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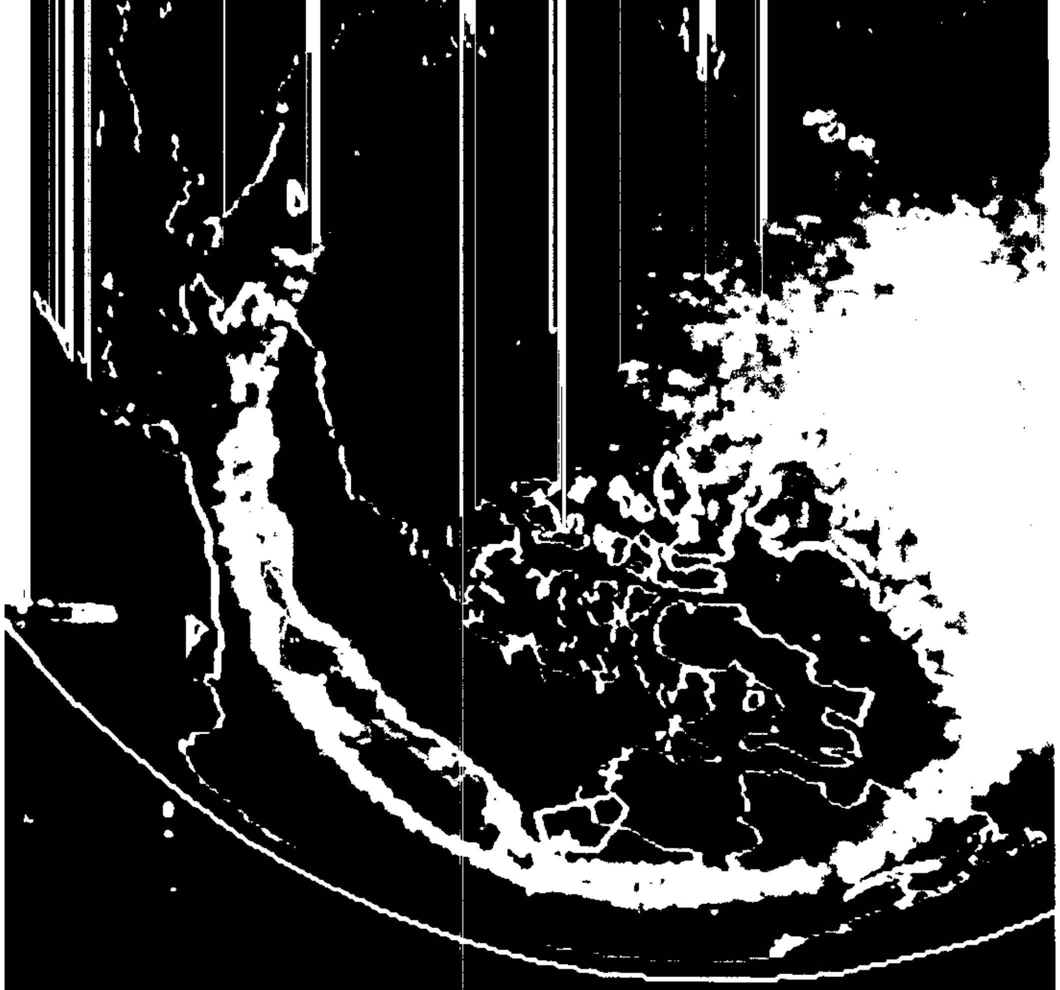
REVISTA

GEOFISICA



INSTITUTO PANAMERICANO DE GEOGRAFIA E HISTORIA

REVISTA GEOFISICA 1988

The forecast of the magnitude 5.8, May 7th 1984, earthquake in Central Italy

Michele Caputo*

Resumen

El 23 de noviembre de 1980 un terremoto de magnitud M=6.5 ocurrió en la parte sur de los Apeninos a la latitud 40°55' y longitud 15°22'. Siguiendo la tradición del análisis estad'stico del catálogo italiano de terremotos que condujo en el pasado al desarrollo de algunos método· le predicción a largo plazo de grandes terremotos (Caputo et al., 1977; Caputo et al., 1983), aquel catálogo fue examinado a efectos de investigar modelos de sismicidad con los cuales fuera posible estimar la probabilidad, a su vez, de una fuerte réplica. El análisis del catálogo de terremotos italiano con intensidades mayores de VIII desde el año 1448 reveló que, entre las latitudes 39°N y 41°57'N (excluyendo Apulia), los sismos ocurrieron en 15 secuencias, cada una compuesta promedialmente de tres eventos dentro de un período de siete años. A su vez, dentro de cada secuencia, el tiempo promedio entre el primer y segundo evento, es de cinco años.

Este modelo de secuencias de grandes terremotos condujo a una tentativa de predicción de nuevos terremotos con una magnitud moderada, a seguir unos pocos años después al evento del 20 de noviembre de 1980 (Caputo, 1983). Estos terremotos realmente ocurrieron en mayo 7 y en mayo 11 de 1984 con magnitudes 5.8 y 5.2, respectivamente.

Los últimos sismos mencionados indicaron que la predicción era correcta y que, por lo tanto, era apropiado estudiar con mayor detalle el conjunto de secuencias de terremotos, así como las secuencias de todos los eventos y la distribución de eventos dentro de aquellas secuencias, a efectos de encontrar posibles leyes físicas que pudieran regular el comportamiento de los terremotos dentro de las secuencias y la agregación de los mismos para formar aquellas. Un análisis más refinado reveló que la distribución de los tiempos entre las secuencias era exponencial, lo que implica que no es posible prever

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a partir del análisis numérico la ocurrencia del primer evento de cada secuencia. Por lo tanto, fue dejado para estudios posteriores la viabilidad de una predicción de una segunda o una tercera fuerte réplica después que el primer evento tuvo lugar. El análisis estadístico indicaba que los tiempos entre todos los eventos, o entre los eventos de una secuencia aislada tienen una distribución no exponencial. Esto implica que después del primer sismo de una secuencia (como es el caso del terremoto de 1980 mencionado), se puede prever la ocurrencia de otro sismo moderado o grande, en el término de pocos años.

