

PRECURSORY SEISMICITY QUIESCENCE IN FOCAL REGIONS OF MODERATE EARTHQUAKES IN CENTRAL MACEDONIA

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ABSTRACT

Seismicity patterns associated with five moderate earthquakes in central Macedonia were studied by monitoring smaller earthquakes through a close network of seismic stations in the region. The feature commonly noticed is precursory quiescence around the epicenters of these events. The periods of seismic quiescence for the cases investigated in the present paper are longer than those given by the known relationships between the earthquake magnitude (M) and the precursor time (T). The relationship between M and the epicentral distance (D) where the precursory quiescence is observed is also studied and found larger than that of the epicentral area. Relying on empirical and theoretical studies of coseismic strain step, it turns out that the precursory quiescence observed reflects a crustal strain of the order of 10^{-8} - 10^{-7} .

1. INTRODUCTION

During the last two decades, attempts have been made to use seismicity patterns as a tool for earthquake prediction. Identification and classification of the patterns depend upon the criterion used, the magnitude threshold, the time period, the depth range and the judgement of the investigators. Closer examination of these factors makes it difficult to classify a seismicity pattern uniquely, particularly if the uncertainty in the epicentral location is high. However, deployment of a close network of stations for a long period removes some of these uncertainties in seismically active regions.

In central Macedonia region, such a network has been functioning since 1981. This, it has recorded well located events in the region, enabling us to study space and time variations of seismicity with a high degree of confidence. This region is a part of the Servomacedonian zone which seismically is the most active zone of the northern Greece and the surrounding area (Comninakis and Papazachos 1979). The last large shock occurred there was the 1978 earthquake ($M=6.5$), producing severe damage in the city of Thessaloniki and a large area around. As far as the lower magnitude seismicity concerns, numerous shocks of intermediate and smaller magnitudes often occur and are felt in Thessaloniki and the region around. The subject of this paper is to detect seismicity patterns before the occurrence of the moderate shocks of this area. From this viewpoint, spatio-

temporal variations in the seismicity were investigated. The precursory quiescence found by this investigation is furthermore examined in order to see how its duration and the distance where it observed, are connected with the main shock magnitude.

2. DATA ANALYSIS

Earthquake data covering the period 1981-1986 were used for the purpose of the present study. Hypocentre locations from 1981 to 1984 were obtained from a catalog compiled by Scordilis (1985) while from 1985 to 1986 by Scordilis and his colleagues (1987). The mean error in epicentral determination is 1.4 ± 0.5 Km. The data of the above catalogues are complete for earthquakes with magnitudes larger or equal to 2.5. The earthquakes having magnitude $M \geq 4.5$ are listed in Table I.

Table I. List of earthquakes of magnitude 4.5 or more in the area of central Macedonia during 1981-1986.

No	Date	h: m: s	φ_N^0	λ_E^0	h(Km)	M
1	Mar. 2, 1981	21:37:47.1	40.66	23.22	9	5.1
2	June 14, 1983	04:40:43.2	40.44	23.97	13	4.7
3	Aug. 26, 1983	12:52:10.7	40.46	23.89	9	5.2
4	Feb. 19, 1984	03:47:22.1	40.63	23.39	14	5.7
5	May 8, 1984	05:04:04.9	40.35	22.85	15	4.5
6	July 8, 1984	03:31:40.0	41.16	22.55	6	4.6
7	Oct. 5, 1984	14:22:48.6	40.97	23.32	6	4.7
8	Nov. 14, 1984	14:53:50.9	40.69	23.38	1	4.7
9	Feb. 2, 1986	14:34:04.0	40.73	22.21	11	4.9
10	Feb. 18, 1986	05:34:42.0	40.67	23.16	12	4.5
11	May 5, 1986	16:45:25.0	41.84	23.17	14	4.9

In order to study the seismicity patterns in relation to these moderate size earthquakes, the data concerning events of which the epicenters are located in a distance of 30 Km of the main events epicenters were considered. This has been done by the use of a computer program compiled by Papazachos and his colleagues (personal communication). After this procedure, it was found that the events numbered (1), (8) and (10) are in the same region with the event (4) and therefore were studied together. The event numbered (2) was included in the data sample concerning the event (3) for the same reason. In the later cases, where more than one events in the same data sample had magnitude $M \geq 4.5$, the event with the largest magnitude was considered as the main one. The events numbered (7) and (11) were excluded from the present study because of the lack of enough data.

