ГОДИШНИК НА МИННО-ГЕОЛОЖКИЯ УНИВЕРСИТЕТ "СВ. ИВАН РИЛСКИ", Том 53, Св. I, Геология и геофизика, 2010
ANNUAL OF THE UNIVERSITY OF MINING AND GEOLOGY "ST. IVAN RILSKI", Vol. 53, Part I, Geology and Geophysics, 2010

PREDICTION THE OCCURRENCE OF EARTHQUAKES (M>5.0) IN SE AUSTRALIA USING A STOCHASTIC MODEL

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ABSTRACT. A stochastic prediction of an earthquake occurrence (as well as any other attempt of seismic event prognosis) requires the determination of five elements: two co-ordinates, depth, magnitude and time. It is well known also that predicting the time is the crucial factor for the lack of success in earthquake prediction. The larger the magnitude, the territory and time span of the investigation are the more likely is that the results will be closer to the reality. Southeast Australia is the first region on the continent with a documented history of earthquakes occurrence. But even here, only 130 years of written documenting is available, and this is a short term as far as seismological prediction is concern. The instrumentally recorded data are even more limited. The magnitudes of the intraplate events in this region are on the moderate size of the Richter scale. All these factors are imposing a number of limitations on earthquake prognosis, which may be one of the main reasons for nearly complete lack of studies on this subject. The use of the earlier developed stochastic model is based on geometry considerations as well as the statistical distributions of the main parameters of any two consecutive seismic events: temporal and space positions and the magnitude differences. The obtained bi-modal distributions require the consideration of the most probable position of the next expected seismic event. The results obtained show the applicability of the suggested model.

ПРОГНОЗИРАНЕ НА ЗЕМЕТРЕСЕНИЯ (M>5.0) В ЮИ АВСТРАЛИЯ ЧРЕЗ ИЗПОЛЗУВАНЕ НА СТОХАСТИЧЕН МОДЕЛ

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РЕЗЮМЕ. Стохастическото прогнозиране на земетресенията изисква определянето на пет компонента: две координати, дълбочина, магнитуд и време на случване. Добре известно е, че най-труден за определяне параметър е времето на случване. Югоизточна Австралия е регион с най-много и добре документирани земетресения, въпреки кратката история на сеизмологията в Австралия Сеизмичността на този регион е доминирана от средни по сила сеизмични събития. Тези фактори имат ограничително действие върху всеки опит за стохастично прогнозиране. Независимо от това е използуван предварително конструиран стохастически модел, основаващ се на геометрични построения и статистически разпределения на основните параметри на всеки две последователни земетресения – временен и магнитуден интервал, място на реализация и посока. Въз основа на този подход се конструира номограма отчитаща максималната вероятност за ставане на земетресения в ЮИ Австралия Приложението на модела показва, че е възможно неговото използуване за целите на средносрочното прогнозиране на земетресения в този регион.

Introduction

A stochastic prediction of an earthquake occurrence (as well as any other attempt of seismic event prognosis) requires the determination of five elements: two co-ordinates, depth, magnitude and time. It is well known also that predicting the time is the crucial factor for the lack of success in earthquake prediction. The larger the magnitude, the territory and time span of the investigation are the more likely is that the results will be closer to the reality.

Southeast Australia is the first region on the continent with a documented history of earthquakes occurrence. But even here, only 130 years of written documenting is available, and this is a short term as far as seismological prediction is concern. The instrumentally recorded data are even more limited. The magnitudes of the intraplate events in this region are on the moderate size of the Richter scale. All these factors are imposing a number of limitations on earthquake prognosis, which may be one of the main reasons for nearly complete lack of studies on this subject.

Nearly forty years of instrumentally well documented seismological history has been collected in the Research School of Earth Sciences' Seismology Group. These records provide thirteen events with magnitude greater than 5.0, which will be the data basis of present study. The idea to make the present attempt was given by the bi-modal distribution of the local seismicity in time (Fig. 1). Furthermore, the maximums on this distribution clearly marked consequent strong events as shown by the arrows. The cumulative graphics of the energy release for the same time period (1959-1995) is presented in Fig. 2 and does not show any specific features and no clear periodicity in the energy release distribution.