Asimismo fue encontrado que en el 50% de los casos el segundo evento en las secuencias ocurre dentro de los cuatro años contados desde el primero; en el 50% de los casos el tercer evento tuvo lugar dentro del año y medio después del segundo. Las secuencias con más de dos eventos son el 47% y las secuencias con más de tres eventos son solamente el 20% del total, lo que indica que la probabilidad de un cuarto evento después de aquel de noviembre de 1980 es bastante baja. Por otra parte, los datos existentes no permiten preveer la ocurrencia de un tercer evento de la secuencia señalada, con aceptable confianza.

Parece que las secuencias ocurren de acuerdo a una distribución de Poisson, mientras que el conjunto de eventos dentro de las secuencias pueden tener una distribución exponencial generalizada. Sin embargo, puede ser más probable que estos eventos ocurran de acuerdo a una ley exponencial del tiempo. Esta distribución sugiere que cada shock altera la distribución de tensiones, liberándola en el volumen epicentral y concentrándola en otro lado hasta que un número de asperezas sujetas a una tensión cercana a su punto de ruptura, son fracturadas. Parece, por lo tanto, que estas asperezas están generalmente presentes pero en un número limitado.

El conjunto de todos los eventos no tiene una significativa probabilidad de seguir una distribución de Poisson o una distribución exponencial. La ley de distribución exponencial de los eventos dentro de las secuencias queda enmascarada por la adición de la distribución incierta de las secuencias mismas.

La región sísmica considerada en este trabajo es de una extensión aproximadamente un tercio de la totalidad de la zona de los Apeninos. El catálogo de los terremotos de la porción norte de los Apeninos ha sido también estudiado, pero no hay evidencia de una posible concentración tal como ha sido determinada para las regiones sur y central.

Asimismo ha sido hallado (Caputo, 1983) que en un círculo de 140 Km. de radio alrededor de Mesina, que incluye la mayoría de los terremotos con intensidad X⊘ mayores, están concentrados como muestra la Tabla 5. Aunque un par de sismos está separado por 24 años; la concentración parece remarcable, principalmente en los últimos 200 años; el máximo tiempo entre los eventos en las concentraciones en los últimos dos siglos es de ocho años y la separación entre estos grupos es de alrededor de 35 años. El número de eventos y grupos no es suficiente para permitir un análisis estadístico con aceptable confianza; sin embargo, esta aparente concentración merece atención porque han pasado 80 años desde la última concentración en el intervalo 1905-1908.

Abstract

Analysis of the catalogue of Italian earthquakes with intensities larger than VIII from the year 1448 reveals that, between the latitudes 39°N and 41°57'N (excluding Apulia), the earthquakes occurred in 15 sequences, each composed of an average of 3 events within an average time of 7 years. The average time between the 1st and 2nd events of each sequence is 5 years, which led to the tentative prediction of new earthquakes with moderately large magnitude to follow a few years after the event of November 20, 1980 (Caputo 1983). These earthquakes actually occurred on May 7th and May 11th, 1984 with magnitudes 5.8 and 5.2. A more refined analysis reveals that the distribution of the times between the 15 sequences is exponential; while the times between all the events, or between the events of one sequence have a non-exponential distribution. This implies that after the first earthquake of a sequence, as in the case of the 1980 earthquake, one may foresse the occurrence of other earthquakes after few years, while it would be difficult to foresse the occurrence of a future sequence of earthquakes.

The data do not allow us to foresse the occurrence of the third event of the sequence with acceptable confidence. These occur with about 46% probability. On average, they occur within 7 years from the first earthquake of their sequence and within 2 years from the second.

Introduction

The statistical distribution of earthquake parameters has been studied since the beginning of modern seismology. Work by Ishimoto and Iida (1939), who discovered that the log of the density distribution of the magnitude M is a linear function of M, which led to the definition of the now well-known b value.

Aki (1956) and Knopoff (1964) studied sequences of events in catalogues of earthquakes and concluded that they are not Poissonian; however Gardner and Knopoff (1974) found that California earthquakes with $M > 3.8$ between 1952 and 1971, after proper removal of aftershocks, have a Poissonian distribution. The same is true also for $M > 4.3$, $M > 4.8$, and $M > 5.3$; but for $M > 5.8$ the number of events is not sufficiently large to draw any reliable conclusion.

Caputo (1980a, 1982, 1981b) and Caputo and Console (1980) studied the statistical distribution of the scalar moments M_0 as a function of the length of the fault l and of the stress drop p and found that their density distributions $n_0(M_0)$, $n_l(l)$, and $n_p(p)$ are powers of M_0, l and p respectively, as predicted theoretically (Caputo 1976, 1980), and that some of the exponents of power laws are related.

$$\log n_o(M_o) = e_o - b_o \log M_o,\ b_o = \frac{\nu+2}{3}$$

$$n^{(l)}\ \alpha\ l^{\omega},\ \nu = 3b + \frac{1}{c} \qquad (1)$$

$$n_p(P)\ \alpha\ p^{1+\alpha},\ \alpha < 0$$

where b is obtained from the empirical law of Ishimoto and Iida (1939), c ≅ 1.5 is the slope of the empirical log (moment)/magnitude relation (e.g. Hanks and Kanamori; 1979) and α as well as ν have been estimated by Caputo (1980a, 1980b, 1981c, 1981b, 1982, 1985) for several seismic regions or earthquakes sequences.

Other examples of statistical analysis pertinent to the present note are given by Caputo (1981a) who studied the Ente Nazionale Energia Elettrica (ENEL) catalogue of Italian earthquakes, and concluded that the catalogue seems complete in the time intervals given in Table 1. He also studied the seismicity of the Southern Appennines after the November 23, 1980 Irpinia earthquake in order to establish the possibility of occurrence of another earthquake in the same area in the near future. This led to the suggestion that other earthquakes of moderate magnitude should occur within several years. This was proved correct by the May 7th 1984 magnitude $M_s = 5.8$ earthquake and the May 11th 1984 magnitude $M_s = 5.2$ earthquake which occurred in the South-Central Appennines. The present paper examines the possibility of a fourth earthquake in the same area in the near future.

