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SOME PROPERTIES OF FORESHOCK SEQUENCES IN THE AREA OF GREECE

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ABSTRACT

A complete data set of 417 shallow main shocks that occurred in the area of Greece during 1911-1985, is used in the present study. In 187 case, these main shocks had been preceded by at least one foreshock. It is found that in about 60% of these cases the largest foreshock or the second largest foreshock occurred within one day before the main shock, while in about 30% and 15% of the cases, these foreshocks occurred 10 days or more and 1 month or more before the main shock occurrence. This conclusion reconfirms previous results which were bsed on smaller data sets. On the other hand, the composite temporal distribution of all foreshocks in the 187 cases reveals an increase in seismic activity that starts about 2 months before the main shock, culminating in a final rapid acceleration of the occurrence rate during the last day before the main shock generation.

ΠΕΡΙΛΗΨΗ

Στην παρούσα μελέτη, εξετάζονται οι προσεισμοί που έγιναν πριν από 417 επιφανειακούς κύριους σεισμούς στην περιοχή του Αιγαίου. Σε 187 περιπτώσεις υπάρχει τουλάχιστον ένας προσεισμός. Βρέθηκε, ότι σε ποσοστό περίπου 60% των περιπτώσεων αυτών ο πρώτος ή ο δεύτερος μεγαλύτερος προσεισμός έγινε σε διάστημα μιας μέρας πριν από τον κύριο σεισμό, ενώ σε ποσοστό περίπου 30% και 15% των περιπτώσεων, αυτοί οι προσεισμοί έγιναν 10 μέρες ή περισσότερες και 1 μήνα ή περισσότερο πριν από τη γένεση του κύριου σεισμού. Τα συμπεράσματα αυτά επιβεβαιώνουν προηγούμενες μελέτες, στις οποίες χρησιμοποιήθηκε μικρότερο δείγμα δεδομένων.

Η σύνθετη κατανομή της συχνότητας γένεσης όλων των προσεισμών, όλων των 187 κυρίων σεισμών έδειξε ότι υπάρχει αύξηση της προσεισμικής δραστηριότητας που αρχίζει δύο περίπου μήνες πριν από τον κύριο σεισμό, και η οποία επιταχύνεται την τελευταία μέρα πριν από αυτόν.

INTRODUCTION

Foreshock activity has been a matter of primary concern, since foreshocks are the most obvious and common premonitory phenomena preceding strong earthquakes. Previous studies on foreshocks have concetrated on the rate of foreshock occurrence before strong earthquakes and, on the other hand, on the assessment of the probability that a given earthquake will be followed by a main shock during a certain time interval.

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Some properties of foreshock sequences have been studied by Drakopoulos (1968). Papazachos(1975), considering all shallow main shocks which occurred in the Aegean area from 1914 to 1973 with magnitudes larger than or equal to 6.0, found that the cumulative frequency distribution, N(T), of the time difference between the main shock and its largest foreshock, is given by the relation

$$N(T) = c - k \log T \qquad (1)$$

where c and k are constants with values equal to 0.49 and 0.31, respectively.

Tsapanos and his colleagues (1988), using data sets with shallow main shocks which occurred all over the world, determined similar values for the constants c and k.

The aforementioned results suggest that in cases where foreshocks occur, there is an almost 50% probability that the main shock will occur within 1 day after the occurrence of its largest foreshock.

Jones(1985) found that the probability that an earthquake in southern California ($M \geq 3.0$) will be followed by an earthquake of larger magnitude within 5 days and 10 Km (i.e., will be a foreshock) is 6 ± 0.5 per cent. She also found that the main shock will most likely occur in the first hour after the foreshock.

Regarding the rate of foreshock occurrence before strong earthquakes, Jones and Molnar(1979) found an increase in seismic activity that starts about 3 months before the main shocks and that close to the epicenters of the main shocks, there are a very large number of events that occur in the day immediately preceding the main shocks in about 50 out of 250 cases.

In this paper, the values of the constants c and k of the cumulative frequency distribution of the time difference between the main shocks and their largest foreshocks are redetermined, using a larger data set of foreshock sequences which occurred in the the Aegean area, values for the same constants for the cumulative frequency distribution of the time difference between the main shocks and their second largest foreshocks are calculated and the temporal distribution of the foreshocks which occurred in the few hours, days and months before main shocks is examined.

