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PROBABILITIES OF OCCURRENCE OF LARGE EARTHQUAKES IN VERY ACTIVE ZONES OF THE EARTH

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ABSTRACT

Analysis of the seismicity in 24 active zones of the world is attempted in terms of the repeat times of strong earthquakes. A recently compiled homogeneous catalogue of large earthquakes ($M_s \geq 7.0$), which covers the time span 1898-1985, was used in this analysis. A probabilistic approach is then applied to forecast the likelihood of large future earthquakes in the world's seismic zones on the basis of time dependent and time independent seismicity models. The results obtained in terms of the time dependent seismicity model show very high probabilities of occurrence which can be associated mainly with the dimensions of the seismic zones. The calculations show that several seismic zones of the globe exhibit high probability to be sources of great earthquakes ($M_s \geq 8.0$) during the time period 1986-2006. The highest probabilities were calculated for the zones 11 (:North Japan), 15 (:Philippines Islands), 16 (:Guinea) 17 (:Solomon Islands), 22 (:East China) and 23 (:Himalayas). Very large ($M_s \geq 7.5$) earthquakes which occurred during 1986-1991, are given as evidence, in order to establish the obtained probabilities.

ΠΕΡΙΛΗΨΗ

Στην εργασία αυτή γίνεται μελέτη της σεισμικότητας 22 σεισμικών ζωνών της Γής με τον καθορισμό της μέσης περιόδου εμφάνισης των ισχυρών σεισμών. Τα δεδομένα που χρησιμοποιήθηκαν ήταν ένας ομογενής κατάλογος ισχυρών ($M_s \geq 7.0$) σεισμών, ο οποίος ήταν πλήρης για το μέγεθος αυτό για το διάστημα 1898-1986. Στη συνέχεια έγινε προσπάθεια πρόγνωσης των ισχυρών σεισμών στις 22 σεισμικές ζώνες με τη χρήση του χρονικά εξαρτημένου και του μή εξαρτημένου χρονικά μοντέλλου σεισμικότητας και παρουσιάζονται τα αποτελέσματα τους για το χρονικό διάστημα 1986-2006. Τα αποτελέσματα δείχνουν ότι αρκετές περιοχές της Γής έχουν υψηλές πιθανότητες για τη γένεση μεγάλων ($M_S \geq 8.0$) σεισμών για το διάστημα αυτό. Το χρονικά εξαρτημένο μοντέλλο σεισμικότητας δίνει υψηλές τιμές οι οποίες μπορούν να αποδοθούν στις μεγάλες διαστάσεις των σεισμικών ζωνών. Οι υψηλότερες πιθανότητες (με βάση το μοντέλλο Poisson) βρέθηκαν για τις περιοχές 11 (:Βόρεια Ιαπωνία), 15 (:Φιλιππίνες), 16 (:Γουινέα), 17 (: Νησιά Σολομώντα), 22 (:Ανατολική Κίνα) και 23 (:Ιμαλάϊα). Τέλος, ενδεικτικά, δίνεται χάρτης των μεγάλων ($M_s \geq 7.5$) σεισμών οι οποίοι έγιναν κατά το διάστημα 1986-1991.

INTRODUCTION

Different methods of analysis have been applied by the seismologists, in order to study the seismicity of the Earth (Gutenberg and Richter, 1954; Duda,1965; Ullmann and Maaz,1966; Karnik, 1969, 1971; Kaila and Narain, 1971; Mogi, 1974; Bath and Duda, 1979; Tsapanos, 1985, 1988; Papazachos, 1990; Tsapanos and Burton, 1991).

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Qualitative methods, as well as quantitative techniques have been applied for the seismicity parameters determination of a given region. Common quantities which are depending on the magnitude and on the frequency of earthquakes and thus they could be considered as measures of the seismicity, are the annual number N(M) of the earthquakes with magnitudes greater or equal to a given value M, the sum of the energy, the slope of Benioff graph, the M_{max} observed and the mean repeat times T_m of the shocks.

