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Spatial and temporal distribution of seismicity before the Umbria-Marche September 26, 1997 earthquakes

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Abstract

Spatial and temporal distribution of seismicity occurring prior to the Umbria-Marche earthquake of September 26, 1997, are studied. By applying the RTL prognostic parameter, a quiescence stage followed by a period of foreshock activation is observed before the event. The main shock occurred soon after the recovery of the RTL parameter to its normal background level. An investigation of the clustering process is performed on the earthquakes with **M≥3.5,** occurred since 1989 in the area of the epicenter of the September 26, 1997 event. In comparison to the average background of the previous period, the increase of the area of rupture activated during the twelve months leading up to the Umbria-Marche concentrates in the vicinity of the main shock. Some results of application of the time-to-failure model to seismicity before the Umbria-Marche main shock, are also discussed.

Introduction

Research has shown that anomaly fluctuations of weak seismicity, electrical and magnetic properties of rocks, deformation of crust, level of underground water and its chemical composition etc., can all be observed before the occurrence of a large earthquake. Nevertheless, attempts to predict large earthquakes on the basis of these anomalies are generally unsuccessful due to the many different factors that influence the manifestation of each particular irregularity. In our opinion, the absence of a deep insight into the process of earthquake preparation inhibits the development of a reliable forecast method. We believe that a systematic study of the behavioral peculiarities of possible precursors to a large earthquake and the application of these precursors to the parameter of future earthquakes, may help to provide a solution to the problem of earthquake prediction.

To date, seismic precursors are the most extensively studied. Scientific literature provides in depth discussion on the many features of weak seismicity before a large earthquake such as; seismic quiescence (Mogi, 1979; Wyss and Habermann, 1988); foreshock activation (Ma Zonglin et al., 1989; Prozorov and Schreider 1990, for example); and clustering (Caputo et al., 1977; Sobolev and Zavyalov, 1981). In this paper we examine the peculiarities of weak seismicity which were observed before two severe earthquakes (ML = 5.6 and ML = 5.8) that occurred within a nine hour interval on September 26, 1997, near the border of the provinces of Umbria and Marche (Central Italy). The earthquakes were a part of a sequence which started with a ML = 4.5 foreshock on September 3 and continued until October with strong aftershock activity. The last damaging event of this sequence (ML = 5.5) occurred on October 14, 1997. We would like to stress that we do not discuss the problem of prediction of this series in the paper. We only hope that presented analysis may be useful in solution of this problem in the future.

The analysis is principally based on data from the Istituto Nazionale di Geofisica (ING) earthquake catalogue for 1986–1998 (Barba et al., 1995). The level of completeness of the catalogue for Central Italy is M_{min} = 2.3 and weaker earthquakes are not involved

Table 1. List of earthquake clusters with M≥3.5 which occurred during the time interval 01/01/1975–26/09/1997, within the area 42.0<Lat<44.0, 11.9<Long<13.9

NN	Date (in years)	Latitude	Longitude	Magnitude
Cluster 1	1979.207	42.93	12.99	3.7
	1979.224	42.92	13.03	3.9
	1979.515	42.96	13.03	3.6
Cluster 2	1979.388	43.05	12.96	3.6
	1979.418	43.05	12.93	3.7
Cluster 3	1979.071	42.83	13.15	4.3
	1979.677	42.77	13.03	3.7
	1979.720	**42.80**	**13.04**	**5.5**
Cluster 4	1982.795	43.16	12.60	4.0
	1982.795	43.16	12.61	4.0
	1982.795	43.18	12.62	4.3
Cluster 5	1989.732	42.54	12.54	3.5
	1989.734	42.53	12.59	3.6
Cluster 6	1989.885	42.88	12.99	3.6
	1989.887	42.87	12.95	3.6
Cluster 7	1993.427	43.14	12.67	4.1
	1993.430	43.15	12.67	4.4
Cluster 8	1995.411	43.48	12.71	3.8
	1995.412	43.43	12.72	3.8
Cluster 9	1995.989	43.08	13.43	3.5
	1995.992	43.09	13.47	3.7
	1995.999	43.10	13.46	3.7
	1996.004	43.12	13.50	3.7
	1996.062	43.08	13.55	3.7
	1996.206	43.08	13.47	3.5
Cluster 10	1997.337	42.83	12.78	3.8
	1997.337	42.84	12.77	3.8
Cluster 11	1997.677	43.06	12.84	4.4
	1997.737	43.02	12.91	5.6
	1997.738	**43.02**	**12.93**	**5.8**

in the analysis. The ING catalogue for the period 1975 - 1986 records a level of completeness of M_{min} = 3.4 (Wyss, Console and Murru, 1997) and the 1975–1998 catalogue is used for the study of the clustering process of earthquakes with M≥3.5. Using the algorithm proposed by Molchan and Dmitrieva (1991) and coded by V. Smirnov, aftershocks were deleted from the catalogue.