An attempt to compile a complete set of strong earthquakes in Southeast Australia is presented in Table 1**.** The data for the events unto 1959 have been collected from different Australian Geological Survey Organization Reports (1993; 1995) and a number of other publications (Everyngham et al., 1982; Lambeck et al., 1984; McCue et al., 1989). Those 22 events give an average of six years time period between the sequential quakes, but one should consider the poor detecting and recording capabilities before and in the beginning of this century.

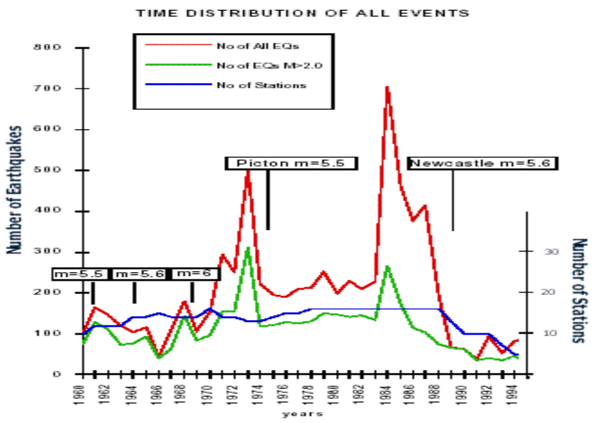


Fig. 1. Temporal distribution of all events in South East Australia

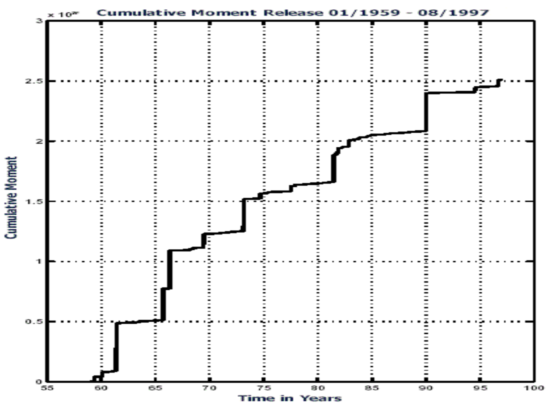


Fig. 2. Cumulative graphics of the energy release

DATA AND METHOD

Even with a limited amount of information we had to restrict our database to the last 15 events. This is the most homogeneous and reliable part of the presented catalogue. The number of earthquakes with magnitude greater than 4.0 for the same time period (after 1959) is 55 and would give a better basis for statistical study. With such a low magnitude however, it is much more probable that the stochastic distribution is more random and some of the events could be fore or aftershocks of main earthquakes. Their detection as such is not an easy task while the method requires only independent seismic events.

Table 1. List of the 15 events with M>5.0 in South East Australia

Year	Mont	Day	Hour:Min	Lat	Lon	Depth	M
1959	5	18	6:12	36.22	148.66	17.00	5.0
1960	1	28	23:37	36.85	147.17	21.00	5.0
1961	5	21	21:40	34.55	150.50	19.00	5.5
1966	5	3	19: 7	37.04	147.13	8.00	5.6
1969	6	20	11:15	38.38	146.27	0.00	6.0
1973	2	17	8:56	38.73	145.29	19.00	5.0
1973	3	9	19: 9	34.17	150.32	21.00	5.5
1974	9	16	7:37	38.38	149.45	0.00	5.0
1977	7	4	20: 5	34.65	148.89	21.00	5.0
1981	11	15	16:58	34.26	150.85	21.00	5.0
1982	11	21	11:34	37.19	146.94	22.00	5.4
1989	12	27	23:26	33.03	151.73	22.00	5.5
1994	8	6	11: 3	32.98	151.31	21.00	5.3
1996	8	13	4:30	30.08	143.52	2.0	5.1
1996	9	25	7:50	37.88	146.47	11.0	5.0