In recent studies (Rikitake, 1976; Shimazaki and Nakata, 1980; Sykes and Quittmeyer, 1981; Goswami and Sarmah, 1983; Wesnousky et al., 1984; Srivastava and Dattatrayam, 1986; Papazachos et al., 1987) mean repeat times have been used to examine the seismicity of various seismically active regions of the world.

The repeat times of great earthquakes in 22 active seismic zones of the world, determined here, were used for the probability estimation of the occurrence of big earthquakes during the time period 1986-2006.

THE DATA SET

This study is restricted only to large shallow ($h \leq 60$ Km) earthquakes which occurred along major seismic zones. Practical reasons led us to use data of earthquakes with magnitudes $M_s \geq 7.0$. This magnitude interval puts a condition that our considerations must cover a long time of recorded earthquakes.

Five sources of data were used for the compilation of a catalogue which forms the data set of the present study: 1) The catalogue of earthquakes of Duda (1965), which gives information on earthquakes that occurred from 1897 to 1963, 2) the catalogue of Kanamori and Abe (1979), which gives information on earthquakes that occurred from 1897 to 1903, 3) the catalogue of Gutenberg and Richter (1954), which gives the parameters of the earthquakes from 1904 to 1952, 4) the catalogue of Rothe (1969), which informs about the parameters of the earthquakes occurred from 1953 to 1965. The magnitudes in these catalogues are given in the surface wave magnitude scale. The last catalogue used is a global catalogue of strong earthquakes during the time period 1966-1985 (Tsapanos et al., 1990). The magnitude of the earthquakes in the last catalogue was the surface wave magnitude, obtained mainly from the ISC bulletins or in few special cases from bulletins issued by other seismological centres. These catalogues were merged in one and the data were found complete for magnitudes $M_s \geq 7.0$ for the time period 1898-1985 (Papazachos et al., 1991).

The map in figure (1) shows the geographical distribution of the epicenters of large shallow earthquakes ($M_s \geq 7.0$) on the Earth during the time period 1898-1985. The examined seismic zones are also illustrated in this figure.

MEAN REPEAT TIMES

For each seismic zone the observed repeat time, T_m, (as a difference in years between successive events), was calculated for all earthquakes of each magnitude class (differing by 0.1 magnitude values) and its logarithm was plotted versus the corresponding magnitude value. Figure (2) demonstrates plots of the logarithm of the mean repeat time, T_m, in years, as derived directly from the observations, versus the surface wave magnitude M_s, for shallow earthquakes which occurred in three seismic zones (Aleutian Islands, Chile and Philippines Islands). Such plots were produced for every zone and in all plots the linear trend was evident. For four of them, the zones 6 (:Peru), 13 (:Marianes Islands), 19 (:Kermandec & Tonga Islands) and 20 (:New Zealand), the available data were insufficient.

Return periods, T_m, and magnitudes are related in the following way:

$$\log T_m = a + bM_s \qquad (1)$$

The straight lines, drawn through the observations in the graphs of figure (2), were determined by the application of the least squares' method for the determination of the parameters a and b of the formula (1). Their values are presented in Table (I).

An attempt has been also made to determine the errors in the estimated repeat times. For this reason, the logarithms of the observed standard deviations for each observation of re-