Table 1
Completeness of the ENEL (1978) Catalogue of Italian Earthquakes

Intensity, I	Completeness of catalogue
≥ VI	1885-1975
≥ VII	1775-1975
≥ VIII	1700-1975
≥ IX	1600-1975
≥ X	1550-1975
≥ XI	1000-1975

Completeness of the ENEL Catalogue of Italian earthquakes occurred from the year 1000 through 1975.

When was due a fourth event in the sequence which began in 1980?

The November 23, 1980 earthquake in Irpinia occurred in a location which was found in the pattern recognition studies of Caputo et al, (1980) and

Benvenuti and Caputo (1982), to be prone to events with M ≥ 6.5 (see Fig. 1). It was preceded by a swarm precursor (Caputo et al. 1983); for a detailed discussion of the precursors of this event see Del Pezzo et al. (1983).

A detailed analysis of the catalogues of earthquakes (ENEL 1978, Carrozzo et al, 1973) of the portion of the Appennines between latitudes 39°N and 42°N, from the year 1448 through 1964 (Caputo 1983), indicates that the events with intensity larger than or equal to IX tend to cluster in time. These events are listed in Table 2.

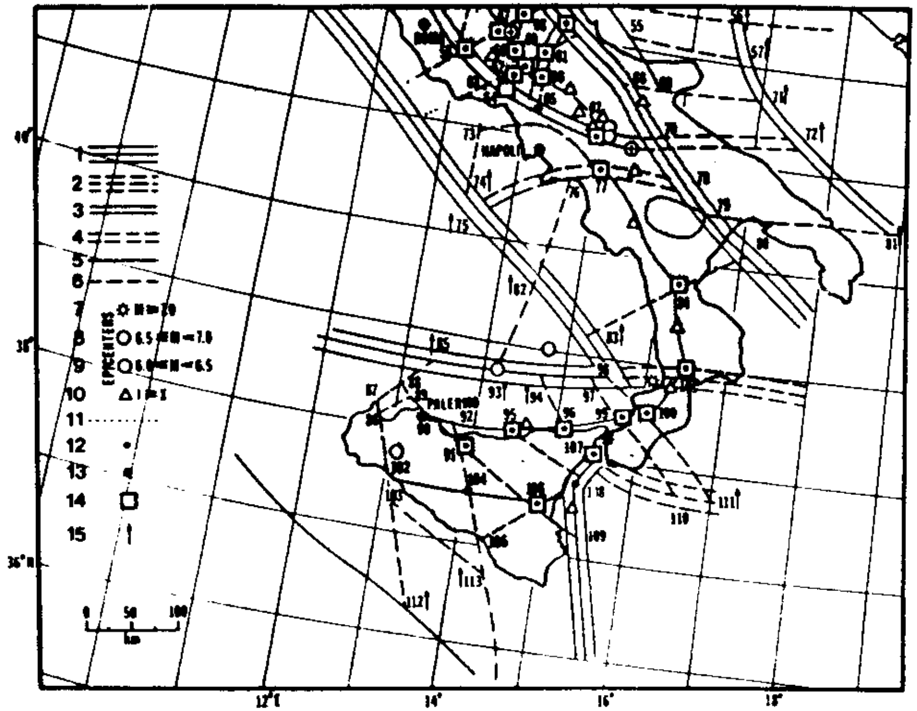

Figure 1. Map of the major lineaments of the Italian region, and of the intersections of the lineaments considered as potentially dangerous. Numbers in the key refer to the following classification of lineaments, epicenters, boundaries and intersections. Lineaments: 1,2 = first order; 3,4 = second order; 5,6 = third order; 1, 3 and 5 longitudinal, 2, 4 and 6 are not expressed in topography. 7, 8, 9 and 10 = epicenters, 11 = uncertain lineaments (covered by sediments or sea). Intersections: 12 = recognized as D in the basic variant; 13 = recognized as uncertain in the basic variant; 14 = recognized as D in the earthquake future experiment; 15 = not used because the intersections are on the outer boundaries of the regions.

In Table 1, the three earthquakes which occurred in 1984 are listed without their intensities because we have not obtained an official report on them. Since the magnitudes of the two events which occurred in 1984 is larger than 5, as are the magnitudes of all the other events in Table 2, it seemed acceptable to include the two events of May 7th and 11th 1984 in Tables 2 and 3.

We shall call a subset (of 2 or more events) of the set of 43 events listed in Table 2 a "sequence" when the events of the subset occur in a time interval of 14 years or less. The first sequence begins in 1448. The events can be divided in sequences in many ways; we chose that indicated in Table 2. There are 15 sequences; the average number of events in each sequence is about 3; the average time between first and last events of each sequence is about 7 years, and ranges from a few minutes to 12 years. Two consecutive sequences are separated by an average of 31 years. The total of the times between the

Table 2

YEAR	MON	DA	HO	MI	SE	LONG	LAT	INT	MAG	MAG
1448						40 45	14 15	9.0	5.6	5.0
1456	12	5	22			41 18	14 42	11.0	6.6	6.1
1456	12	30	8			41 15	14 45	9.0	5.6	5.3
1550	8	25				40 20	15 35	9.0	5.6	5.3
1560	5	11				41 20	16 30	9.0	5.6	5.4
1561	7	31	23			40 20	15 35	9.0	5.6	5.3
1561	8	19	19			40 20	15 35	10.0	6.1	5.7
1627	7	30	15	30		41 50	15 20	9.0	5.6	5.4
1627	8	9				41 50	15 20	9.5	5.8	5.4
1638	3	27	19	30		39 0	16 15	10.0	6.1	5.8
1638	6	9	4			39 0	17 15	9.0	5.6	5.4
1646	5	31	1	30		41 50	15 50	9.0	5.6	5.4
1654	7	23	24			41 45	13 30	10.0	6.1	5.7
1654	9	8				40 50	15 40	9.0	5.6	5.3
1688	6	5	13	15		41 12	14 54	10.0	6.1	5.7
1694	9	8	16	45		40 48	15 35	10.0	6.1	5.7
1702	3	14	4	23		40 57	14 50	9.0	5.6	5.3
1731	3	20	8	30		41 30	15 30	10.0	6.1	5.9
1732	11	29	12	30		41 10	15 4	9.0	5.6	5.8
1755	11	1	9			41 0	13 0	9.0	5.6	
1767	7	14				39 40	15 0	9.0	5.6	5.4
1796	3	18	16	30		40 45	13 50	9.0	5.6	5.0
1805	7	26	21	1	40	41 31	14 34	10.5	6.3	5.9
1826	2	1	4			40 35	15 40	9.0	5.6	5.3
1828	2	2	9	15		40 54	13 45	9.0	5.6	5.0
1832	3	8	18	15		39 0	17 0	10.0	5.6	5.4

