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The Occurrence of Large Earthquakes in South Italy

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THE OCCURRENCE OF LARGE EARTHQUAKES IN SOUTH ITALY

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ABSTRACT

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An analysis of the data in the catalogues of Italian earthquakes indicates that large earthquakes which occur in the area of radius of about 140 km centered in the Straits of Messina occur in sequences. Each sequence is generally formed by two events and covers an average time window of 10 years.

The last four sequences occurred in the time windows 1783–1891, 1818–1823, 1865–1870, 1905–1908 and are separated by about 40 years indicating that in that area there is now a gap in the time domain.

The analysis of the data in the Catalogue for the region between the latitudes 39°N and 41°50′N indicates that in that region the large earthquakes occurred in 13 sequences. Each sequence is formed by 3 events in average and covers an average time window of 7 years. This indicates that, after the earthquake of Nov. 1980, which occurred after a gap of 67 years, other moderately large earthquakes may be expected in that area in the next few years.

INTRODUCTION

The seismicity of the Southern Apennines and Sicily is well described in the catalogues of the Italian earthquakes (Baratta, 1901; Carrozzo et al., 1973; ENEL, 1978). The most recent and complete of them is the ENEL catalogue which contains 20,568 events occurred in Italy between the years 1000 and 1975.

Considering reasonably long time intervals one may verify in all catalogues of earthquakes that the number $n(I, \Delta, t)$ of events with the same intensity recorded in the time interval Δ (centered in t) is generally increasing with t. Since smaller events have smaller probability to be recorded it is generally considered that the increase of $n(I, \Delta, t)$ with time is due to the incompleteness of the information although one may not rule out that the number of earthquakes $n(I, \Delta, t)$ which really occurred in a region may vary in time.

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The catalogue of Carrozzo et al. (1973) lists about 10,000 events from the year 0 until 1970 (however, only 94 of them occurred prior to the year 1000). The Baratta (1901) catalogue was compiled at the end of the 19th Century, although it is an important document, it is not as complete as the others, mostly for the smaller events; it does not give intensities nor coordinates of the events but important detailed description of the locations and the damages which occurred there. In the ENEL catalogue (1978) the epicentral coordinates of the events which were recorded instrumentally have been recomputed using the most updated models of the Italian territory, where this was not possible the epicenters were estimated from the isoseismals or assuming it where the largest damage was recorded or, in case of the smaller events, where the event was felt. In most cases we may assume the accuracy of the epicentral coordinates is less than 10 km.

A comparison of the two catalogues made by Caputo (1981) shows that the most frequent disagreement between the catalogues of ENEL (1978) and Carrozzo et al. (1973) concerns the intensity of historic earthquakes which had to be inferred from the description of the events in very old books or cronicles; the disagreements between the intensities of the events of the areas considered in this study is limited to at most one degree of intensity; in all Italian earthquakes with $I \geqslant$ IX, for 38 events I is larger in the Carrozzo et al. (1973) catalogue, for 5 events I is larger in the ENEL catalogues. The ENEL catalogue is not only the most complete but apparently it is also more accurate in the epicentral coordinates and intensity of the events. For this study we therefore used the ENEL catalogue.

Assuming that the statistical density distribution of the number of earthquakes does not change with time in 1000 years and provided reasonably long time intervals for the statistics are considered, we obtain for the completeness of the ENEL catalogue the time windows listed in Table I; as in most catalogues of earthquakes, the completeness is increasing with time. Table I was obtained by considering time windows at 10 and 25 years which gave the same results. The distribution of events in time windows of 25 years is shown in Table II.

