



Probabilistic seismic hazard at Mt. Etna (Italy): The contribution of local fault activity in mid-term assessment

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ABSTRACT

In this work, we tackle the problem of seismic hazard at Etna deriving from the recurrent seismogenic activity of local faults, by adopting two independent methods based on probabilistic approaches. We assess the hazard in terms of macroseismic intensity and represent the occurrence probability calculated for different exposure times both on maps and at fault scale. Seismic hazard maps obtained by applying the “site approach” through the SASHA code and a new probabilistic attenuation model, indicate the eastern flank of the volcano as the most hazardous, with expected intensity (I_{exp}) in 50 years (i.e. the standard exposure time adopted in the seismic regulations) ranging from degrees IX to X EMS. In shorter exposure periods (20, 10, 5 years), values of I_{exp} up to IX are also reached in the same area, but they are clearly determined by the earthquakes generated by the Timpe fault system. In order to quantify the contribution of local seismogenic sources to the hazard of the region, we reconstruct the seismic history of each fault and calculate with SASHA the probability that earthquakes of a given intensity may be generated in different exposure times. Results confirm the high level of hazard due to the S. Tecla, Moscarello and Fiandaca faults especially for earthquakes of moderate intensity, i.e. $VI \leq I_0 \leq VII$, with probabilities respectively exceeding 50% and 20% in 10 years, and 30% and 10% in 5 years. Occurrence probability of major events ($I_0 \geq VIII$) at the fault scale has also been investigated by statistics on intertimes. Under stationary assumptions we obtain a probability of 6.8% in 5 years for each structure; by introducing the time-dependency (time elapsed since the last event occurred on each fault) through a BPT model, we identify the Moscarello and S. Tecla faults as the most probable sources to be activated in the next 5 years (2013–2017). This result may represent a useful indication to establish priority criteria for actions aimed at reducing seismic risk at a local scale.

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1. Introduction

Seismic hazard assessment is a practice generally carried out through consolidated probabilistic methods, known as the Cornell (1968) or McGuire (1995, 2008) approaches, in which earthquakes are represented by a Poissonian point process, and the seismicity is considered to be uniformly distributed inside seismogenic zones, following the Gutenberg–Richter (G–R) frequency–magnitude relationship. These studies produce probabilistic maps expressed in terms of peak ground acceleration (PGA) expected in a given exposure time, which are then translated into seismic regulations defining macro-zones characterized by different levels of building earthquake-resistant design; this is the actual situation in Italy, where the last update of probabilistic seismic hazard maps delivered in 2004 (MPS Working Group, 2004; Stucchi et al., 2011) has been adopted by law in 2006. In regions where seismotectonics knowledge is more complete, approaches

considering individual faults and time-dependency in the process of earthquake occurrence—i.e. the elapsed time since the last event occurred in the past—have been proposed in recent decades. This generation of fault-oriented seismic hazard has mainly been developed by countries lacking written historical records, USA (e.g. Working Group on California Earthquake Probabilities, 2007) and New Zealand (e.g. Stirling et al., 2002) being the prime cases. Nowadays, these techniques are becoming popular also in areas with low strain rate, and fault-based methods are sometimes used jointly with time-dependent approaches. This is the case of some pilot studies in Italy (Peruzza et al., 1997; Pace et al., 2006; Akinci et al., 2009; Peruzza et al., 2010); recently a fault-based zonation scheme has been introduced in the logic tree of seismic hazard computation for Europe too (e.g. Haller and Basili, 2011; SHARE, 2011).

Regarding the volcanic regions in particular, the problem of seismic hazard due to volcano seismicity (Smith et al., 1996; Zobin, 2001) has generally been tackled by the aforementioned Cornell–McGuire approach at two different levels: (i) large-scale applications on regional volcanic systems crossed by crustal faults generating large ($M > 7$) earthquakes, such as along the Andes in Argentina (Perucca and Moreiras, 2009), the Trans-Mexican Volcanic Belt (Norini et al., 2006),

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the Central Volcanic Ridge in Costa Rica (Fernández and Rojas, 2000) or El Salvador (Bommer et al., 1998), the Rift Valley in Africa (Mavonga et al., 2010), Iceland (Stefánsson et al., 2011) and Hawaii (Klein et al., 2001), also in view of nuclear facilities (e.g. Beaulieu and Peterson, 1981; McBirney et al., 2003; Coppersmith et al., 2009); (ii) local applications to individual volcanoes, affected by volcano-tectonic systems capable of moderate ($M < 6.5$) events involving smaller damage areas as in the case of Tatun volcano in Taiwan (Kim et al., 2005), Canary islands (González de Vallejo et al., 2006) and Santorini in Greece (Konstantinou and Yeh, 2012). In Italy, a few applications have concerned Mt. Vesuvius-Campi Flegrei (Cubellis et al., 2007; Convertito and Zollo, 2011), and some more literature is available for the Etna region. The opportunities that this last mentioned volcano offers for testing methodological approaches in different application fields, derive from its high degree of instrumental monitoring, together with the availability of a long record of historical information on seismic and volcanic phenomena occurring in the last centuries. These have led, through the compilation of a local earthquake catalogue (Azzaro et al., 2000a; CMTE Working Group, 2008) and the analysis of coseismic surface faulting (Azzaro, 1999), to obtain a seismotectonic model and a detailed mapping of active faults (Azzaro et al., 2012a). A first probabilistic seismic hazard assessment (PSHA) was carried out by Azzaro et al. (2008) at Etna by applying a procedure based on the use of macro-seismic data, namely the “site approach” (Albarelo and Mucciarelli, 2002). The method produces PSHA expressed in terms of maximum intensity (I_{exp}) expected in a given exposure time, a parameter more readily manageable for civil protection purposes than the PGA or peak ground velocity (PGV) typically directed towards planners and engineers. This study demonstrated that for an exposure time of 50 years, the standard