Table 2
(continued)

YEAR	MON	DA	HO	MI	SE	LONG	LAT	INT	MAG	MAG
1835	10	12	12			39 25	16 15	9.0	5.6	5.4
1836	4	24	23	15		39 40	16 45	9.0	5.6	5.4
1836	11	20	7	30		40 0	15 45	9.0	5.6	5.3
1851	8	14	13	22	35	41 0	15 40	10.0	6.1	5.7
1854	2	12	17	30		39 20	16 10	9.0	5.6	5.4
1857	12	16	21	15		40 37	15 17	9.0	5.6	5.3
1857	12	16	21	18		40 17	15 55	10.0	6.1	5.7
1858	8	6	10	30		40 37	15 17	9.0	5.6	5.5
1870	10	4	16	55		39 17	16 17	10.0	6.1	5.8
1883	7	28	20	25		40 45	13 54	9.0	5.6	5.0
1910	6	7	2	4		40 54	15 27	9.5	5.8	5.3
1913	6	28	8	53	2	39 37	16 9	9.0	5.6	5.3
1962	8	21	18	10	30	41 8	15 7	9.0	5.6	5.8
1962	8	21	18	19	30	41 8	15 7	9.0	5.6	5.8
									M_L	M_s
1980	11	23	18	34	54	40 55	15 22		6.5	6.9
1984	5	7	17	49	42	41 46	13 54		6.0	5.8
1984	5	11	10	41	50	41 50	13 58		5.4	5.2

Coordinates, time of occurrence, intensities and magnitudes of the events considered in the region between latitudes of 30°N and 41°50'N in Italy (Apulia excluded). The intensities are those reported in the ENEL Catalogue. The magnitudes of the events until 1968 are those listed in the ENEL catalogue and estimated from the intensities according to empirical formulae of Karnik (1969). The events occurred after 1962 have M_L computed at Observatorio Geofisico of Trieste, while M_s is taken from Preliminary Determination of Epicenters Bulletin of U.S. Geological Survey lists.

first and the second event of all sequences is 75 years, or about 14% of the total time since 1448; these periods will be called "alarm times".

In Figure 2 one may see that there is no correlation between the number of events in the sequence and their duration. One may also see in Figure 3 that there is no correlation between the number of events in a sequence and the time to the preceeding or following sequence.

In 60% of the sequences (exceptions are those which began in the years 1638, 1688, 1731, 1870, 1910, 1980) the first event of the sequence is not that with the largest intensity. All sequences except those which began in 1755 and 1962 include an event with intensity larger than IX. The average time between the events with I ≥ IX½ and the preceeding event is 11 years; the average time to the following event is 10 years. Comparing these averages with the average interval time of all the events, 12.5 years, one may infer that there is no evidence for either the time- or slip-predictable models.

Table 3
Sequences of large earthquakes in the Southern Apennines (between the latitudes 39°N and 41°50'N)

Time window	Events (intensity, year)	Number of events	Time to second event of sequence (years)	Length of time window of each sequence (years)	Gap between successive sequences (years)
1448.496-1456.997	IX,1448.496; XI,1456.928; IX,1456.997	3	8.432	8.501	93.652
1550.649-1561.636	IX,1550.649; IX,1560.359; IX,1561.581; X,1561.636	4	9.710	10.987	65.942
1627.578-1627.606	IX,1627.578; X½,1627.606;	2	0.028	0.028	10.630
1638.236-1638.438	X,1638.236; IX,1638.438;	2	0.202	0.202	7.876
(1627.578-1638.438)	(IX,1627.578; X½,1627.606; X,1638.236; IX, 1638.438)	(4)	(0.028)	(10.860)	(7.977)
1646.414-1654.688	IX,1646.404; X,1654.562; IX,1654.688	3	8.148	8.284	33.739
1688.427-1702.200	X,1688.427; X,1694.688; IX,1702.200	3	6.261	13.573	29.016
1731.216-1732.912	X,1731.216; IX,1732.912;	2	1.696	1.696	22.924
1755.836-1767.534	IX,1755.836; IX,1767.534;	2	11.698	11.698	28.677

Table 3
(Continued)

Time window	Events (intensity, year)	Number of events	Time to second event of sequence (years)	Length of time window of each sequence (years)	Gap between successive sequences (years)
1796.211-1805.570	IX,1796.211; X½,1805.570	2	9.359	9.359	20.518
1826.088-1836.888	IX,1826.088; IX,1828.090 X,1832.186; IX,1835.781; IX,1836.315; IX,1836.888	6	2.002	10.800	14.731
1851.619-1858.597	IX,1851.619; IX,1854.021; IX,1857.962; X,1857.962; X,1858.597	5	2.511	6.978	12.165
1870.762-1883.575	X,1870.762; IX,1883.575	2	12.813	12.813	26.858
1910.433-1913.490	IX½,1910.443; IX,1913.480	2	3.057	3.057	49.148
1962.638-1962.638	IX,1962.638; IX,1962.638	2	0.000	0.000	18.258
1980.896-?	X,1980.896; 1984.351; 1984.359	3	3.455	?	?
Average		2.87	5.24	7.00	31.01
		(3.07)	(5.63)	(8.35)	(32.59)

Sequences of earthquakes formed with the events of Table 2 and discussed in the paper. In brackets is also indicated the sequence substituting the two sequences beginning on 1627 and 1638 respectively; the discussion of this new set of sequences does not alter the conclusion of the paper, only the average interarrival times of Fig. 7 change slightly, those pertinent to this new set of sequences are indicated by a dashed line. Time is in years.