The time T_I, after which the catalogue was tentatively considered complete for the intensity I, was estimated assuming that the average number of events $n(I, \Delta, t)$ in

TABLE I

Completeness of the ENEL (1978) Catalogue of Italian Earthquakes

Intensity, I	Completeness of the catalogue
⩾ VI	1885–1975
⩾ VII	1775–1975
⩾ VIII	1700–1975
⩾ IX	1600–1975
⩾ X	1550–1975
⩾ XI	1000–1975

TABLE II

Number of earthquakes of the ENEL Catalogue of Italian earthquakes in different time windows

Years	Intensity: VI	VII	VIII	IX	X	XI
1000–1024	2	2	1	0	0	0
1025–1049	0	0	0	0	0	0
1050–1074	0	1	1	0	0	0
1075–1099	0	3	0	1	0	0
1100–1124	1	2	4	0	1	0
1125–1149	1	5	1	0	1	0
1150–1174	1	4	2	0	0	1
1175–1199	0	3	1	1	2	0
1200–1224	0	4	0	1	1	0
1225–1249	5	8	2	0	0	0
1250–1274	1	1	3	2	0	0
1275–1299	2	11	14	3	2	0
1300–1324	6	13	8	0	0	0
1325–1349	2	4	3	1	2	1
1350–1374	3	10	6	1	0	0
1375–1399	10	12	4	0	0	0
1400–1424	6	9	4	3	0	0
1425–1449	8	8	2	2	0	0
1450–1474	11	18	7	4	1	1
1475–1499	7	15	6	1	0	0
1500–1524	10	15	5	4	1	0
1525–1549	8	15	7	2	1	0
1550–1574	5	18	5	6	1	0
1575–1599	8	12	6	1	0	0
1600–1624	12	15	9	3	1	0
1625–1649	12	19	7	7	1	0
1650–1674	7	8	5	5	2	0
1675–1699	34	17	7	5	3	0
1700–1724	26	32	16	4	3	0
1725–1749	36	50	16	6	1	0
1750–1474	54	30	7	8	0	0
1775–1799	55	94	20	13	1	2
1800–1824	31	49	14	2	3	0
1825–1849	82	70	16	7	3	0
1850–1874	99	73	16	5	4	0
1875–1899	192	109	26	4	0	0
1900–1924	369	129	27	5	3	3
1925–1949	168	60	15	5	1	0
1950–1974	234	72	28	4	0	0

contiguous successive time windows Δ_I are distributed according to a Gaussian distribution with mean value $\langle n_{\Delta I} \rangle$ and standard deviation $\sigma_{\Delta I}$; $\langle n_{\Delta I} \rangle$ and $\sigma_{\Delta I}$ are estimated in time windows (obviously much larger than Δ_I) in which the Italian seismic network and/or the macroseismic service were such to secure the completeness of the catalogue. For instance, one may assume that from the beginning of the century the seismic network and macroseismic service would detect all events of intensity VII or larger, or that all events with intensity XI and XII were reported in the cronicles from year 1000.

Given a Δ_I which secure $n(I, \Delta, t) \geqslant 10$ (note that for all Δ_I considered and $I <$ IX there is one exception, namely for $I =$ VIII and $\Delta_{VIII} = 1774-1750$) one compares $|\langle n_{\Delta I}\rangle - n(I, \Delta, t)|$ with $\sigma_{\Delta I}$; the catalogue is then considered complete after the year T_I if $|\langle n_{\Delta I}|\rangle - n(I, \Delta, t)| < \sigma_{\Delta I}$ for $t \geqslant T_I$. It has always been verified that for time windows prior to T_I one finds $|\langle n_{\Delta I}\rangle - n(I, \Delta, t)| > \sigma_{\Delta I}$. For $I =$ VI we used $\Delta_I = 10$ years, for VI $< I <$ IX we used $\Delta_I = 25$ years; for $I =$ IX we used $\Delta_I = 50$ years; in this case $n(I, \Delta, t) \geqslant 9$.

