Contour mapping of seismic areas by numerical filtering and geological implications

M. Caputo (*) - D. Postpischl (**)

Received on December 22nd, 1974

SUMMARY. — A method is described that makes possible the identification of the independent seismic units of a given area (Caputo and Postpischl, 1973 b).

The seismic information is treated as a bidimensional signal disturbed by a certain background noise. The filtering of this noise makes it possible to delineate the seismic areas objectively.

An indirect check on the method was made by estimating with respect to the various regions identified the a and β parameters of the law

$$N_y = a\, e^{-\beta y}$$

which gives the number of earthquakes with magnitude (intensity) greater than or equal to y.

RIASSUNTO. — In questa nota viene descritto un metodo che rende possibile l'identificazione delle unità sismiche indipendenti di una data zona.

L'informazione sismica è considerata come un segnale bidimensionale disturbato da un certo rumore di fondo. Filtrando detto rumore, si possono tracciare, da un punto di vista oggettivo, le aree sismiche.

Il metodo usato è stato verificato indirettamente, mediante la stima — rispetto alle varie regioni identificate — dei parametri a e β della legge:

$$N_y = \alpha\, e^{-\beta y}$$

legge che rappresenta il numero di terremoti con magnitudo (intensità) maggiore o uguale a y.

(*) Istituto Nazionale di Geofisica, Roma.
(**) Istituto di Geofisica, Università, Bologna.

1. Introduction

Italy is part of a seismic band that is among the most active in the world and which extends from the Azores to the East to link up with the seismic system ringing the Pacific.

In recent times some disastrous earthquakes have thrown a whole nation into mourning and caused enormous damage and brought the direst poverty to populations already sorely tried by the difficulties incidental to their lives.

As regards seismic calamities it is very unlikely that any form of direct control can ever be achieved; however, the seismic history of a region enables certain parameters to be evaluated, which, suitably interpreted, may lead to the formulation of criteria of estimating the seismic risk for economic development planning.

The problem is usually approached by considering certain statistical models on the basis of which, from the seismic history of the region considered, quantitative information can be gathered regarding the probability of the occurrence of destructive tremors (Caputo et al., 1973; 1974).

The critical point in this type of investigation consists in the delineation of the regions to investigate.

In fact, the lack of precision in epicentral determinations leads to an irregular dispersion of epicentres so that these cannot often be grouped in unambiguously delimited regions. This may lead to a distortion of the results of the statistical analysis of the events in the region, since we must expect that some of the relations implied by the chosen statistical model represent an average characteristic as the result of the superimposition of various effects corresponding to as many independent seismic units present in the region being considered.

The purpose of this paper is the definition of an objective method on seismic regionalization.

There is no intention of laying down here a seismic regionalization of Italy, it is desired simply to suggest a new method for defining it, to be used with complete catalogues of events and together with information deriving from other types of investigation such as, for example, geologically determined faults, the structure and composition of the crust gathered from both seismic methods and through gravimetric analysis, etc., which, it is to be hoped, can be expressed also in an analytic form.

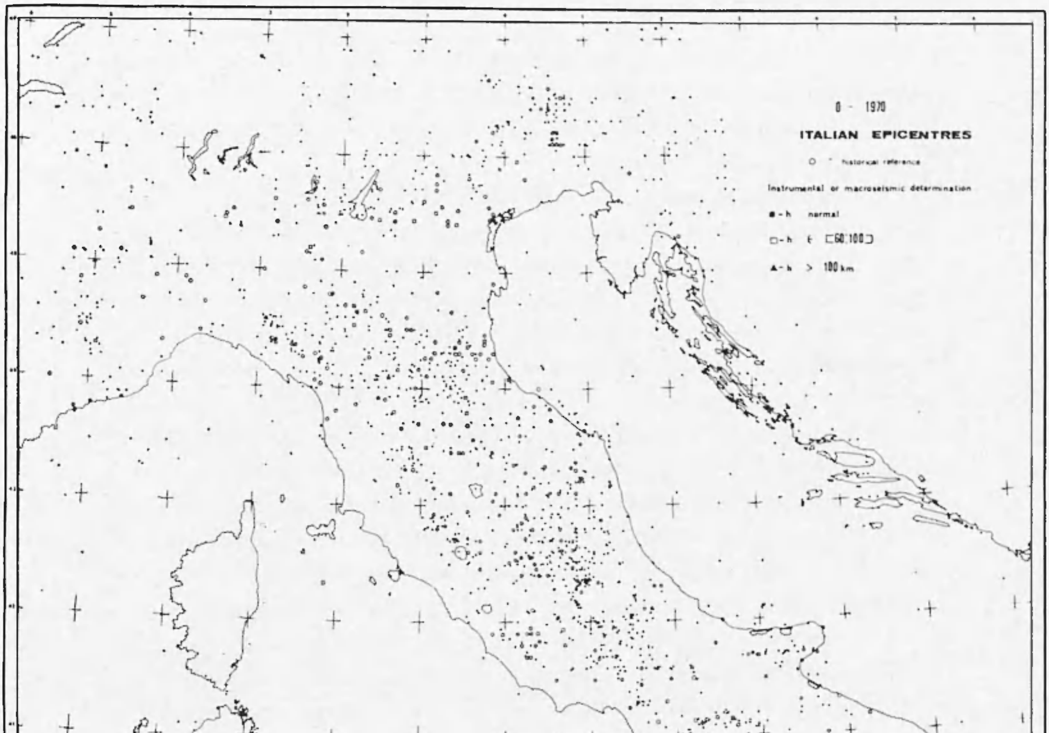

Fig. 1 – Distribution of Italian instrumental macroseismic and hystorical epicentres.

2. The Data

The data utilized were taken from the Catalogue of Italian earthquakes from the year 0 to 1970 of M. Caputo and D. Postpischl (1972), and the corresponding epicentres are set out in fig. 1 (Caputo and Postpischl, 1972, 1973a).

As regards the quality of the available information, the events are grouped into four classes according to the precision of the epicentral determination (Karník 1969). We have in fact events defined as historical for which the intensity was calculated on the basis of the descriptions in historical chronicles of the damage caused, and the epicentre is associated with the city, town or village that suffered the greatest damage.

A second class (indicated by the letter C in the catalogue) groups the instrumental events weakly determined, so that one may expect an error greater than 0.9° in the epicentral determination.