Finally the events numbered (3), (4), (5), (6) and (9) were considered. For each case the completeness of the data set was again checked and found slightly different. The event (4) was preceded and followed by an enormous number of smaller shocks and therefore only those with $M \geq 3.5$ were taken.

In fig. (1) a regional map is shown. The circles having radii equal to 30 Km denote the areas around the epicenter of each main event, in which the epicenters of the earthquakes taken for each data sample are included. The numbers in the center of each circle denote the epicenters of the main events according to Table (I).

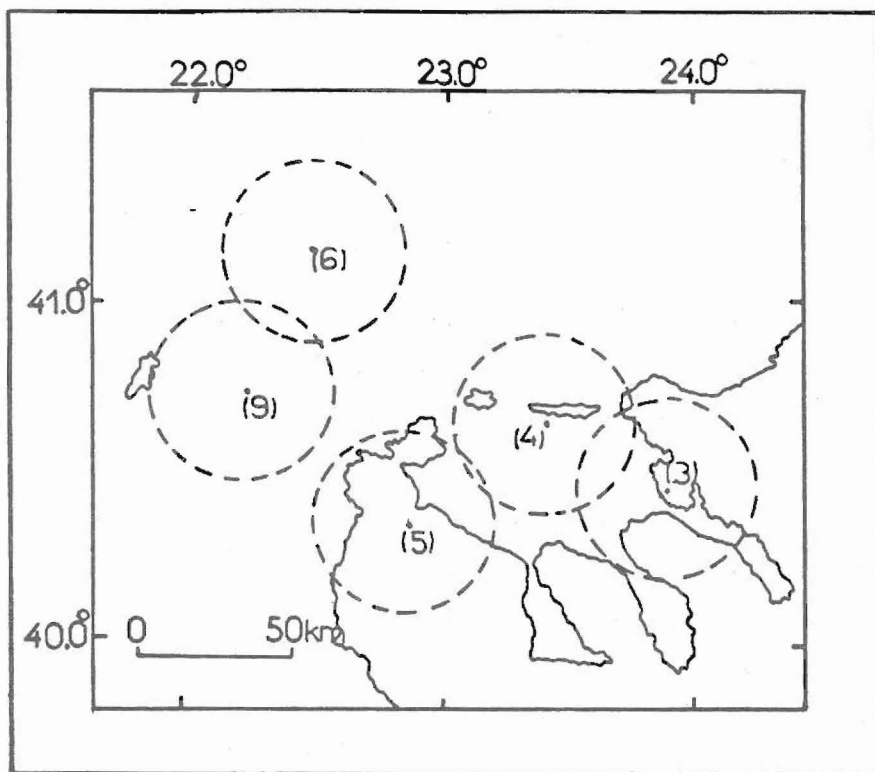


Fig. 1. Regional map of the central Macedonia with the epicenters of the main events (center of each circle). The hatched circles denote the areas of which the data sample for each case is taken.

3. SPATIO-TEMPORAL VARIATION OF SEISMICITY

Space-time plots can provide information on the behavior of seismic activity in a certain area. Such plots are shown in Fig. (2) concerning the areas around the epicenters of the five moderate shocks examined here. In each case the epicentral distance of each event versus the date of its occurrence was plotted. By the large polygons the epicenters of the main events are represented.

It is evident in all the cases the seismic quiescence before the occurrence of each main event. Increased activity around the occurrence of the main events is due to their foreshock and aftershock activity. Thereafter the seismic activity continued to its background level (Fig. 2a, 2b) or disappeared again in the area which was quiescent before the occurrence of the main event (Fig. 2c, 2d, 2e).

In order to see in more detail the behavior of the seismic activity in each case, the spatial distribution of the epicenters in different time periods as derived by the space-time plots are shown in figures (3) through (7).

