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PROPERTIES OF THE GLOBALLY DISTRIBUTED AFTERSHOCK SEQUENCES: EMPHASIS IN THE CIRCUM-PACIFIC BELT

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ABSTRACT

Research on properties of aftershock sequences has been carried out here, in the light of new data. Aftershock sequences, with magnitudes of the main shock $M_s \geq 7.0$, globally distributed during the time span 1964-1986 are taken into account. Relation between the magnitude of the main shock and the number of the following aftershocks has been found, as well as between the ratio of the aftershocks energy to the energy of the main shock against the main shock has been derived. The latter depends on the geotectonic conditions in the seismic region. The spatial distribution of the seismic moment release, in the circum-Pacific belt, can provide information about the mechanical properties in the focal region.

ΣΥΝΟΨΗ

Οι ιδιότητες των μετασεισμικών ακολουθιών μελετώνται στην εργασία αυτή, σύμφωνα με τα πλέον πρόσφατα δεδομένα. Για τον σκοπό αυτό επεξεργάσθηκαν μετασεισμικές ακολουθίες μεγάλων σεισμών, με μέγεθος του κύριου σεισμού $M_s \geq 7.0$, που έγιναν σε όλη τη Γη κατά το χρονικό διάστημα 1964-1986. Βρέθηκαν σχέσεις, μεταξύ του μεγέθους του κύριου σεισμού και του αριθμού των μετασεισμών, καθώς και μεταξύ του κύριου σεισμού και του λόγου της ενέργειας των μετασεισμών προς την ενέργεια του κύριου σεισμού. Ο λόγος αυτός εξαρτάται από το γεωτεκτονικό περιβάλλον του σεισμογόνου χώρου. Η χωρική κατανομή της σεισμικής ροπής, στην Περιειρηνική ζώνη, μπορεί να δώσει πληροφορίες για τις μηχανικές ιδιότητες του εστιακού χώρου.

INTRODUCTION

A large amount of the residual seismic energy, caused by the heterogeneity of the focal region, is released by the aftershocks.

Aftershock sequences are sources of information about earthquake nucleation and the physical properties of the materials in the fault zone (Benioff 1951, Utsu 1961, Mogi 1963, Scholz 1968, Dieterich 1986, Frohlich 1987). The tectonic setting and the mode of faulting are factors other than the fault surface properties that might control the behaviour of the sequences (Kisslinger and Jones 1991). Chracteristics of sequences that may provide useful information are the spatial distribution, the total number of aftershocks, and the rate with which the sequence decays with time. Also the seismic moment which is released through the aftershocks can be used to investigated some properties of the Earth's material in the aftershock region.

A large number of studies which focus on the properties of aftershock

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sequences have been published (Utsu 1961, 1969, Papazachos et al. 1967, Page 1968, Ranalli 1969, Papazachos 1974, Tsapanos 1990a, 1992).

The purpose of the present work is to study some properties of the aftershock sequences globally distributed. On the other hand emphasis is given in the circum-Pacific belt which is the most seismically active system of the world.

THE DATA SET

Recently Tsapanos et al. (1990) constructed a global complete and homogeneous catalogue with magnitudes $M_s \geq 5.5$ covering the time period 1897-1986. The method used to obtain the completeness of the data of this catalogue has been described elsewhere (Papazachos et al. 1990, Tsapanos 1990b). This catalogue is very recently improved by considering the magnitudes given by Pacheco and Sykes (1992). This revised catalogue is used in the present work. For lower magnitudes the monthly bulletins of the I.S.C., have been used as well. The examined number of the aftershock sequences is 184 and they occurred in the time span 1964-1986. Only shallow earthquakes with magnitudes of their main shock $M_s \geq 7.0$ are taken into account, which are (main shocks and aftershocks) quantified on the surface wave magnitude scale.

An earthquake is considered to be an aftershock if it occurs within 100 days after the main shock and its location is within a distance L (Km) from the epicenter of the main shock. L is the dimension of the aftershock area and is related to the surface wave magnitude of the main shock by the empirical formula ($L=0.5M_s-1.8$ in Km) given by Utsu (1969). Recently Tajima and Kanamori (1985) suggested that the aftershocks of the large shocks may extend to 1 year. In view of this, we examine the properties of the aftershock sequences, taken into account the aftershocks which were occurred 1 year after the main shock.

DEPENDENCE OF THE NUMBER OF AFTERSHOCKS ON THE MAGNITUDE OF MAIN SHOCK

It is well known that the number of the aftershocks increases with the magnitude of the main shock and is also known the great influence that the focal depth plays on the number of earthquakes. Papazachos et al. (1967) suggested the number of aftershocks depends on the properties of the materials in the aftershock region and on the distribution of the applied stress. On the other hand Mogi (1969) proposed that in regions of complex tectonics, where there are many weak points, earthquakes have more aftershocks than elsewhere. The number of aftershocks characterizes the sequence because this number is related to the tectonic structure and is simply determined parameter (Olsson 1979). Singh and Suarez (1988) found that the number of aftershocks correlates with the degree of coupling on the plate interface.