The third class (B) includes those events for which the epicentre is estimated with an error between 0.3° and 0.9°.

Finally, the fourth class (A) comprises the instrumental events for which the epicentre may be associated with an error of less than 0.3°.

We wish to emphasize that it is not claimed that the catalogue is complete in an absolute sense; in fact we deliberately limited the collection to a statistically representative sample, so as to be able to set out the working method. A detailed investigation may be made later by means of the application of the above mentioned method to a catalogue of earthquakes as complete as possible, which can be the outcome only of the collaboration of all who are concerned at present, with the collection of seismic data in Italy.

In this work we have utilized only the data relative to instrumental events, grouping them in different ways in order to satisfy diverse variants as will be more fully explained below.

We have deliberately excluded earthquakes with a depth exceeding 60 km, since the deep seismic activity affecting our region is limited to a small number of events all located in the South Tyrrhenian sea (Caputo, Panza, Postpischl, 1970, 1972).

Moreover all those events that might be considered as aftershocks have also been eliminated from the catalogue, it being presumed that there is an aftershock when the interval of time between two events is less than a week and the distance between the epicentres is less than 10 km (Caputo, Keilis-Borok et al., 1973). In this way the majority of aftershocks is eliminated and their closer identification is not necessary for the purposes of this paper.

3. Completeness of the catalogue and seismic stability.

In this paragraph we analyse the catalogue of the data from the point of view of completeness, since this parameter determines in a significant manner both the results of a regionalization study and the results of a statistical analysis directed to the evaluation of the return periods and of the seismic risk.

Obviously one may expect that for each region events with larger magnitude should have more probability of being present in the catalogue, also that the probability is a decreasing function of time counted backwards from the end of the catalogue. For these reasons one should establish the time interval for which all the events of a fixed magnitude which actually occurred are recorded; this leads to the determination of a function:

$$M = f(t), \qquad f'(t) < 0$$

where t is the lower bound of that interval. Practically, for the Italian catalogue we drew two by two matrix shown in Table 1, where the

Table 1 – Time intervals in which the catalogue is complete for a fixed magnitude.

Years	Intensity 3	4	5	6	7	8	9	10	11	Total
1885	3.0	4.0	1.0	23.5	19.0	4.0	2.5	0.0	0.0	57.0
1890	5.0	3.0	3.0	19.0	9.0	4.0	2.0	1.0	0.0	46.0
1895	0.0	1.0	3.5	43.5	29.5	9.5	3.5	0.5	0.0	91.0
1900	10.5	9.5	5.0	45.5	14.5	6.5	1.5	0.0	0.0	93.0
1905	2.0	17.0	11.5	73.0	36.5	8.5	4.5	0.0	1.0	154.0
1910	3.0	11.0	16.0	144.0	48.5	11.5	3.0	1.0	1.0	239.0
1915	0.0	3.0	0.5	81.5	20.0	2.0	2.0	2.0	0.0	111.0
1920	27.0	33.0	28.0	56.5	26.5	7.5	3.0	1.5	0.0	183.0
1925	2.5	11.0	16.5	57.5	18.0	3.5	0.0	0.0	0.0	109.0
1930	23.5	53.0	26.5	58.0	15.5	3.5	2.5	1.5	0.0	184.0
1935	8.5	18.0	22.0	33.5	15.0	1.0	1.0	0.0	0.0	100.0
1940	2.0	13.5	18.5	43.0	12.5	6.5	1.0	0.0	0.0	97.0
1945	4.5	11.0	14.5	21.0	11.5	1.5	1.0	0.0	0.0	65.0
1950	2.5	9.0	11.5	34.5	16.5	5.0	1.0	0.0	0.0	80.0
1955	15.0	32.5	50.5	36.5	12.5	2.0	0.0	0.0	0.0	149.0
1960	105.0	118.0	90.5	41.5	18.5	2.5	0.0	0.0	0.0	408.0
1965	59.0	123.5	64.0	46.5	12.5	9.5	1.5	0.0	0.0	351.0
1970	60.0	80.0	47.5	29.0	0.0	5.0	2.5	0.0	0.0	266.0

heavy line gives the time interval in which the catalogue is complete for a fixed magnitude. The line has been drawn considering for each magnitude a subdivision of the catalogue in a set of equal time intervals of such lengths as to contain a sufficient number of events (therefore not necessarily the same length for all the magnitudes) and defining the time where there is a sharp and stable change in the number of events for each interval. Luckily, there has never been any doubt in establishing this time. In the Table 1 the length of the interval has then been standardized for all magnitudes for the sake of simplicity of presentation. Repeating this procedure for each seismic region, we can therefore assume that in Italy in the periods in which the catalogue was completed, for each magnitude there was stability in the seismic activity.

Obviously these criteria could be formulated more accurately from a statistical and mathematical point of view, for instance, to establish the confidence level of the statements, to determine more accurately the intervals of completeness of the catalogue, etc.

4. Regionalization

We wish to propose a completely objective method of seismic regionalization and one with a degree of reliability that is directly proportional to the quantity and quality of the available information.

In the case of seismic events the available information is found to be very weak. We must in fact take into account at least two types of errors that are usually the cause of considerable distorsion in the seismic picture of a region:

a) incompleteness of the data for events belonging to the lower end of the scale of magnitude;

b) errors in the determination of the epicentres and of the focal depth.

The *a*) type of errors depends essentially on the insufficience and on the distribution of the elements of the existing Italian seismic network. The *b*) type of errors is to be attributed both to the causes already mentioned and to the lack of correct travel-times for Italy.

It must be emphasized that the structure of the crust and the upper mantle of the Mediterranean basin, and above all in the area

Fig. 2 – Frequencies of the occurrence of earthquakes for each element of a grid of ~ 10 km side, after elimination of aftershocks.

of the Appennines, even though not yet known in detail, present highly differentiated characteristics.

The general seismic picture resulting from the sum of these two types of errors is considerably distorted, in particular the dispersion of the epicentres leads to a multiply of possible solutions to the problem of regionalization.

In our opinion the problem can be reduced within certain limits to a problem of bidimensional filtering.