It has also been verified that for $I =$ VII the windowings with $\Delta_I = 10$ years and $\Delta_I = 25$ give the same results, taking into account the lower resolution of $\Delta_I = 25$; and also that for $I =$ VIII, the windowing with $\Delta_I = 25$ and $\Delta_I = 50$ give the same results. Moreover the initial time of the windowing with $\Delta_I = 10$ has been shifted by 2 years, that with $\Delta_I = 25$ has been shifted by 5 years, and that with $\Delta_I = 50$ has been shifted by 25 years verifying that one obtains for T_I the same results.

The $I =$ X deserves special attention because the number of events per century in the last five centuries in general is less than 10, for instance the number of events in the interval 1875–1975 is 4; considering the historic conditions of Italy prior to 1500 and that between 1400 and 1500 only one event was recorded, after applying the above mentioned criterion we tentatively assumed $T_x = 1500$ verifying that $\sigma_{\Delta x} > |\langle n_{\Delta x}\rangle - n(x, \Delta, t)|$ for $t < T_x$. However, we cannot rule out that the large fluctuation prior to 1500 be real.

Another test of completeness has been done by comparing the a_1 and b_1 values of the law:

$$\log n = a_1 - b_1 I$$

for time windows beginning at different times in the past. The results of this test are in agreement with those of the previous tests.

In this study we consider two areas: the circle of 140 km radius centered in the Messina Strait (area B) (see Fig. 1) and the portion of the Southern Apennines between latitudes 39°N, 41.8°N (area A) (see Fig. 2). Both areas have been very seismic in the past. For the area A, the ENEL (1978) catalogue lists 38 earthquakes with intensity IX or more occurring after 1448. For the area B, the ENEL (1978) catalogue lists 16 events with intensity X or more occurred after the year 1100. It is worth noting that both areas include a large or complete portion of the D (dangerous) areas defined in southern Italy by a pattern recognition study of earthquake-prone areas of Italy (Caputo et al., 1980). Area A includes the epicenter of the November 23rd 1980 earthquake ($M_s = 6.9$) which coincides with intersection 77 of Fig. 2.

