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SEISMIC HAZARD OF LOW SEISMIC ACTIVITY ZONES. THE CASE OF WESTERN CUBA

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ABSTRAC

Low seismic activity zones are characterized by a low frequency of earthquake occurrence, and sometimes relatively strong earthquakes occur in places with not known seismic history. Western Cuba is in such a case, with a strong historic earthquake (January 23, 1880, Io=VIII - MSK scale), and another one reported by international agences (December 16, 1982, Ms=4.7). Seismic history of this region consist of only 70 earthquakes with maximum felt intensities ranging from IV to VIII degrees, and there is not a network of seismic stations. With those data it is not possible to make an univoque delimitation of seismic source zones (SSZ) and correspondingly a reliable estimation of its parameters: a and b of magnitude-frequency graphics, isoseismal model, Mmax and depth of occurrence. For this reason three models of SSZ were used. The first consist of principal lineaments "knots", with Mmax estimated by analogy with maximun earthquakes that held in Cuban territory. The second one is a scheme of more sure fault zones, with Mmax estimated from fault dimensions. The last one was taken from a study of historical-tectonic development zoning of the region, with Mmax estimated from fault dimensions and by analogy with other regions.

For the whole region an intensity-frequency graphic was constructed. Its slope was considered constant for all the area, and the intercept was adjusted for particulars SSZ. An explicit transformation from slope and intercept of intensity-frequency graphics to parameters a and b of magnitude-frequency ones was developed. By assuming a middle hypocentral distance of 30 km for the reported maximun intensities were obtained the transformed values of a and b for all the SSZ. Seismic hazard calculations were performed with programm SACUDIDA, by considering an elliptical isoseismal model and fixed depth of 20 km. Results obtained from the three models were compared with areas of felt earthquakes. The best fit (predicted areas - reported isoseismals) was obtained with the second model of SSZ; the first one shows a slight underestimation of seismic hazard, while the last one tends to hazard overestimation. However, taking into account that data is scanty to make high reliable seismic hazard estimations, it seems more reasonable to use interval estimations considering extremal values from the three models, instead of from a particular one. The present approach is believed to be a useful tool for a first hand seismic hazard estimation in low seismic activity zones, prior to a detailed seismicity study with a dense network of seismic stations.

INTRODUCTION

Seismic hazard estimation in low seismic activity zones is not a simple procedure. First of all, there is not a good definition about the seismic source zones, and second and more difficulting, there is not a reliable knowledge of seismicity. In these zones earthquakes are not frequent and in general there is a low possibility of great earthquakes occurrence. Western Cuba is in such a case; located several hundreds kilometers from Caribbean-North America plate boundary zone, is a tipical case of intraplate seismicity, characterized by scarce occurrence of earthquakes. The first report of felt earthquakes correspond to 1678, and with the exclusion of two cases, intensity of shaking for all the shocks did not exceed V degrees in MSK scale in isolated points and it is not possible to determine its coordinates and magnitude with an acceptable level of accuracy. In this paper is presented a method for using the intensity-frequency information for seismic hazard estimation with the aid of computer program SACUDIDA (Alvarez and Bune, 1985).

THEORETICAL BACKGROUND

Hazard estimation is based on the calculation of shakeability (Riznichenko, 1965):

$$B_I = \iiint N_I(M_I)\, dV \qquad (1)$$

which gives the recurrence periods of shakes of intensity $\geq I$. Probabilistic estimations are obtained assuming that recurrence period ($T_I = 1/B_I$) is the mathematical expectation of the interarrival time between earthquakes (Riznichenko, 1979). In the case of Poissonian process the probability of no ocurrence of earthquakes with intensity $\geq I$ in t years is:

$$p(t) = \exp(-t/T_I) \qquad (2)$$

The quantity $N_I(M_I)$ is the cummulative frequency of earthquakes with magnitude $\geq M_I$, which is calculated by:

$$N_I(M_I) = 10^{a-bM_I}.[1-10^{-b(Mmax-M_I+Mmax+\Delta M_I/2)}].10^{b\Delta M_I/2}/[b.\ln(10)] \qquad (3)$$