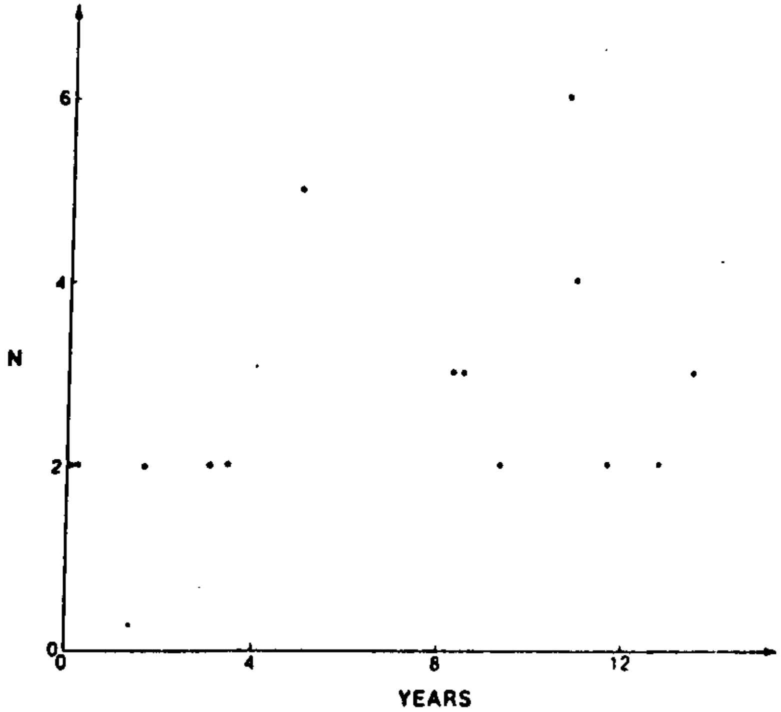

Figure 2. Number of events in each sequence as a function of the length of the sequence.

The earthquakes which occurred in May 7th 1984 and May 11th 1984 in that area proved that the tentative suggestion of Caputo (1983) "that another earthquake could possibly follow that of November 1980 in that area" was correct. Considering that the suggestion was based on the fact that the earthquakes in that area occur in sequences it seems reasonable to investigate whether this sequence will include more than three events, and when we might expect a fourth event to occur. We shall supplement here the analysis of Caputo (1983) with more studies trying to answer these questions.

For this purpose we studied the statistical distribution of three sets of interarrival times: of the sequences themselves (Set I), of the events within the sequences (Set II) and of all the events (Set III).

Since the density distribution of the seismic energy radiated W, is a power of W (Caputo 1976, 1980b), and assuming that the time t to accumulate the energy of large earthquake should be proportional to the elastic energy released and that this is proportional to W, we may tentatively propose that

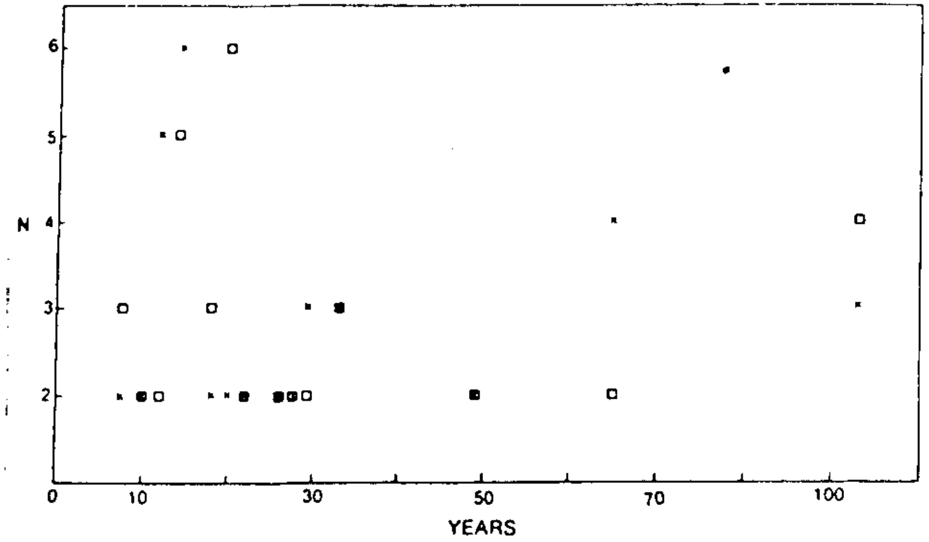

Figure 3. Number of events in each sequence as function of the interarrival time to previous sequence (squares) or to the following sequence (crosses).

the density distribution n of the interarrival times of the events should be a power law of the time. However, we know that the process of accumulation of the energy for the next earthquake, begins before last occurrs. To take into account both phenomena, we will tentatively add a constant c, to the time t, to represent an average time elapsed from the beginning of the accumulation of the stress until the new regime installed at the previous earthquake. Then

$$\ln(n) = a + b \ln(t + c) \tag{2}$$

which implies that after each large earthquake, time has a new role depending on the local geologic environment, (particularly the asperities), on the mechanism of the earthquake which triggered the new energy accumulation regime, as well as on the mechanism of the earthquake to be released.

The same could also be tentatively applied to the sequences of events, considering them as bursts of earthquakes preparing for a successive burst, although the mechanism involved would probably be different from that triggering the single earthquakes.

Before discussing the fit of the three sets of data to equation (2), in order to test the randomness of the data, we consider also the fit of the three sets to the function representing the Poisson distribution

$$n_{e1} = \mu^{-1}e^{-\mu^{-1}t} \tag{3}$$

where μ is the average number of events in each set. To test the randomness of the data, we also considered the fit to the function representing a generalized Poisson distribution

$$n_{e2} = Ae^{-Bt} \tag{4}$$

where $A > 0$, $B > 0$, $A \geq B$ for normalization. Obviously, the comparision of the σ^2 of the fits to the three functions is a measure of the nonrandomness of the data.