RTL analysis of seismicity before the Umbria-Marche earthquake

The RTL parameter was proposed by Sobolev and Tyupkin (1996a) to investigate peculiarity of seismicity before strong earthquakes. The method is formulated to investigate the supposition that the quiet stage and the foreshock activation consecutively follow one another in the focus of a future strong earthquake. In this process, the quiescence almost always occurs during the stage of accumulation of seismic energy in the course of earthquake preparation. The RTL parameter has been discussed in detail elsewhere (Sobolev and Tyupkin 1996a, 1996b; Di Giovambattista and Tyupkin, 1999) and for this reason it will not be considered here except for comments related to this application.

The RTL (**x**,t) prognostic parameter is calculated at the tested space-time point (**x**, t) resulting from the multiplication of the following functions:

epicentral function

$$R(x,t) = [\sum_{i=1}^{n} \exp(\frac{r_i}{r_0})] - Rs$$

time function

$$T(x,t) = [\sum_{i=1}^{n} \exp(-\frac{t-t_i}{t_o})] - Ts$$

earthquake source size function

$$L(x,t) = [\sum_{i=1}^{n} (\frac{l_i}{r_i})] - Ls$$

where $\mathbf{r}_i$ represents the distance between the seismic events that occurred before the time t and the tested point, $\mathbf{t}_i$ is the time of the preceding events and $\mathbf{l}_i$ is the size of source of the earthquakes preceding the tested moment. The value of $\mathbf{l}_i$ is calculated in accordance with the empirical relation between the size of source and the magnitude of the earthquake M_i. In the present study we use the relation:

$$log(l_i) = 0.44M - 1.289 \quad (1)$$

(Papadopoulos and Voidomatis, 1987).

The sum of the above formulas is calculated over the earthquakes with magnitude $\mathbf{M}_{min}<\mathbf{M}<\mathbf{M}_{max}$, which fall into the time interval **(t–2$\mathbf{t}_0$, t)** and within a circle of radius $\mathbf{2r}_0$ with the center located at the tested point. The value of $\mathbf{M}_{min}$ is defined by the catalogue level of completeness. $\mathbf{r}_o$, $\mathbf{t}_0$ and $\mathbf{M}_{max}$ parameters were selected empirically. Basing on the results of RTL analysis of strong earthquakes of Kamchatka, Caucasus and Greece (Sobolev and Tyupkin, 1996a,b, 1999; Sobolev et al., 1997) we used $\mathbf{r}_0$ = 50 km, $\mathbf{t}_0$ = 1 year, $\mathbf{M}_{max}$ = 3.8. **Rs, Ts** and **Ls** are linear trend corrections. The functions **R, T** and **L** are normalized to a single variance. In such a way the value of the **RTL** parameter is measured in units of its variance. Aftershocks were deleted from the analyzed catalogue.

When the previous earthquake is located near (in distance and time) to the tested time and place, it can be seen that the weight coefficients of the functions **R** and **T** exponentially increase. Respectively, a greater distance reveals an exponential decrease. The function **L** grows if the preceding earthquakes have a greater energy, or respectively decreases when the opposite situation occurs. In other words, the **RTL** parameter is designed in such a way that seismic quiescence is indicated as a negative anomaly of the parameter in comparison to the average background of the previous period, and activation of seismicity initiates a growth of its value.

Figure 1a presents the plot of the **RTL** parameter calculated for the instrumental epicenter of the September 26, 1997 Umbria-Marche main shock. A quiescence stage can be clearly observed from the beginning of September 1996, with the **RTL** parameter reaching its minimal value on March 3, 1997. After that date the quiescence stage is replaced by a period of foreshock activation. The Umbria-Marche mainshock occurred soon after the **RTL** parameter recovery to the level of its average background. Figure 1b shows the plot of the number of earthquakes, occurring inside a two year moving time window, used in our estimation of the RTL parameter.

Figure 2 shows (in shades of gray) the spatial distribution of the minimal values of the **RTL** parameter from September 5, 1996 to September 5, 1997. Black dots indicate the events of the Umbria-Marche sequence with **M**$\geq$**4.5** that are located in the area of the negative anomaly of the **RTL** parameter, approximately within 40 km of the center of the anomaly. The epicenter of the Massa Martana earthquake (**M = 4.5**) that occurred on May 12, 1997, is located at the center of this anomaly. We believe that the Massa Martana earthquake can be considered as a distant foreshock (in the broad sense of this term) of the Umbria-Marche main shock.

The results of foreshock activation analysis

To analyze the process of foreshock activation before the Umbria-Marche main shock we used an algorithm based on the ideas proposed by G. Sobolev (Sobolev, 1993; see also Sobolev and Tyupkin, 1999). The values of the parameter $Spr = \frac{1}{\Delta T}\sum_{i=1}^{n}(\frac{E_i}{E_0})^{\frac{2}{3}}$ are calculated in the cells of a geographical net. In this formula, the summation is made over all the events that occurred within the cell during the period of time Δ**T** before the date of test. The energy $\mathbf{E}_i$ is estimated in accordance with an empirical relation between the energy and the magnitude of earthquakes. We use the relation: **log(E) = 1.44 M+5.24** (Papadopoulos and Voidomatis, 1987).