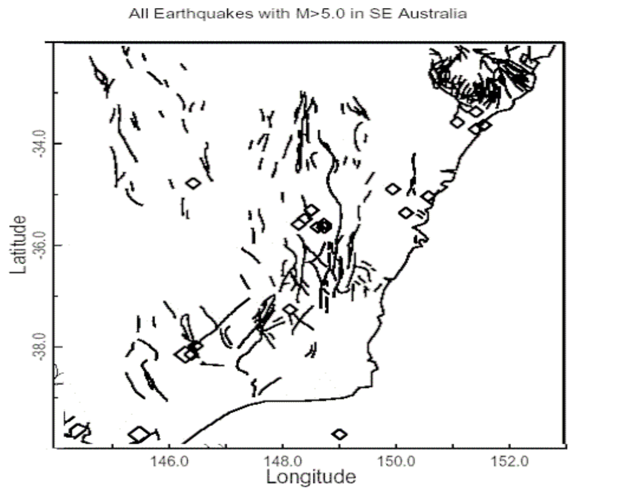


Fig. 3. Spatial distribution of the quakes with M>5.0, plotted over the fault system

The spatial distribution of these quakes plotted over the fault system in the region is shown in Fig. 3. The plot confirms the results in Spassov et al. (1996), that unlike the weak seismicity, the strong events in this area are aligned in a relatively narrow strip with NW-SE orientation along the Pacific coast of Australia. And again on very few occasions epicenters coincide with the known faults even if considering an error in location determination of 5-10 km (Lambeck et al., 1984).

The principles of the method applied have been developed by several authors (Christoskov et al., 1989; Ranguelov, 1990; etc.). Briefly, for every couple of two sequential events N_i and N_{i+1} with parameters: X, Y, T and M we could create the differences:

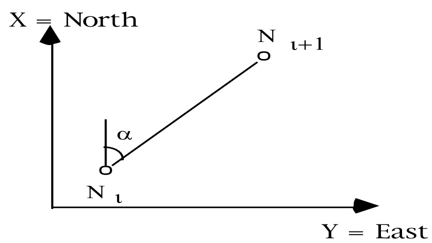
$$\Delta T = T_{i+1} - T_i; \quad (1)$$

$$\Delta M = M_{i+1} - M_i; \quad (2)$$

$$\Delta L = [(X_{i+1} - X_i)^2 + (Y_{i+1} - Y_i)^2]^{1/2}, \quad (3)$$

where

$$\alpha = \mathrm{arctg}(\Delta X / \Delta Y); \quad (4)$$



Since the magnitude interval is strictly limited, magnitude can not be used as a criterion. In such a case the total probability for the next event occurrence will be (if the events are independent in time and space domain):

$P = P(\Delta T) * P(\Delta L) * P(\alpha)$ (5)

By using the empirical distributions of those parameters and after normalization with the maximum value of each parameter we could produce compatible mutual distributions and even plot the comprehensive results on the map of probabilities.

RESULTS AND DISCUSSION

The plot of the temporal distribution of the strong earthquakes is presented in Fig. 4. Its bi-modal shape is quite pronounced with maximums at about 12 (with “one sigma” interval of about 1.5 months) and 53 (with “one sigma” – 6.5) months. It is quite possible that the minimum at 36 month represents an average time gap required for compensation of the stress release before an accumulation of elastic energy starts again.