In fact in the case of a sufficiently large statistical sample, we can think of the distribution of the epicentres as a bidimensional signal distorted by a certain casual background noise. The problem is therefore reduced to the filtering of this noise. Obviously, there is not a perfect parallel, in fact the causes of the *a*) and *b*) types of errors do not theoretically lead to a purely casual distortion, and as it has been stated above some systematic effect must be admitted, due to the special structure of the crust.

This type of error is to be regarded as systematic, and only a greater knowledge of the structure of the crust and upper mantle can lead to its being reduced to a minimum. As regards the stochastic element in the distortion, this may be partly removed by using suitable filters. The question of the optimum filter for this type of research was not treated.

The available information was distributed over a grid with a 10 km-sided mesh, and a count was made of the frequency of the epicentres for each element of the network, a differentiation being made both with respect to the classes of epicentral determination and with respect to the value of the intensity of the events. The choice of 10 km as the width of the mesh was decided upon simply because of the necessity of having a certain number of events for each element in the network in the seismic areas and because the errors in epicentral coordinates are of this rate.

The research was begun with the following cases being considered:

1) Complete catalogue of instrumental events

2) Complete catalogue of instrumental events without aftershocks (fig. 2)

3) Catalogue of A and B class instrumental events

4) Catalogue of A class instrumental events

5) Catalogue of instrumental events $I \geqslant$ VII

6) Catalogue of instrumental events $I \geqslant$ IX

In all these cases a normal low-pass bidimensional filter (Bozzi-Zadro and Caputo, 1968) was applied, both the cut-off frequency f_c and the number of weights being varied from time to time. The weights of the filter are:

$$\omega_{ij} = \omega_{ji} = \omega_{-ij} = \omega_{i-j} = \omega_{j-i}$$

$$\omega_{ij} = V_i \; V_j$$

$$V_i = f(i)/\beta, \qquad \beta = f(0) + 2 \sum_{n=1}^{I} f(n)$$

$$f(i) = \frac{2\,(I+1)}{\pi\, i^2} \sin\,(\pi f_c) \sin \frac{\pi\, i}{I+1} \qquad f(0) = 2\, f_c$$

The total number of the weights is $(2\,I + 1)^2$; that is $|\,i\,| \leqslant I$.

It was thus possible to establish that an optimization of the filter is achieved in our case with a cut-off frequency $f_c = 1/4$ (expressed in Nyquist units), with $I = 10$. Tests were made considering $I = 5$, $I = 10$ and $I = 25$. The passage from 5 to 10 is significant in the sense that there is a better definition of the areas corresponding to zones where the information is greater and a smoothing of the signal in those areas where the information is weaker. The step from 10 to 25 does not produce significant improvements.

The application of the filter to the cases 1 to 6 indicated above makes it possible to identify certain seismic units. In fig. 3 the result is shown of the application of the filter to the catalogue of instrumental events without aftershocks. This was regarded as the principal case; the other variants were utilized as a check on the solution illustrated in fig. 3. By way of example, there are shown in fig. 4 the results of filtering applied to the catalogue of only class A and B events, and in fig. 5 the results of the application of the filter to the catalogue without aftershocks, but considering a cut-off frequency $f_c = 1/12$ in Nyquist units.

In this way it is possible to trace the contours of some independent seismic units. Each of these units can in its turn be subdivided into two or more subregions, in accordance with a predetermined pass.

Considering these units from a physical point of view, if the filter has really separated independent seismic units, then for each of these the mechanism of the earthquake should be found constant, while the seismicity should decrease as one proceeds from the innermost towards the outermost zones of the seismic unit considered. This type of analysis is indirectly possible through the evaluation of the α and β parameters of the law

$$N_y = \alpha\, e^{-\beta y} \qquad [1]$$

which gives the number of earthquakes with magnitude (intensity) $I \geqslant y$.

The α parameter depends on the level of the seismic activity per unit of time and area (Isacks and Oliver, 1964; Kárnik, 1966), and therefore, especially in our case, it should be decreasing as one proceeds from the innermost to the outermost zones of a seismic unit.

As regards the β parameter, there is evidence that this depends largely on the stress, the strain and the homogeneity of the rocks in the focal area (Mogi, 1963) or also on the average depth of the earthquakes considered (Kárník, 1966; Galanopoulos, 1968-1971).

For a given geotectonic unit there are no significant variations in β in relation to time or the number of shocks (Isacks and Oliver, 1964; Miyamura, 1962; Riznichenco and Nersessov, 1968).

For these reasons we estimated the values of α and β for each seismic unit identified by the filter. The results obtained are listed in Table 2 and are to be referred to the regions indicated in fig. 6, which was obtained from fig. 3.

For many of the regions illustrated in fig. 6, the particular sample of available events would have called for the application of highly sophisticated methods to obtain estimates of α and β, and in all cases these would have been somewhat uncertain. For these reasons we limited ourselves to the investigation of those regions that allowed a realistic estimate to be made, by means of Gumbel's method (Gumbel E. J., 1958; Lomnitz G., 1966).

The analysis of the Table 2 enables the following considerations to be made.

4.1. – A, B, C Regions

The statistics relative to these regions are too weak to permit a significant estimate to be made of the α and β parameters.

4.2. – D Region

In this case, on the basis of values supplied by the filtering, we were able to extend the subdivision to a maximum of four subregions

D1, D2, D3, D4, each contained within the successive one. The values of α normalized as to unit of area and unit of time are decreasing as one proceeds from the innermost towards the outermost areas, when the subregions are considered as having a ring structure D2-D1; D3-D2; D4-D3. The estimated values of β tend on the contrary to remain constant. The test of the hypothesis H_o: $\beta_i = \hat{\beta}$ against the alternative H_1: $\beta_i \neq \hat{\beta}, i = 1,2,3$, is here acceptable.

4.3. - E Region

This area covers the most active region in Italy from a seismic point of view. Also from a geotectonic standpoint the area is the site of remarkable phenomena; it is in fact traversed by the Anzio-Ancona tectonic line, and it is, besides, fractured into a considerable number of superficial faults (Malaroda and Raimondi, 1957). The data given by the filtering enabled us to divide this region into eight subregions. It is not possible to extend the subdivision further since the statistics relative to the various rings E3-E2; E4-E3; E6-E5; E7-E6; E8-E7 become too weak.

In this case E2-E1 does not appear, since the E1 subregion does not by itself make possible an estimate of the parameters.