In Figures 4, 5, and 6 one may compare the fits of n, n_{e1}, and n_{e2} to sets II and III and the fits of n_{e1}, and n_{e2} to set I. It is not significant to make a fit of n to set I because it was possible to obtain only three points from the data available and the parameters to fit are three (a, b, c) which would give $\sigma^2 = 0$. Also the fit of set III to n_{e2} is not consistent because it gives $A < B$ and therefore is not listed in Table 4.

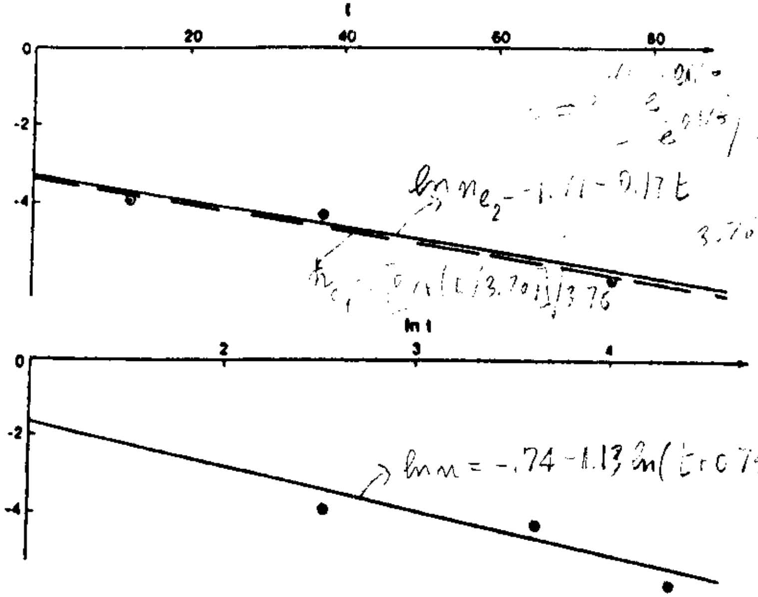

Figure 4. Best fit of (4) and (2) (continuous line top ln n_{e2} = −1.709 − 0.173t and bottom ln n = −0.739 − 1.13 ln (t + 0.75)), to the density distribution of the interarrival times of the events within the sequences. The dashed line is (3) with μ = 3.76 average interarrival time of events within sequences.

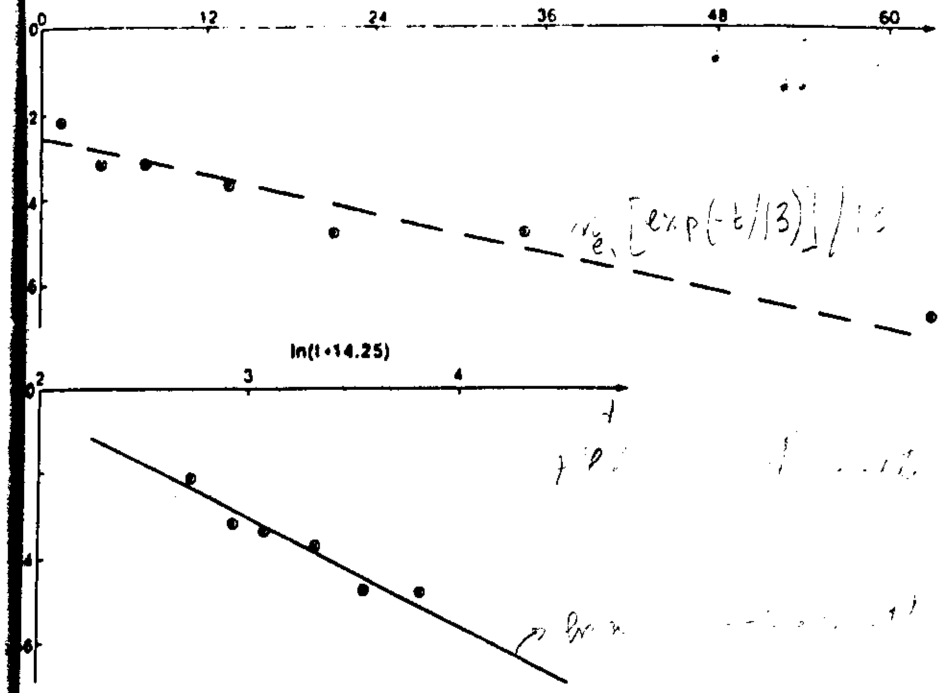

Figure 5. Best fit of (2) (continuous line bottom ln n = −4.65−2.58 ln (t + 14.25)) to the density distribution of the interarrival times of all events. The dashed line is (3) with μ = 13.1 interarrival time of events.

Since the average of the magnitudes estimated for each event considered differ from 5.9 by at most 0.6, we may tentatively consider that the earthquakes of the set have released energies of the same order of magnitude.

One may also check that there is no correlation between the intensity of each earthquake and the time from the previous one in sets I and II; te same applies to set III, considering the correlation between the energy released in each sequence and the time to the sequence preceeding it.

The results of the fit of the three sets of data to the three density distributions laws, shown in Table 4 and Fig. 4, 5, and 6 indicates that the law (2) always has the smallest σ^2 and is the closest to the data, which in turn seems to indicate that the process of release of the elastic energy in this region, through earthquakes of comparable order of magnitudes, is not random. The σ^2 of the fit of n_{e1} and n_{e2} to set I is relatively small and we could also infer that the interval times of the sequences have a nearly exponential distribution.

We should note however that if the earthquakes of the region were a random, stationary, uncorrelated process, the probability that clustering as the observed one arises by chance, is about 3%.

Certainly one may devise a multiparameter statistical law representing a random process which would fit the data better than n; however the random processes most used to represent earthquake catalogues are n_{e1}, and n_{e2} which we may tentatively rule out for sets II and III on the basis of the smaller σ^2.