interval used by the national seismic hazard map (MPS Working Group, 2004), the hazard in the Etna region is controlled by the destructive regional earthquakes ($6.6 \leq M_W \leq 7.4$) that struck eastern Sicily in 1169, 1693, 1818 and 1908 (Fig. 1a), while for a shorter period (30 yrs) the local seismicity ($M_L \leq 5.1$ according to Azzaro et al., 2011) due to the seismogenic faults in the eastern flank of the volcano (Fig. 1) begins to influence the hazard at a smaller scale. More recently, Azzaro et al. (2012b) tested a fault-based seismic hazard approach using the same macro-seismic dataset, in order to investigate alternative earthquake occurrence models, under the Poissonian (stationary) and time-dependent assumptions. The study focused on the methodological approach and validation of results in the perspective of a mid-term (5 years) earthquake rupture forecast also in a volcanic region such as Etna.

In this paper we present the state-of-the-art of sub-regional, detailed PSHA at Etna, as a contribution to the definition of the integrated hazards related to the flank dynamics of this volcano (Progetto V4 Flank, 2007–2009). Following the previously mentioned approaches, we analyze the importance of the local seismogenic sources in the mid-short term PSHA (30, 20, 10, 5 years) (i) by generating different maps based on an extended historical earthquake catalogue and a new probabilistic attenuation model (Azzaro et al., 2013, this volume); (ii) by comparing them with the estimates of earthquake occurrence on the faults with higher seismic potential, considering also a time-dependent perspective.

2. Site-based seismic hazard maps

The “site approach” has proven to be an alternative to the Cornell–McGuire procedure in areas where the instrumental ground-motion

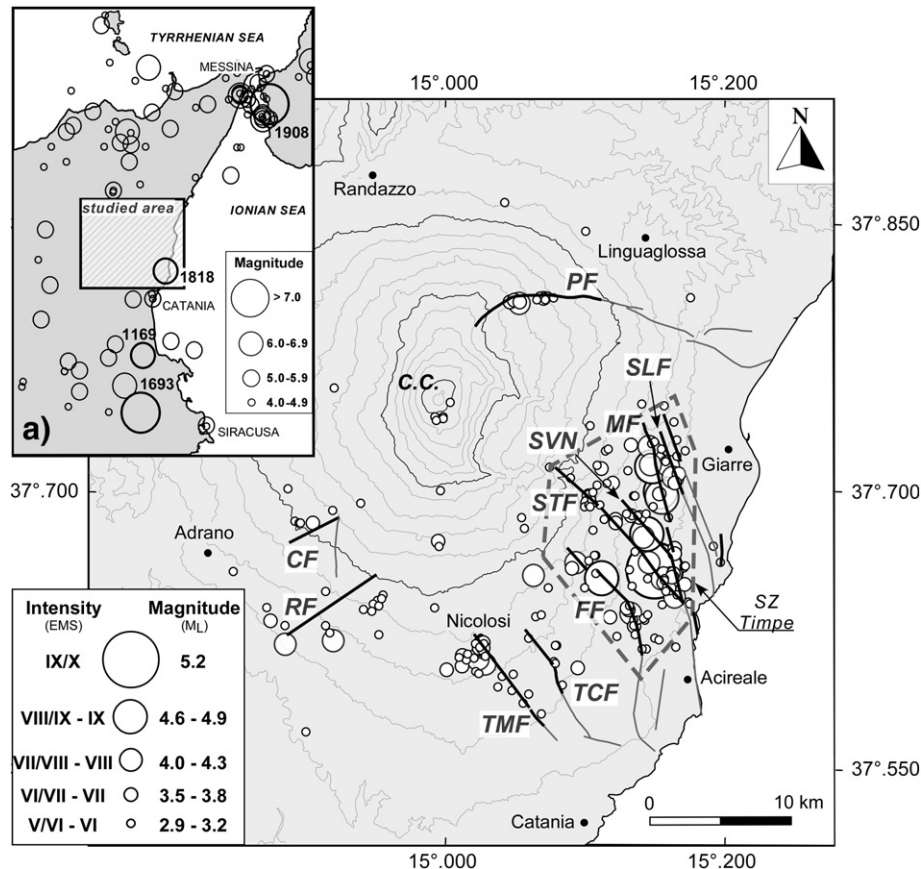


Fig. 1. Distribution of the main seismicity ($I_0 \geq V-VI$) in the Etna region from 1600 to 2010 (data from CMTE Working Group, 2008; Azzaro et al., 2010); the pattern of the active faults is also shown: thick lines, seismogenic segments; thin lines, creeping sectors (from Azzaro, 2004). C.C. indicates the central craters; fault abbreviations: CF, Calcerana; RF, Ragalna; TMF, Tremestieri; TCF, Trecastagni; FF, Fiandaca; STF, S. Tecla; SVN, S. Venerina; MF, Moscarello; SLF, S. Leonardello; PF, Pernicana. Inset map (a) shows the regional seismicity from 1000 to 2002 (CPTI Working Group, 2004); dates indicate the largest regional events influencing the seismic hazard at Etna.

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