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EFFECT OF STRESS INTERACTION ON PROBABILITY OF OCCURRENCE OF CHARACTERISTIC EARTHQUAKES IN SOUTHERN APENNINES

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Introduction

We compute the effect of stress change due to previous historical earthquakes on the probability of occurrence of future earthquakes on neighboring faults. Following the methodology developed in the last decade, we start from the estimate of the probability of occurrence in the next 50 years for a characteristic earthquake on known seismogenic structures, based on a time-dependent renewal model. Then, a physical model for the Coulomb stress change caused by previous earthquakes on these structures is applied. The influence of this stress change on the occurrence rate of characteristic earthquakes is computed taking into account both a permanent (clock advance) and a temporary (state-and-rate) perturbation.

We apply the method so developed to the computation of earthquake hazard of the main seismogenic structures recognized in the Southern Apennines region, for which both historical and paleoseismological data are available.

Method

A standard procedure for seismic hazard assessment assumes that all relevant earthquakes occur on well recognized faults with characteristic mechanism and size. The procedure needs the adoption of a probability density function $f(t)$ (pdf) for the inter-event time between consecutive events on each fault, together with some basic parameters of the model. One can adopt either a time independent Poisson model or a renewal model. For the former model, the expected recurrence time T_r is the only necessary piece of information. For the latter, also a parameter as the coefficient of variation (also known as aperiodicity) α of the inter-event times is required.

We adopt the Brownian Passage Time (BPT) distribution introduced by Matthews et al. [2002] to represent the inter-event time probability distribution for earthquakes on single sources in Italy. This distribution is expressed as

$$f(t,T_r,\alpha)=\left(\frac{T_r}{2\pi\alpha^2t^3}\right)^{1/2}\exp\left\{\frac{(t-T_r)^2}{2T_r\alpha^2t}\right\}$$

Earthquake probability may be either increased or decreased with respect to what would be expected by a simple renewal model. The interaction is taken into consideration by the computation of the Coulomb static stress change or the Coulomb Failure Function (ΔCFF) caused by previous earthquakes on the concerned fault [King et al., 1994]:

$$\Delta CFF=\Delta\tau+\mu'\Delta\sigma_n$$

where $\Delta\tau$ is the shear stress change on a given fault plane (positive in the direction of fault slip), $\Delta\sigma_n$ is the fault-normal stress change (positive when unclamped), and μ' is the effective coefficient of friction.

As ΔCFF is strongly variable in space, we consider its value in the point of the triggered fault where it may have the largest effect. For this computation, the knowledge of the fault parameters (strike, dip, rake, dimensions, average slip) is necessary for both triggering and triggered sources.

The influence of ΔCFF on the probability for the future characteristic event is considered in two ways [Stein et al., 1997]. The first (permanent effect) assumes that the time elapsed since the previous earthquake is modified from t to t' by a shift proportional to ΔF, that is

$$t'=t+\frac{\Delta CFF}{\dot{\tau}}$$

Where $\dot{\tau}$ is the tectonic stressing rate.

We consider also the so-called "transient effect", due to rheological properties of the slipping faults. The application of the Dieterich [1994] constitutive friction law to an infinite population of faults (imagined as characterized by a complete distribution of states) leads to the expression of the seismicity rate as a function of time after a sudden stress change:

$$R(t)=\frac{R_0}{\left[\exp\left(\frac{-\Delta CFF}{A\sigma}\right)-1\right]\exp\left(\frac{t}{t_a}\right)+1}$$

where R_0 is the seismicity rate before the stress change, A is a fault constitutive parameter, σ is the normal stress acting on the fault, t_a is a time constant equal to $A\sigma/\dot{\tau}$, and $\dot{\tau}$ is supposed unchanged by the stress step.

The expected number of events N over a given time interval $(t,t+\Delta t)$ is computed by integration. Under the hypothesis of a generalized Poisson process, we may estimate the probability of occurrence for the earthquake in the given time interval:

$$P=1-\exp\left(-\int_t^{t+\Delta t}R(t)dt\right)$$

The database of Italian seismogenic sources

We make use of the most comprehensive source of information available about Italian seismogenic sources: the Database of Individual Seismogenic Sources (DISS) owned by Istituto Nazionale di Geofisica [DISS Working Group, 2006].

Individual seismogenic sources are supposed capable of primary slip during a large earthquake and are assumed to exhibit "characteristic" behavior with respect to rupture length/width and expected magnitude. For each of them DISS stores, among others, the following parameters, estimated from various kinds of geological, geodetic, geomorphological and seismological data, or inferred from other parameters through physical relationships:

Location (lat/lon) of the center of the fault
Length and width of the fault
Minimum and maximum depth
Strike, dip and rake of the fault
Average slip
Slip rate (minimum and maximum)
Recurrence time (minimum and maximum)
Maximum magnitude (Mw)
Date of the latest earthquake
Date of penultimate earthquake (when available)

Data and Results

Table I. List of seismogenic structures reported by DISS for the study area of Southern Apennines (Basilicata Region). Also reported are the minimum and maximum recurrence time and the time elapsed since the latest event.