The magnitude M_I is evaluated by means of a model of eliptical isoseismals, which is determined by the parametric equations of an ellipse and a modified Kovesligethy's type macroseismic field equation:

$$I = \beta M - k\,lg(r_e) - p\,r_e + d \qquad (4)$$

where $r_e = (\Delta e^2 + h^2)^{1/2}$ and Δe is a radio vector between semiaxes A and B in which direction is valid equation (4). For Caribbean region are recommended the following values of parameters: $\beta = 1.5$, $k = 2.63$, $p = 0.0087$ and $d = 2.5$ (Alvarez and Bune, 1977), obtained by Fedotov and Shumilina (1973) for the region of Kamchatka.

A complete description of isoseismal model is given the relation between semiaxes of ellipses A/B, direction of Δe and by coeficients of that equation. A more detailed explanation of this calculation scheme may be found in (Alvarez and Bune, 1985), and about the model of elliptical isoseismals in (Alvarez and Chuy, 1985)

It is common to prepare with intensity data the so called intensity-frequency graphics:

$$lg(N_I) = C - D\,I \qquad (5)$$

where N_I is the number of earthquakes with intensity I.

From other hand, the magnitude-frequency graphics have the equation (Alvarez and Bune, 1985)

$$lg[N(Mi)/F(b,\Delta Mi)] = a - bMi \qquad (6)$$

$$F(b,\Delta M) = [10^{b\Delta M/2} - 10^{-b\Delta M/2}] / [b.\ln(10)] \qquad (7)$$

where N(Mi) is the number of earthquakes in interval $(Mi-\Delta Mi, Mi+\Delta Mi)$.

Under the assumption that all the earthquakes are reported to the same hypocentral distance r_0 it is possible to consider that the magnitude-frequency graphic is equivalent to intensity-frequency one, and the parameters a and b may be obtained by combining equations (4-7):

$$b = 1.5\,D \qquad (8)$$

$$a = C + 1.5\,D\,M_{r_0} - lg[F(b,0.66)] \qquad (9)$$

$$M_{r_0} = [\,k.lg(r_0) + p\,r_0 - d\,] / \beta \qquad (10)$$

At is easily seen from these formulae, parameter "a" and correspondingly cummulative frequency of earthquakes depends on hypocentral distance r_0. The minimum value of r_0 may be the depht of occurrence h, and its increment means that intensity reports belong to more distant points from epicenter. Relation between cummulative frequencies obtained for the general case r_0 and the particular one $r_0 = h$ is:

$$\gamma = 10^{D\{k.lg(r_0/h) + p\,(r_0-h)\}} \qquad (11)$$

It allows us to determine the level of error in T_Σ estimations for different selections of (r_o, h) combinations. In fig 1 are presented the values of coeficient γ for the depth of 20 km and diferent b values.

SEISMICITY OF WESTERN CUBA

Western Cuba is a region of low seismicity. Nevertheless, in that region occurred a relatively strong earthquake in 1880 (Jan. 23), which strongly shaked the localities of San Cristobal and Candelaria (Imax = VIII) and was felt all over the region; its magnitude was estimated by macroseismic data about Ms = 5.9. There is only one case of instrumental earthquake epicenter determination by international agences (16-XII-1982, Ms = 4.7, Imax = VI). An earthquake catalogue with a brief description of principal effects was compiled by Chuy et al (1988). An epicenter map is presented in fig. 2a, and isoseismal maps for the two above mentioned earthquakes are presented in fig. 2b,c.

The problem of seismic source zones (SSZ) delimitation with this poor data is not easy at all to solve with high accuracy. For these reason different researches made theirs own tectonic interpretations. As a result, at present there are three models of SSZ obtained from different approachs of combining geological-tectonical-geomorphological and seismological data:
-Model A (Cotilla et al., 1988). Delimitation of SSZ from a map of lineaments and its "knots" obtained by cosmic image interpretation and comparation with tectonical knowledge of region. Strong earthquakes are believed to occur only in that "knots". The Mmax values are estimated by analogies with the greatest occurred in intraplate zones of Cuban territory.
-Model B (Chuy et al., 1988). SSZ delimitation from faults determined by geological and geophysical investigations. Earthquakes are believed to occur with equal probability along the faults. The Mmax values are estimated from fault dimensions.
- Model C (Orbera et al., 1987). SSZ as a result of tectonical evolution zoning by procesing geological, geomorphological and tectonical informations. Mmax estimation from fault dimensions and by analogy with other regions.