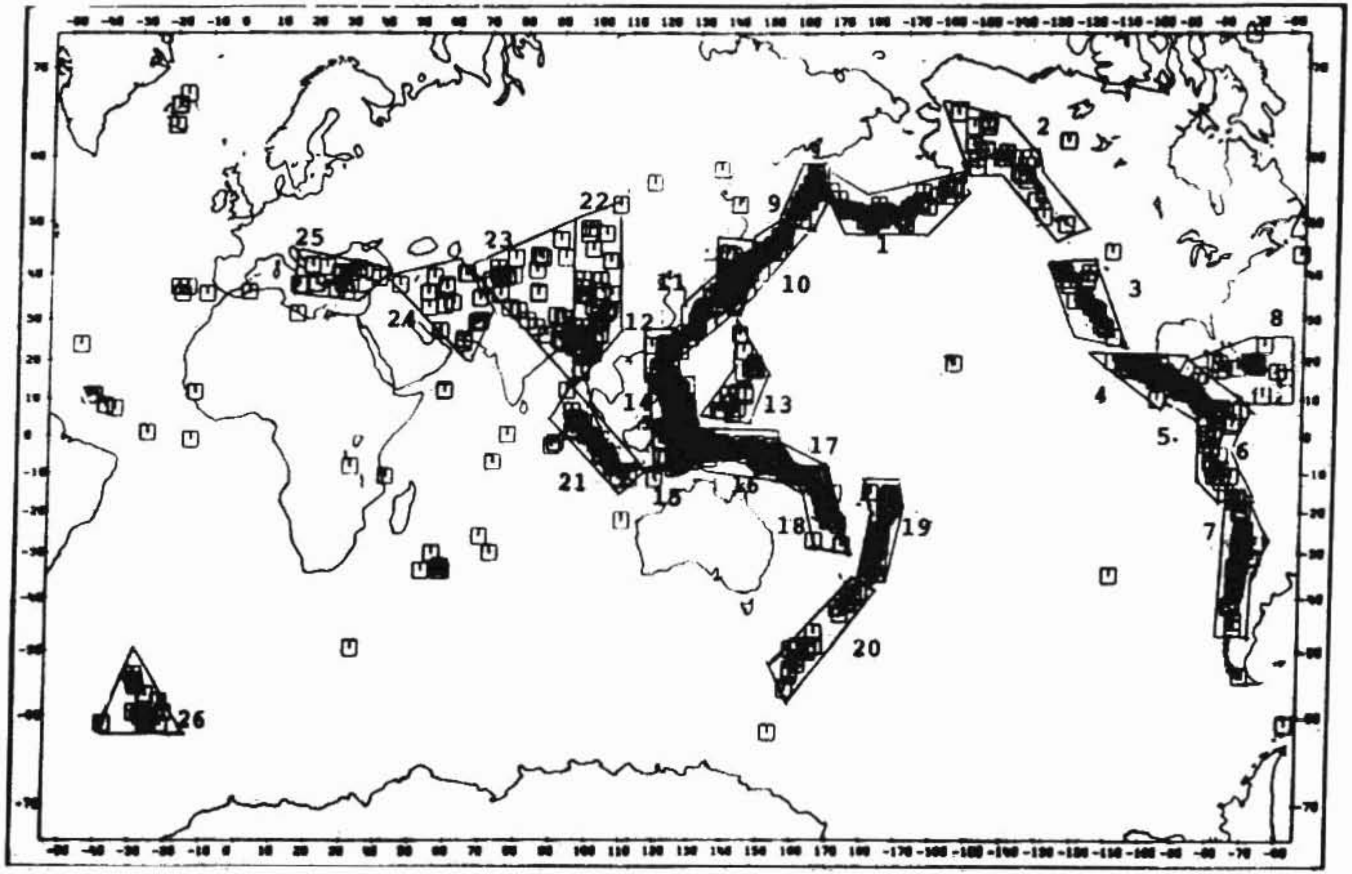

Fig. 1.- *Geographical distribution of the epicenters of large (M≥7.0) shallow earthquakes on the whole Earth during the time period 1898-1985.*