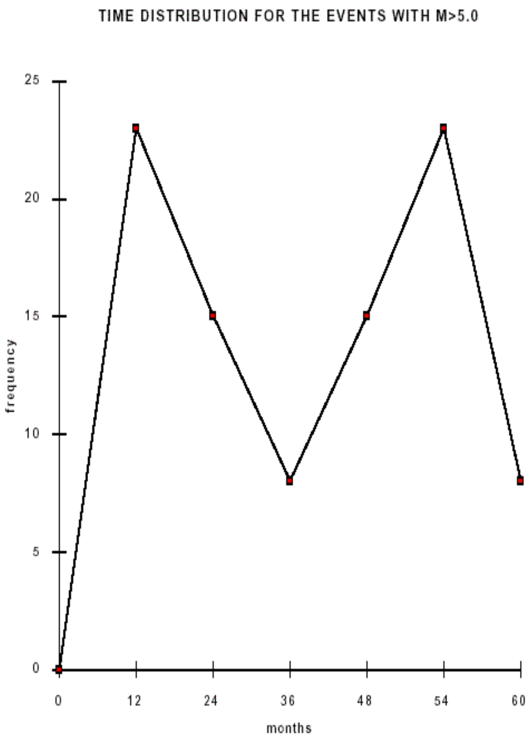


Fig. 4. Time distribution of all events with M > 5.0 in South East Australia

In support of previously made statement about the disadvantages of using earthquakes with lesser magnitude, a similar distribution but for all events with M>4.0 is presented in Fig. 5. The shape of the graph does not show any wide and clear maximums as could be expected when the data sample contains aftershocks. The minimum at 12 months if, regarded in relation to the previous figure, comes to suggest that a strong drop in the background seismicity usually precedes a strong event occurrence and even follows it a few months after until a stress release compensation takes place. Time inconsistency of the historic data could be demonstrated from Fig. 6. The graph is again bi-modal, but the time span of nearly 100 years and the increasing number of reported events with the years is making difficult the sensible use of this information for the purposes of the suggested model. It is also possible, especially in the beginning of the period, that earthquakes of that size have not been noticed and/or recorded.

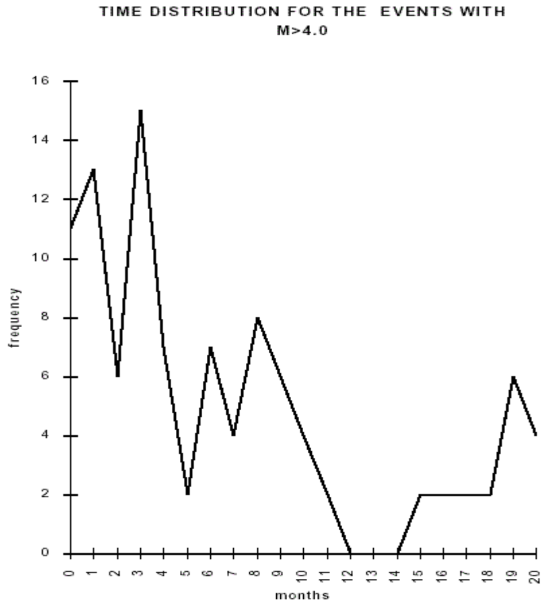


Fig. 5. Time distribution for all events with M>4.0 for the same region

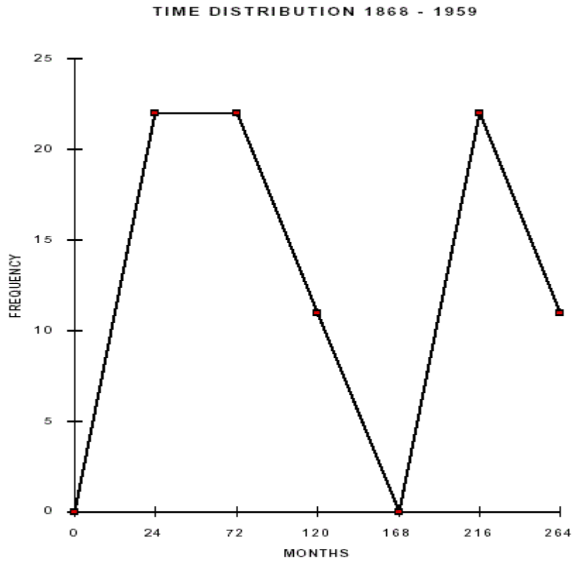


Fig. 6. Time distribution for all historic events with M>5.0 for the same region

Fig. 7 shows the distance distribution of the strong events in the area. The most characteristic feature here again is the bi-modal shape of the curve. This could suggest a seismogenic block structure of an average of 500 km (with “one sigma” of about 120 km.) required for accumulation and generation of an event with magnitude greater than 5.0. The minimum of this graph could be used in search of some real geologic boundary conditions, defining such a block structure. All the data available for the whole period have been put together (Fig. 8). Even with perhaps incomplete catalogue of seismic data the block structure in the area is so well defined, that it is encouraging in the creation of a territorial distribution of the probabilities.