DISS code	Fault name	Date of latest event	Magnitude	Recurrence time (years)		Elapsed time (years)
				min	max	
ITGG008	Val D'Agri	1857/12/16	6.5	740	7400	149
ITGG010	Melandro-Pergola	1857/12/16	6.3	570	5700	149
ITGG077	Colliano	1980/11/23	6.8	1680	3140	26
ITGG078	San Gregorio Magno	1980/11/23	6.2	1680	3140	26
ITGG079	Pescopagano	1980/11/23	6.2	1680	3140	26
ITGG084	Potenza	1990/05/05	5.8	700	2600	16

Table II. List of seismogenic structures as in Table I. For each fault the minimum and maximum probability for an earthquake occurring in the next 50 years is given for a time independent Poisson model and for the BPT (α=0.5) renewal model respectively. In most cases the probability computed by the BPT is negligible, due to the short time elapsed since the latest event, compared to the recurrence time.

DISS code	Fault name	50 y Poisson Probability		50 y BPT Probability	
		min	max	min	max
ITGG008	Val D'Agri	$6.8\ 10^{-3}$	$6.8\ 10^{-2}$	0	$3.6\ 10^{-3}$
ITGG010	Melandro-Pergola	$8.8\ 10^{-3}$	$8.8\ 10^{-2}$	0	$1.8\ 10^{-2}$
ITGG077	Colliano	$1.6\ 10^{-2}$	$3.0\ 10^{-2}$	0	0
ITGG078	San Gregorio Magno	$1.6\ 10^{-2}$	$3.0\ 10^{-2}$	0	0
ITGG079	Pescopagano	$1.6\ 10^{-2}$	$3.0\ 10^{-2}$	0	0
ITGG084	Potenza	$1.9\ 10^{-2}$	$7.1\ 10^{-2}$	0	0

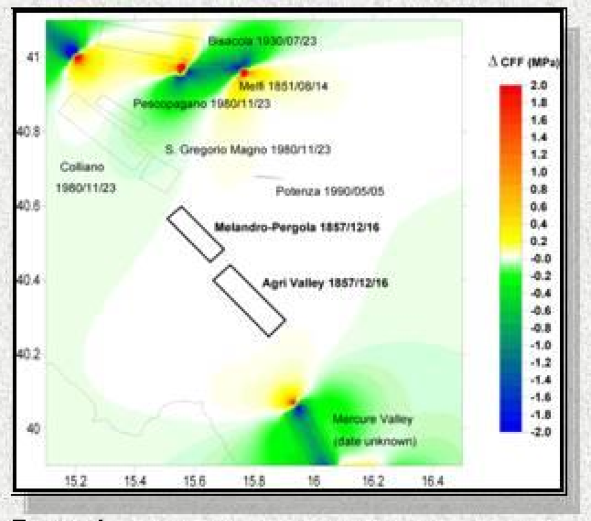

Figure 1

Maps of the Coulomb Stress changes ΔCFF generated by all the earthquakes preceeding the 1857 (Val D'Agri, **Fig. 1**), 1980 (Colliano, **Fig 2**), and 1990 (Potenza, **Fig 3**) events. ΔCFF is computed on the basis of the fault mechanism of the concerned earthquake. No evidence is visible of precursory stress change.