The test of the hypothesis H_o: $\beta_i = \hat{\beta}$ against the alternative hypothesis H_1: $\beta_i \neq \hat{\beta}$, $i = 1,2,3,4,5,6$ gives an acceptable response.

However the rapid increase in the $|\beta|$ values for E7-E6 and E8-E7 suggests the theory that there are included, with the E7 and E8 areas, events belonging to a new seismic unit independent of the first, not identified by the filter because of insufficient information, but distinguished later through the estimate of the α and β parameters of the law [1] for the different subregions.

As we have already said the E region is traversed by the Anzio-Ancona tectonic line, which also separates structures of different homogeneity, in particular the more Northerly structures are more fissured than those South of the line (Malaroda and Raimondi, 1957). This fact suggests the cutting of the E7 and E8 areas along the Anzio-Ancona line (see fig. 7). In this way the values indicated by VE7-E6 and VE8-VE7 are obtained (VE8 and VE7 are the new areas derived from E7 and E8). As can be seen, the variant VE7-E6 leads to values in the estimate that are fully compatible with those obtained for the inner areas. Also the 95% confidence interval of the considered parameters for the VE7-E6 and VE8-VE7 subdivisions are better than those of E7-E6 and E8-E7 subdivision.

An analysis of the structure of the VE8 region shows that it stretches towards the West with a lateral branch to embrace a zone involved in superficial vulcanica phenomena. We therefore tried a new variant (VVE8) of excluding this tail from the VE8 region. The result was what had been expected, the estimate of β for the VVE8-VE7 area was found immediately to be compatible with the β estimates obtained for the innermost areas.

Table 2 – a AND β ESTIMATES OF THE PARAMETERS OF THE LAW [1] (SEE THE TEXT); $\Delta \ln a$ AND $\Delta\beta$ ARE 95% CONFIDENCE INTERVALS OF $\ln a$ AND β.

Region	$\ln a$	$a/(Q.\Delta t)$	β	$\pm\Delta \ln a$	$\pm\Delta\beta$
D2-D1	2.98	0.13	—0.58	4.9	0.82
D3-D2	3.07	5.92	—0.58	1.1	0.18
D4-D3	3.19	1.33	—0.63	2.0	0.33
E3-E2	2.96	13.74	—0.57	0.6	0.09
E4-E3	3.15	12.66	—0.62	0.7	0.12
E5-E4	3.18	8.12	—0.66	0.9	0.15
E6-E5	5.52	6.81	—0.63	1.3	0.19
E7-E6	5.04	22.43	—0.83	1.6	0.24
E8-E7	4.39	6.10	—0.77	2.3	0.36
VE7-E6	3.31	1.90	—0.62	1.1	0.18
VE8-VE7	4.55	8.90	—0.81	2.3	0.35
VVE8-VE7	2.98	2.76	—0.63	1.2	0.21
Q_3	1.88	0.98	—0.36	0.4	0.06
R_3	4.68	19.24	—0.67	2.3	0.29

The method is therefore working on two levels; in the first stage an analysis is made of the purely geometric distribution of the epicentres being considered; while in the second stage, consideration is given to the physical nature of the shocks and other geophysical aspects of the problem are involved. In particular, what escapes analysis at the first level is brought to light at the second stage of the investigation and can be included in the analysis by having recourse to the supplementary information that can be got from our store of geophysical and geological information relative to the region being investigated.

