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RECENT 2005-2006 STRONG SEISMIC ACTIVITY IN GREECE UNDER THE ASPECT OF SEISMICITY PARAMETERS TEMPORAL VARIATION ANALYSIS

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Abstract

Recent strong seismic excitation (2005-2006), which occurred at the northwestern part of the Hellenic arc and north of Samos Island close to the coasts of the Asia Minor, is investigated under the aspect of temporal variation seismicity profile of activated seismic zones. Seismicity profile is constructed by the means of the FastBEE analysis introduced recently. Seismicity parameters considered in this study are b-value, energy released in the form $logE^{2/3}$ and the quantity logN of the cumulative number of events, in the examined area.

Due to homogeneity and completeness reasons, the earthquakes with magnitudes $M_L \geq 3.0$ since 1990 from the earthquake catalogue of the Geodynamic Institute of the National Observatory of Athens, is used to perform the present analysis in both areas.

Temporal variation profiles for both areas show a remarkable fluctuation around their mean value and specifically above the limits of the calculated standard errors behaviour forming a temporal pattern, which can be attributed to earthquake preparation process. In this temporal pattern, b value, which is related to the seismogenic process in many previous studies all over the world shows a tendency to increase and then to decrease before the occurrence of a strong earthquake, and at the same time the quantity $logE^{2/3}$ shows a tendency to decrease and then to increase before the strong event occurrence Misidentification of such a clear pattern for a period of time can be attributed to the lack of adequate data.

Key words: *Seismicity parameters, b- value, energy, temporal variation, seismicity pattern.*

Περίληψη

Στην παρούσα εργασία εξετάζεται η πρόσφατη και σημαντικότερη ισχυρή σεισμική δραστηριότητα που εκδηλώθηκε στο βορειοδυτικό τμήμα του Ελληνικού τόξου και στην περιοχή βόρεια της Χίου κατά το χρονικό διάστημα 2005-2006, Η εξέταση έγινε κάτω από το πρίσμα της μελέτης του σεισμικού προφίλ της χρονικής μεταβολής της σεισμικότητας των διεγερμένων περιοχών. Το σεισμικό προφίλ δημιουργήθηκε με τη χρήση του πρόσφατα προταθέντος αλγορίθμου FastBEE. Η ανάλυση με τον προαναφερθέντα αλγόριθμο περιλαμβάνει τη μελέτη της χρονικής μεταβολής διαφόρων σεισμικών παραμέ-

τρων, όπως το b–value, ενέργεια με τη μορφή $logE^{2/3}$ και την ποσότητα logN όπου N είναι ο αθροιστικός αριθμός των σεισμών στην περιοχή μελέτης.
Η ανάλυση περιλαμβάνει σεισμούς από τον κατάλογο του Γεωδυναμικού Ινστιτούτου του ΕΑΑ για την περίοδο 1990 έως πρόσφατα, επειδή το δείγμα των δεδομένων στην χρονική αυτή περίοδο αφενός καλύπτει τις ανάγκες της ανάλυσης, αφετέρου θεωρείται πιο ομοιογενές και πιο πλήρες σε σχέση με προηγούμενες περιόδους. Τα δεδομένα των σεισμών είναι πλήρη για μεγέθη M_L=3.0 ή μεγαλύτερα
Τα αποτελέσματα της μελέτης της χρονικής μεταβολής των σεισμικών παραμέτρων στα πλαίσια της προσέγγισης έχουν τη μορφή γραφημάτων τριών χρονοσειρών με τα αντίστοιχα τυπικά σφάλματα των εξεταζόμενων σεισμικών παραμέτρων.
Οι χρονικές μεταβολές και στις δύο περιοχές δείχνουν μια σημαντική διακύμανση γύρω από τις μέσες τιμές των παραμέτρων για το εξεταζόμενο χρονικό διάστημα σχηματίζοντας ένα χρονικό πρότυπο για κάθε περιοχή που μπορεί να αποδοθεί στις διεργασίες προπαρασκευής μιας σεισμικής διέγερσης. Ειδικά συγκεκριμένες φάσεις των χρονικών μεταβολών των παραμέτρων b και ενέργειας, για τις οποίες υπάρχουν σαφείς αναφορές στη διεθνή βιβλιογραφία, ότι η μεταβολή τους συνδέεται με τις διεργασίες προετοιμασίας γένεσης σεισμών, δείχνουν να ταυτίζονται με κάθε σεισμική δραστηριότητα στις υπό εξέταση περιοχές. Η μορφή του προτύπου της σεισμικότητας είναι ιδιαίτερα σαφής στην περίπτωση της δραστηριότητας του Ιονίου απ΄ ότι στη δραστηριότητα βόρεια της Σάμου. Οι προαναφερόμενες χρονικές μεταβολές χαρακτηρίζουν κάθε περιοχή και μπορούν να αποδοθούν στις συνθήκες, στις γεωδυναμικές διεργασίες και τα γεωτεκτονικά της χαρακτηριστικά. Ωστόσο η ποιότητα της εμφάνισης ενός σαφούς χρονικού προτύπου μπορεί να επηρεάζεται από το πλήθος των σεισμών και άρα το ρυθμό έκλυσης της σεισμικής ενέργειας.
Λέξεις κλειδιά: *Σεισμικές παράμετροι, Χρονική μεταβολή, Σεισμική ενέργεια, Παράμετρος b.*