Fig. (3) refers to the epicentral distribution around the epicenter of the earthquake that occurred on Aug. 26, 1983 with magnitude 5.2. Du-

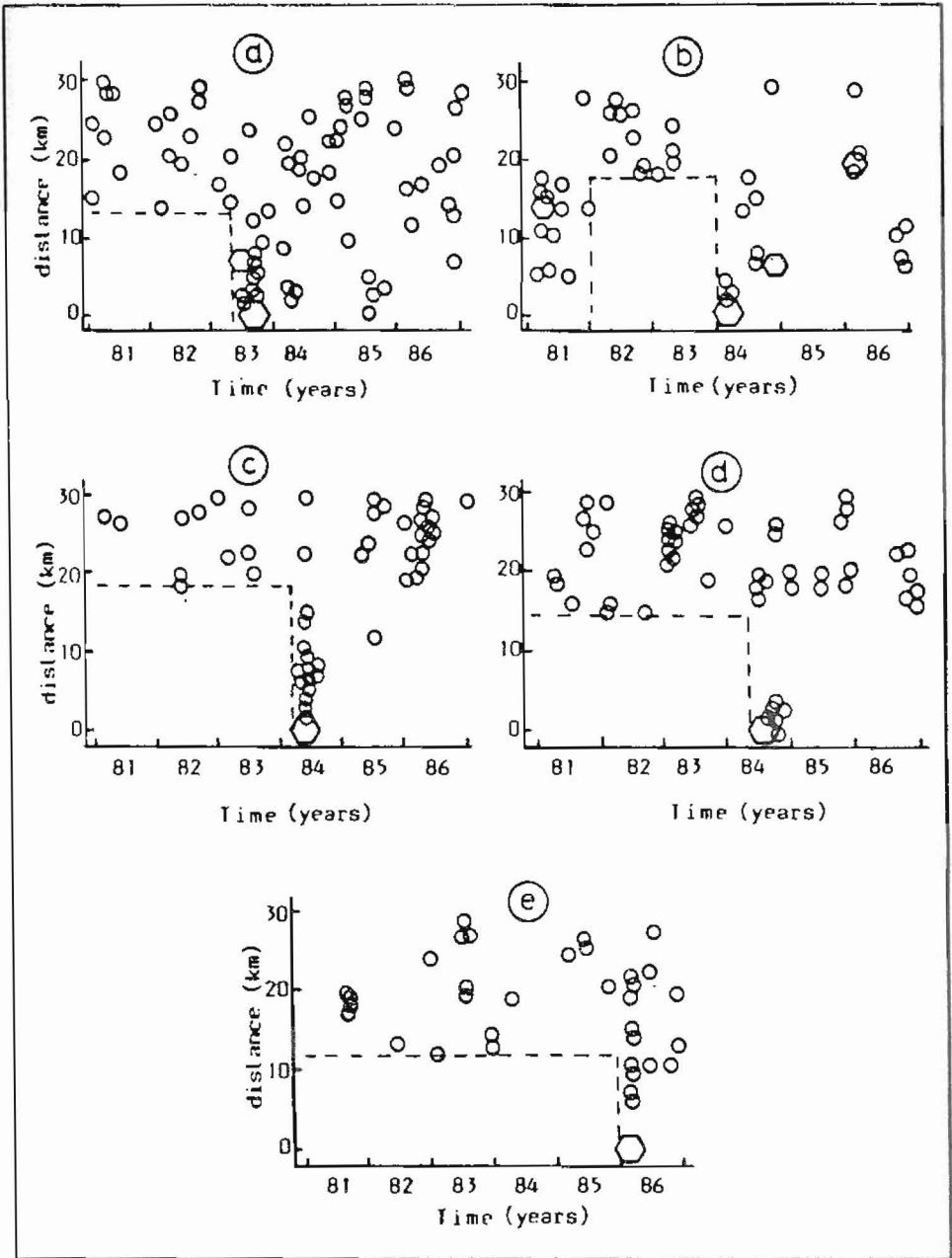


Fig. 2. Space-time distribution in the areas of the five main events. (a) 830614, $M=5.2$, (b) 840219, $M=5.7$, (c) 840508, $M=4.5$, (d) 840708, $M=4.6$, (e) 860218, $M=4.9$. By the polygons the earthquakes with $M \geq 4.5$ are represented.