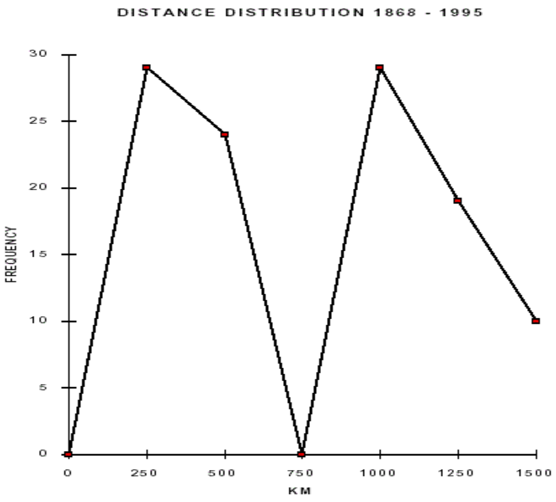


Fig. 7. Distance distribution of the strong events in the area

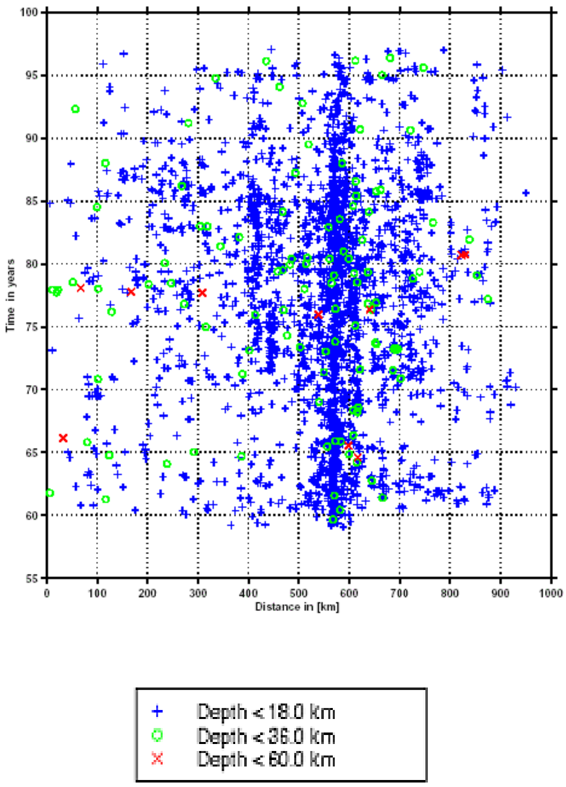


Fig. 8. Distance distribution of the ALL events in the area

The azimuthal distribution of the main events for this study is investigated**.** The orientation of its maximum could easily be expected from the space distribution of the events (Fig. 3). Unexplained remains the minimum in opposite direction, which could be due to the exceptions in overall distribution rather than to a particular feature. Probably the most real representation of the azimuthal preferences of the strong events occurrence could be obtained from such distribution of all events with M>5.0**.**

The normalization of the values and their comprehensive consideration allows a construction of a probability nomogram shown in Fig. 10. Each of its circular segments contains the percentage probability of an earthquake occurring in the sector if the centre of the nomogram is placed over the location of the epicentre of the last strong event. Similar graph could be more useful in a more rapidly changing seismicity or for planning some long term investigations.

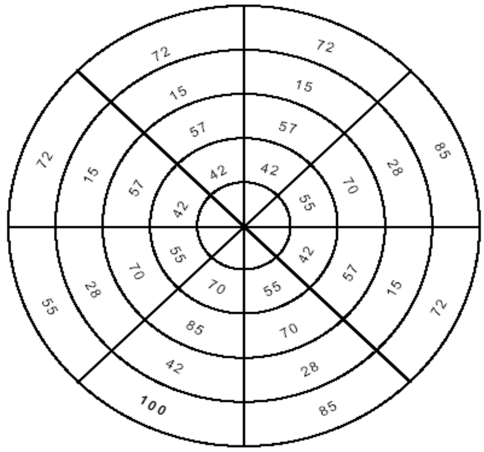


Fig. 10. Probability nomogram after normalization of the values and their comprehensive consideration

Probably the most important effect of the suggested model is that it is giving the opportunity to transfer the result on to the territory of study. Dividing the area into individual cells (in this case in 1 by 1 geographical degrees dimensions) one could calculate the total probability of occurrence for each cell. The interpolation of the data then would give a probability map as the one presented in Fig. 11 for this particular set of data. The two maximums in the distance distribution (Fig. 6) are marked here by a 70% margin, but the overall probability is greatest in the shadowed area.