PROBABILITY OF OCCURRENCE OF THE LARGEST FORESHOCKS

All of the foreshock sequences which are studied, come from the catalogue of Comninakis and Papazachos(1989). This catalogue gives information for the origin times and magnitudes for the known foreshocks and aftershocks of all main shocks of the following magnitude ranges which occurred during the corresponding time periods:

$M \geq 5.6$, 1911 - 1965
$M \geq 5.0$, 1966 - 1985

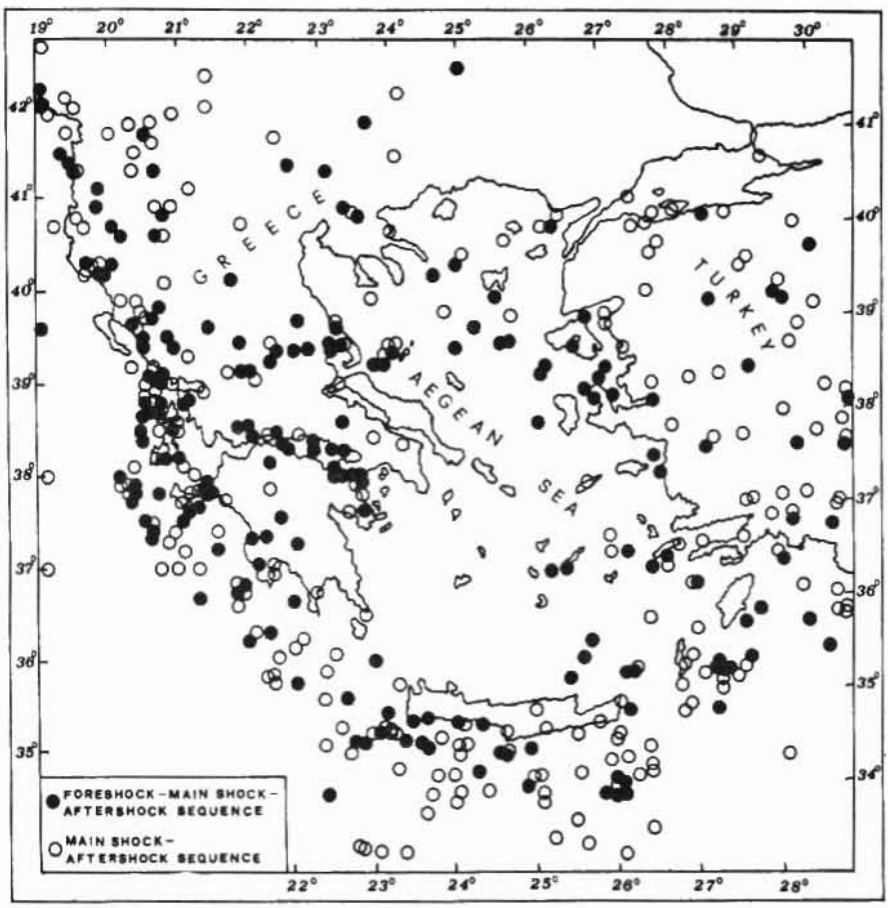

Fig. 1. Full circles denote shallow main shocks which occurred in the area of Greece during 1911-1985 and were preceded by at least one foreschock.

It was found that 187 main shocks were preceded by at least one foreshock. These main shocks are denoted by full circles in figure (1). The time difference between each main shock and its largest foreshock was calculated. Figure (1) shows the probability, $N_1(T)$, as a function of the time difference, T, between the main shock and its largest foreshock. The data are fitted in the least squares' sense by the relation

$$N_1(T) = 0.60 - 0.30 \log T \qquad (2)$$

The probability function, $N_2(T)$, of the time difference, T, between each main shock and its second largest foreshock (107 cases), is presented in Figure (2). The theoretical curve is given by

$$N_2(T) = 0.62 - 0.32 \log T \qquad (3)$$

Both relations suggest that there is an approximately 60% probability that the main shock will occur within 1 day after the occurrence of its largest foreshock or its second largest foreshock.