1. Introduction

Strong earthquakes are not isolated events. Their occurrence time is affected by tectonic loading due to the slow motion of the tectonic plates and stress changes caused by the occurrence of previous events (Scholz 1990, Harris 1998). In this sense temporal variation of geodynamic regime studies have received little attention, mostly due to the lack of data sets that are suitable for detecting such variations. These can be expressed in terms of seismicity parameter analysis, like energy release, focal mechanism studies, seismic *b-value* estimates etc (Romanowicz 1993, Press and Allen 1995). It is well established that the *b-value* of the freqnency-magnitude distribntion of earthquakes is related to the seismogenic process and changes of *b-value* contain information on differences in the physics of the process that generates earthquakes (Mogi 1962, Scholz 1968, Wyss 1973, Wang 1988, Carter and Berg 1981). Since stress in a region varies with time due to the generation of large earthquakes (build-up and release of stress) an analogous time variation, of *b-value* and energy should be followed. Therefore, a relation should be existing between energy, *b-value* and the time of occurrence of large earthquakes in a tectonically homogeneous region.

Temporal variations of *b-value* have been detected prior to major earthquakes in Japan and Greece, (Imoto 1991, Baskoutas *et al.* 2004). On the other hand the number of earthquakes and the rate of energy released in space and time introduce the measure of seismicity in certain areas. It is now well known that strain is accumulated over time and then is released in the form of large earthquakes. Therefore spatial and temporal behaviour of seismicity, expressed in the terms of these parameters, could be related also to the geodynamic process (Kisslinger *et al.* 1985).

The Aim of this study is to investigate the temporal behaviour of seismicity, under the aspect of new approach of analysis of seismicity parameters in the central Ionian Sea in the western part of the Hellenic arc and in Cesme Gulf, north of Samos Island, which recently, during 2005-2006, were affected by a series of strong earthquakes.

2. Data and analysis

Cesme Peninsula north of Samos Island (hereafter Samos earthquake activity) during October 2005 has experienced a strong seismic activity with magnitudes of the stronger events ranging from 5.2 to 6.1 within a time period of fourteen days. In the central part of the Ionian Sea at the same month (October 2005) one more significant seismic activity started and lasted until April 2006. This excitation also included a number of strong shocks located south of Zakynthos Island (hereafter Zakynthos earthquake activity) and with magnitudes ranging from 5.7 to 6.1 Richter scale. Table I and II respectively. In order to examine the temporal profile of seismicity parameters of the areas affected by these two strong seismic activities, within a time period of fourteen days Table I and II respectively. In order to examine the temporal variation of seismicity parameters of the areas affected by these two strong seismic activities, FastBEE algorithm (Papadopoulos *et al.* 2003), has been applied on data sets taken from the Earthquake Catalogue of the Geodynamic Institute, of the National Observatory of Athens (NOA), from 1990 to 2006 in the broader area of the respective seismic activities. The epicenters of the earthquakes taken into account to perform the seismicity profile analysis have been plotted on figures 1 and 2 respectively. The examined period in the present analysis was considered since 1990 because of the homogeneity of the catalogue data comparing to the previous period. Here it is noteworthy to mention that usual errors on magnitude and location of earthquake don't affect qualitatively the results of FastBEE analysis. The completeness threshold magnitude in the examined space and time period is 3.0 for both areas.