The density distribution laws considered need discussion. The laws n_{e1} and n_{e2} are mere statistical laws representing random processes; n_{e1} is estimated using only the mean interval time and does not fit the data well, as one may see from σ^2. An improvement is obtained with n_{e2} because of one additional parameter (which would imply a normalization to a finite time (since $A > B$) as the data make reasonable to assume). A better fit is obtained with n,

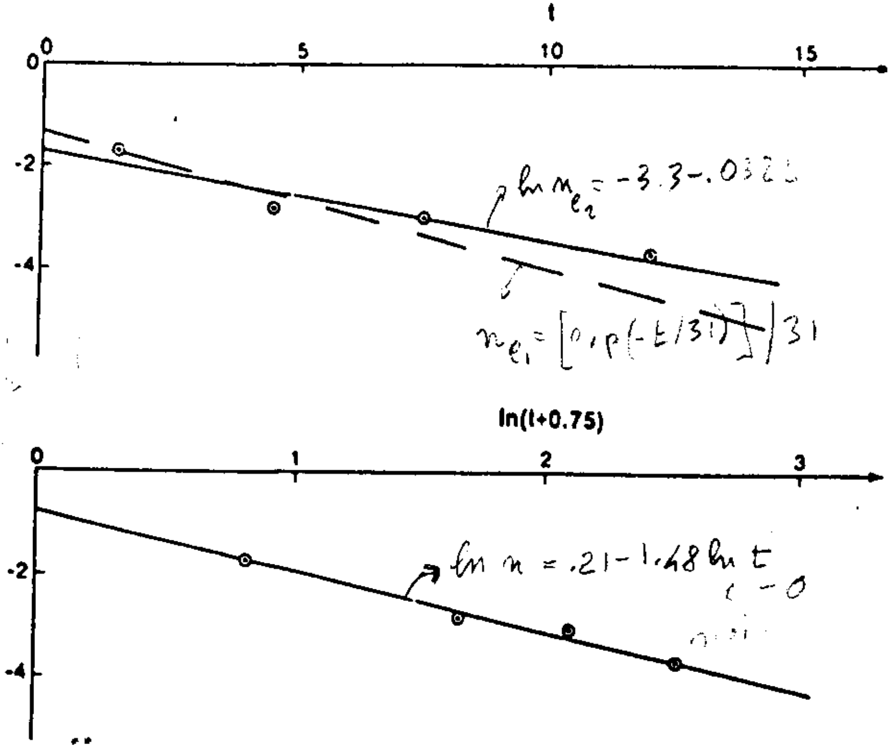

Figure 6. Best fit of (4) and (2) (continuous line top $\ln n_{e2} = -3.33-0.032t$, and bottom $\ln n = -0.21-1.48 \ln t$, t 1), $c = 0$) to the density distribution of the interarrival times of the sequences. The dashed line is (3) with $\mu = 31.0$ interarrival times of the sequences.

Table 4

SET	a	b	c	σ^2	lnA	−B	σ^2	μ	−lnμ	$-\mu^{-1}$	σ^2
I					−3.335	−0.032	0.042	31.02	−3.435	−0.032	0.047
II	−0.739	−1.132	0.75	0.010	−1.709	−0.173	0.035	3.76	−1.325	−0.265	0.211
III	4.653	−2.585	14.25	0.069				13.07	−2.570	−0.077	0.285

Numerical values of the parameters of the density distributions n, n_{e1}, n_{e2} defined by (2), (3) and (4), obtained with least square method fit to the data sets I, II and III. σ^2 is the variance of the data with respect to the lines fitted.

which represents a tentative physical model; however n contains three arbitrary parameters to fit the data and therefore has a higher probability of giving a smaller σ^2.

The catalogues of earthquakes whose interval times proved to be exponential (Gardner and Knopoff, 1974), cover a large area where the process of release of seismic energy may be severe. By selecting appropriates sets of events from an experimental distribution, one may "prove" that an exponential distribution may always be considered the sum of distribution which are not necessarily all exponentials. That could be the case of the catalogues of

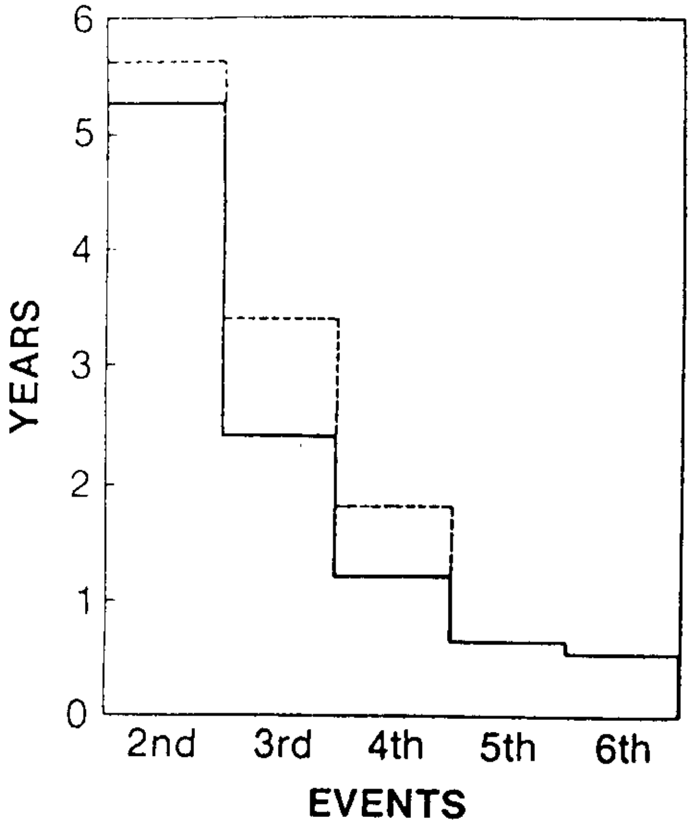

Figure 7. Average interarrival time between the nth and the (n + 1)th events of the sequences. The dashed lines give the values for the set of sequences of Table 5 in which the sequence indicated in brackets substitutes the two sequences beginning on 1627 and 1638.