For all the region an intensity-frequency graphic was constructed (intensities ranging from IV to VIII); its parameters were obtained by least square regression: (C = 1.65, D = 0.53). For magnitude-frequency parameters evaluation was considered that maximun earthquakes intensities of the catalogue occurred in points lying, as a mean, at an hypocentral distance of 30 km. In that case, by aplying formulae (8-10), the following values were obtained: a = 2.52, b = 0.79. Parameter "b" was considered constant all over the region and particular values of "a" for every SSZ were obtained by:

$$a^{SSZ} = a^{region} + \lg[\, N_{\Sigma I}^{SSZ} / N_{\Sigma I}^{region} \,] \qquad (12)$$

where $N_{\Sigma I}$ is the cummmulative frequency of intensities for the minimum value considered (I=IV). For every model, a particular association of maximum intensities to SSZ was made.

As there is not instrumental determinations of earthquake's depth, a value of 20 km was assumed for all the SSZ; it corresponds to 2/3 of Earth crust thickness in the region, and is the same value that was obtained from macroseismic data for the earthquakes of fig. 2b,c. From these two earthquakes were determined the parameters for the isoseismal model for the region (Alvarez and Chuy, 1985): the direction of validity of formula (4) is along major axis of ellipses, and ratio of major to minor semiaxis "A/B" are 1.6 and 1.8 respectively. The three SSZ models are presented in fig. 3, with the values of SSZ's parameters.

RESULTS

Intensity maps for different recurrence periods, as well as probabilistics estimations of seismic hazard were obtained by using programm SACUDIDA (Alvarez and Bune, 1985) for the three SSZ models. In fig.4 are presented the ones correponding to T_Σ = 100, and T_Σ = 1000 years.

A way to evaluate the quality of that results may be to compare the predicted areas of different intensities for every map with observed intensity areas for "strong" earthquakes (the ones presented in fig 2b,c). It was made with a slight modification of Mokrushina and Shebalin (1982) methodology. Let Sir be the observed isoseismal areas in a time of observation To, and correspondingly Sie the "effective" value converted to the recurrence time Tm of a particular map. From other hand the areas of different intensities in a particular map are represented by Sim. There are two different errors: first kind (loss objective) - Sie > Sim, and second kind (false alarm) - Sie < Sim. That errors may be quantitatively evaluated :

$$\mu_T = \sum_I (\mu_{1I} + \mu_{2I}) \qquad (13)$$

$$\mu_{1I} = Sie / Sim \qquad (14)$$

$$\mu_{2I} = Sim / Sie \qquad (15)$$

where μ_{1I} is the first kind error and μ_{2I} is the second kind error for the intensity I.

Times of observation To were estimated under the assumption that for detecting earthquakes with low seismic intensities it is necessary a high density of populating points. They are closely related with the time of foundation of princippal cities or towns in the region. It was not possible to estimate the values of S_{Ir} for all the earthquakes with that intensity in the catalogue, but we consider that they are negligible with respect to the corresponding to earthquake of 23-I-1880. In table 1 are presented the results of this analysis, it were also included the maps obtained for the return period T_I = 10000 years. The values of μ_T are 10.86 for model A, 5.58 for model B, and for model C it is not possible to calculate because there are not reported intensities of IX, and in the map for 10000 years there are more than 3000 km^2 of expected area for that intensity, being the value of μ_{2I} undefined. It follows that model B is the one who best fit the data under this analysis because errors of every tipe occur alternatively and they are not great. Model A in general underestimates the hazard, while model C always overestimates it.

