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Is a geometric-kinematic approach valid for estimating the expected seismicity rates in volcano-tectonic areas? Ideas and results from seismogenic sources at Mt. Etna (Italy)

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Abstract: *At Mt. Etna (Sicily, Italy), the Timpe fault system is a structurally homogeneous domain characterized by a high seismic potential; several considerations led us to assume that faults are, on average, constantly loaded in time, supporting the idea that the faults behaviour is controlled by tectonic processes more than magma-induced, transient, stresses. The seismicity rates that have been till now assigned to the fault sources are based on macroseismic and instrumental data; they can be considered complete respectively above the damage threshold during the last two centuries, and for about ten years above* M_L*=2. We are now testing if these results are coherent with the seismicity rates that can be obtained using a geometric-kinematic approach, widely used if only geological and structural data are available. The characterization of a magnitude-size scaling relationship in volcanic environment is a key step for closing the loop, but the preliminary results are encouraging.*

Key words: *Mt. Etna, volcano-tectonic faults, time-dependent seismic hazard, magnitude-size scaling relationships.*

INTRODUCTION

Seismic hazard studies have been undertaken at Etna volcano in the last years with the aim of estimating the potential of local fault's activity in generating destructive earthquakes.
The methodologies applied at Mt. Etna area include probabilistic approaches based on the use of historical macroseismic data (the "site approach" by the software code SASHA, see Azzaro et al., 2008) and fault-based time-dependent models in which occurrence probabilities of major earthquakes are estimated through the Brownian Passage Time (BPT) function and the time elapsed since the last event (Azzaro et al., 2012b; 2013b). Mean return period of major earthquakes - strong to destructive events with epicentral intensity I_0 ≥ VIII EMS, considered as "proxies" of "characteristic" earthquakes – have been obtained by the fault seismic histories, i.e. by the associations "earthquake-seismogenic fault" derived from the historical catalogue of the Etnean earthquakes (CMTE Working Group, 2014). Inter-time statistics of major earthquakes have been applied to the Timpe tectonic system, considered as a homogeneous seismotectonic domain obtaining a mean recurrence time (Tmean) of about 70 years, and an aperiodicity factor α (σTmean/Tmean) that spans from values of 0.4-0.9, thus indicating semi-periodic to quasi-stationary processes.
In the present study we present the preliminary results of an analysis aimed at verifying the variability of the mean occurrence times of major earthquakes generated by the main tectonic systems at Etna (Pernicana and Timpe faults) by using a geological approach based on geometric-kinematic parameters (3D dimensions, slip-rates, etc.) representative of fault activity.

METHOD AND INPUT DATA

The analysis has been carried out through the software code ErrorPropagation (EP), a Matlab® routine produced in the framework of the projects DPC-INGV S2 in order to quantify the seismic activity from geometry and slip-rates of a fault (Pace et al., 2013). The adopted approach is based on the criterion of "segment seismic moment conservation" (Field et al., 1999), where the T_{mean} can be obtained by estimating the M_{max}, provided that three-dimensional geometry and slip rate of a seismogenic structure are known. In the probabilistic procedure for calculating the seismic hazard, the mean recurrence time (T_{mean}) of the maximum magnitude (M_{max}) expected on a fault, together with the quantification of its variability, are the basic ingredients to compute occurrence earthquake probabilities, both under Poissonian assumptions as well as in a time-dependent perspective. The best situation for a given fault segment is to have a long list of associated events, so that mean and variability derive directly from observations. Cases of effective repetition in Italy of characteristic events occurring on the same fault segment are definitely few, mostly represented by recent active sources along the Central Apennines (e.g., Paganica fault). More favourable conditions are present at Etna, where some ten major earthquakes (M_L 4.3-5.2) repeatedly occurred along fault segments of the Timpe system. Peruzza et al. (2010) extended the "segment seismic moment conservation" approach by introducing some errors propagation concepts in the estimated T_{mean} and α. Applying this methodology, Peruzza et al. (2011) demonstrated that the probability of occurrence of an event with M> 6 for the Paganica fault before the 6 April 2009 earthquake, considering an exposure time of 5 years, was the highest of Central Apennines (~3.5%).

The EP code uses different empirical and analytical relationships between the geometry of each input source and the characteristics of the expected earthquake, in order to quantify several values of M_{max} and associated T_{mean}. EP, therefore, formally propagates the errors of magnitude and slip-rate obtaining, for each seismogenic source, the most likely value of recurrence interval and the associated error. Finally, it uses the selected values to calculate the hazard rates, for a given exposure time, following a BPT probability density function (time-dependent) and a Poissonian distribution.