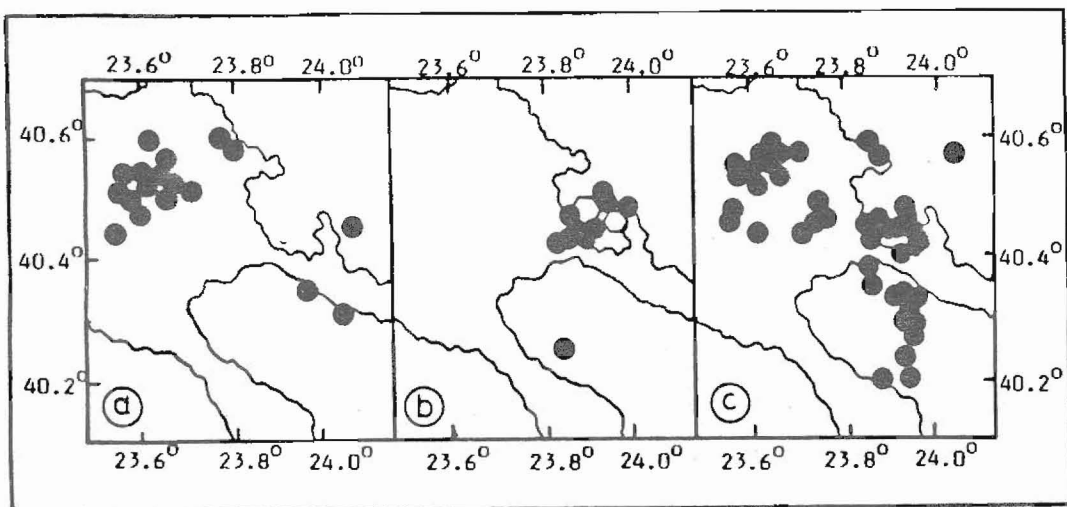


Fig. 3. Spatial distribution of shocks with $M \geq 2.7$ in the area of the 830614 ($M=4.7$) main event. (a) 810114 - 830428, (b) 830614 - 830830, (c) 831026 - 861212.

ring the first time period (810114-830428) it is shown that the seismic activity did not affect the central part of the area studied (Fig. 3a) whereas during the second period (830614-830830) the main event with its aftershocks occurred (Fig. 3b). During the third and last time period (831026-861212) the seismic activity is distributed in the whole area (Fig. 3c).

Epicentral maps for different time periods concerning the seismic activity around the epicenter of the Feb. 19, 1984 event, are shown in Fig. (4). During the first time period (810217-810804) the seismic activity took place in the central part of the area (Fig. 4a) including an event with $M=5.1$. This part remained unbroken (Fig. 4b) during the second period (811114-830419). This quiescence which lasted about one and a half year followed by a period of high activity concentrated almost in the central part and included the main event ($M=5.7$) and additionally an event with $M=4.7$ (Fig. 4c). An event with $M=4.5$ and its aftershocks occurred during the fourth period in the northwestern part of the region, which remained quiescent during the third period, while in the last period the seismic activity shifted to southeast without a main event (Fig. 4d, open circles).

Figure (5a) shows the epicentral distribution of shocks that occurred during the time period (810202-830721) around the epicenter of the May 8, 1984 main event ($M=4.5$). This distribution defines quite well a gap in the central part where the main event with its foreshocks and aftershocks occurred (Fig. 5b). Afterwards (850424-861207) the seismic activity distributed to the rest region (Fig. 5c).

In Fig. (6a) we can obviously see a gap surrounded by the epicenters of shocks occurred during the period (810407-840703). Part of this gap filled by the main event of July 8, 1984 ($M=4.6$) and its aftershocks (solid circles in Fig. 6b). During the last period (850605-861127) the seismic activity took place in the north part of the region (Fig. 6b, open circles).

A gap for more than four years is also defined for the last case studied here as it is seen in Fig. (7a). The main event of Feb. 2, 1986 occurred in the center of this gap (Fig. 7b). Its aftershock activity (solid circles) lasted about three days and afterwards the seismic activity (open circles) covered the east part of the region (Fig. 7b).