TEMPORAL DISTRIBUTION OF FORESHOCKS

Recent investigations showed that during the latest phase of the seismic cycle, called pre-shock activity phase, an accelerated energy release rate (or earthquake occurrence rate) takes place, which culminates just before the second main shock of the seismic cycle. Its duration, being independent of the magnitude of the main shock which follows, is 2.7 years. The last part of this phase starts several days up to several weeks before the main shock and concerns the foreshocks, in the strict sense (Karakaisis et al., 1991).

In search of temporal patterns of foreshock activity, the seismicity during a time interval of approximately four months before every main shock is examined. Since many of the individual foreshock sequences contained few events, thus making difficult the definition of temporal patterns of foreshock occurrence, all of the sequences were combined into a single sequence. This was done by putting all of the sequences onto the same time axis where the origin is the time of occurrence of each main shock. The resulting time series were smoothed by a seven-point filter. The same configuration has been used by Jones and Molnar (1979).

Figure (3) exhibits the foreshock activity during the last four months before the main shocks, as a function of time. It is observed that the daily frequency of foreshock occurrence starts to increase gradually, approximately two months before the main shock and lasts up to the main shock generation. Figure (4) shows the frequency of occurrence during the 10 days before the main shock. It is obvious that a large part of foreshocks occur in the day immediately preceding the main shocks. Looking for very

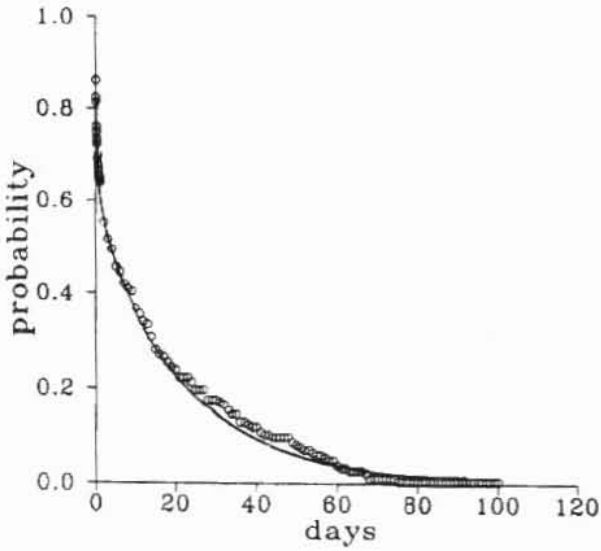

Fig.2. Distribution of the probability $N_1(T)$, of the occurrence of the largest foreshocks that precede shallow main shocks in the Aegean area.

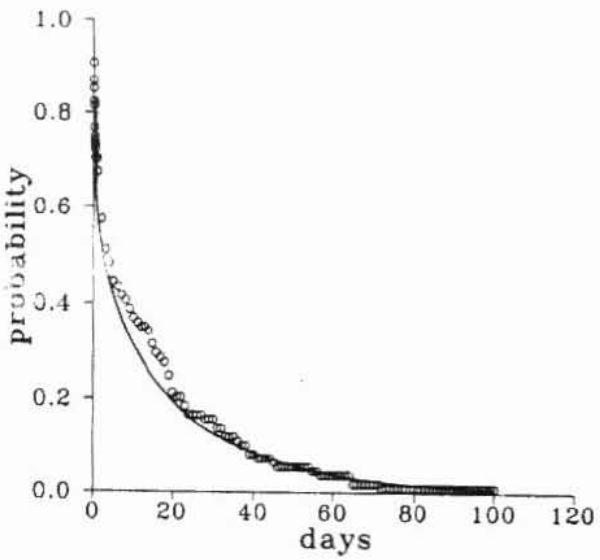

Fig.3. Distribution of the probability, $N_2(T)$, of the occurrence of the second largest foreshocks that precede shallow main shocks in the Aegean area.