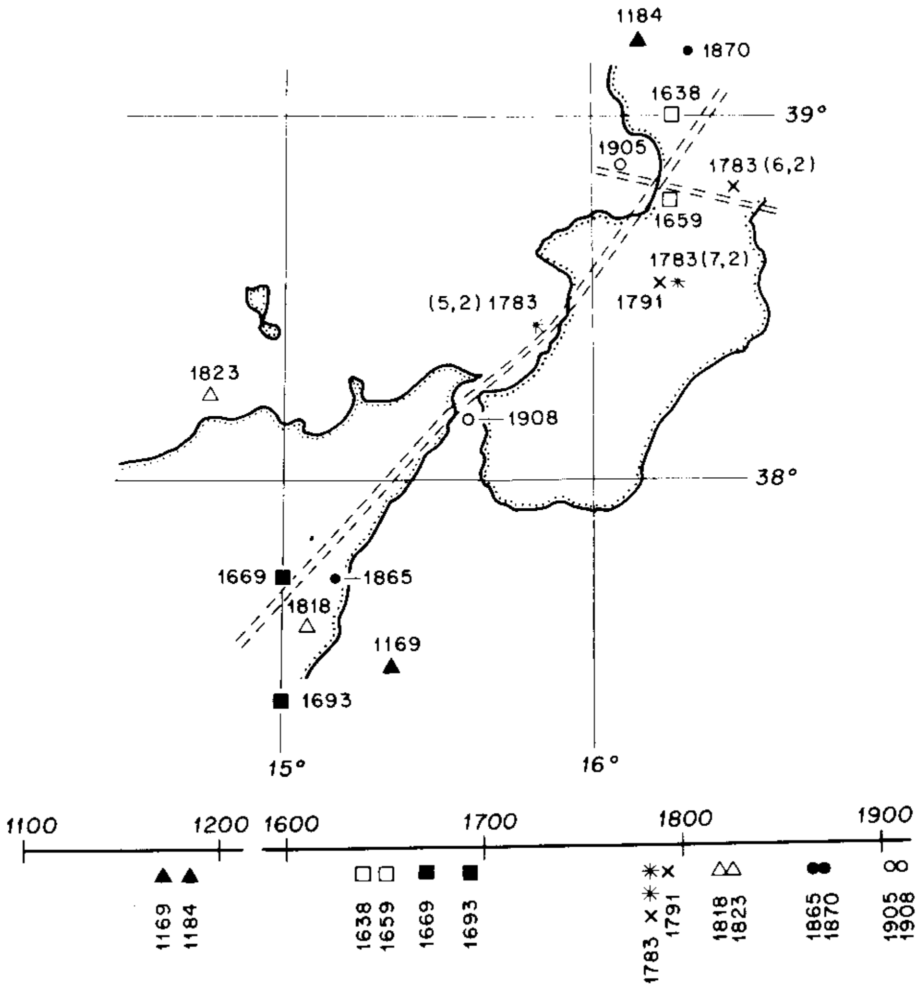

Fig. 1. Earthquakes of intensity $I \geqslant X$ within a radius of 140 km from Messina. As can be seen in the time scale, the earthquakes seem to occur in pairs in the time domain. The time elapsed since the last pair suggests that another pair is due soon. The two events of each pair are separated by the geologic lineaments marked by the double dashed lines. The epicenters of the three events in 1783 are marked also with the day and the month.

The number of events recorded in the last decades in both areas suggests that there has been continuity of the seismic activity for the small and moderate size earthquake: we shall assume here that this seismicity will continue in the future with the same statistical distribution over a reasonably long time window and also for the large earthquakes. With this assumption, a systematic analysis was made of the ENEL (1978) catalogue to search for periodicities and for gaps in the occurrence of large earthquakes in the areas A and B.