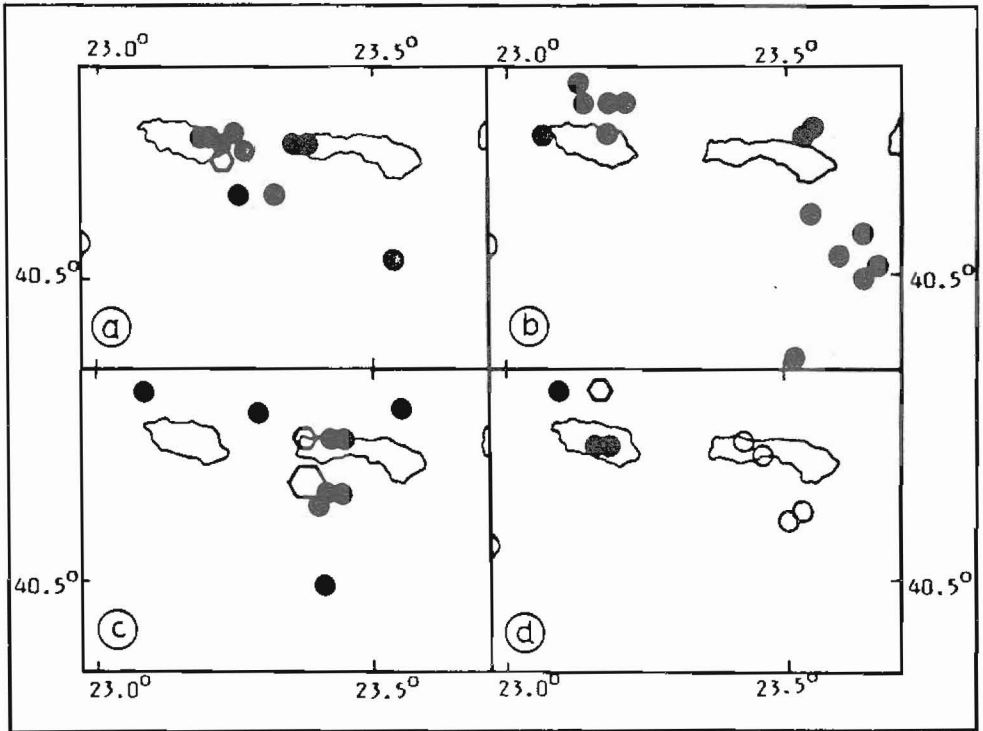


Fig. 4. Spatial distribution of shocks with $M \geq 3.5$ in the area of the 840219 ($M=5.7$) main event. (a) 810217 - 810804, (b) 811114 - 830419, (c) 840219 - 841114, (d) 860205 - 860218 (black circles) and 861029 - 861115 (open circles).

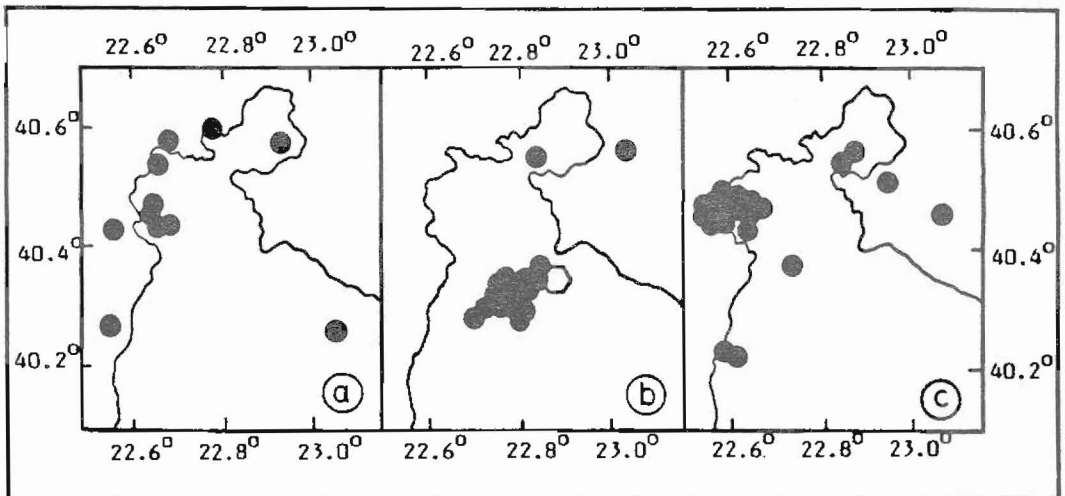


Fig. 5. Spatial distribution of shocks with $M \geq 2.6$ in the area of the 840508 ($M=4.5$) main event. (a) 810202 - 830721, (b) 840425 - 840727, (c) 850424 - 861207.