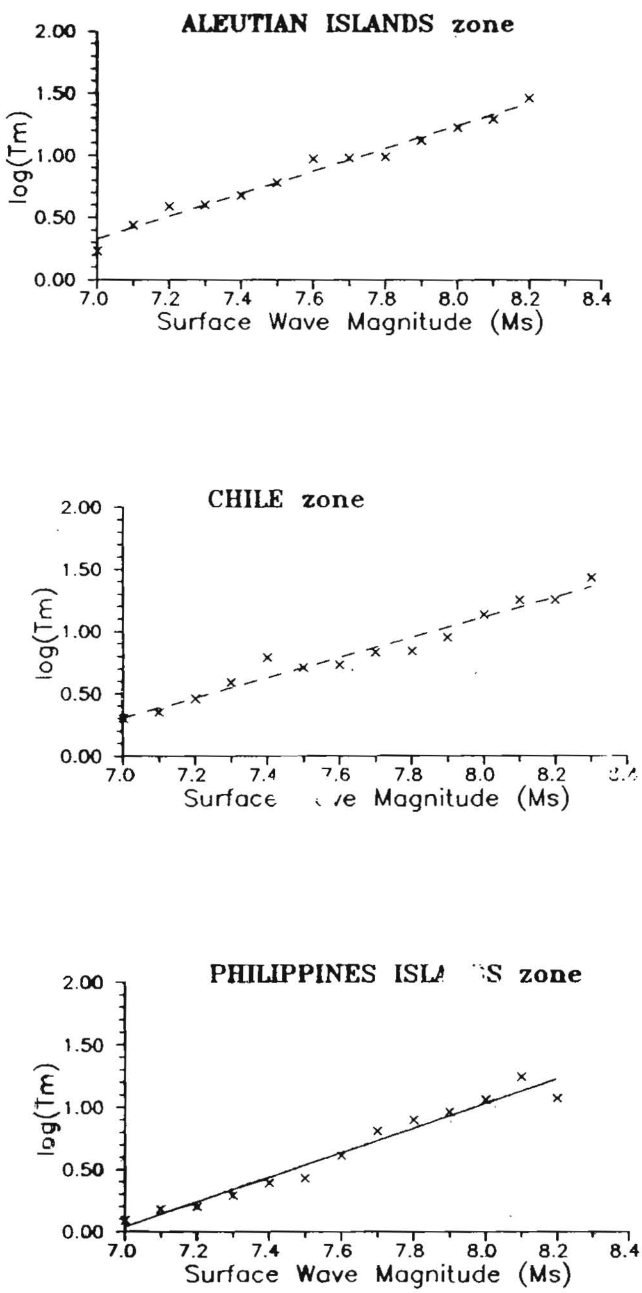

Fig. 2.- *The logarithm of the mean repeat time, versus surface wave magnitude, M_S, for the seismic zones 1 (:Aleutian Islands), 7 (:Chile) and 15 (:Philipinnes Islands).*

Table I. Computed values of the parameters a and b of the relation (1) for every zone.

Seismic zone	a	b	Seismic zone	a	b
1	-6.02	0.91	14	-6.03	0.92
2	-5.04	0.78	15	-6.89	0.99
3	-5.34	0.86	16	-8.97	1.30
4	-7.07	1.04	17	-2.71	0.45
5	-6.52	0.97	18	-5.50	0.84
6	insufficient data		19	insufficient data	
7	-5.36	0.81	20	insufficient data	
8	-4.73	0.78	21	-3.42	0.57
9	-4.25	0.68	22	-5.16	0.77
10	-3.81	0.63	23	-3.92	0.62
11	-5.79	0.86	24	-5.73	0.92
12	-4.40	0.70	25	-5.01	0.82
13	insufficient data		26	-4.72	0.76

peat time were plotted as a function of magnitude. Figure (3) shows the plot of the logarithm

