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Characterization of seismicity at Mt. Etna volcano (Italy) by inter-event time distribution

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ABSTRACT

The space–time inter-event time (IET) distributions of earthquakes occurring from 1988 to 2011 at Mt. Etna are analysed in order to identify the periodicity or stationary behaviour of seismicity, and to correlate it with the volcano-tectonic features of the region. The comparison between IET distributions at Etna with those obtained both for Sicily and Italy, shows that IETs at a larger scale are well-modelled by a gamma distribution, whereas at Etna local scale they are characterised by a bimodal curve, in which the two peaks are related to: (i) the contribution of local seismic swarms with very short inter-event times, and (ii) the background regional stationary seismicity.

IET analysis is an important tool to investigate the behaviour of seismicity at different crustal levels in the Etna region, distinguishing sectors that are influenced by volcano dynamics or regional tectonics. Indeed, the spatial variation of IET distributions, obtained by analysing different Etna crustal sectors, shows that seismicity shallower than 5 km is almost entirely characterised by short inter-event times and is mainly confined to the summit area. For earthquakes deeper than 5 km occurring in the eastern flank of the volcano, as well as in eastern Sicily, IET distributions are characterised by independent events which suggest that both areas are influenced by the same extensional regional regime. By contrast, IET distributions obtained for the western flank and north-western Sicily are marked by two peaks, indicating that the compressional stress is acting in both areas.

1. Introduction

Mt. Etna, the highest active volcano in Europe, is located in southern Italy in a complex geodynamic framework (Fig. 1), along the main Eurasia–Africa convergent plate boundary (Dewey et al., 1989; Serpelloni et al., 2007). Geodynamics in Sicily are characterised by two distinct stress domains: the western sector, governed by a N–S compression generated by continental collision (Fig. 1c); the eastern one, controlled by WNW–ESE extension related to the south-east-directed expansion of the Calabrian Arc (Palano et al., 2012 and references therein).

Like other volcanic areas, the stress regime at Mt. Etna results from the interaction of regional tectonics and local volcanic processes (Azzaro et al., 2013 and references therein). The dominant compressive N–S domain and the WNW–ESE extensional regimes coexist and interplay with flank instability and magma intrusions (Barberi et al., 2004; Monaco et al., 2005; Walter et al., 2005).

The most active area from the seismotectonic point of view is the eastern flank of the volcano, where the Timpe fault system (TFS in Fig. 2) consists of a set of parallel normal faults striking from NNW to NW (Azzaro et al., 2012). The activity of these structures generates frequent volcano-tectonic earthquakes which, although of moderate magnitude ($M < 5$), can cause severe damage and destruction. TFS has traditionally been considered the northernmost extension of the Malta Escarpment (MEF in Fig. 1a), a major lithospheric fault zone developing in the Ionian offshore (Monaco et al., 1997; Neri et al., 2005; Presti et al., 2013), though recent seismic profiles (Argnani et al., 2013) have not evidenced any link between these structural features.

Other seismogenic structures, which are involved in flank instability processes, are the E–W trending Pernicana fault (PF) in the north-eastern sector, and the NW–SE trending Tremestieri–Trecastagni fault system (TMF, TCF) in the southern one (e.g. Azzaro et al., 2013 and references therein). Although the geometry and kinematics of unstable blocks are defined (Bonforte et al., 2011), the mechanisms driving the flank sliding towards the Ionian Sea, i.e. regional tectonic stress, gravity-induced sliding and dike-induced rifting, are still a matter of debate (Solaro et al., 2010; Norini and Acocella, 2011).

It is well known that stress variations due to volcanic sources (magma chamber, dike intrusions) locally modify the stress field induced by large-scale tectonic processes (Gudmundsson, 2006; Roman et al., 2008; Savage et al., 2010). As a consequence, they can significantly affect both the locations and the mechanisms of local seismic events (Musumeci et al., 2004; Alparone et al., 2011). Some authors (e.g. Bell and Kilburn, 2008; Traversa and Grasso, 2010) have argued that distinct