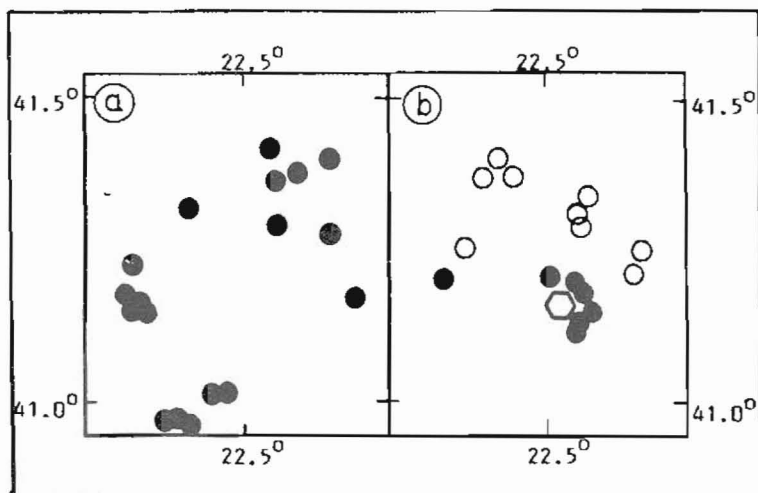


Fig. 6. Spatial distribution of shocks with $M \geq 3.0$ in the area of the 840708 ($M=4.6$) main event. (a) 810407 - 840703, (b) 840708 - 840813 (black circles) and 850605 - 861127 (open circles).

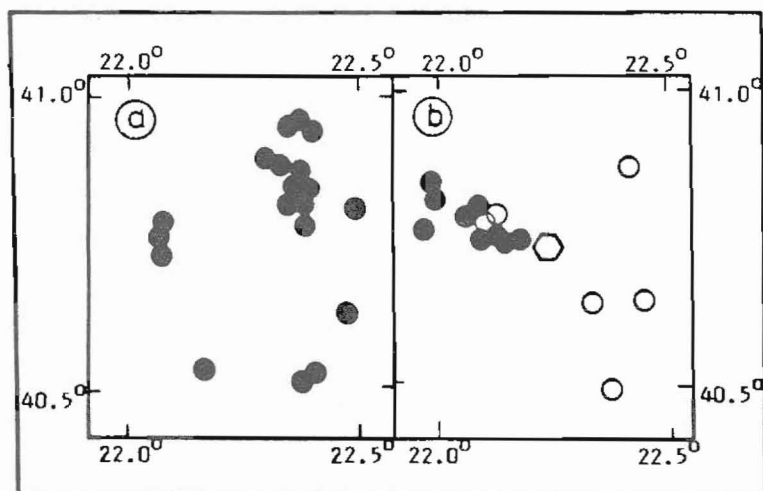


Fig. 7. Spatial distribution of shocks with $M \geq 2.5$ in the area of the 860218 ($M=4.9$) main event. (a) 810814 - 851016, (b) 860218 - 860220 (black circles) and 860502 - 861123 (open circles).

4. RELATIONSHIP BETWEEN THE MAGNITUDE OF THE MAIN SHOCK AND THE PRECURSOR TIME AND DISTANCE

In order to see how the main shock magnitude is related with the duration of the precursory quiescence and with the distance where this quiescence is detected, it was deciding to examine if our data follow certain relationships proposed for analogous cases. Furthermore, to compare

our data with these ones obtained for other regions in the world. Published data are available for the area of Japan (Rikitake 1987).