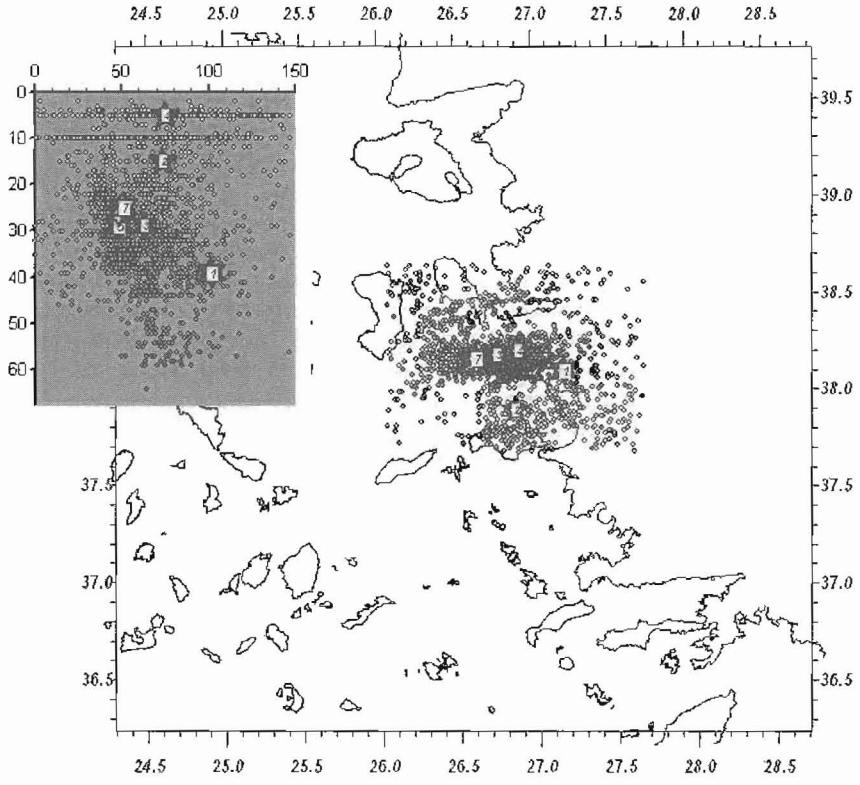

Figure 1 – Epicenters of events for the analysis of seismicity parameter in Samos 2006 strong earthquake activity. Numbered stars show the stronger events in chronological order (Table 1)

Table 1 – List of M≥5.2 earthquakes of Samos 2005 seismic activity

A/A	Date	hh.mm	Lat	Lon	Magn (Ms)
1	17-10-2005	05.45	38.13	26.59	6.0
2	17-10-2005	09.46	38.14	26.59	5.9
3	20-10-2005	21.40	38.15	26.63	6.1
4	31-10-2005	05.26	38.12	26.66	5.2

