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Foreland segmentation along an active convergent margin: New constraints in southeastern Sicily (Italy) from seismic and geodetic observations

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ABSTRACT

We performed an in-depth analysis of the ongoing tectonics of a large sector of southern Sicily, including the Hyblean Foreland and the front of the Maghrebian Chain, as well as the Ionian Sea offshore, through the integration of seismic and GPS observations collected in the nearly two decades. In particular, a dataset consisting of more than 1100 small-to moderate-magnitude earthquakes ($1.0 \leq M_L \leq 4.6$) has been used for local earthquake tomography in order to trace the characteristics of the faulting systems, and for focal mechanisms computation to resolve the current local stress field and to characterise the faulting regime of the investigated area. In addition, GPS measurements, carried out on both episodic and continuous stations, allowed us to infer the main features of the current crustal deformation pattern. Main results evidence that the Hyblean Plateau is subject to a general strike–slip faulting regime, with a maximum horizontal stress axis NW–SE to NNW–SSE oriented, in agreement with the Eurasia–Nubia direction of convergence. The Plateau is separated into two different tectonic crustal blocks by the left-lateral strike–slip Scicli–Ragusa Fault System. The western block moves in agreement with central Sicily while the eastern one accommodates part of the contraction arising from the main Eurasia–Nubia convergence. Furthermore, we provided evidences leading to consider the Hyblean–Maltese Escarpment Fault System as an active boundary characterised by a left-lateral strike–slip motion, separating the eastern block of the Plateau from the Ionian basin. All these evidences lend credit to a crustal segmentation of the southeastern Sicily.

1. Introduction

Foreland segmentation, approaching an active convergent margin, has been widely observed worldwide. Among others, active segmentation was recognised along the Kuqa foreland basin of the Tarim Basin (Lu et al., 2000) and the Junggar Basin in China (He et al., 2004), along the Qilian Shan at the margin of NE Tibet (Tapponnier et al., 1990), at the Sierras Pampeanas, at the eastern margin of Central Andes (Iaffa et al., 2013), and along the eastern margin of Italy in the Adriatic–Apulian foreland (Oldow et al., 2002). The mechanism of segmentation depends on several factors such as the convergence rate variations along the convergent margin strike, the basement structures, the block thickness, the rock strength, etc. (e.g. Jordan et al., 2001). Furthermore, the patterns may be complicated by the presence of pre-existing structures that can be reactivated in order to accommodate the deformation related to the convergence process. Here we focus on the Hyblean Foreland (or Hyblean Plateau in Fig. 1a), one of the most seismically hazardous zones in the central Mediterranean region, where the presence of active faults suggests a possible segmentation of it.

The current tectonic setting of the Hyblean Foreland is related to the long-term Eurasia and Nubia convergence (e.g. Faccenna et al., 2001; Fig. 1). The boundary of these plates, running through Sicily and the Ionian Sea, gives rise to a very complex tectonic framework, with several tectonic blocks, in which all of the structural domains characterising a collisional belt are exposed: the Maghrebian fold-and-thrust Belt, the Gela-Catania Foredeep, the Pelagian Block and, further to the east, the subduction complex of the Ionian oceanic basin beneath the Calabro-Peloritan Arc (see Finetti et al., 2005; Mantovani et al., 2009 and references therein). The outcome of this structural framework is the high seismic potential that characterises the region. In particular, in historical times it experienced several destructive events such as the 1169 and 1693 earthquakes (MCS intensities of XI, with estimated magnitudes of about 7 or higher; Boschi et al., 2000), and more recently, a M_L = 5.4 earthquake occurred on December 13, 1990, about 10 km offshore (Amato et al., 1995).

Recent advances achieved through geological (e.g. Barreca, 2014; Bousquet and Lanzafame, 2004; Catalano et al., 2008), petrological (Manuella et al., 2013), seismological (Brancato et al., 2009; Musumeci et al., 2005; Presti et al., 2013; Scarfì et al., 2007) and geodetic studies (e.g. Devoti et al., 2011; Ferranti et al., 2008; Mattia et al., 2012; Palano et al., 2012) have contributed to depict the rough picture of the