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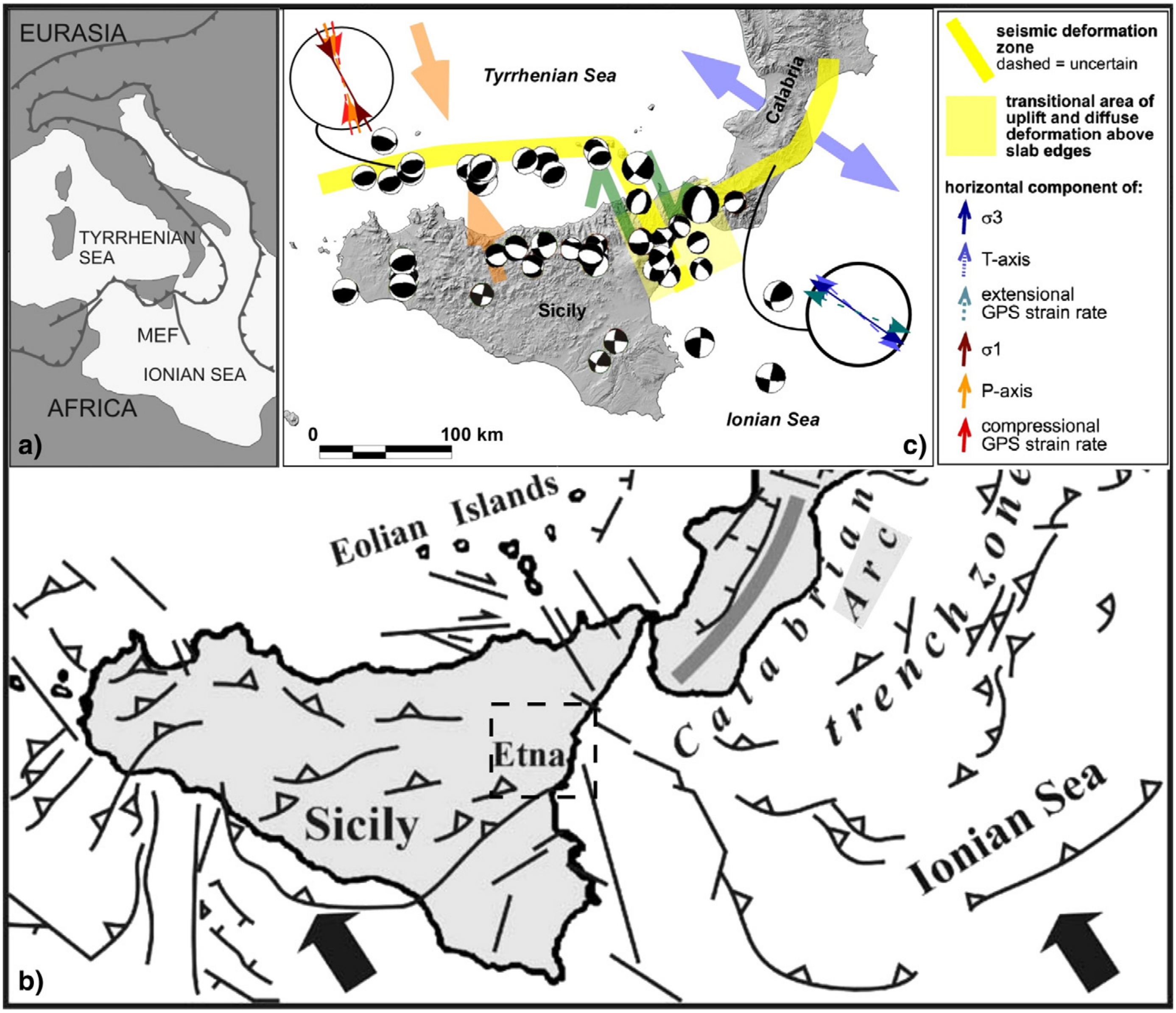

Fig. 1. a) The Africa–Eurasia plate configuration. b) Structural map of Sicily and Calabrian Arc (modified from Meletti et al., 2000): ticks evidence downthrown block in normal faults; arrows show the fault strike-slip component; in the thrust structures teeth mark the hangingwall; dashed square shows the location of Fig. 2. c) Focal mechanisms distribution and limits between different tectonic regimes.
Modified from Sgroi et al. (2012) and Presti et al. (2013).

seismogenic sources can be recognised in a volcano by different patterns of inter-event times (IETs). An IET is defined as the waiting time between two consecutive earthquakes, related to a specific period of time and a particular threshold of magnitude. The waiting time distribution of global or national catalogues is usually modelled using a gamma law (Corral, 2003). This single-peaked distribution is clearly different from IET distribution for local scale catalogues that generally have a bimodal shape deriving from the combination of both correlated aftershocks (which have short inter-event times) and independent events (which tend to be separated by longer time-spans) (Naylor et al., 2010). Therefore, for a small region, the bimodal shape of IET distribution is heavily influenced by the high percentage of correlated events (aftershocks).

In order to identify the periodicity or stationary features of seismicity at Mt. Etna, and distinguish sectors influenced by magma-induced dynamics or regional tectonics, we analyse the space-time IET distribution of the volcano-tectonic earthquakes occurring in the last twenty years. The results are then compared with IET distributions calculated for the regional (Sicily) and national (Italy) seismicity, to separate different stress fields acting on the volcano.

2. Seismic catalogues and methods

The dataset used in this study consists of 8716 earthquakes, recorded between January 1988 and December 2011 by the seismic networks of IIV-CNR (Istituto Internazionale di Vulcanologia), Sistema Poseidon, and INGV (Istituto Nazionale di Geofisica e Vulcanologia) (Patanè et al., 2004; Gruppo Analisi Dati Sismici, 2011). A statistical analysis of the catalogue shows that the completeness magnitude M_c, gradually decreases according to the technological upgrade (higher-quality instrumentation and higher station density), with duration magnitude threshold decreasing from $Md = 2.5$, in 1988–1995, to $Md = 1.0$ to date. In order to use a homogeneous and complete catalogue over the whole studied period, we performed the analysis using a magnitude threshold of $Md > 2.5$. The horizontal and vertical errors of the hypocentre location considered