Table 1. Comparition of equivalent felt areas with predicted ones in the different calculated maps. Explanation of simbols is given in text. Time is in years, areas in square kilometers

Int.	To	Sir	Model	Tm	Sim	Sie	μ_{1I}	μ_{2I}
V	155	19140	A	100	14083	12348		1.14
			B	100	21422	12348		1.73
			C	100	21422	12348		1.73
VI	235	8288	A	1000	18899	35268	1.87	
			B	100	2936	3527	1.20	
			C	100	5459	3527		1.55
VII	285	2669	A	1000	2936	9365	3.19	
			B	1000	12156	9365		1.30
			C	1000	17661	9365		1.89
VIII	365	527	A	10000	2936	13688	4.66	
			B	10000	10138	13688	1.35	
			C	10000	16972	13688		1.24
IX	450	0	C	10000	3211	0		undef.

CONCLUSIONS

Was presented a method for seismic hazard estimation for low seismic activity zones. It seems to be a useful tool for a first hand evaluation prior to a detailed seismicity study with a dense network of seismic stations. Procedure was applied to seismic hazard estimation of Western Cuba. In this case it was not possible to make an univoque delimitation of seismic source zones, and its parameters' evaluation was made under some assuptionts which substitute the lack of information. For these reasons obtained results are not a high reliable ones and should be precised in future investigations.

Althoug that it was pointed out that model B of SSZ is the one which best fits the data, it is not recomended to use it alone for seismic hazard estimation. It is believed that the use of interval estimates by combining the results for the three analized SSZ models would yield a more reliable solution to the problem.

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Fig. 1. Values of parameter γ as a function of r_0 for the depth of 20 km and for parameter "b" of magnitude-frequency graphic ranging from 0.3 to 0.8 (indicated over the lines in figure)

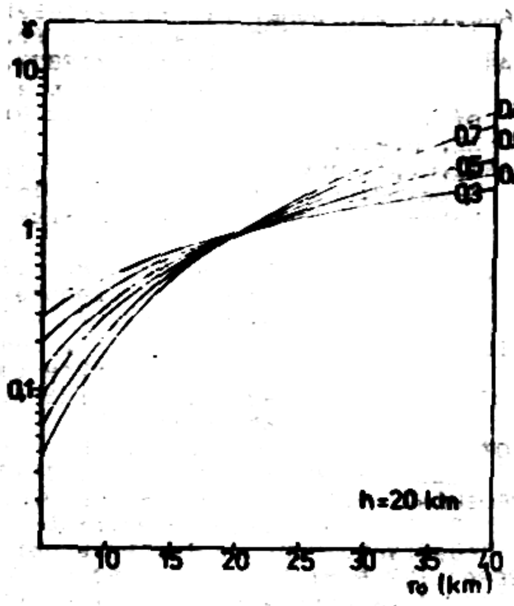


Fig. 2. Seismicity of Western Cuba. a) Macroseismic epicenters' map. 1 - felt without especifications, 2 - I=III, 3 - I=IV, 4 - I=V, 5 - I=VI, 6 - I=VII, 7 - I=VIII, 8 - indefination between expresed and the next by order intensity. 9 - instrumental epicenter determined by short period seismograph of Soroa station. b) Isoseismal map of 23-I-1880 earthquake. c) Isoseismal map of 16-XII-1982 earthquake.