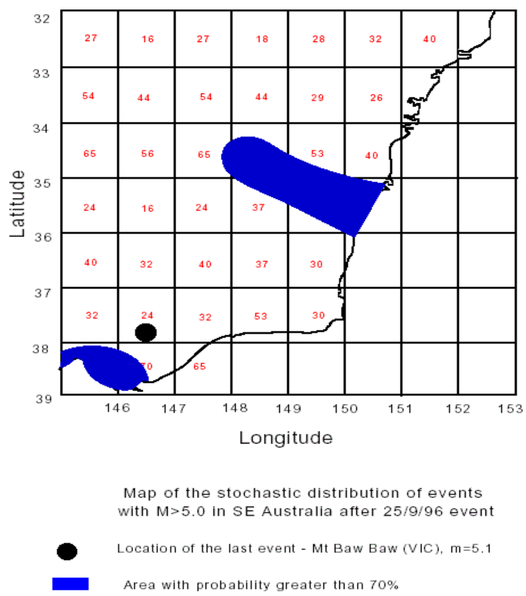


Fig. 11. Probability map based on the stochastic model described here

A retrospective analysis of the data has been performed in order to evaluate the reliability of the method and the results. The worst of the scenarios is between the events 14 and 15. Its failure is mainly due to the unusually short time period between the two events. The best of fits is between the couple 3 and 4 for events in 1961 and 1965. A retrospective check of all couples gives an average success rate of nearly 70%, while on two occasions the success rate is 93%. Another estimate shows that in 68% of the retro-analyses the success is 65% or more.

After this study was done an event with M=5.0 has occurred in the area and its epicentre felt well within the small predicted zone in the South-West (Fig. 12). Its time interval from the previous event is 47 months, very close to the established second maximum of 53 months.

Year	Mont	Day	Hour: Min	Lat	Lon	Depth	M
2000	8	29	12:05	38.41	146.29	18.0	5.0

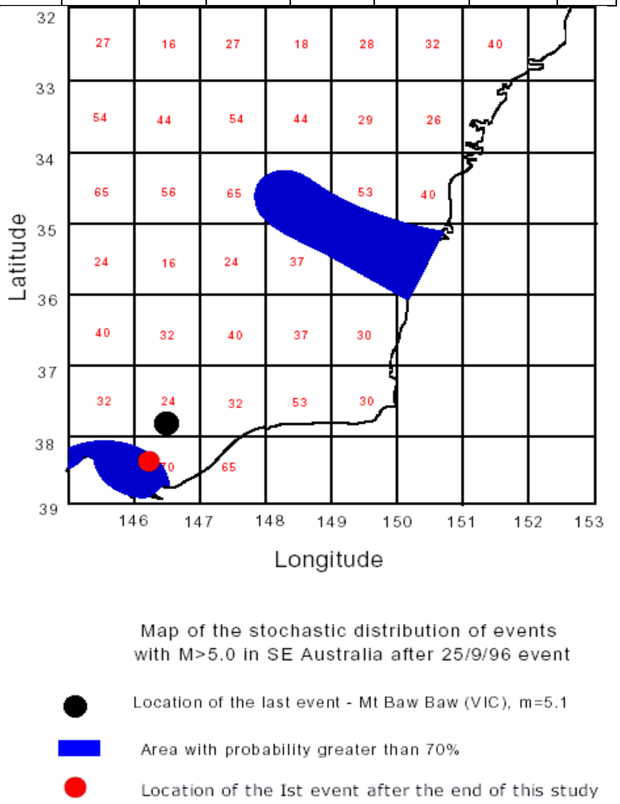


Fig. 12. A successful event occurrence within predicted areas

Conclusions

The midterm stochastic model for studying the earthquakes with magnitude greater than 5.0 in SE Australia gave clearly defined bi-modal distributions of both time and distance. A probabilistic map created could give some grounds for expecting the next strong earthquake in a certain confidence interval (+/- “one sigma”). Although the historic data of the seismic events with such size may not be complete, a block structure of the territory and a predominant azimuthal orientation of the quake occurrence are likely to be distinct features of the seismicity in SE Australia.

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Препоръчана за публикуване от
Катедра “Приложна геофизика”, ГПФ