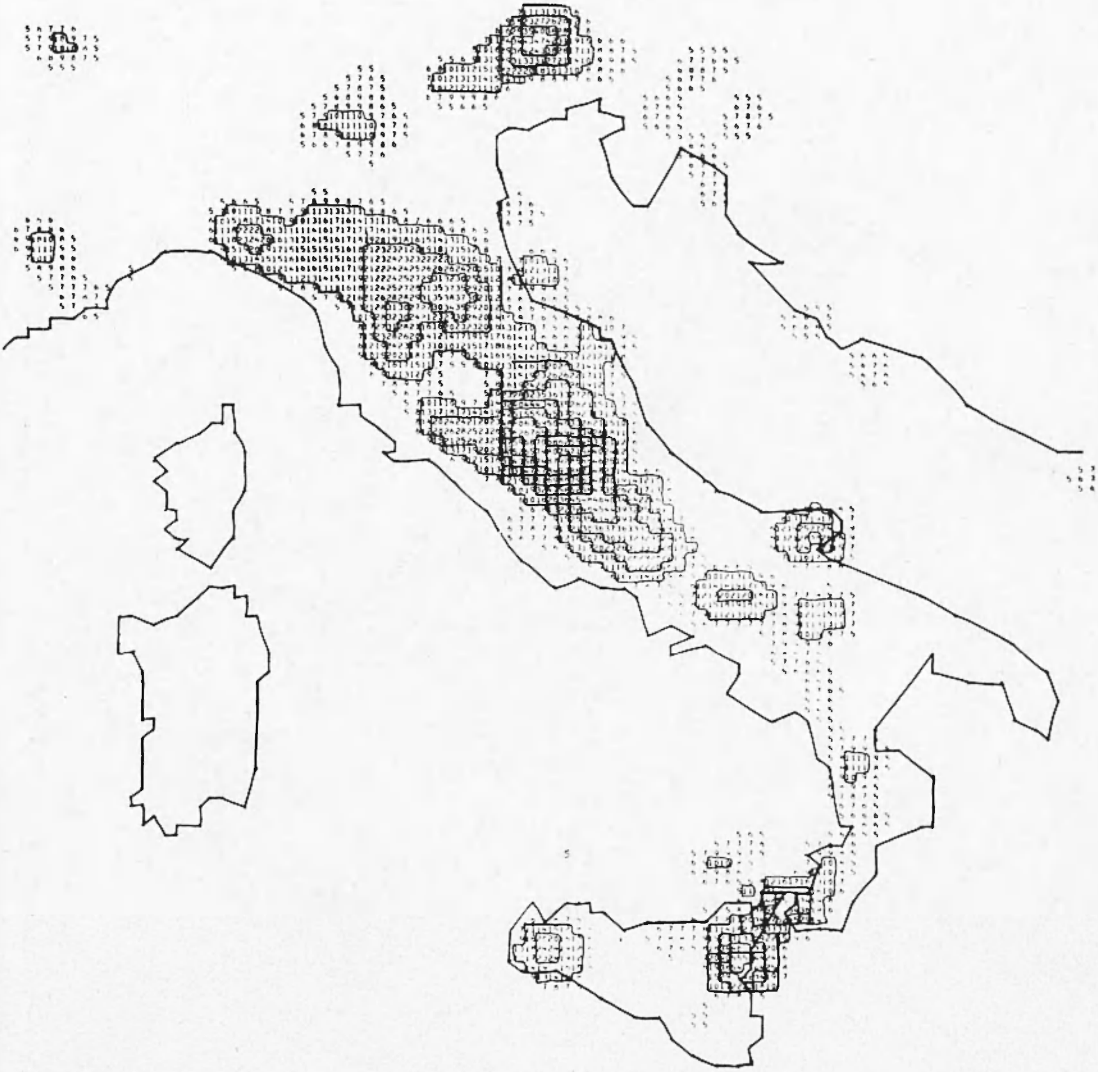

Fig. 3 – Seismic regionalization obtained by the application to the data of fig. 2 of a low-pass bidimensional filter with a cut-off frequencies $f_c = 1/4$ (in Nyquist units).

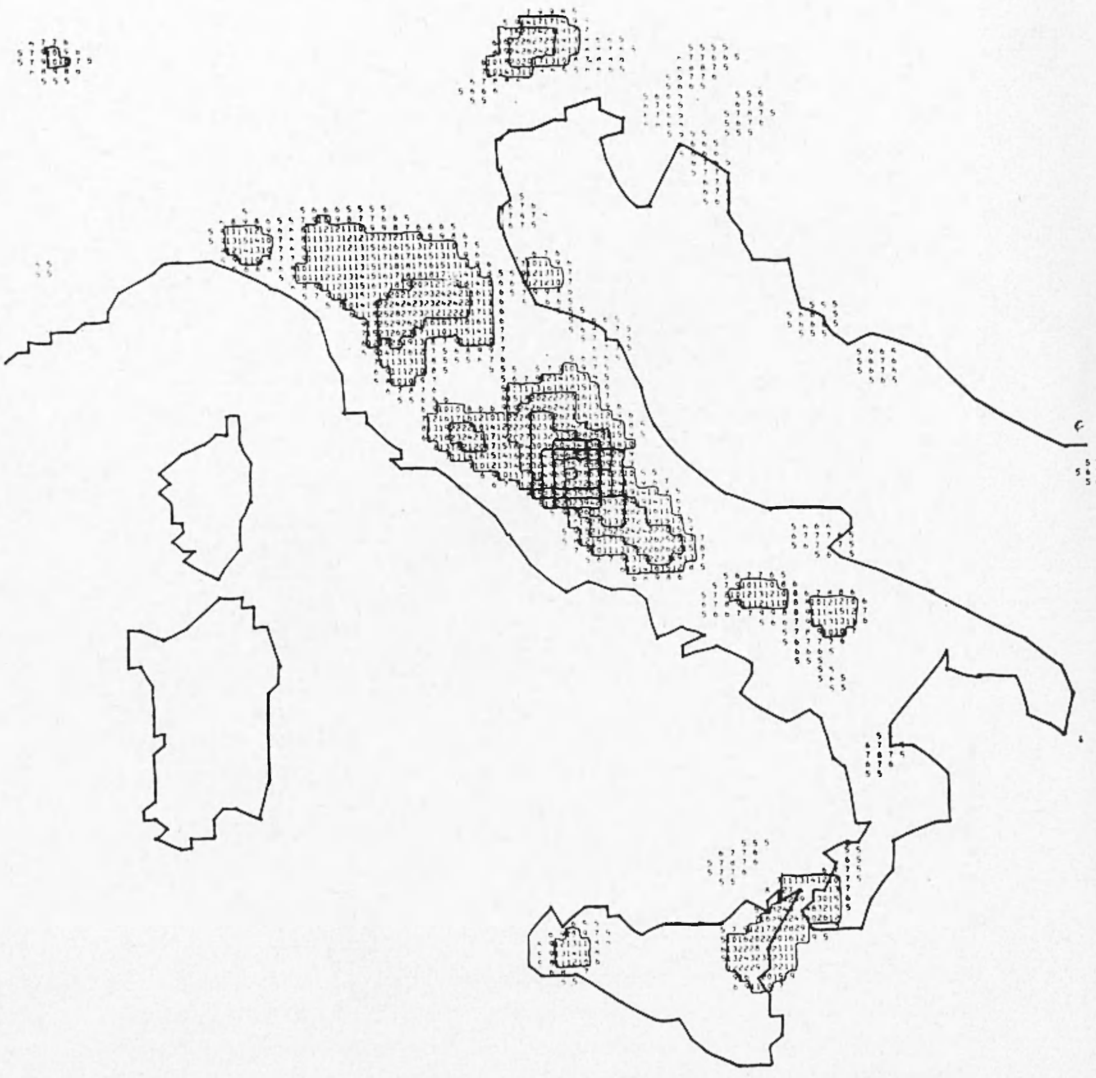

Fig. 4 – Seismic regionalization obtained by filtering the data relative to events of epicentral class A and B only ($f_c = 1/4$, in Nyquist units).