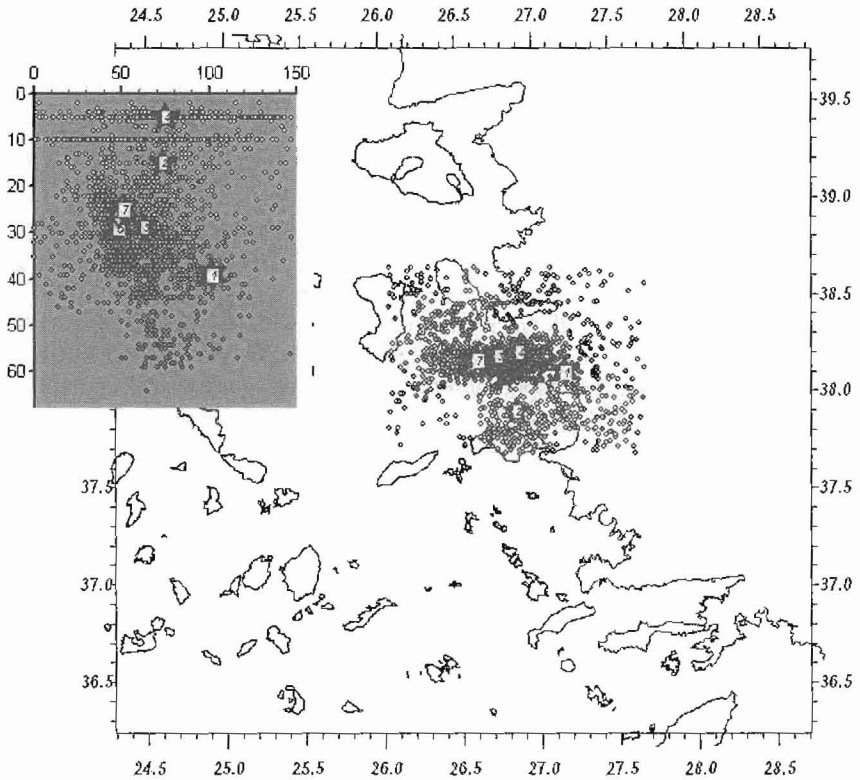

Figure 2 – Epicenters of events for the analysis of seismicity parameter in the seismogenic zone S-SW of Zakynthos Island. Numbered stars show the stronger events in chronological order (Table 2)

Table 2 – List of M≥5.2 earthquakes of Zakynthos 2005-2006 seismic activity

A/A	Date	hh.mm	Lat	Lon	Magn (Ms)
1	18-10-2005	15.25	37.58	20.86	6.1
2	04-04-2006	22.50	37.58	20.93	5.7
3	11-04-2006	02.20	37.64	20.92	5.7
4	11-04-2006	17.29	37.68	20.91	5.9
5	12-04-2006	16.52	37.61	20.95	5.9

Analysis was performed for 4802 and 2115 events respectively. Seismicity parameters, in this study, are expressed in terms of the logarithm of the cumulative number of earthquakes N, energy release in the form $E^{2/3}$ and *b-value*. This last was obtained by the maximum likelihood estimation method attributed at the end of each time window. Time series were obtained with a step of one month and smoothing by the mean of a triangular filter on overlapping time window of 9 months.

3. Results

Seismic excitations that took place near Zakynthos Island (western part of the Hellenic Arc) and Samos Island (back arc Aegean area), in 2005 to 2006 were examined in terms of the temporal variation of seismicity parameters (Figs 3, 4). For this purpose earthquake data since 1990 up to 2006 were used, a period when the catalog is complete and homogeneous and the respective seismicity parameters were estimated and shown as an function of time.

In all cases, the calculated standard errors are shown with continue bold lines for quantities *logN* and $\log E^{2/3}$ and standard deviation for each *b-value* estimate, as well as time series smoothing with a red bold line. Moreover timely on the graph stronger eveuts within tbe examined time period also have been marked by red arrows on the time axis.