The multiplier $\mathbf{E}_0$ **= 3.6*10**^{6} **J** normalizes the parameter **Spr**. The **Sav** parameter is calculated in accordance with the same algorithm as the **Spr** parameter but it is calculated for a period of observation of many years (**T-**Δ**T**). Maps depicted in Figure 3 show the positive values of the parameter Δ**S=Spr-Sav.** The actual calculations were made with a cell size equal to 0.5°; Δ**T** is equal to one year and **T** is equal to eleven years. The Δ**S** parameter in the first approximation, indicates an increase of the total area of ruptures activated during the year leading up to the main shock, as compared to the average background of the previous period. In contradiction with RTL parameter we have no restriction on mmax when the map of parameter Δ**S** is calculated.

As mentioned, the **RTL** parameter reached its minimal value on March 3, 1997 and then it began to increase. This means that seismicity during the second part of 1997 contributes to a positive anomaly of the Δ**S** parameter in the area of the Umbria-Marche earthquake. The catalogue revealed that a more intensive foreshock activation commenced following September 4, 1997. With this in mind, Figure 3 depicts two versions of the map of the **S** parameter, with data up to September 1, 1997 used for the construction of Figure 3a, and data up to September 25,1997 used for construction of Figure 3b. The analysis of these maps implies that foreshock activation was characterized by a concentration of seismic activity in the vicinity of the September 26, 1997 Umbria-Marche earthquake.

Analysis of clustering process results

Leading up to the Umbria-Marche main shock, the process of clustering of earthquakes with **M**$\geq$**3.5** can be observed. The idea of earthquake swarms as forerunners of strong earthquakes in Italy, was first discussed by Caputo et al. (1977). We used the following rule to identify a group (a cluster) of earthquakes (Sobolev, 1993; Sobolev and Tyupkin, 1999):

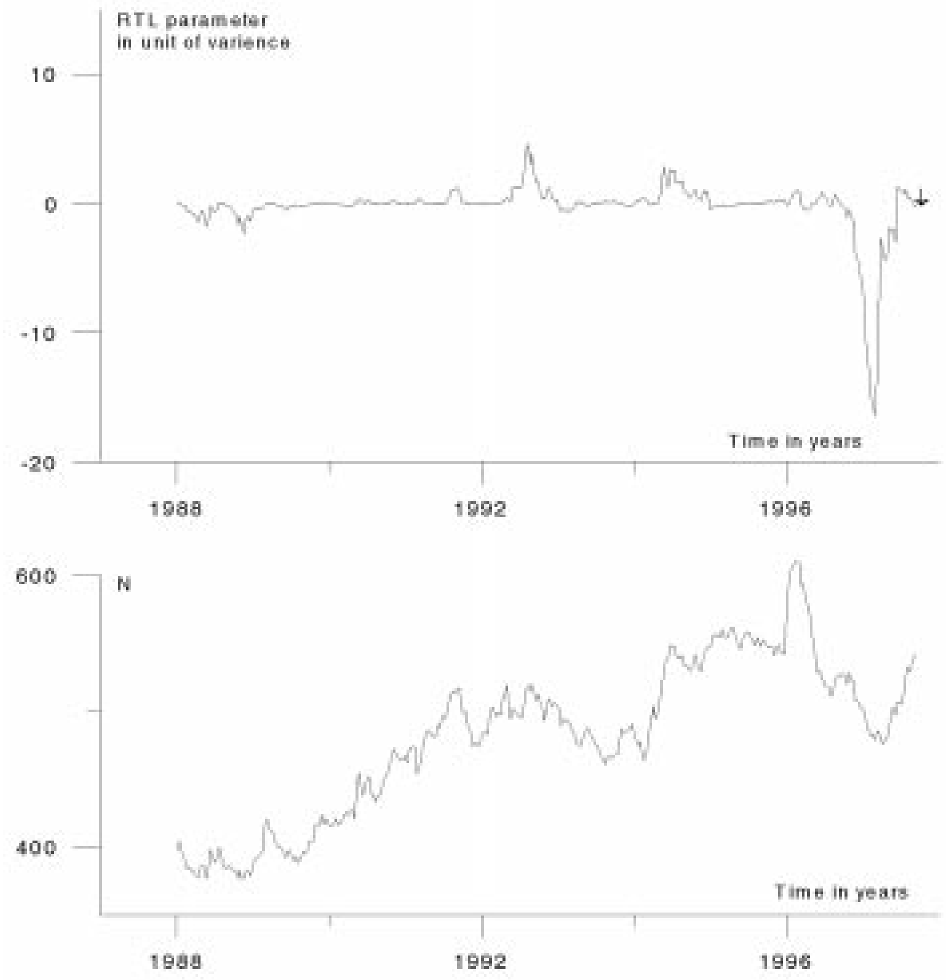

Figure 1. The plot of the RTL parameter calculated for the instrumental epicenter of the Umbria-Marche main shock (1a) and the plot of the number of earthquakes that were used for estimation of the RTL parameter which occurred within a two year time window (1b) are presented. The arrow indicates the time of occurrence of the main shock. The moving time window step is 10 days.