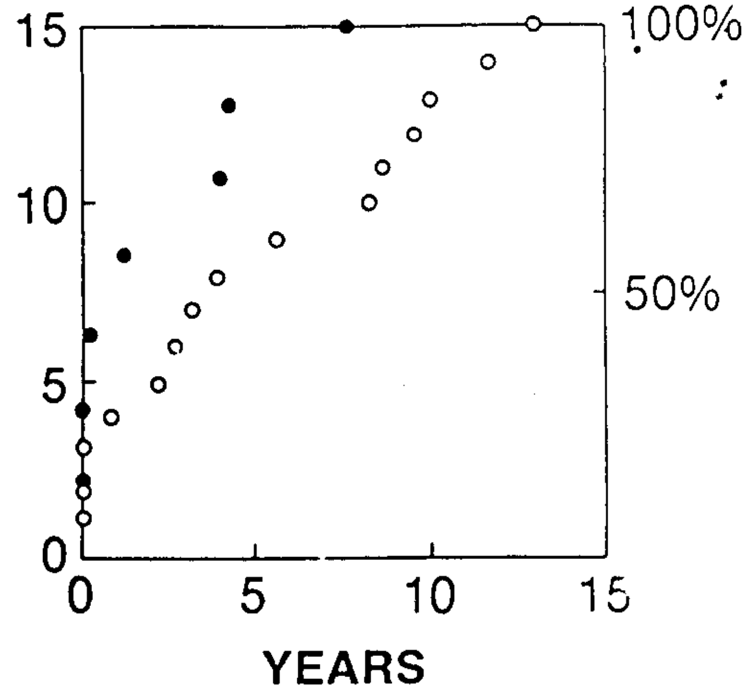

Figure 8. Cumulative distribution of the interarrival times between the first and the second event (open circles) and between the second and the third events (solid circles) in the sequences.

earthquakes of large regions: they may be the result of the sum of several different non-exponential processes.

Since in no case was it possible to prove that a regional catalogue of large events has an exponential distribution, it seems reasonable to consider that sets I and II have density distribution represented by n, rather n_{e1} or n_{e2}, on the basis of their σ^2.

We may thus suggest that it should be possible to predict the interval time between the successive events in the sequences.

Figure 7 shows the average interval time between the successive events of the sequence. It is clear that the events cluster towards the last one of each sequence.

Figure 8 shows the cumulative distribution of the interval times between the first and second events of each sequence and between the second and third events of each sequence, which reflects a property of Fig. 7. This may imply that each shock alters the distribution of stress, releasing it in the epicentral volume and concentrating it elsewhere, until a number of asperities with stress close to their fracture stress are ruptured. In 50% of the cases the second event occurs within four years from the first; in 50% of the cases the third event arrives within 1.5 years of the second.

In the paper of Caputo (1983) the two events in 1962 were omitted accidentally. Howeverm this does not change the results significantly.

Figure 9 shows the cumulative distribution of the time windows in which the sequence occur, and one may note that 50% of them have duration less than 8.5 years.

The sequences with more than two events are 47% of the total, and the sequences with more than three events are only 20%. It seems therefore that the probability of a fourth event in the sequence which began in 1980 is rather low; according to the data of Figure 7 we may say that a possible fourth event should have occurred within 1.2 years from the third, that is by June 1985. At present, the summer of 1987, the fourth event did not yet occur. This would indicate that the sequence of earthquakes which began in November 1980 actually ended in May 1984.

The seismic region considered in this paper is about one third of the Apennines; the catalogue of earthquakes of a northern portion of the Apennines has also been studied but no evidence has been found of a possible clustering such as that found in the south central portion. The study of the seismic region around the Messina Straits brought different results. It was found (Caputo, 1983) that in a circle of 140 km radius around Messina, which includes most earthquakes with intensity X or larger, are clustered as shown in Table 5. The clustering here seems to occur mostly in couples of events. Although one couple of events is separated by 24 years, the clustering seems remarkable, mostly in the last 200 years; the maximum time window of the events in the clusters of the last two centuries is 8 years. The number of events and clusters is not sufficient to allow a statistical analysis with acceptable confidence, however this apparent clustering deserves attention.

Table 5

	Number of events	Time window (years)
1169-1184	2	15
1638-1659	2	21
1669-1693	2	24
1783-1791	4	8
1818-1823	2	5
1865-1870	2	5
1905-1908	2	3

Earthquakes with intensity I > X in a circle with 140 km radius centered in the Messina Straits.

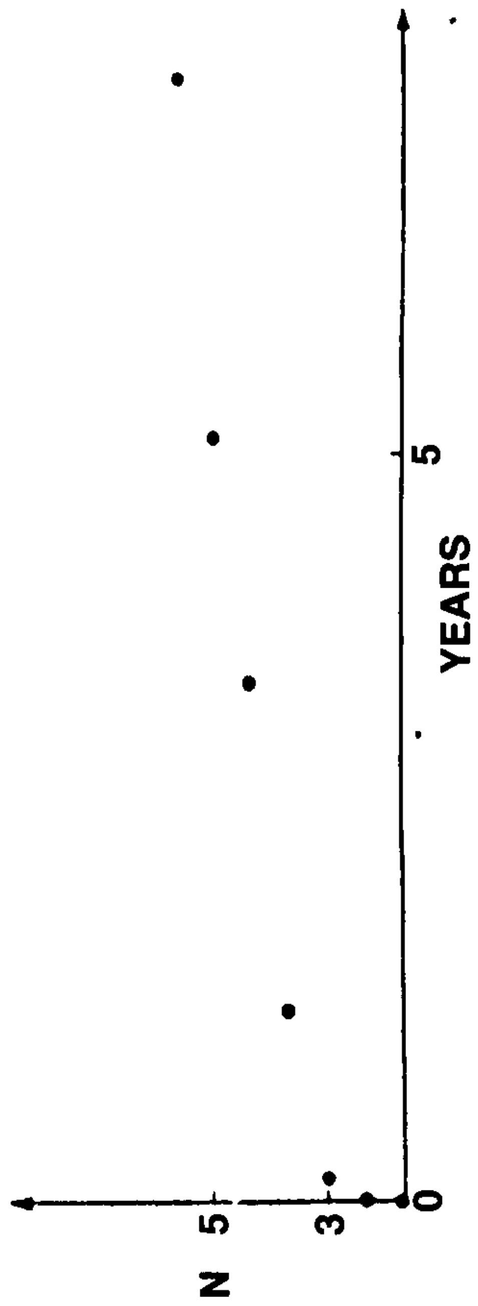

Figure 9. Cumulative distribution of the length of the time windows of the sequences.

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