Time series show a remarkable fluctuation around their mean value and specifically above the limits of the calculated standard errors, for both examined seismogenic zones. Nevertheless form and quality characteristics of temporal variation time series are different for each region.

re specifically, in the case of the area located S-SW of Zakynthos Island, the temporal variation for all three parameters show a sinusoidal curve which fluctuate around their mean values and which is more clear in case of *b-value* and energy release and less in case of the quantity logN (Fig. 3). Especially the variation of b-value follows a sinusoidal curve with alternation of six relative minima and maxima, with mean value of 1.09 and 1.40 respectively, around the global mean b-value, which is equal to 1.25. On the same graph, the time coincidence of the strong earthquake activity with the correspondiug appearance of relative minima of b-value are evident. Approximate recurrence period of relative minima and maxima since 1990, is found to be three years. Discrepancy for events numbered 4, 6, and 7 can be neglected since their epicenters lie at the edge of the examined area (Figs 3, 1). The mean time duration of the decreasing phase of *b-value* estimates, starting from previous relative maximum is about two years. On the other hand the fluctuation of temporal variation of the quantity $\log E^{2/3}$ around its mean value,. in the same time period shows the same appearance of relative maxima and minima which seems to be anti-correlated to the *b-value* estimates. In figure 3 strong earthquake activity is observed mostly during the increasing phase of quantity $\log E^{2/3}$ after a relative minimum. Duration and shape of relative minima and maxima are more irregular than in the case of b-value.

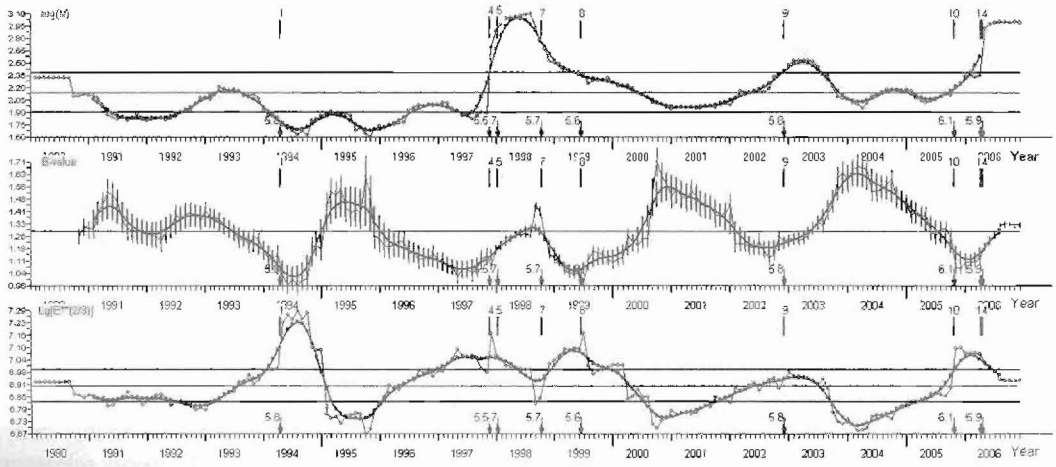

Figure 3 – Temporal variation time series of seismicity parameters *logN*, *b-value* and $E^{2/3}$ for zone S-SW of Zakynthos Island. Arrows to the time axis shows the events reported in Table-3

Table 3 – List of $M_L \geq 5.2$ earthquakes for Zakynthos seismic area during 1990-2006

A/A	Date	hh.mm	Lat	Lon	Magn (Ms)
1	1994-04-16	23.09	37.43	20.58	5.3
2	1997-11-18	13.07	37.26	20.49	6.1
3	1997-11-18	13.13	37.36	20.65	5.6
4	1997-11-18	15.23	37.25	21.16	5.0
5	1998-01-10	19.21	37.12	20.73	5.2
6	1998-10-06	12.27	37.18	21.12	5.2
7	1998-10-08	03.50	37.79	20.27	5.2
8	1999-06-11	07.50	37.57	21.12	5.1
9	2002-12-02	04.58	37.80	21.15	5.3
10	2005-10-18	15.25	37.58	20.86	5.6
11	2006-04-04	22.05	37.58	20.93	5.2
12	2006-04-11	00.02	37.64	20.92	5.2
13	2006-04-11	17.29	37.68	20.91	5.4
14	2006-04-12	16.52	37.61	20.95	5.4

However, the relative increases and decreases of the quantity *logN* do not exhibit a clear correlation with *b-value* and energy temporal variations This pattern concerns the cases of the end of 1997, 2002 as well as of the end 2005 and beginning of 2006 in the considered seismogenic zone. Strong earthquakes take place after a long period of low *logN* values, like a seismic quiescence period, and can be considered as a formation of a qualitative temporal pattern, which can be attributed to earthquake preparation process.