1. The distance Δ**R** between two events of the cluster should be less than $\mathbf{R}_{cr}$, where the $\mathbf{R}_{cr}$ is equal to three times the characteristic linear size **l** of the source of the first of the two compared earthquakes, plus the possible location errors. The $\mathbf{R}_{cr}=3*\mathbf{l}$ value was used in the concept of the concentration criterion of seismogenic ruptures, which determines the density of the accumulated ruptures before the earthquake (Sobolev and Zavyalov, 1981). The relation **(1)** is used for estimation of the value of **l** for Italian earthquakes.

2. The time Δ**T** (in years) between the events included in the group (cluster) is determined by the relation $\Delta T < T_{cr} = (\frac{E_i}{E_0})^{\frac{1}{2}}$. Here $\mathbf{E}_i$ is the energy of the first in time of two compared earthquakes, $\mathbf{E}_0$ is equal to the energy of earthquake with **M = 4.5,** ΔT and T_{cr} are in years

3. A group is not considered as a cluster if the first event is the strongest earthquake of the group (aftershock-like group).

The ING catalogue for 1975–1997 was used for this analysis. The area 42.0<Lat<44.0, 11.9<Long<13.9 was analyzed. Before the series of two 1997 Umbria-Marche earthquakes, an earthquake with M = 5.5 occurred in this area on September 19, 1979 (Lat = 42.80, Long = 13.04). The list of clusters of earthquakes with **M≥3.5,** which occurred within the area 42.0<Lat<44.0, 11.9<Long<13.9 is presented in Table 1. This table reveals that there are no clusters from January 1, 1975 (the beginning of the catalog)

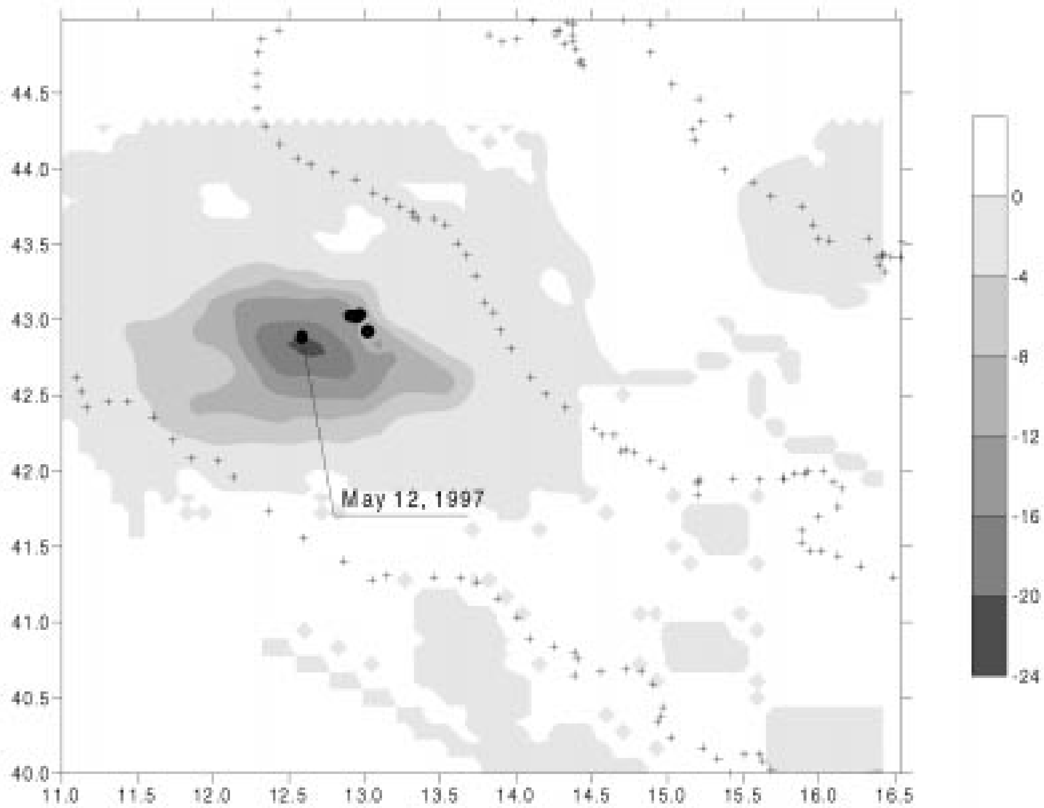

Figure 2. Map of the distribution of minimal values of the RTL parameter for the one year time interval, 5 September, 1996 to 5 September, 1997.