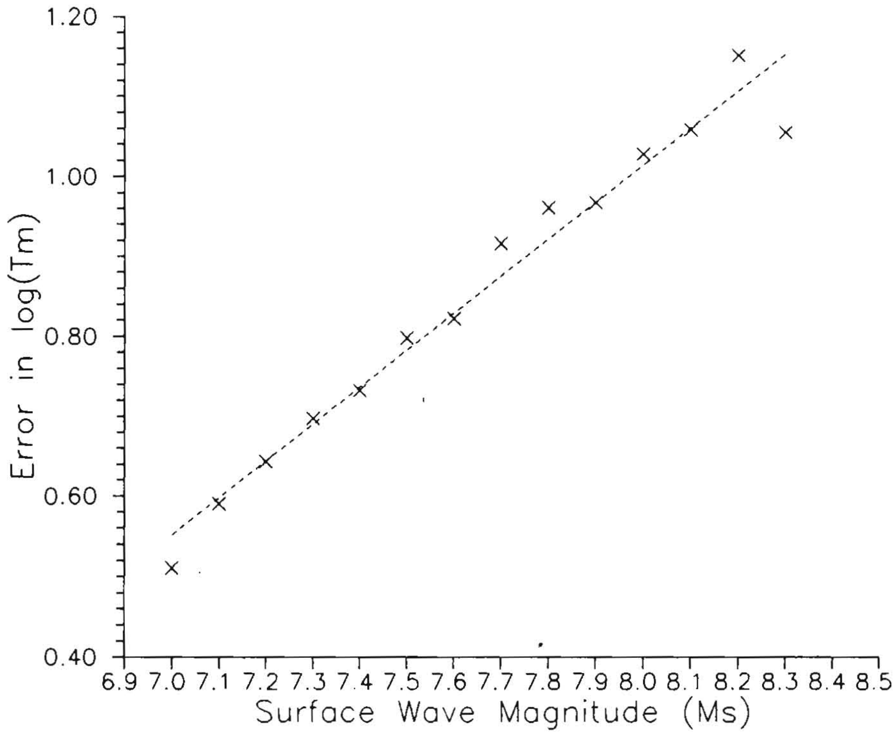

Fig. 3. - *Plot of the logarithm of the error in the calculation of the repeat time versus its corresponding magnitude.*

of the observed standard deviation of the repeat time, log $\sigma(T_m)$, versus its corresponding magnitude, M_s, showing a linear trend of the observed data points. Thus the following relation was determined in the least squares' sense .