In this temporal pattern, *b value*, which has been related to the seismogenic process in many previous studies all over the world, shows a tendency to increase and then to decrease before the occurrence of a big earthquake. At the same time the quantity $\log E^{2/3}$ shows a tendency to increase before the occurrence of a big earthquake after passing a period of relative low as well as logN. Some times weakness in constructing such a clear pattern for a period of time can be attributed to the lack of a sufficient number of data adequate to support this temporal fluctuation of these three parameters.

In the second case, the temporal variation of the same parameters was examined for the same time period (1990 to 2006). The temporal variation of b-value shows a sinusoidal form till 1995, afterwards it flattens around a mean equal to 1.04, lasting from 1996 to 2001. Nevertheless alternate minima and maxima can also be observed at the beginning of 1993, 1995, end of 2003 and 2005, respectively (Fig. 4). Mean b-values of relative minima and maxima are 0.88 and 1.30, respectively.

Once more, strong earthquake activity (marked with red arrows on the graph of figure 4) can be correlated with the presence of relative minima although in the case of 2003 activity is not so clear (mostly because the values of the graph are auto ranged). The 1992 and 2006 activities seem to be correlated although a little delayed in respect to the observed relative minimum.

The fluctuation of temporal variation of the quantity $\log E^{2/3}$ around the mean value in the examined period, as in the Zakynthos case, seems to be anti-correlated to the *b-value* estimates. In figure 4 strong earthquake activity it is observed mostly during the increasing phase of quantity $\log E^{2/3}$ time series after passing a relative minimum. The relative minima of the quantity *logN* and especially the increasing phase of their temporal variations show a clear correlation with occurrence of strong earthquake activity of the beginning of 1996, 2003 and the end of 2005, respectively.

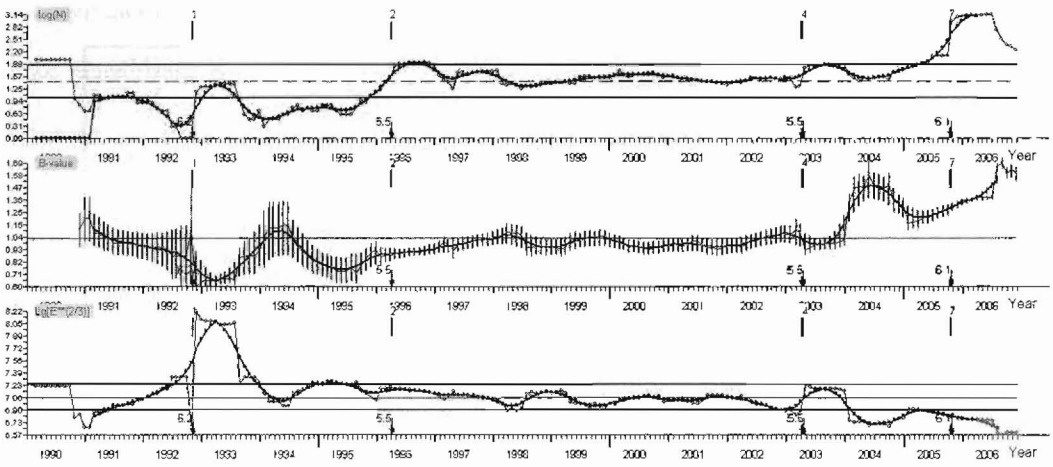

Figure 4 – Temporal variation time series of seismicity parameters *logN*, *b-value* and $E^{2/3}$ for Cesme peninsula seismic area. Arrows to the time axis shows the events reported in the table 4