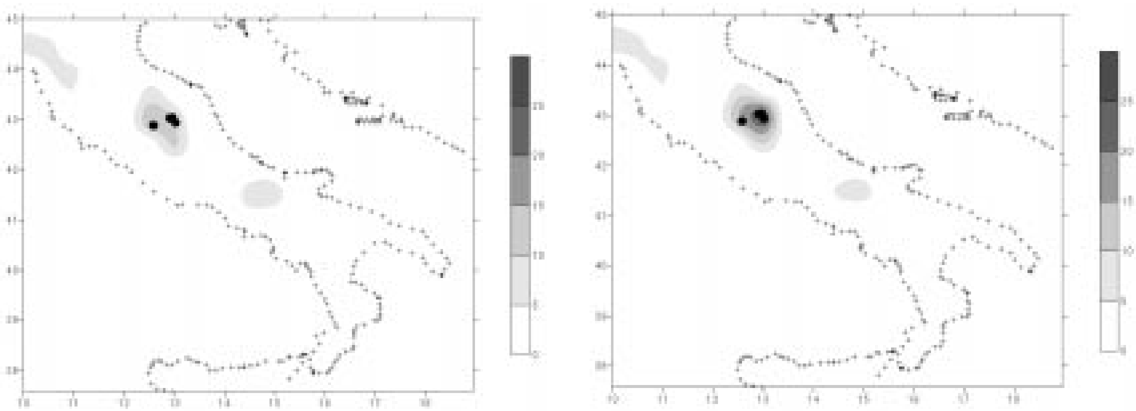

Figure 3. Map of the parameter $\Delta\mathbf{S}$. The data up to September 1,1997 was used for construction of Figure 3a, and the data up to September 25, 1997 was used for construction of Figure 3b. Black circles indicate the Massa Martana earthquake and the sequence of Umbria-Marche shocks with M>4.4.

until March 1979. Between March 16, 1979 and the earthquake of September 19, 1979, three clusters occurred. The next cluster occurred on October 17, 1982 and then there follows a seven year gap in the temporal succession. The process of clustering again began to develop in the analyzed area either on September 24, 1989, or on June 4, 1993. The intensity of this process then increases to the time of Umbria-Marche main shock on September 26, 1997 (see Figure 4).

Two types of randomized catalogues were created from the ING catalogue, to test the hypothesis that the observed process of clustering before an earthquake with M≥5.5 was not the result of a random process: Firstly, the time of events on the temporal interval 1975–1998, together with the coordinates of epicenters on the geographical cell 42.0<Lat<44.0, 11.9<Long<13.9, were randomized (randomized catalog type 1). Secondly, only the time of events was randomized on the temporal interval 1975–1998 (randomized catalog type 2). Fifty realizations of each type of randomized catalog were generated from the original catalog of events occurring in the area under consideration. The resulting selection of clusters from these catalogues is presented in Table 2. In consideration of the three earthquakes with **M≥5.5** within the analyzed versions of randomized catalogues, we had no example where more than one cluster occurred in the time interval < 2.5 years before the events (the first on September 19, 1979 and the second & third on September 26, 1997) The randomized catalogue tests demonstrate that clustering of original events is not the result of a random process. A computer generation of 10^7 realizations of the random distribution of 11 events (clusters) within the time interval 1975.0–1997.74 grants the probability of five or more events occurring during the 4.21 years before 1997.74 as being equal to p =3.77%. The more demanding requirement of at least five clustering events occurring during the 4.21 years leading up to the two earthquakes of 1997.74 and at least three clustering events occurring before the event of 1979.72, gives a probability of only p =0.43%. Such a result suggests that the observed process of clustering of earthquakes with **M≥3.5** before Umbria-Marche main shocks, can not be accidental.

Application of the time-to-failure model

The time-to-failure model (Varnes, 1983; Bufe and Varnes, 1993) has its origins in crack propagation (Das and Scholtz, 1981) and damage mechanics (Leckie and Hayhury, 1977; Kachanov, 1961; Rabotnov, 1969). It is based on the supposition that seismic release is accelerated in the epicentral area of future main shock, in the time period leading up to the event. The initial version of time-to failure equation is:

$$\frac{dQ(t)}{dt} = \frac{k}{(t_x - t)^{1-m}} \tag{2}$$

where **Q(t)** is a cumulative sum of the square root of the seismic energy released at time **t** within a selected area, $\mathbf{t}_s$ is the time of failure, **k** and $\mathbf{0<m<1}$ are constants. Integration of equation (2) yields the following time-to-failure equation:

$$Q(t) = Q_{total} - b * (t_s - t)^m \tag{3}$$

where $b = \frac{k}{m}$.

