloni et al., 2010; Devoti et al., 2011; Palano et al., 2012; Angelica et al., 2013; Faccenna et al., 2014). On the contrary, only a few attempts have been made to relate the geodetic deformation to interseismic strain buildup at faults, which is challenging in an area characterized by a complex tectonic and geodynamic setting, but fundamental for our understanding of their seismogenic potential.

Early GPS observations (Nocquet and Calais, 2003; D'Agostino and Selvaggi, 2004; Serpelloni et al., 2005) showed Sicily moving

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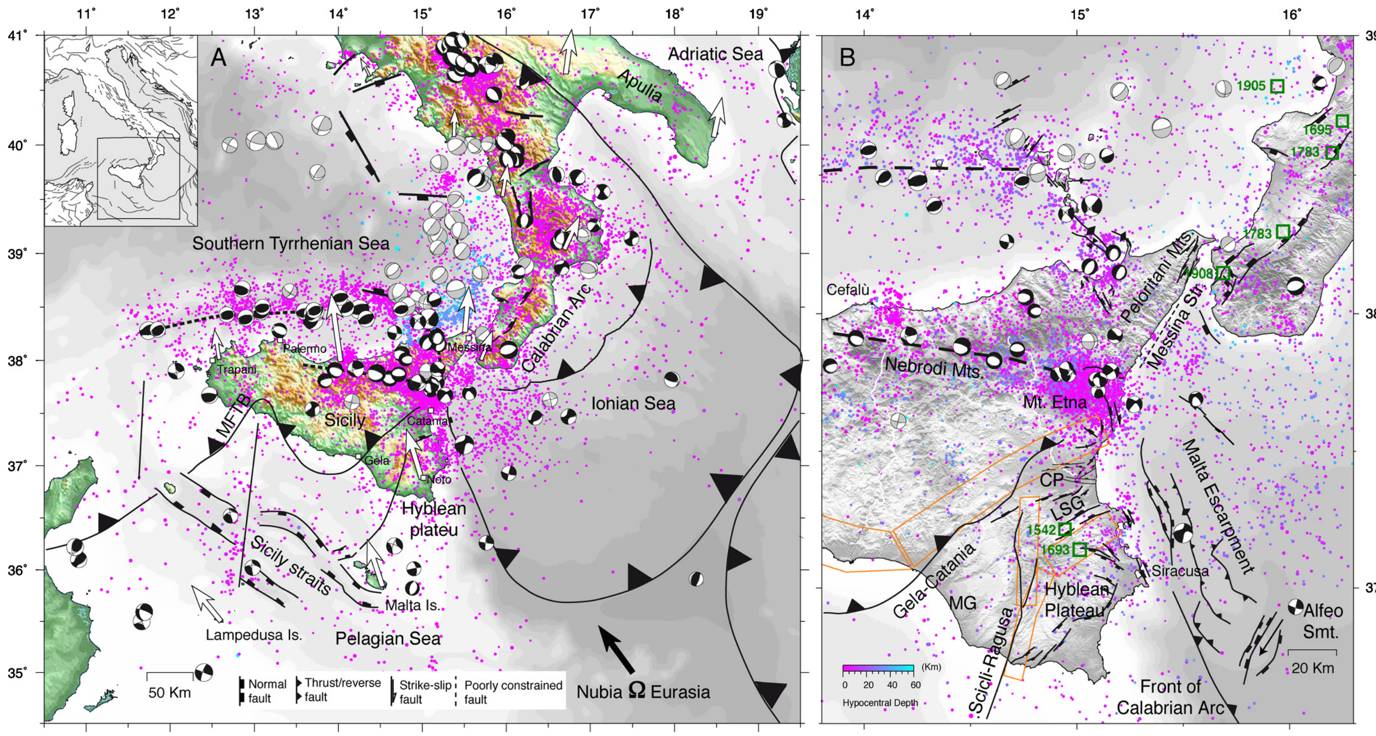