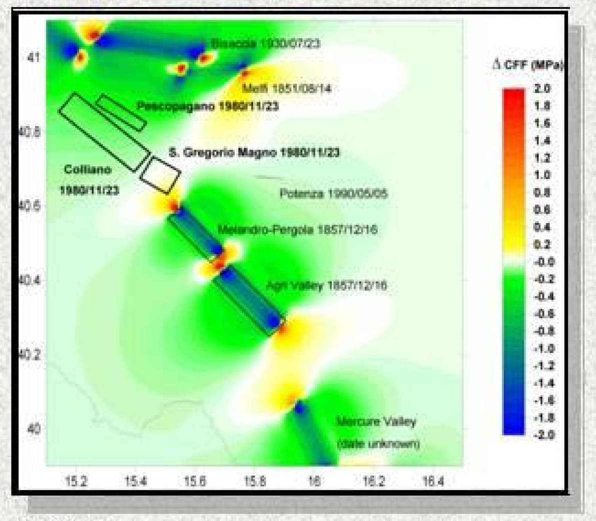

Figure 2

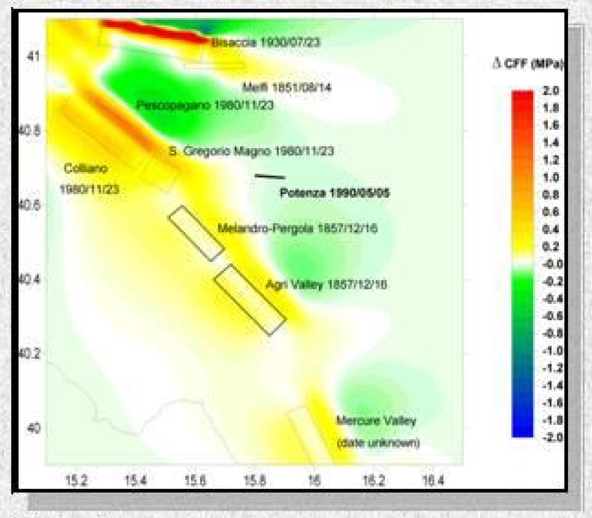

Figure 3

Maps of the Coulomb stress change ΔCFF cumulatively released by all the earthquakes following the 1857 (Val D'Agri, **Fig.4**), and 1980 (Colliano, **Fig. 5**) events. ΔCFF is computed on the basis of the fault mechanism of the concerned event. A positive ΔCFF is visible for the northern corner of the Melandro-Pergola fault.

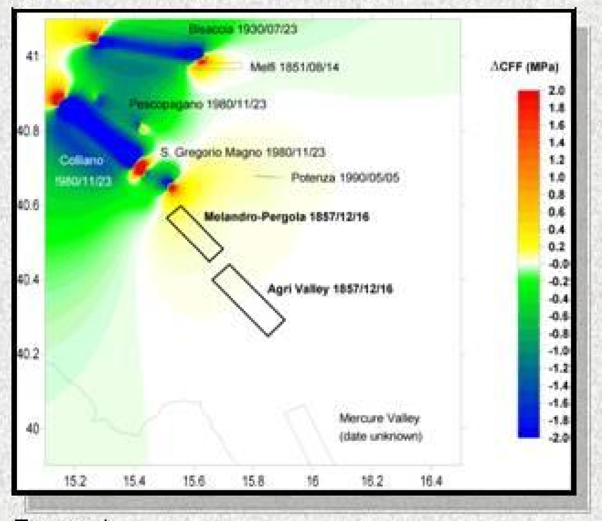

Figure 4

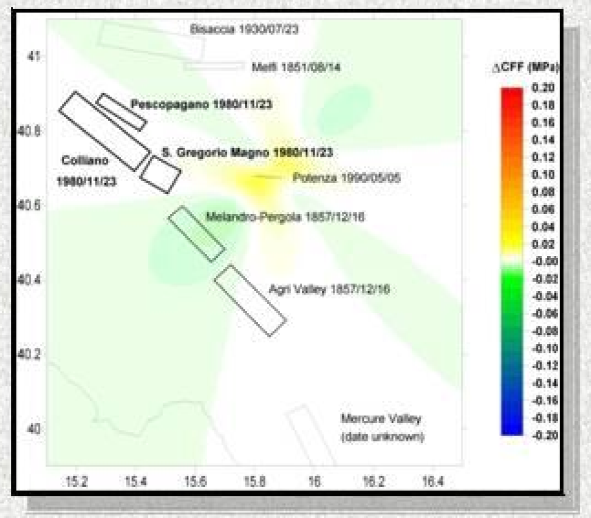

Figure 5

The clock advance computed for the Melandro–Pergola fault is 2 years. This raises the probability for the future earthquake in the next 50 years from 1.8% up to 1.9% .

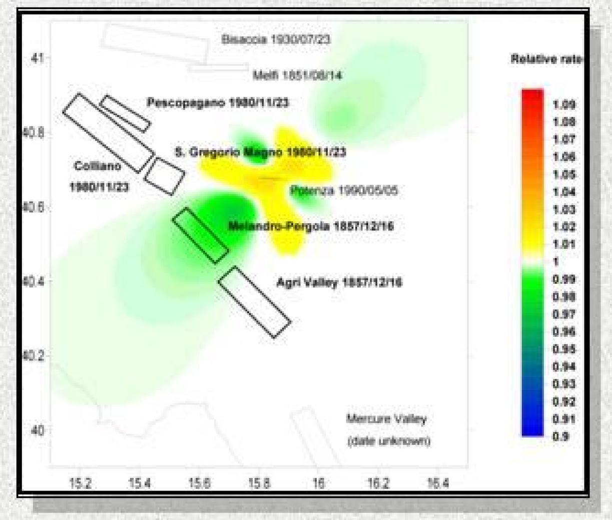

Figure 6

Fig.6 Map representing the relative rate change caused by the transient effect of the 1990 Potenza earthquake on the other faults. The effect is negligible or even negative

Conclusions

1 - The occurrence probability for the next strong earthquake in Southern-Apennines according to the BPT model is small in comparison with the time independent Poisson Model, due to the short time elapsed since the latest event with respect to the recurrence time.

2 - The permanent effect caused by the stress released by the previous earthquakes is generally small.

3 - The transient effect is, at the present time, not affecting the probability of future events.

4 - The information available from DISS concerning the recurrence time of the Italian seismogenic sources doesn't allow a clear definition of the sismic hazard.

5 - New information about the strain rate in the region is expected to significantly improve the reliability of hazard assessment.

References

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