If we have data until the time $\mathbf{t}_1 < \mathbf{t}_s$, it is useful to present $\mathbf{Q}_{total}=\mathbf{Q}_0+\mathbf{a}$, where $\mathbf{Q}_0$ is the total cumulative sum of the square root of the seismic energy of events preceding time $\mathbf{t}_1$ and **a** is the total cumulative sum of the square root of the seismic energy of events that occurred in the time interval $\mathbf{t}_1<\mathbf{t}\leq\mathbf{t}_s$, including the main shock.

We used a log-periodic generalization of this model (Newman et al., 1995; Sorrette and Sammis, 1995):

$$Q(t) = Q_0 + a - b * (t_s - t)^m * [1 + C * cos(2\pi \frac{log(t_s - t)}{p} + \phi)] \tag{4}$$

with $\mathbf{C<<1}$.

We will normalize the function Q by the multiplier c^{-1}, where c is equal to the square root of the seismic energy of event with magnitude M = 3.5. In such a way the function Q and all parameters of the right part of (4) are dimensionless, except the coefficient b which has a dimension $[t]^{-m}$ and the coefficient p which has a dimension log[t].

Model (3) has at least six free parameters: the characteristic linear size $\mathbf{R}_o$ of the selected area, which is proportional to the characteristic linear size of the source of the predicted earthquake; the time interval $\mathbf{T}_o$ of the precursory seismic sequence which is used for modeling; the predicted time $\mathbf{t}_s$ of the main shock; the predicted magnitude $\mathbf{M}_p$ of the main shock $(\mathbf{a=a(M}_p\mathbf{)})$; the power **m**; and a coefficient **b.** Model (4) has three additional parameters: $\mathbf{C<<1}$, **p**, and ϕ. It is evident that at least parameters $\mathbf{R}_o$, $\mathbf{T}_o$ and **a,** depend on the magnitude of the 'predicted' main shock.

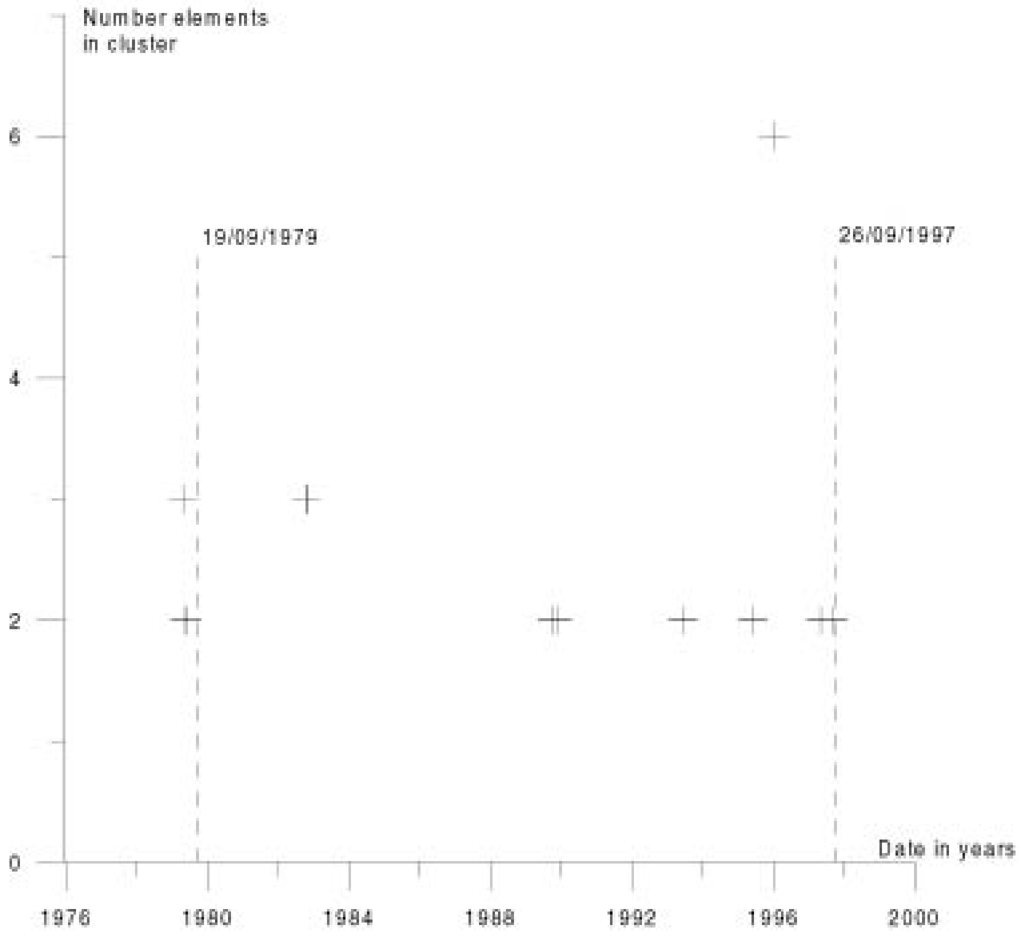

Figure 4. Plot of temporal distribution of earthquake clusters with M≥3.5 that occurred during the time interval 01/01/1975–26/09/1997 in the area 42.0<Lat<44.0, 11.9<Long<13.9. The first group of clusters is identified with the time of a first event of the cluster. The first group of clusters are concentrated before the earthquake that occurred on 19 September, 1979, (M = 5.5, Lat = 42.8, Long = 13.04) and the second group of clusters is concentrated before the September 26, 1997, Umbria-Marche earthquake (M = 5.8, Lat = 43.02, Long = 12.93).