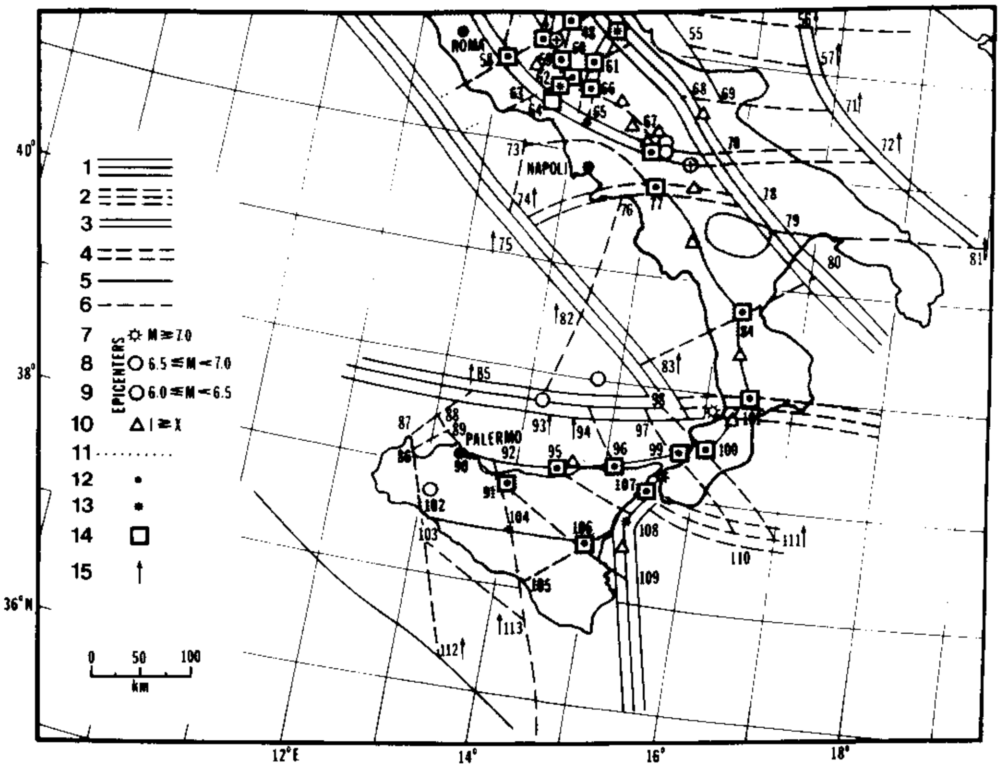

Fig. 2. Map of the major lineaments of the Italian region, and of the intersections of the lineaments considered as potentially dangerous. Numbers in the key refer to the following classification of lineaments, epicenters, boundaries and intersections. Lineaments: *1*, *2* = first order; *3*, *4* = second order; *5*, *6* = third order; *1*, *3* and *5* longitudinal, *2*, *4* and *6* are not expressed in topography. *7*, *8*, *9*, *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.

THE MESSINA STRAIT AREA

The 16 earthquakes shown in Fig. 2 have intensity X or more in one of the catalogues of Carrozzo et al. (1973) and ENEL (1978). The probability that 16 events distributed over 980 years are agregated in 8 pairs, and that the two events of each pair are separated by at most 25 years, is less than $7 \cdot 10^{-5}$.

Let E_i be the earthquake that occurred at time t_i ($t_{i+1} > t_i$; $i = 1,16$). We shall consider a pair of two earthquakes E_{2j}, E_{2j-1} ($j = 1,8$); the time ($t_{2j} - t_{2j-1}$) separating the two elements of each pair (see Fig. 1) is less than 23 years, $\langle t_{2j} - t_{2j-1} \rangle = 10$ years. The time separating two successive pairs, $t_{2j+1} - t_{2j}$, has an average value of about 100 years.

We call $t_{2j+1} - t_{2j}$ the alarm period for the event E_{2j+1} after the event E_{2j} has occurred, and see that the total alarm time is 81 years or 10% of the total time for 8 pairs. Also from the year 1791 three pairs occurred at regular time intervals of about 40 years: since 73 years have already elapsed since the last pair, another pair of the earthquakes of intensity X or more may be expected in that area in the near future. But if we consider the preceding period, we may see that larger gaps have occurred prior to 1783 and the present gap is significant only if the seismic regime after 1783 will be continued. One may also note in Fig. 2 that the two events of each pair are separated by the double lines which are first order (long one) and second order (the short one) lineaments of the pattern recognition study of the earthquake-prone areas of Italy (Caputo et al., 1980; Benvenuti and Caputo, 1982); this gives an indication on where the second of the two events may occur.

The earthquakes of 1905 and 1908 have been preceded by swarms in Sicily in the years 1905 and 1906 in agreement with the theory of Caputo et al. (1977); the fact that no precursors have been found for the pairs of earthquakes occurring prior to 1905 is not surprising and is probably due to the incompleteness of the catalogue.

We may therefore infer that a future couple of events in that area may be preceded by a swarm (Caputo et al., 1977). Also, since the events expected should have intensity $I \geqslant$ X, which correspond to magnitudes 6.5 or more, the future event may occur in one of the points anticipated by the pattern recognition study.

THE SOUTHERN APENNINES AREA

The recent November 23, 1980 earthquake in Irpinia occurred in a location which was found previously to be seismically prone for events with $M \geqslant 6.5$ in the pattern recognition studies of Caputo et al. (1980) and Benvenuti and Caputo (1982), and 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); however, no reddening of the spectral lines of the earthquake parameters (Caputo, 1983) could be detected for lack of pertinent data. A detailed analysis of the catalogues of earthquakes of the portion of the Apennines between latitudes 39°N and 42°N from the year 1448 to the present indicates that the 38 events with intensity larger or equal to IX which occurred since 1448 in that area tend to cluster for this region. The occurrence of these earthquakes is listed in Table III. These events are those with intensities $I \geqslant$ IX of ENEL (1978) catalogue; many of them are listed with intensity $I >$ IX in one of the two catalogues considered in this study.