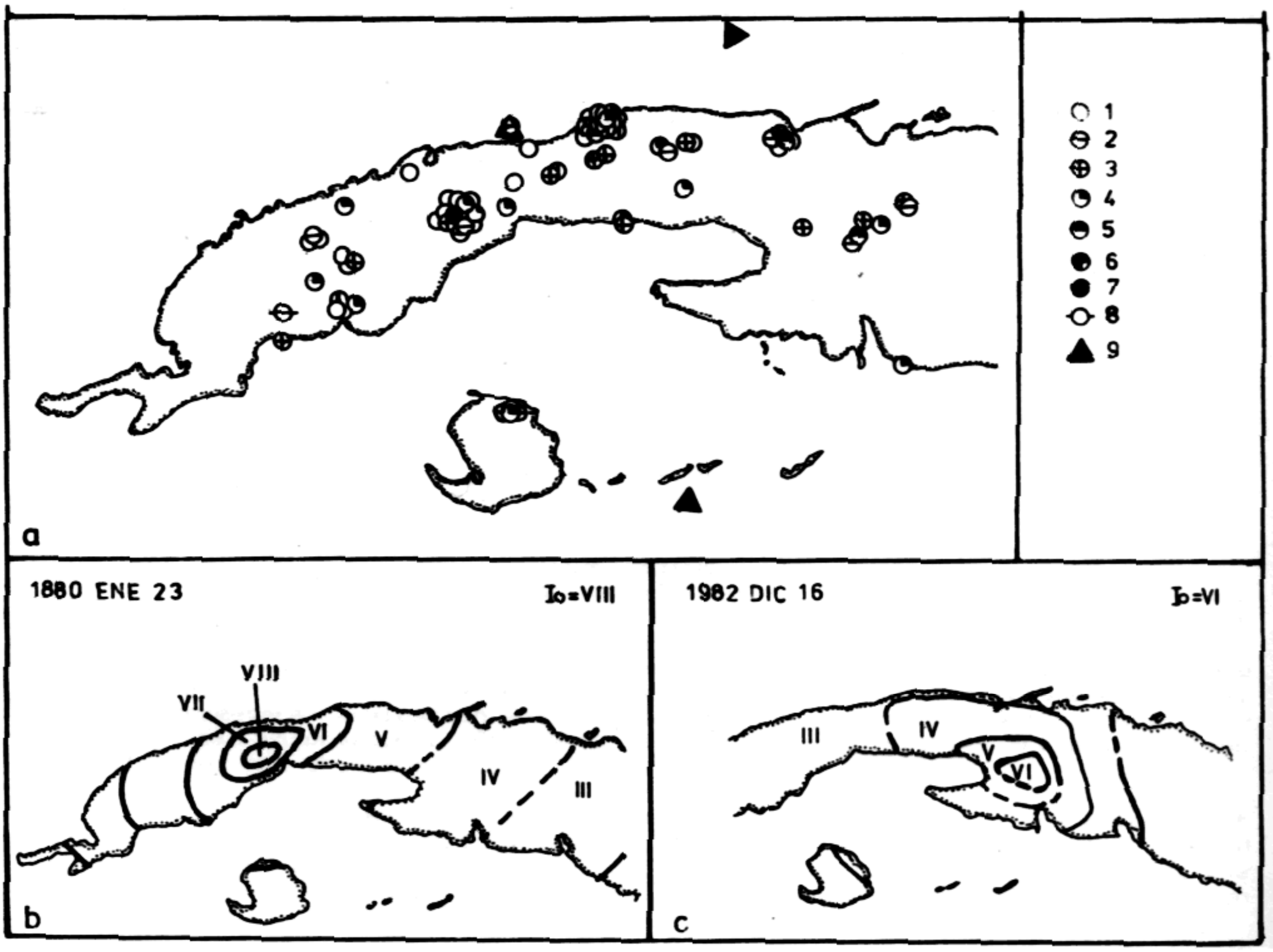
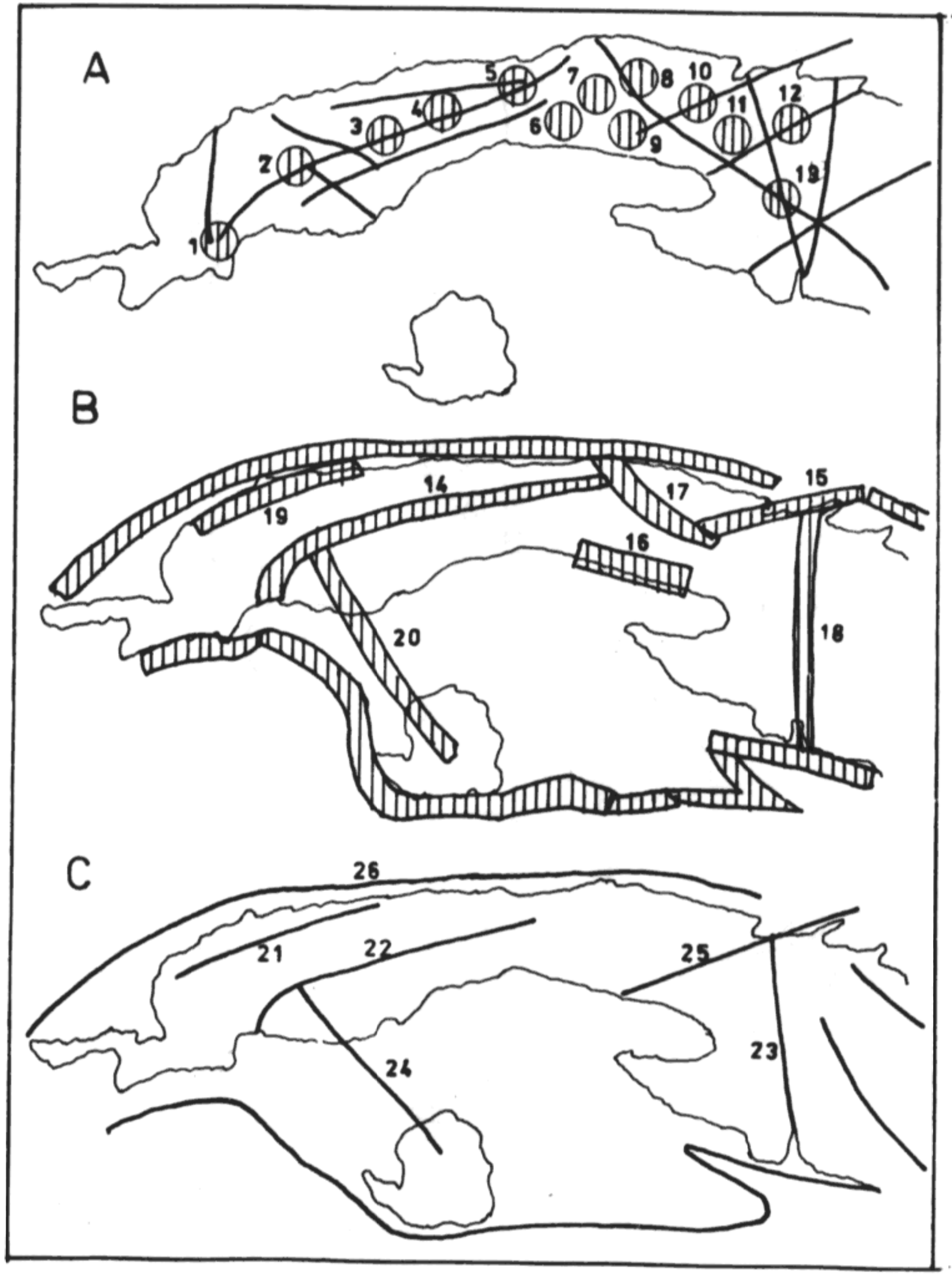