In the present study we used earthquakes which fall into the time interval 25/09/1995–25/09/1997, and within a circle of radius $\mathbf{R}_o$ = 30 **km** with the center located at the epicenter of the Umbria-Marche main shock (Lat = 43.02, Long = 12.93). The coefficients **a**, **b, C<<1, p,**ϕ, power **M,** and time $\mathbf{t}_s$ are defined by the non-linear, least-squares method.

The plot of the model's function **Q(t)** (solid curve) and the cumulative sum of the square root of the seismic energy released by the events of the precursory sequence (crosses) are shown in Figure 5. The two black circles indicate the earthquakes with ML = 5.6 and ML = 5.8 which both occurred on September 26, 1997. The parameters of the model are: $\mathbf{t}_s$ = 1997.8, **m** = 0.12, **a** = 63.71, **b** = 86.27, **C** = 0.01, **p** = 1.957, ϕ = 3.245. The 'Predicted' magnitude is $\mathbf{M}_p$ = 6.01.

We mentioned above that models (3) and (4) have at least six or nine free parameters respectively. Parameters $\mathbf{R}_o$ and $\mathbf{T}_o$ may be defined if an approximate value of magnitude of the predicted earthquake is guessed. Two other suggestions probably can reduce the number of free parameters of the model. Bufe and Varnes (1993) suggested that the **m**-value is constant for a given region and may be estimated from previous mainshock acceleration sequences. Brehm and Braile (1998) demonstrated that, at least in some interval of magnitudes in the Madrid seismic zone, a linear log-log relationship between the seismic moment of a main shock and the **b** coefficient could be used. A special study of the possible application of these suggestions to the Italian seismicity is needed.

Table 2. Results of cluster selections for randomized catalogues

Type of randomized catalogue	Number of clusters identified within a realization of the catalogue	Number of realizations of catalogue	Total number of clusters observed in 50 realizations of the catalogue	Occurrence of cluster within the time interval < 2.5 years prior to an earthquake with M≥5.5
Randomized	0	35		
catalogue	1	13	17	3
type 1	2	2		
(Time and Space)				
Randomized	0	11		
catalogue	1	18		
type 2	2	14	71	12
(Time only)	3	7		
	4	1		

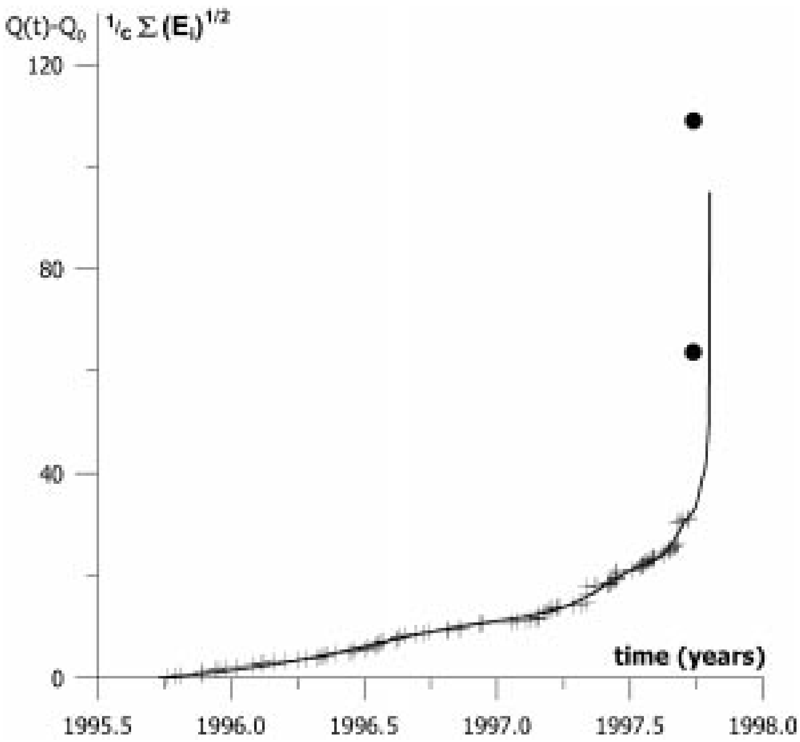

Figure 5. Plot of the best-fit solution for the model **Q(t)** (solid curve) and the cumulative sum of the square root of seismic energy released by events of the precursory sequence (crosses) are shown. The two black circles indicate the earthquakes with ML = 5.6 and ML = 5.8 that occurred on September 26, 1997. The parameters of the model are: $\mathbf{t}_s$ = 1997.8, **m** = 0.12, **a** = 63.71, **b** = 86.27, **C** = 0.01, **p** = 1.957, ϕ = 3.245. 'Predicted' magnitude is $\mathbf{M}_p$ = 6.01. Normalised coefficient **c** is equal to the energy of earthquake with magnitude 3.5. The latest event occurred before the main shock and contributing to the fit occured on September 19.