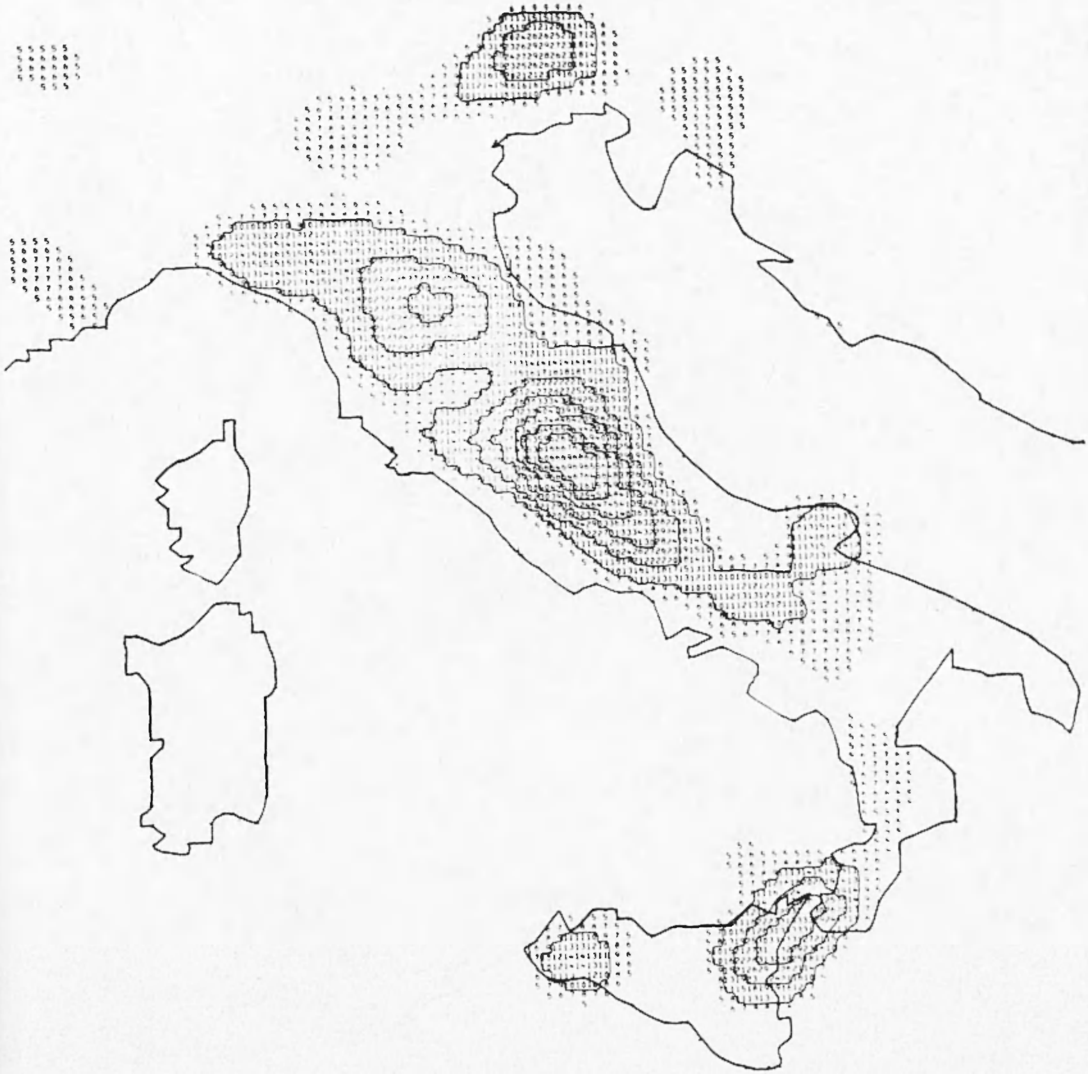

Fig. 5 – Seismic regionalization obtained by filtering the data of fig. 2, considering a cut-off frequency $f_c = 1/12$ (in Nyquist units).

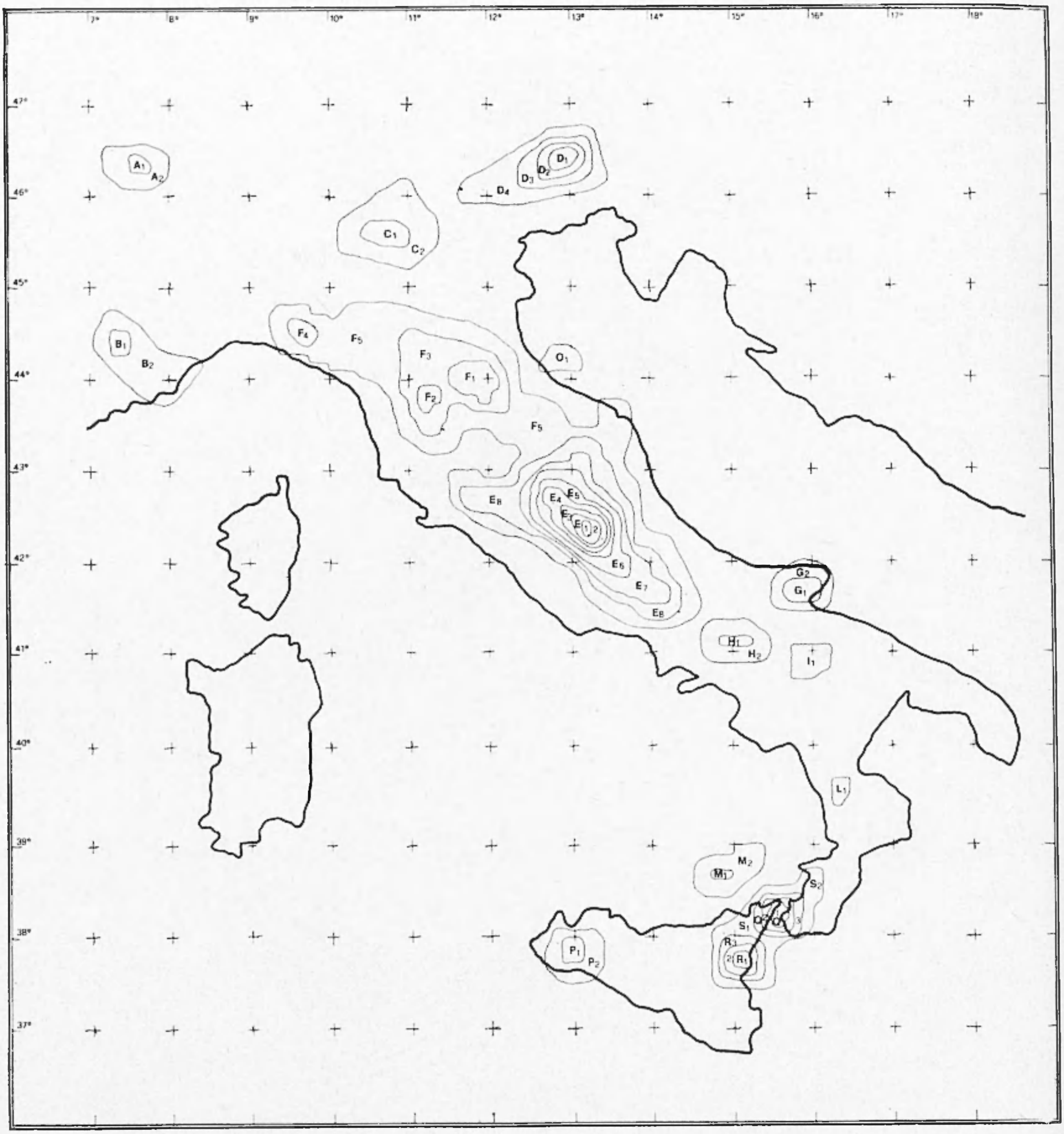

Fig. 6 – Regions and sub-regions considered for the determination of the α and β parameters of the law $N_y = \alpha\, e^{-\beta y}$ (see the text).