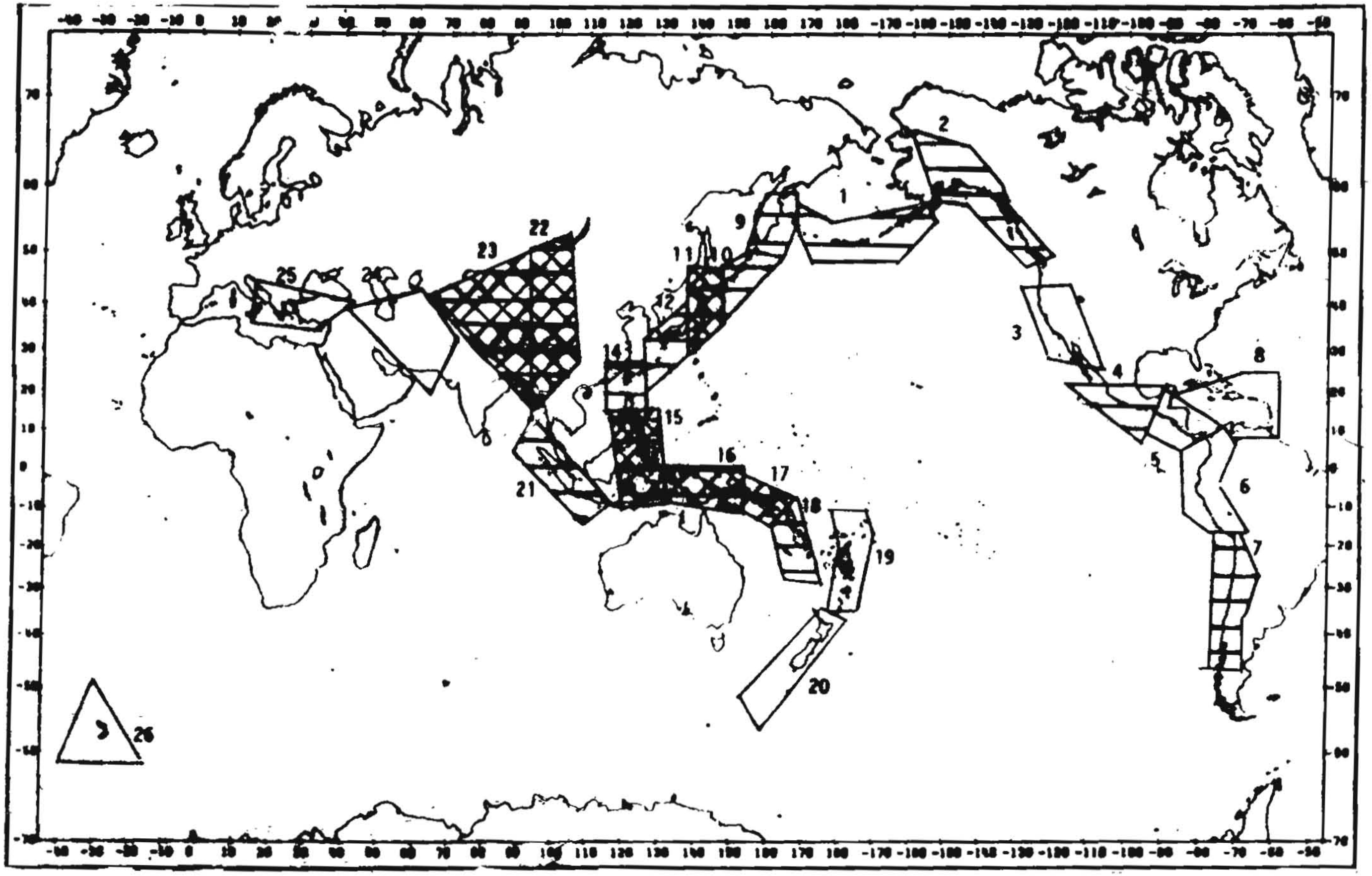

Fig. 4. – *Probability map for the occurrence of shallow earthquakes with $M_s \geq 8.0$ in the period 1986-2006. The triple hatched areas represent the high probability range (P>61%), the single hatched areas stand for medium probability (40%<P<60%) and the open areas stand for probabilities less than 40%. Dashed areas represent the zones for which no probabilities where calculated.*