Relations between the main shock and the number of aftershocks have been derived by many scientists (Mogi 1967, Papazachos et al. 1967, Utsu 1970, Olsson 1979) among others. In the present study the aftershocks, of each individual sequence, with magnitudes $M_s \geq 4.0$ are extracted from the above referred catalogues. The parameters **a** and **b** (of the Gutenberg and Richter law) are computed for each sequence. We observed that the data used were not complete for the same magnitude threshold for all the sequences, due to many factors (i.e. the local seismotectonic conditions, etc.), denoting the lack of the aftershock data. In order to avoid this, we estimated the mean **b** value from all the sequences, as well as its σ (standard deviation). Then the less reliable estimations, which are out of the range $\pm 2\sigma$, were omitted. We repeated this procedure until the omitted b-values were about the 10% of the total estimations. This erasure did not affect to the accuracy of the results. The finally obtained **b** value is equal to $1.00(\pm 0.24)$. In figure (1) we can see the statistical distribution of the parameter **b**.

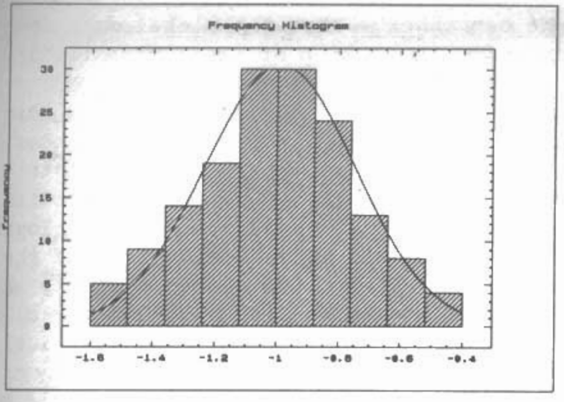

Fig. 1: The frequency distribution of the b-values.

Using constant this **b** value, we recalculated the **a** value and also the number of aftershocks which have a minimum magnitude M=4.0 for each one of the aftershock sequences. Then we calculated the mean number of aftershocks and its logarithm, corresponding to each magnitude (i.e. we calculated the mean number of aftershocks of the all the main shocks with M_s=7.0, M_s=7.1, M_s=7.2, etc.). In figure (2) the distribution of the logarithm of the mean number of aftershocks against the corresponding main shock magnitude is illustrated. The derived relationship is:

$$\log N_{aft} = -3.23(\pm 0.68) + 0.75(\pm 0.09) M_s \qquad (1)$$

with standard deviation 0.12 and correlation coefficient 0.93.

Comparable values for Greece was found by Papazachos (see in Papazachos and Papazachou 1989). There is also an appearance of a relation between the size of aftershock sequences and seismic moment release rates (Davis and Frohlich 1991), suggesting that large aftershock sequences occur where there is a high degree of seismic coupling between plates (Peterson and Seno 1984).

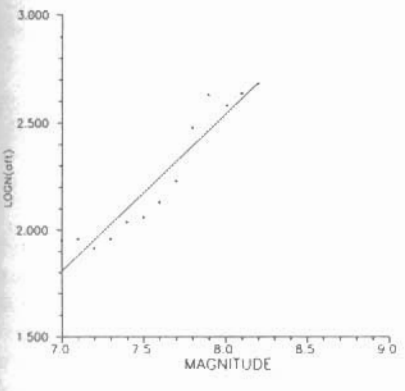

Fig. 2: Relationship between the logarithm of the mean number of aftershocks against the corresponding main shock magnitude.

DISTRIBUTION OF THE RATIO OF THE ENERGY OF THE AFTERSHOCKS TO THE ENERGY OF THE MAIN SHOCK

The logarithm of the ratio, r, of the energy which is released through aftershocks to the energy of the main shock varies with the inhomogeneity of the rocks in the focal region (Papazachos 1973). This quantity has high values in regions of high inhomogeneity, while in regions with great homogeneity the corresponding values are low. In order to be able to examine this ratio, a computer program compiled by Karakaisis (1988) is used. This program needs as an input the magnitude of the main shock, the parameters **a** and **b** of the known formula of Gutenberg-Richter (1944) and the lower considered magnitude of the aftershocks. It allow us not only to assess the released energy of the estimated aftershocks (magnitude threshold ≥4.0), but it also calculates (through Gutenberg-Richter relation) the assumed energy if all aftershocks with magnitudes ≥0.0 could be recorded. Then calculates the logarithm of the assumed energy released, the logarithm of the energy of the corresponding main shock and consequently the quantity logr. In figure (3) we plotted the logr versus the magnitude of the main shock M_s. The graph indicate that this quantity shows weak dependence on the magnitude of the main shock.