FAULT PARAMETERS AND EARTHQUAKE SCALING RELATIONSHIPS

The analysis and integration of different types of data such as tectonics, active faulting and long-term seismicity have produced a first seismotectonic model of the Etna region including information on segmentation, kinematics and seismic behaviour (Azzaro, 2004). Later, geometry and slip-rates of active faults have been constrained by geological/geomorphological field investigations (Azzaro et al., 2012a), while geodetic data modelling provided information on the extension at depth of faults as well as slip-rates and kinematics in the short-term (Azzaro et al., 2013a). Finally, the magnitude of the historical earthquakes has been calibrated by means of new ad-hoc relationships in terms of M_L and M_W (Azzaro et al., 2011).

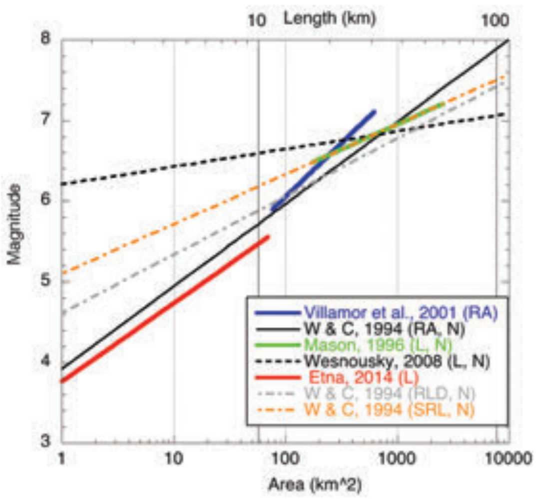

Figure 1: Plot of magnitude vs. surface rupture length equations for the Etna region (this study) and Taupo volcanic zone (Villamor et al., 2001), compared with worldwide relationships for tectonic domains (Wells and Coppersmith, 1994; Mason, 1996; Wesnousky, 2008). RA=rupture area; N=normal kinematics; L=fault length; RLD=rupture length in depth; SRL=surface rupture length.

The missing ingredient for EP calculations is a magnitude-rupture length relationship suitable for the Etnean earthquakes, since the equations derived for purely tectonic domains are proven to be inapplicable outside the domain and magnitude range they have been derived from., To this end, we derived a new empirical relationship specific for the Etna region by using the coseismic surface faulting dataset by Azzaro (1999), updated to 2013. The result is represented in Fig. 1, where our relationship is compared with the one obtained by Villamor et al. (2001) for the Taupo volcanic zone (New Zealand). Considering the different magnitude range the relationships have been calibrated from, and the adopted correlation of x-axes due to the use of different dimensional parameters (subsurface fault length for Etna, and rupture area for volcanic NZ sources), the agreement is quite satisfactory. Note analogies and discrepancies with respect to the relationships suggested by Stirling et al. (2013) for thick crust volcano-tectonic contexts (Wesnousky, 2008; Mason, 1996; normal fault), and the worldwide used relationship (Wells and Coppersmith, 1994) here given as a function of rupture area, subsurface rupture length and surface rupture length. It is important to highlight that the Wells and Coppersmith (1994) relationships are extrapolated outside its definition ranges and applied to volcano-tectonic environments, thus overestimating earthquake fault dimension. These considerations suggested us introducing the Villamor et al. (2001) relationship in the area-based computations of EP code, but leaving the Wells and Coppersmith (1994) ones.

EP, in addition to the M_{max}'s calculated by the above defined empirical scaling relationships, defines for each fault other two expected M_{max}: one from the general formula of magnitude as a function of the scalar seismic moment, starting from a constant strain drop value (here $2X10^{-5}$); and the other by using the aspect ratio relationships derived by Peruzza and Pace (2002).

PRELIMINARY RESULTS AND CONCLUSIONS

Applying the EP code to the Etna case we obtained the most likely values of characteristic expected magnitude (M_{char}) with the associated standard deviation σ, the corresponding mean recurrence times (T_{mean}) and the aperiodicity factor α, for each fault of the Timpe and Pernicana fault systems. The α values suggest fault behaviours that can potentially be modelled by a time-dependent approach. Moreover the M_{max} values calculated by the different methods are comparable to each other as well as with the observed historical earthquakes (except for a few cases).

The results of this work, still in progress, suggest that a geological approach based on geometric-kinematic parameters to estimate the expected seismicity rates can be also adopted with success on the volcanic context of Etna. A comparison between our results with scalar moment rates estimated from seismic and geodetic data will provide important constraints on the fault parameters and validate the goodness of the applied methodology.

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