Rikitake (1979,1982) reported on the relationship between precursor time (T) and magnitude (M) of the main shock for precursors of certain kinds. When T is measured in units of 24 hours, it had been shown that a relation such as:

$$\log T = a + bM \quad (1)$$

approximately holds good.

Figure (8) shows the log T - M relationship for precursory seismic gap and quiescence. By the solid circles the Japanese data are represented while by the open ones the data of the present study. The precursor time in four

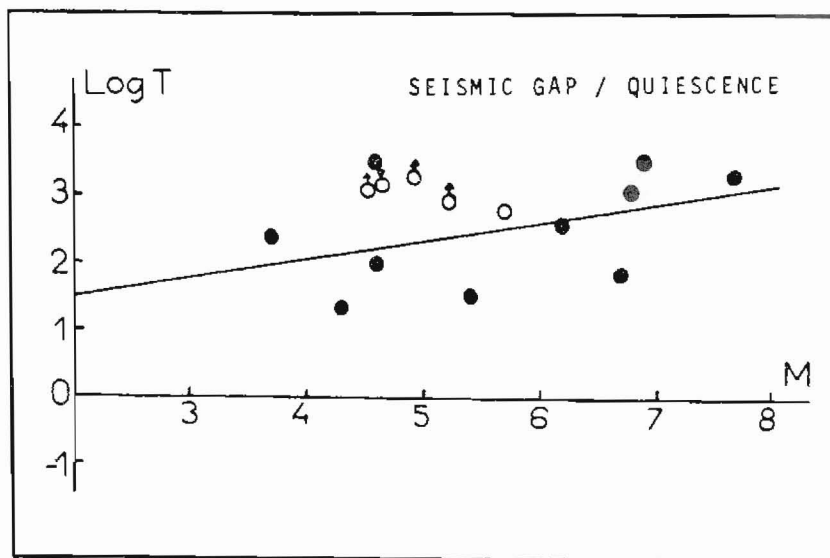


Fig. 8. Log T - M relationship for seismic quiescence for Japanese data (black circles, after Rikitake 1987) and for the data of the present study (open circles).

out of five cases is not precisely defined because the quiescence was observed since the beginning of the available data set. In these cases this time was assumed to be equal or larger than that derived by the space-time plots. The arrows on the circles corresponding to these cases show the tendency of this time to be larger. Apart of this uncertainty in the strict definition of the precursor time, the data of the present study are compatible enough to the Japanese ones.

Rikitake (1987) used the same data to see the relationship between the epicentral distance (D) where the precursor is detected and the main shock magnitude (M). In Figure (9) the M - logD plot is shown for Japanese data (solid circles) and the data of the present study (open circles). The compatibility of both the data sets is obvious. The above author pointed out that although it has customarily been believed that a precursor may be detected only over the epicentral area of an earthquake where most seismic energy is stored, the study of the recent Japanese data indicated that a precursor may in favorable cases be observed even at an epicentral distance

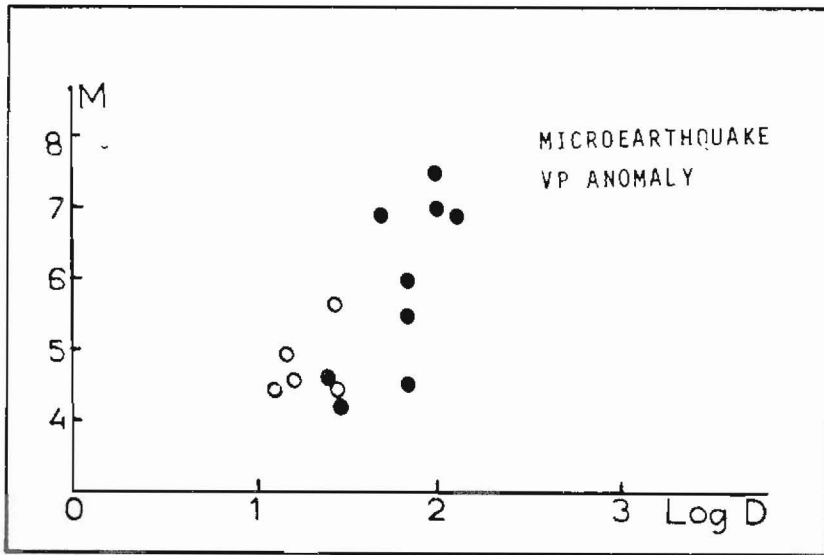


Fig. 9. M - log D plots for microearthquake and seismic wave velocity change for Japanese data (black circles, after Rikitake 1987) and for microearthquakes for the present study (open circles).