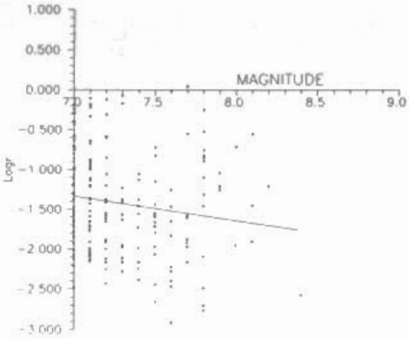

Fig. 3: The weak dependence of the ratio, logr, of the energy of the aftershocks to the energy of the main shock, on the magnitude of the main shock.

We can observe that the global data confirmed the conclusion of Papazachos (1973), about the independence or the weak dependence of the logr on the magnitude of the main shock, for the Greek aftershock sequences. In figure (4) we can see the spatial distribution of the logr in the circum-Pacific belt. Here the values of the quantity logr have been plotted at the epicenters of the main shocks. If the logr depends mainly on the degree of homogeneity of the material, then figure (4) represents the geographical distribution of the degree of homogeneity of the crustal material in the circum-Pacific belt. The conclusions about the distribution of homogeneity obtained from the logr, are in good agreement with previous ones deduced by the application of different method (Tsapanos 1990b). The logr also depends on the stress distribution. Hence, its distribution presents also the distribution of the stresses and is in quite good correlation with the distribution of the b-values (Tsapanos 1990b) around the

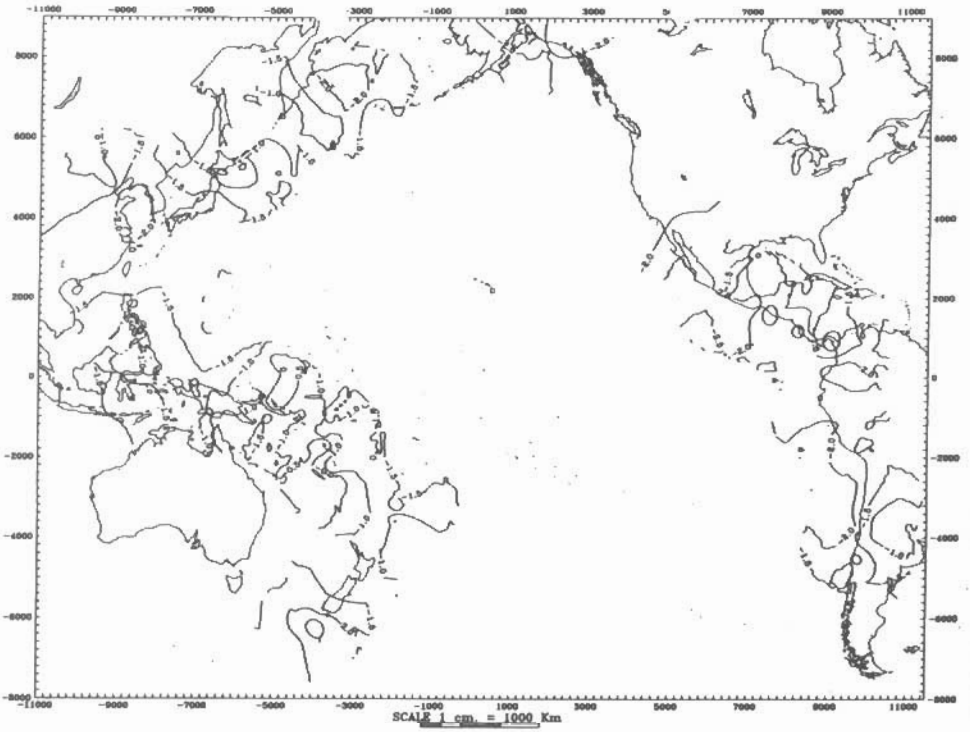

Fig. 4: The spatial distribution of the quantity logr, in the circum-Pacufic belt.