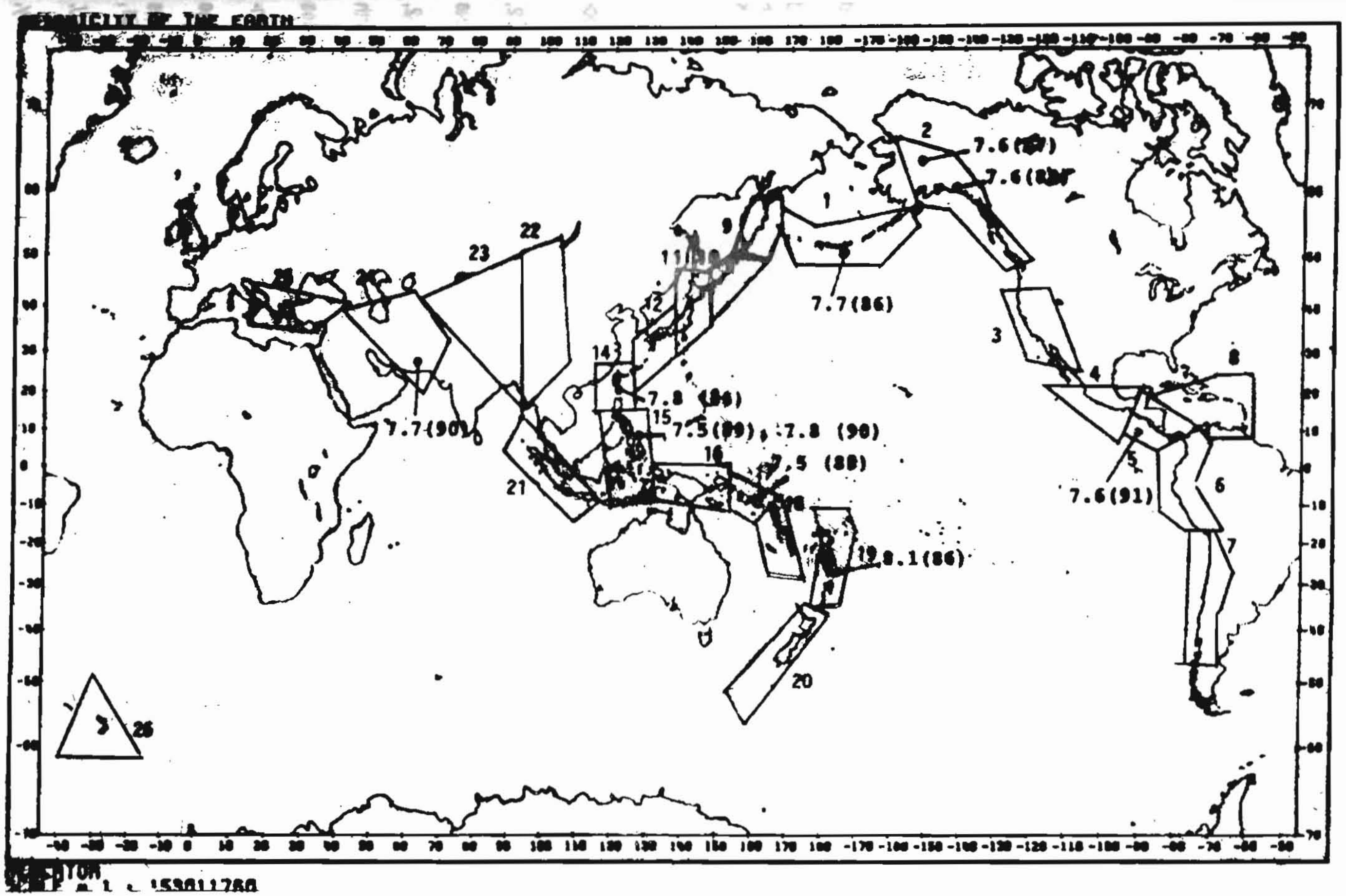

Fig. 5. – *Map which shows the occurrence of earthquakes with $M_s \geq 7.5$ during 1986-1991. For every occurred event, its magnitude and the last two digits of the year of its occurrence (into brackets) are given.*

DISCUSSION

There is a long discussion on the results obtained in terms of the time dependent as well as of the Poisson seismicity models. In most cases it was found that the time dependent seismicity model gives more reasonable results. Moreover, the time dependent seismicity mo- del has a more physical meaning than the memoryless seismicity models (Anagnos and Kiremidjian, 1984; Cornell and Winterstein, 1988), but it must be considered that this observation as well as the reliability of the results are valid if i) we involve in forecasting earthquake magnitudes of the order of the characteristic earthquake in seismic zones having dimensions comparable to the source dimensions of the characteristic shock and ii) the time lag since the last earthquake does not exceeds the average time (+1σ). This can explain the fact that in the present study in most cases the estimated probabilities, in terms of the time dependent seismicity model for earthquakes with magnitudes $M_s \geq 8.0$ are high. The map in figure (4) depicts the probability of a seismic zone to be experienced an earthquake with $M_s \geq 8.0$ during the time interval 1986-2006. The results were obtained in terms of the Poisson seismicity model. The highest probabilities were calculated for the zones 1 (:Aleutian Islands), 2 (:Alaska), 4 (:Mexico), 7 (:Chile), 9 (:Kamtchatka), 10 (:Kuriles Islands), 12 (:South Japan), 14 (:Taiwan - Riuku), 18 (:New Hebrides Islands) and 21 (:Sunda arc). It is important to note the case of the zone 4 (:Mexico), for which the time dependent seismicity model gives more realistic results than those obtained in terms of the Poisson model.

As an evidence of the above considerations, the map in figure (5) was constructed depicting the zones in which earthquakes with magnitudes $M_s \geq 7.5$ occurred during the time interval 1986-1991. The data sources are the ISC bulletins and the NEIC/PDEs. For every shock the surface wave magnitude and the year of occurrence are given.

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