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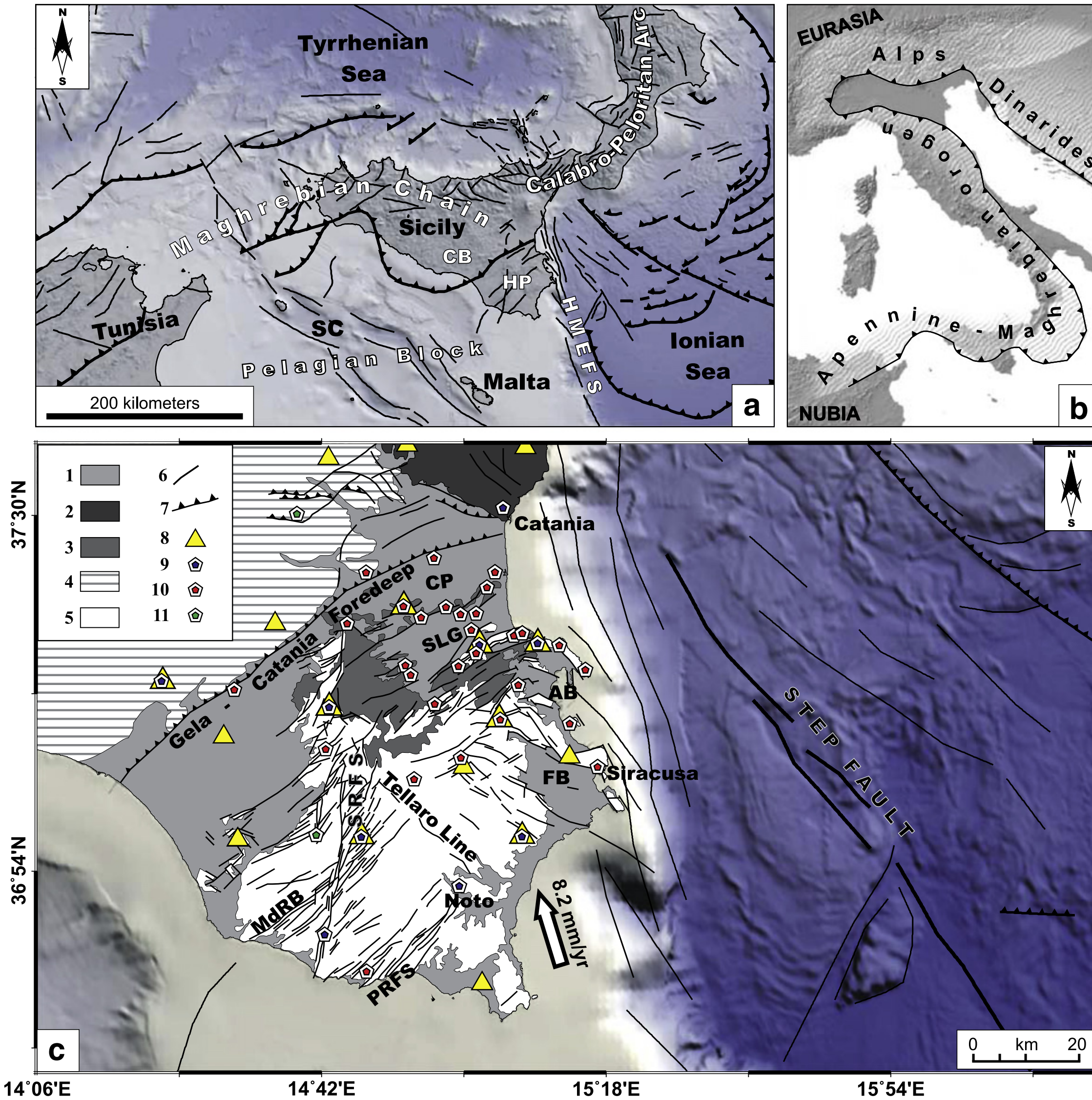

Fig. 1. Simplified tectonic map of Sicily (a); abbreviations are: SC, Sicily Channel; HP, Hyblean Plateau; CB, Caltanissetta Basin; HMEFS, Hyblean–Maltese Escarpment Fault System. The Maghrebian Chain and the Calabro Peloritan Arc are parts of the Apennine–Maghrebian orogen (b), a large scale fold-and-thrust belt formed during the Neogene-Quaternary convergence between Nubia and Eurasia plates. (c) Simplified structural sketch map of southeastern Sicily: 1) Recent-Quaternary sedimentary deposits; 2) Late Pleistocene-Holocene Etnean volcanics; 3) Plio-Pleistocenic Hyblean volcanics; 4) Maghrebian Chain units; 5) Meso-Cenozoic carbonate sediments; 6) main faults, 7) main thrust fronts; 8) seismic stations; 9) continuous GPS stations; 10) episodic GPS benchmarks; 11) GPS solutions coming from Ferranti et al. (2008). Abbreviations are: CP, Catania Plain; SLG, Scordia–Lentini Graben; AB, Augusta Basin; FB, Floridia Basin; PRFS, Pozzallo-Rosolini Fault System; MdRB, Marina di Ragusa Basin; SRFS, Scicli–Ragusa Fault System. Tectonic structures redrawn from Catalano et al. (2010) and Polonia et al. (2011). The white arrow shows the convergence vectors between Nubia and Eurasia according to the Morvel Plate model (DeMets et al., 2010).

tectonic features in southeastern Sicily. However, several aspects related to the ongoing tectonic processes and to the geometry, kinematics and dynamics of individual faults or fault arrays have still not been satisfactorily explored. Moreover, there is a poor consensus regarding the location and extent of the faults involved in the historical earthquakes. As an example, various causative sources (Visini et al., 2009) have been suggested for the 1693 earthquake (Fig. 2), which struck a large portion of eastern Sicily, affecting with maximum intensities the area around Catania and the whole Hyblean Plateau (Guidoboni et al., 2007). These sources range from the Hyblean–Maltese Escarpment Fault System (e.g. Argnani and Bonazzi, 2005; Azzaro and Barbano, 2000; Bianca et al., 1999) to a NNE-oriented 60 km long-fault nearly overlapping the Scicli–Ragusa Fault System (Sirovich and Pettenati, 2001) or to a segment of the S-verging basal thrust of the Maghrebian Chain (Lavecchia et al., 2007). Consequently, the detection and the characterisation of active and seismogenic crustal faults, as well as an improved image on the active tectonic processes, ensure a significant challenge in this area.

Exploiting local monitoring network high-quality data, we performed an in-depth analysis of the ongoing tectonics of southeastern Sicily, through the integration of seismic and GPS-based geodetic observations collected in nearly two decades. In particular, we carried out a simultaneous inversion of both 3D velocity structure and distribution of seismic foci. This resulted in more accurate hypocentres and into mapping the velocity anomalies, which, being strictly dependent on the crustal structure, is of help in the seismotectonic interpretation by tracing the characteristics of a faulting system. In addition, the fault plane solutions for the best recorded earthquakes were determined and used to resolve the current local stress field and to characterise the faulting regime of the main seismogenic sources. Moreover, a dense combination of continuous and episodic GPS measurements allowed us to infer the main features of the current crustal deformation pattern. The results were combined to