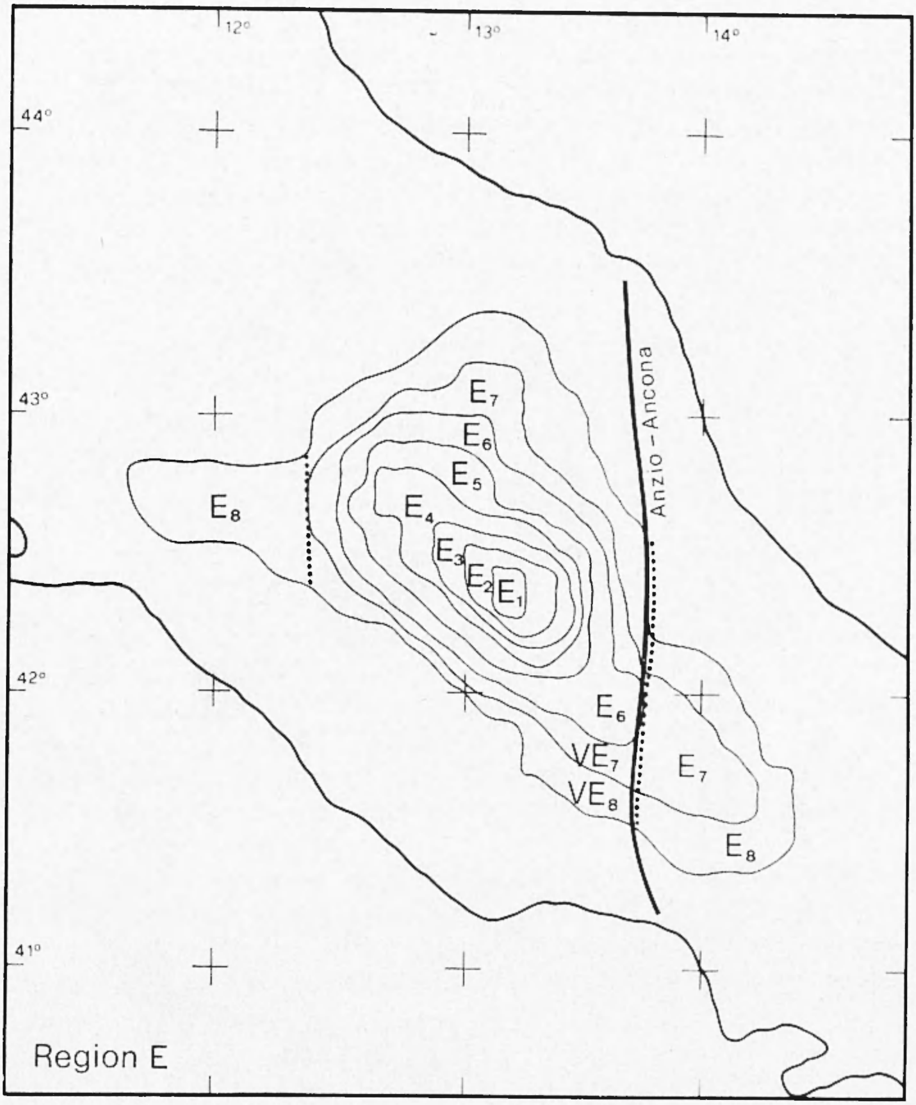

Fig. 7 – Region E. Variants VE7 and VE8 (see the text).

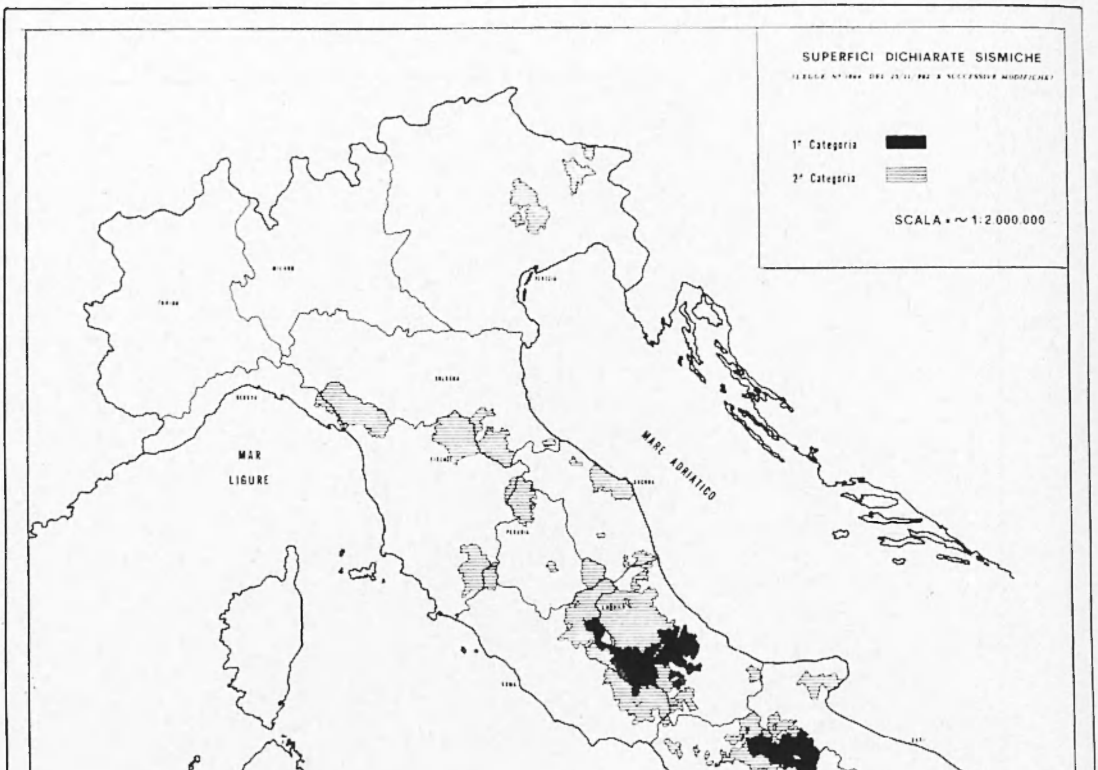

Fig. 8 – Italian seismic law of 25/11/1962.