Discussion

Laboratory experiments and the results of a number of seismological studies, suggest that two stages follow one another in the focal area of the future earthquake: quiescence and foreshock activation of seismicity. Moreover, quiescence occurs much more often and indicates a concentration of seismic energy, without which the earthquake cannot occur. In some cases the foreshock activation is difficult to perceive due to the limited effective sensitivity of the recording instruments and also the low energy of the seismic events preceding the main shock. However, the preparation process leading up to the disastrous Umbria-Marche earthquakes of September 26, 1997 (ML = 5.6 and ML = 5.8) was manifested in both stages. RTL analysis indicates that quiescence made a start about a year before the main shock and it was changed by the activation of seismicity in early in March, 1997. The main shock occurred soon after the RTL parameter recovery to the level of its perennial background. The events of the Umbria-Marche sequence with $\mathbf{M \geq 4.5}$ are located in the area of the negative anomaly of the RTL parameter. The epicenter of the Massa Martana earthquake (May 1997, M = 4.5), which we consider a distant foreshock of the Umbria-Marche main shock, is located near to the center of the anomaly.

Analysis of the spatial-time distribution of the $\Delta\mathbf{S}$ parameter in first approximation indicates an accumulation of rupture areas during the year leading up to the main shock, as compared to the average background of the previous period. A concentration of this process in the vicinity of the future main shock site is also revealed. The positive anomaly of the $\Delta\mathbf{S}$ parameter in the area of Umbria-Marche earthquake, appeared after the Massa Martana earthquake of May 12,1997 (M = 4.5). The most intensive foreshock activation was observed during the short period between September 4, and September 25, 1997, and the magnitude of the $\Delta\mathbf{S}$ parameter anomaly increased significantly in the main shock epicentral zone during this time interval.

Laboratory experiments show that, in the process of deformation of rocks and synthetic materials before the appearance of a macro-rupture of the displacement type, there can be seen the successive stages of accumulation of cracks, their growth, junction and concentration in the future macro-rupture area. (Sobolev and Kol'tsov, 1988). The clustering process of earthquakes with $M \geq 3.5$ before Umbria-Marche main shock discussed above, follows these laboratory observations. Five clusters occurred in the vicinity of the Umbria-Marche main shock during the four and a half years prior to September 26, 1997. Similarly, only three clusters occurred in this area during the thirteen year period from 1980 to 1992. The almost five years of seismicity data available for the period leading up to the earthquake that occurred in the same area on September 19, 1979 (M = 5.5), reveals an absence of clusters during the four years prior to 1979, followed by three clusters which occurred in the epicentral area during nine months leading up to the main event.

Foreshock activation and clustering of earthquakes with $M \geq 3.5$ are the result of accelerated seismic energy release in the epicentral area of Umbria-Marche earthquakes prior to the main shock. This process closely corresponds to the log-periodic, time-to-failure equation. The estimation of parameters of this equation on the basis of earthquakes which fall into the two year time intervals prior to September 26, 1997 Umbria-Marche mainshock and within a circle of radius $\mathbf{R}_o$ = 30 **km** centered at the shock epicenter (Lat = 43.02, Long = 12.93), gives a good approximation of magnitude and time of the 'predicted' earthquake

Conclusion

The preparation process for the two disastrous Umbria-Marche earthquakes of 1997, was manifested in few characteristics of weak seismicity in the area of the future main shock. These characteristics are:

- Seismic quiescence which was then replaced by a foreshock activation.
- The excess of the area of ruptures accumulated during the last year before the Umbria-Marche mainshock, as compared to the average background of the previous period.
- The clustering of earthquakes with magnitude $\mathbf{M \geq 3.5}$
- The process of acceleration of seismic energy release, as described by the log-periodic time-to-failure equation.

The previous literature has discussed these features of weak seismicity as possible precursors to a large earthquake. Nevertheless, the 1997 series of two Umbria-Marche earthquakes is an important example where the complexity of all these anomalies was observed. This complexity of anomalies was also observed prior to some large Kamchatka earthquakes (Sobolev and Tyupkin, 1999; Di Giovambattista, Sobolev and Tyupkin, 1999). We believe that similar analysis of the peculiarities of weak seismicity may help us to understand the physics of the process of earthquake preparation.

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