We shall call sequence a subset (of 2 or more events) of this set of 38 events when the events of the subset occur in a time interval of 13 years or less. The 38 events can be divided in sequences in many ways, we chose that indicated in Table III. There are 13 sequences of events, 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 months to 13 years. Two consecutive sequences are separated by

TABLE III

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)
1448–1456	IX, 1448; XI, 1456; IX, 1456	3	8	8	94
1550–1561	IX, 1550; IX, 1560; IX, 1561; X, 1561	4	10	11	66
1627–1627	IX, 1627; X$\frac{1}{2}$, 1627;	2	0	0	11
1638–1638	X, 1638; IX, 1638	2	0	0	8
1646–1654	IX, 1646; X, 1654; IX, 1654	3	8	8	34
1688–1702	X, 1688; X, 1694; IX, 1702	3	6	14	29
1731–1732	X, 1731; IX, 1732	2	1	1	23
1755–1767	IX, 1755; IX, 1767	2	12	12	29
1796–1805	IX, 1796; X$\frac{1}{2}$, 1805	2	9	9	21
1826–1836	IX, 1826; IX, 1828; X, 1832 IX, 1835; IX, 1836; IX, 1836	6	2	10	15
1851–1858	IX, 1851; IX, 1854; IX, 1857; X, 1857; X, 1858	5	3	7	12
1870–1883	X, 1870; IX, 1883	2	13	13	27
1910–1913	IX$\frac{1}{2}$, 1910; IX, 1913	2	3	3	67
1980–?	X, 1980	?	?	?	
Average		3	5.7	7.4	33

33 years in average. The total alarm time between the first and the second event of each sequence is 75 years or about 16% of the total time for 13 pairs from the first event of the first pair.

In all of these sequences of events except those after the years 1550, 1646, 1796, 1851, the first event of the sequence has the largest intensity.

The statistical distribution of earthquakes was studied since the beginning of seismology; some early studies (AKi, 1956; Knopoff, 1964) concluded that the main sequence events were non-Poissonian. However, it has been noted (Gardner and Knopoff, 1974) that the California earthquakes with $M \geqslant 3.8$ between 1952 and 1971, after properly removing the aftershocks have a Poissonian distribution, that the same property is valid also for $M \geqslant 4.3$, $M \geqslant 4.8$, $M \geqslant 5.3$, but for $M \geqslant 5.8$ the number of events is not sufficient to draw any conclusion. Also the number of events considered in Table III is insufficient to draw any conclusions as to their statistical distribution law; however, assuming tentatively that their distribution is Poissonian, we find that the probability that 38 events distributed over 532 years are aggregated in 13 sequences, such that in each sequence there are at least two events and the time difference between the first and last event of each sequence is less then 3 years, is less than 10^{-10}.

From these considerations it is inferred that the intensity X earthquake which occurred in Irpinia on November 23, 1980, may be followed by other earthquakes in that region. It is of great interest to know when will occur the second event of sequence which began with the earthquake of November 23rd 1980. Assuming again that the distribution is Poissonian the probability that 26 events distributed over 532 years are aggregated in pairs, such that time separation of the two events if each pair is less than 10 years, is less than 10^{-5}. The observed cumulative distribution of the time difference between the first and the second event of each sequence is presented in Fig. 3, where one may verify that in 84% of the cases the second event occurs within 10 years after the first. From Table III one may see that in 52% of the cases the sequence of events is formed by two events only.

The density distribution of the inter-arrival time in each sequence is non-Poissonian, this suggests that it may be possible to foresee the arrival time of the events which suppositevely arrives after the first of the sequence.

The density distribution of the inter-arrival times of the first and the second event of each sequence is very close to that of the length of each sequence, this seems to imply that in each sequence the events cluster near the last event; in fact the average successive inter-arrival time in each sequence is decreasing as shown in Table IV.