Fig. 1. A. Simplified tectonic and kinematic sketch of the Sicily–Calabria region. The thick dashed lines show seismic belts not clearly associated with well constrained fault systems. Black and grey focal mechanisms, from INGV regional CMT solutions (Pondrelli et al., 2011; http://www.bo.ingv.it/RCMT), are for earthquakes with depth <40 km and depth >40 km, respectively. Instrumental seismicity, color-coded with respect to hypocentral depth, is taken from the CSI catalogue (Chiarabba et al., 2005) and the Italian Seismic Instrumental and parametric Database (ISIDE; available at http://iside.rm.ingv.it). White arrows show representative GPS velocities with respect to the Eurasian plate. MFTB: Maghrebian fold and thrust belt. B. Seismotectonic map of eastern Sicily. Green squares show historical earthquakes for events with $M_W > 6.5$ (Rovida et al., 2011). Thin orange boxes show composite seismogenic sources from the DISS database (Basili et al., 2008; available at http://diss.rm.ingv.it). CP: Catania plain; MG: Marina di Ragusa graben; LSG: Lentini–Scordia graben. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

along a (northwestward) African-like oriented trajectory with respect to Eurasia. The increasing number of GPS stations available from mid-2000 showed that velocities of points located on the Pelagian–Sicilian domain deviate from the vectors predicted by a geodetically-defined Nubia rotation pole, suggesting an independent motion of this domain with respect to the Nubian plate (Serpelloni et al., 2007; D'Agostino et al., 2008). Importantly, focal mechanisms (Pondrelli et al., 2004) and GPS velocities (e.g., Serpelloni et al., 2007) reveal internal deformation of the Sicily block, which is still poorly understood. Palano et al. (2012) discussed a contractional deformation along the northern rim of the Hyblean Plateau (southeastern Sicily, Fig. 1b). However, the way the observed internal deformation of Sicily is presently accommodated by faults and the number of faults that may take up this deformation is unclear. Improved understanding of the regional block kinematics and strain accumulation rates across faults is important for the evaluation of the seismic hazard of the region, which is among the highest in the Mediterranean.

Southeastern Sicily is the locus of one of the largest Italian historical earthquakes, the January 11, 1693 Sicily earthquake, with maximum macroseismic intensity of XI and estimated moment magnitude $M_W \sim 7.4$, which was preceded by a $M_W \sim 6.2$ foreshock on January 9, which caused maximum intensity of VIII–IX in the Hyblean area (Guidoboni et al., 2007). The January 11 earthquake was accompanied by a large tsunami wave (Tinti et al., 2004) and affected with maximum shaking intensities the areas around Catania and the whole Hyblean Plateau, causing ∼60 000 fatalities. Despite its catastrophic effects, the location of the causative fault is not resolved and there are no records of surface coseismic ruptures onshore. Based on modeling of the macroseismic intensity pattern, some authors proposed onshore faults as responsible for the earthquake (e.g., Sirovich and Pettenati 1999, 2001), while other authors, looking for structures with tsunamigenic potential, suggested various sources laying in the near offshore region (e.g., Piatanesi and Tinti, 1998; Argnani and Bonazzi, 2005; Gutscher et al., 2006; Gerardi et al., 2008; Argnani et al., 2012).

In this work we present and discuss a new geodetic velocity field obtained from the analysis of continuous GPS stations in Europe and Africa, and a dense survey-mode GPS network in eastern Sicily, with the goal of studying the kinematics and crustal deformation of Sicily in the framework of the broader Nubia–Eurasia plate convergence. We develop our analysis taking into account a range of kinematic boundary conditions around Sicily. We develop an elastic block model in order to explore different scenarios of fragmentation of the Sicily microplate. We explore more detailed models of crustal deformation in eastern Sicily, where a higher density of stations highlights a steep horizontal velocity gradient along a NNW-ward direction. These data constrain fault geometries and slip rates, with implications for earthquake potential and the geodynamics of the Sicily–Calabria–Ionian tectonic domain.

2. Geological and tectonic settings

The main geological structures of eastern Sicily are represented by (Fig. 1): (i) the crystalline units of the Calabrian arc, which belong to the innermost unit of the chain; (ii) the Maghrebian fold and thrust belt, built up during the Neogene as a consequence of the opening of the Tyrrhenian basin with ensuing consumption of different paleogeographic domains of the African margin; (iii) the Catania–Gela foredeep, running roughly NE to SW; and (iv) the Hyblean plateau, which represents the relatively undeformed foreland of the collision zone (Ben Avraham et al., 1990).