which is several times larger than the dimension of the epicentral area. This last holds in all the cases studied in the present paper, that is the quiescent area is obviously larger in all the cases than the epicentral area of the impending shock as we can see in Figures (3) through (7).

Wideman and Major (1967) and Takemoto (1970), who analysed coseismic strain steps associated with earthquakes, presented curves for which a strain step of specified amplitude is to be observed on the M-logD plane on an empirical basis. As long as we assume that precursors are associated with a distant strain field caused by some crustal effects at the focal region prior to an earthquake, it is not unreasonable to assume that the M-logD plots for precursors, reflect the strain state. Figure (10) represents M-logD plot for the five cases together with the lines on which crustal strain approximately takes on a value ranging from 10^{-9} - 10^{-6} . Our data are in the range 10^{-8} - 10^{-7} . This is in good agreement with Rikitake (1987) who pointed out that precursors of various disciplines showed that each discipline represents a peculiar crustal strain state, and furthermore that the precursory quiescence is among the disciplines that represent a strain of 10^{-8} - 10^{-7} .

5. CONCLUDING REMARKS

The occurrence of the moderate shocks in the area of the central Macedonia brings out a common pattern of seismicity, namely the appearance of the seismic of the second kind in their seismogenic volumes. This can provide us a useful tool in forecasting the site of a future shock in this area by monitoring the lower magnitude seismicity.

The dimensions of the seismic gaps in all the cases studied here are larger than the dimensions of their seismogenic volumes. On the other hand

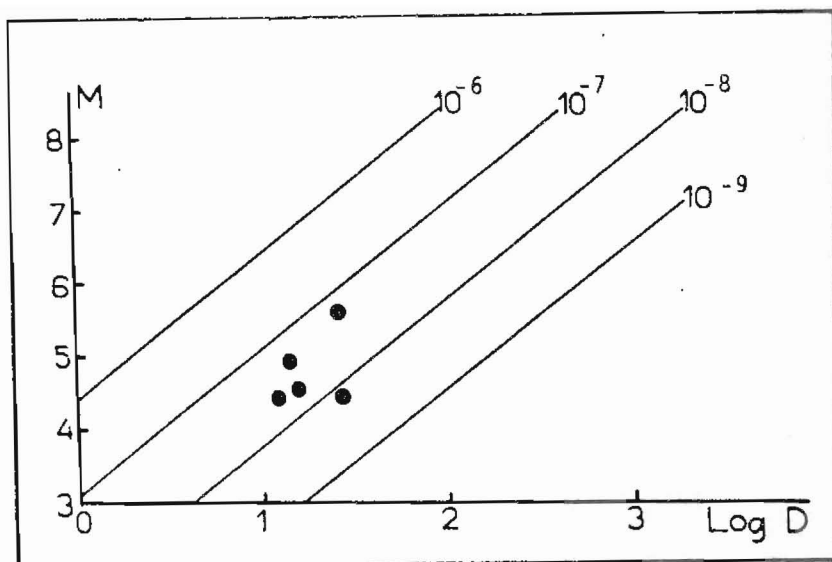


Fig. 10. $M - \log D$ plots for the data of the present study. The approximate straight lines on which crustal strain due to focal process takes on specified value are also shown.

The duration of the precursory quiescence is also larger than the expected one for shocks of this order of magnitude. These last pose the problem of a reliable estimation of the magnitude and the time of occurrence of a future shock. As far as the estimation of the magnitude concerns, following our observations we can say that there is an upper limit, since it seems to be no larger than that one corresponding to an earthquake with an aftershock volume equal to the dimensions of the defined gap. The estimation of the occurrence time is more complicated since we have not a certain value of magnitude and additionally it was shown that this time exceeded the expected one derived by known empirical formulae.

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