4.4. – F Region

We included under this denomination various areas that were independent but weakly delineated by filtering.

The F5 area in particular covers a really extensive surface and extends to link up with the various seismic units described above. It is interesting to note how the F5 region stretches out an extension to embrace the Ancona zone, the site of the more recent disastrous seismic periods involving our country. The data from which F5 was complied did not include this latter seismic period; however, an indication of the presence of this seismic unit was brought out by the filter.

4.5. – G, H, I, L, O, P, M. Regions

In this case the filter clearly delineates a seismic unit, the statistical sample does not however enable a significant estimate of the α and β parameters to be made.

4.6. – Q, R, S. Regions

With these regions once again find ourselves discussing areas of special geotectonic interest. The filtering shows a diffused elongated S area following the Comiso-Messina tectonic line (Ogniben, 1969) in the interior of which there appear two centres of seismic activity. Oneof these is indicated by the letter Q, and is centred on the Straits of Messina, the other is indicated by R and is centred further South in the neighbourhood of Etna.

The filtering of the data enabled both the Q and R regions to be subdivided into three subregions.

The β values in the two cases are significantly different and indicate in this way a different physical nature for the events belonging to the two regions.

Conclusions

The exposed example shows one of the possibilities deriving from the application of modern numerical methods to original field studies.

In our case the numerical method selected seems to be particularly effectual, in fact it surpasses the objective of purely numerical zoning, becaming source of geologic and geophysical information.

In this work, although original, we do not pretend to give final results, we test only the possibilities involved in the new methodology. Of course, definitive results, more significant in the statistical sense, could derive from the application of the exposed method to a more complete collection of data.

Though our results are to be considered provisional, a comparison with the geological knowledge (Modello strutturale d'Italia, 1973), confirms the validity of the method proposed. Moreover the comparison with the Italian Seismic law of 1962, puts in evidence that discrepancies are not big, and suggests the opportunity of more detailed studies that can derive only from the cooperation of the scientists that actually are involved in this problem.

REFERENCES

Bozzi Zadro M., Caputo M., 1968. – *Filtri multidimensionali e loro applicazioni geofisiche.* "Annali di Geof.", **XXI**, 3, pp. 287-304.

Caputo M., Panza G. F. and Postpischl D., 1970. – *Deep structure of the Mediterranean Basin.* "J. Geophys. Res.", **75**, 4919-4923.

Caputo M., Panza G. F. and Postpischl D., 1972. – *New evidences about the deep structure of the Lipari arc.* "Tectonophysics", **15**, 219-231.

Caputo M. and Postpischl D., 1972. – *Italian earthquakes from the year 0 up to 1970.* Internal report. Institute of Geophysics, Univ. Bologna.

Caputo M. and Postpischl D., 1973a. – *Seismicity of the Italian Region.* To be published in "La ricerca Scientifica", quaderno n. 90.

Caputo M. and Postpischl D., 1973b. – *Numerical seismic zoning and seismic stability.* Report of the Institute of Geophysics, University of Bologna. See also abstract of the General Assembly IASPEI, Lima.

Caputo M., Keilis-Borok V. I., Kronrod T., Molchan G., Panza G. F., Piva A., Podgaetskaja V., Postpischl D., 1973. – *Model of earthquake occurrence and isoseismals in Italy.* "Ann. di Geof.", **XXVI**, 2-3, pp. 421-444.

Caputo M., Keilis-Borok V. I., Kronrod T., Molchan G., Panza G. F., Piva A., Podgaetskaja V., Postpischl D., 1974. – *The estimation of seismic risk for Central Italy.* "Annali di Geofisica", **XXVII**, 1,2.

Galanopoulos G. A., 1968. – *On Quantitative determination of earthquake risk.* "Ann. di Geof.", **XXI**, 2, pp. 193-206.

Galanopoulos G. A., 1971. – *Minimum and Maximum magnitude threshold in the area of Attica, Greece.* "Ann. di Geof.", **XXIV**, 1, pp. 29-54.

Gumbel A. E. J., 1958. – *Statistics of extremes.* Columbia University Press, New York.

Isacks B. and Oliver J., 1964. – *Seismic waves with frequencies from 1 to 100 Cycles per second recorded in a deep mine in Northern New Jersey.* "Bull. Seism. Soc. Am.", **54**, pp. 1941-1979.

Kárník V., 1966. – *Magnitude. Frequency Relation and seismic activity in different regions of the European area.* "Travaux de l'Inst. Geoph. de l'Acad. Tchécoslovaque des Sciences". **13** (222), pp. 247-272.

Kárník V., 1969. – *Seismicity of the European Area.* Vol. 1, Reidel, Dordrecht (Holland).

Lomnitz G., 1966. – *Statistical Prediction of Earthquakes.* "Reviews of Geophysics", **4**, 3.

Malaroda R. and Raimondi C., 1957. – *Le linee di faglia e di scorrimento in Italia.* "Boll. di Geod. e Sc. Affini", **XVI**, 3, pp. 273-323.

Miyamura S., 1962. – *Magnitude-Frequency Relations and other Bearings to Geotectonics.* "Proc. Japan Ac.", **38**, 1, pp. 27-30.

Modello strutturale d'Italia, 1973. Carta 1 : 1000000. Consiglio Nazionale delle Ricerche, Roma.

Mogi K., 1963. – *Study of elastic shocks caused by the fracture of heterogeneous materials and its relation to earthquake phenomena.* "Bull. Earthq. Res. Inst.", **40**, pp. 125-173, 831-853; **41**, pp. 615-668.

Ogniben L., 1969. – *Schema introduttivo alla Geologia del Confine Calabro-Lucano.* "Mem. Soc. Geol. Ital.", **8**, pp. 453-763.

Riznichenco J. V. and Nersessov I. L., 1968. – *A detailed study of the seismic region in the Garm epicentral region.* "Ann. di Geof.", **XIV**, 2, pp. 287-304.