Fig. 3. Seismic source zones' maps. A - Model of Cotilla et al. (1988); B - Model of Chuy et al. (1988); C - Model of Orbera et al. (1987). Next are expresed the values of parameters used for calculations: Mmax, parameter "a" of magnitude-frequency graphic, and ratio A/B of isoseismal model. Numbers are in correspondence with those indicated on the maps. There are zome 557 not numbered because they were not used in calculations.

No.	Mmax	a	A/B
1	5.25	1.667	1.6
2	6.25	1.667	1.6
3	6.25	1.667	1.6
4	6.25	1.727	1.6
5	6.25	1.727	1.6
6	5.25	1.426	1.0
7	5.25	1.426	1.0
8	6.25	1.827	1.8
9	5.75	1.627	1.6
10	5.75	1.475	1.6
11	5.25	1.174	1.0
12	5.75	1.475	1.6
13	5.25	1.475	1.6
14	6.5	2.224	1.6
15	5.3	1.256	1.6
16	5.1	1.301	1.6
17	5.4	1.646	1.8
18	5.5	1.592	1.0
19	5.6	0.963	1.6
20	5.6	1.480	1.6
21	7.0	0.963	1.6
22	7.0	2.224	1.6
23	6.0	1.592	1.0
24	5.0	1.480	1.6
25	6.5	1.680	1.6
26	7.0	1.529	1.6