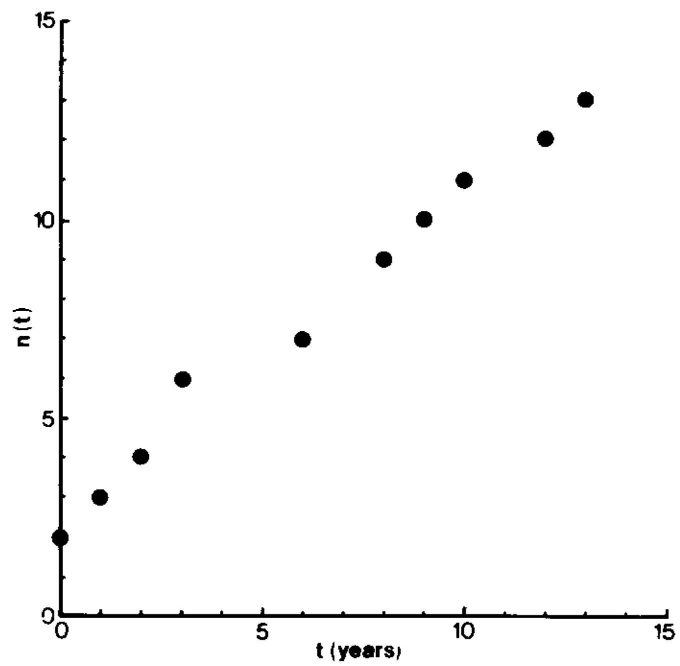

Fig. 3. $n(t)$ is the number of cases in which the second event of each sequence of Table III occurred within the time t measured from the first event of the sequence.

TABLE IV

Average successive inter-arrival time in each sequence of Table III

	1st–2nd	2nd–3rd	3rd–4th	4th–5th	5th–6th
Inter-arrival time in years	5.9	2.8	1.2	0.63	0.57
Number of cases	13	6	3	2	1

The pattern recognition study of the earthquake prone areas in Italy does not necessarily forecast the location of the expected earthquakes in area B because the intensity of these events is anticipated to be IX or more which in turn could imply a magnitude less than 6.5 which escapes the possibilities of the pattern recognition study aiming to magnitudes $M \geqslant 6.5$. The same reasoning applies to the swarm precursors which generally aim at magnitudes $M \geqslant 6.5$. However, other precursors such as variation of radon content in subterranean waters of tilts or deformations of the ground, may indicate the time and location of the future epicenters; the presence of these signals prior to some earthquakes has been already proven possible in the Apennines (Alessio et al., 1980).

CONCLUSIONS

According to this study the two areas considered may experience a large earthquake in the near future.

Concerning the area around the Strait of Messina the earthquake may occur in one of the points of that area indicated as D in the pattern recognition study of the Italian region made by Caputo et al. (1980) shown in Fig. 2.

If we focus our analysis to the period after 1783 we see that the groups of earthquakes are regularly separated by about 40 years and the present gap of 73 years is very significant. But if we consider also the preceding period, we see that larger gaps have occurred and the present gap would be significant only if the seismic regime after 1783 will be continued. Also we must consider that we cannot firmly exclude that some large earthquakes which occurred prior to the year 1500, are not listed in the catalogue.

In the Southern Apennines the earthquake expected may not occur in one of the points indicated as D in the pattern recognition study of Caputo et al. (1980) because this aims to earthquakes with magnitudes $M \geqslant 6.5$ while the earthquake expected here may have a smaller magnitude.

The catalogue used in this study (ENEL, 1978) should be complete for intensities $I \geqslant$ IX only after the year 1550. Therefore the incompleteness could affect only the first sequence of Table III. The gap of 67 years recorded before the last event is then very significant. If the past experience is repeated, the earthquakes which will probably occur after that of November 1980 may occur in a time window of 13 years or shorter. There is a 46% probability that the next event will occur within 3 years.

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