Table 4 – List of M≥5.2 earthquakes for Samos seismic area during 1990-2006

A/A	Date	hh.mm	Lat	Lon	Magn (Ms)
1	11-06-1992	19.08	38.09	27.19	5.7
2	02-04-1996	07.59	37.89	26.88	5.0
3	10-04-2003	00.40	38.17	26.76	5.3
4	17-04-2003	22.34	38.19	26.90	5.9
5	17-10-2005	05.45	38.13	26.59	5.9
6	17-10-2005	09.46	38.14	26.59	6.1
7	20-10-2005	21.40	38.15	26.63	5.6

4. Conclusions

In this study the recent strong earthquake activity, during 2005-2006, which occurred in the northwestern part of the Hellenic arc, and in the eastern Aegean sea was investigated under the aspect of temporal variation of specific seismicity parameters by the mean of the new proposed, FastBEE algorithm. Seismicity parameters considered in this approach are used worldwide from many researchers for their premonitory character and their relationship to the seismogenic process

Results of this study have shown that is possible to construct temporal variation profile for an area which can be correlated with strong earthquake seismic activity where *b-value* and energy released estimates form relative minima and maxima respectively.

The high and constant rate of seismic activity seems to play an important role to formation of the temporal pattern of previously mentioned parameters, as the case of Zakynthos case has shown.

Weakness in constructing such a clear pattern for a period of time can be attributed to the lack of data. Even though detailed examination of each area under the aspect of FastBEE approach, through the construction of respective seismicity parameters, temporal variation profiles can give a significant indication of the remaining time of the forthcoming strong earthquake.

5. Acknowledgments

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6. References

Baskoutas, I, Papadopoulos, G., and Panopoulou, G., 2004. Long temporal variation of seismic parameters for seismic patterns identification in Greece, *Bulletin of Geological Society of Greece. Proc. of the 10th Inter. Con. Thessaloniki, April 2004.* (in press)

Carter, J.A., and Berg, E., 1981. Relative stress variations as determined by b-values from earthquakes in Circum-Pacific subduction zones, *Tectonophysics*, 76, 257– 271.

Harris, R.A., 1998. Forecasts of the Loina Prieta, California, earthquake, *Bull. Seismol Soc. Am.*, 88: 898-916.

Imoto, M., 1991. Changes in the magnitude-frequency b-value prior to large (M _ 6.0) earthquakes in Japan, *Tectonophysics*, 193, 311 –325.

Kisslinger, C., Mc Donald, C., and Bowman, J.R., 1985. Precursory Time-space Patterns of Seismicity and their Relation to Fault Processes in the Central Aleutian Islands Seismic Zone, *Abstracts, 23rd. General Assembly of IASPEI*, 32p.

Mogi, K., 1962. Magnitude-frequency relation for elastic shocks accompanying fractures of various materials and some related problems in earthquakes, *Bull. Earthq. Res. Inst.*, 40, 831–853.

Papadopoulos, G., Baskoutas, I., and Stavrakakis, G., 2003. Tools for theFast Estimation of Expected Big Earthquake in predefined seismic prone areas, *1th International Workshop on Earthquake Prediction. Athens, November 2003.*

Press, F., and Allen, C., 1995. Patterns of seismic release in the southern California region, *J. Geophys. Res.*, 100, 642I–6430.

Romanowicz, B., 1993.Spatiotemporal patterns in the energy release of great earthquakes, *Science*, 260, 1923– 1926.

Scholz, C.H. 1968. The frequency-magnitude relation of microfracturing in rocks and its relation to earthquakes. *Bull, seismol. Soc. Amer.*, 58, 1, 399-415.

Scholz, C., H., 1990. *The Mechanics of Earthquakes arid Faulting*, Cambridge University Press, Cambridge, UK.

Wang, J. H., 1988. b-values of shallow earthquakes in Taiwan, *Bull. Seismol. Soc. Am.*, 78, 1243–1254.

Wyss, M., 1973. Towards a physical understanding of the earthquake frequency distribution, *J. R. Astron. Soc.*, 31, 341– 359.