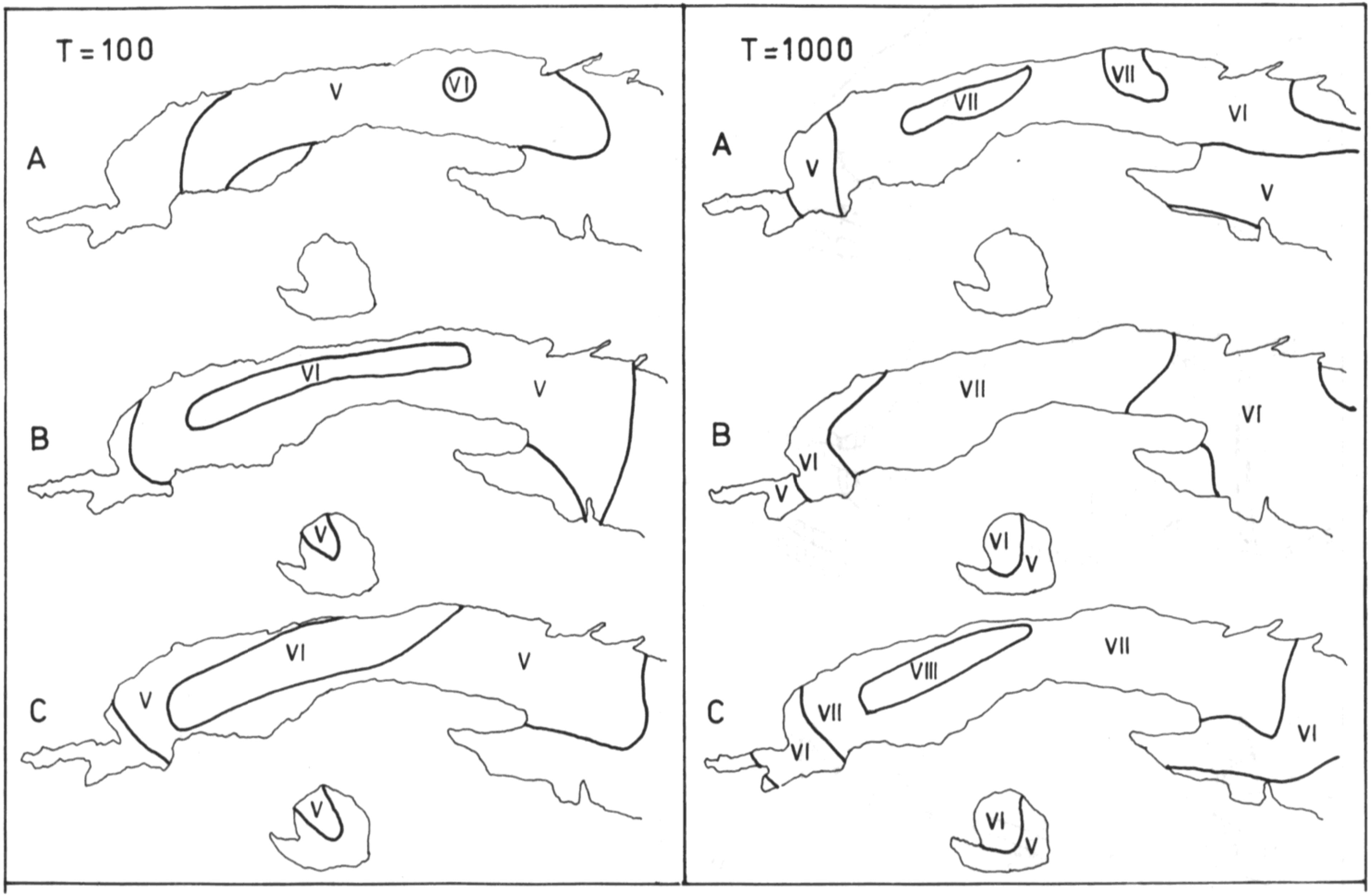


Fig. 8. Intensity maps for recurrence periods of 100 and 1000 years obtained for the 3 models of seismic source zones.