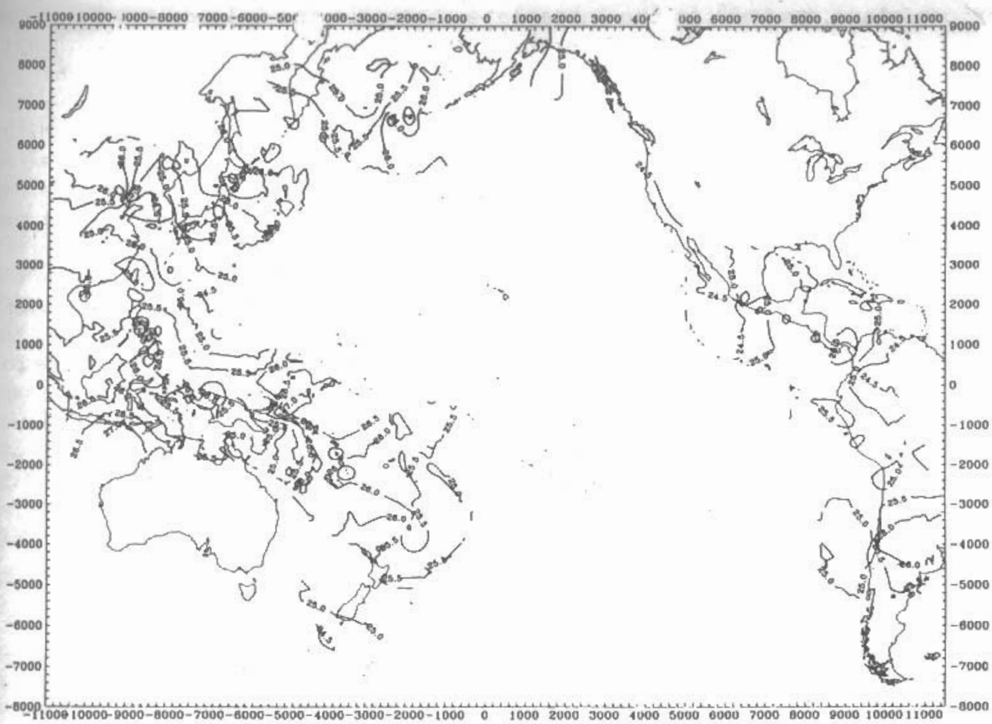

Fig. 5: The spatial distribution of the logarithm of the seismic moment release in the circum-Pacific.

Pacific, which shows low values in the eastern Pacific (American plate) and high values in its western part.

SEISMIC MOMENT RELEASE IN THE CIRCUM-PACIFIC BELT

The seismic moment describes the "size" of the earthquakes and is a fundamental parameter which controls the static aspects of them. The seismic moment released through the aftershocks of a seismic sequence was calculated for each one of the 184 examined aftershock sequences using the Molnar's (1979) formulation. In figure (5) well-defined zones of the logarithm of the seismic moment release are presented, in the circum-Pacific belt. High values of seismic moment release, represent high seismic energy release and consequently large number of aftershocks.

Values which covered the whole range of the seismic moment release (24.5-27.0) are illustrated in the western Pacific, while low and intermediate (24.50-26.0) values are presented in the eastern Pacific. This means relative large number of aftershocks occurred in the western Pacific, than in the eastern part. Same results for these two parts of the Pacific are found by Singh and Suarez (1988).

They interpreted it that the degree of coupling controls the scale length of the heterogeneities present on the plate interface: strong coupling results in fewer heterogeneities, whereas a large number of heterogeneities exist in regions of weak coupling.

In details, low values are indicated in the place where Nazca underthrusts

American plate, as well as the intraplate shocks in the inland of Colombia and Venezuela. Anomalously low values are shown in offshore of Jalisco region (Mexico). Same values are illustrated in the Idaho, Oregon and Washington states and at the north part of British Columbia (W. Canada). Relative high values are demostrated only in the central part of Chile. Generally, in this place of Pacific we can not observe sharp changes in the seismic moment release and consequently large areas exhibit almost constant moment release values. This can be interpreted by the existance of large areas having the same homogeneity in the crustal materials. From the British Columbia to the Aleutian islands the seismic moment release is gradually going from low to high values. From the Aleutian islands to the Kamchatka peninsula the opposite situation exists.

The highest values in the western Pacific are presented in the northern part of Honshu island, Sumbava and Flores islands, and the New Britain island. High values are shown in New Hebrides, Solomon and Halmahera islands. Low values are illustrated in the south of New Guinea, Kyushu and Riu-Kiu islands, Philippines islands and in the back-arc of Marianas trench. Abrubt changes in the values of the seismic moment release are demostrated throughout this part of Pacific. This maybe indicates a multifracture area with high degree of heterogeneity.

CONCLUSIONS

The most reliable data of aftershock sequences globally distributed are examined in the present study. Empirical relations, which maybe useful in any study of aftershock hazard, are derived. We found a relation between the number of the aftershocks, released in an aftershock sequence, and the magnitude of the main shock. The obtained results are in very good agreement with previous ones estimated for Greece by Papazachos. The distribution, of the ratio of the energy of the aftershocks to the energy of the main shock, shows weak dependence on the magnitude of the main shock. Its spatial distribution in the circum-Pacific belt reveals the distribution of the homogeneity of the crustal material, as well as the distributions of the stresses which prevail, in the most seismically active zone of the world. Finally the obtained results from the distribution of the seismic moment, released by the aftershocks, in the circum-Pacific belt strongly supports the previous obtained results.

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