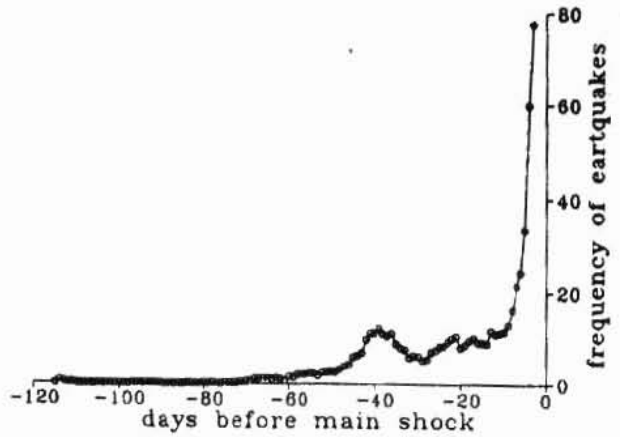

Fig.4. The daily foreshock activity in the last 4 months.

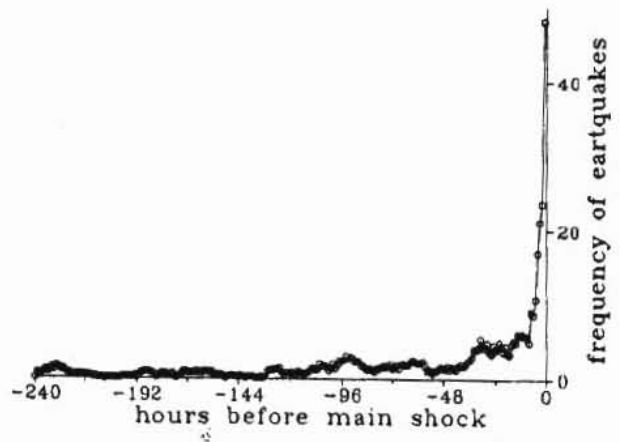

Fig.5. The hourly foreshock activity in the last 10 days.

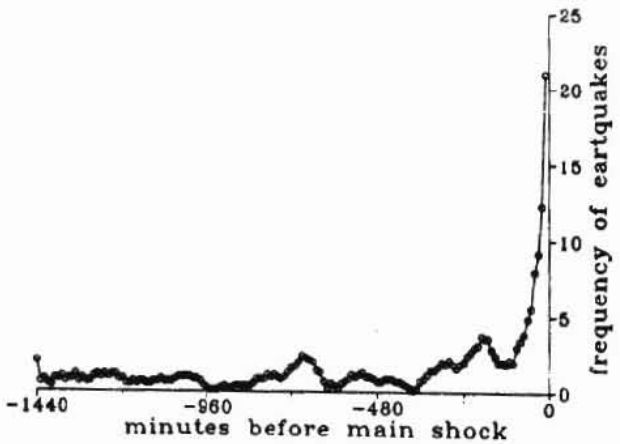

Fig.6. Foreshock activity every 10 minutes in the last day before the main shock.

short-term foreshock activity pattern, the frequency of occurrence every 10 minutes during the last day before the main shock is plotted in Figure (5). It is observed that the frequency decreases a few hours before the main shock, while the peak in the foreshock activity starts 2 hours before the main shock generation.

DISCUSSION

It is reconfirmed that there is a probability of about 60% that the main shock will occur within 1 day after the occurrence of its largest foreshock or of its second largest foreshock. This makes relations (2) and (3) very useful to studies of seismic hazard assessment, given that in the area of Greece, about 45% of the shallow main shocks which occurred during 1911-1985 (187 out of 417) were preceded by at least one foreshock.

Examining the temporal distribution of seismicity a few months before the main shocks, it was found that an increase in activity starts about 2 months before the main shocks. Similar results have been obtained by Jones and Molnar (1979), although they found an apparent increase 3 months before the main shocks. They concluded that this was probably not a common feature of foreshock sequences. Furthermore, the plot of all the data in Figure (4) reveals a further increase in seismic activity beginning about 1 day before the main shocks, which appears to be the culmination of the increasing frequency of foreshock occurrence beginning earlier, as Jones and Molnar (1979) have also found.

Regarding the foreshock seismicity variations the day immediately preceding the main shock, it seems to exist a decrease in the frequency of occurrence a few hours before the main shock, which is followed by the high rate of occurrence that lasts up to the main shock generation. However, more work is needed to clarify this point, although similar results have been obtained by Jones and Molnar (1979), as well as by Sobolev and his colleagues (1987) on the basis of laboratory experiments.

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