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Seismic Quiescence Patterns and Earthquake Prediction Research

Testing Hypotheses for Greece and China

BY

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Abstract

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The main aim of this investigation is to evaluate the most well known hypotheses and models in earthquake prediction research. For this reason we investigate the "localized" seismic quiescence hypothesis using the Z value griding method as well as the recently introduced Seismolap hypothesis of "extended" seismic quiescence.
The results indicate that precursory seismic quiescence has preceded crustal main shocks in China and Greece and also that aseismic quiescence can be attributed to "silent earthquakes " such as creep events in subduction zones. The application of the Z-value method in investigating the recent seismic quiescence regime in Greece has given indications of three areas in Greece where significant quiescence is observed and which also are candidate areas for strong earthquakes according to their previous seismic history.
Recently, the Gulf of Corinth in Central Greece has been appointed as an official multiparameter site for earthquake prediction research by the European Council and in this framework, magnetotelluric and seismological investigations revealed the presence of fluids in the Earth's crust that are mainly responsible for the observed seismic and electromagnetic anisotropy which correlates well with the local stress field as revealed from GPS measurements. In addition, the spectral fitting method was used on digital short period data from this region in order to obtain dynamic source parameters from local earhquakes and also to determine scaling relations using two different earthquake source models.

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Dedicated to my family

Konstantin, Penelope, Kristine and Nicolas

Seismic Quiescence Patterns and Earthquake Prediction Research: Testing Hypotheses for Greece and China

Gerasimos Chouliaras

The thesis consists of the following six papers :

I) Chouliaras, G., Drakatos, G., Stavrakakis, G.N and J. Zschau, 1997. Precursory seismic quiescence patterns in Greece revealed by the SEISMOLAP method. (Accepted for publication, Annali di Geofisica, Dec. 1998).

II) Chouliaras, G. and G.N Stavrakakis. 1999. Current seismic quiescence in Greece; Implications for seismic hazard. (Submitted to the Journal of Seismology, Feb. 1999).

III) Chouliaras, G., Li Mingfeng, Drakatos, G., Stavrakakis, G. and Chen Yong. 1998. Seismic quiescence in the Chinese Earthquake Catalog. (Submitted for publication, Geophys. Res. Letters, Dec. 1998).

IV) Bernard, P., Chouliaras, G., Tzanis, A., Briole, P., Bouin M.-P., Tellez, J., Stavrakakis, G. and K. Makropoulos., 1997. Seismic and electrical anisotropy in the Mornos delta, Gulf of Corinth, Greece, and it's relationship with GPS measurements. Geophys. Res. Letters, Vol. 24, No., 17, 2227-2230.

V) Chouliaras, G., Pham Van Ngoc, Boyere, D., Bernard, P. and G. N. Stavrakakis, 1997. Crustal structure of the Gulf of Corinth in Central Greece, determined from magnetotelluric soundings. Annali di Geofisica, vol.,XL, No. 1., pp.61- 67.

VI) Chouliaras, G. and G.N. Stavrakakis, 1997. Seismic Source parameters from a New Dial-up Seismological Network in Greece. Pure and Applied Geophysics, 150, 91-111.

Introduction

One of the pioneers in Earth sciences had recognised that " the study of earthquake phenomena makes contact with many fields of knowledge, namely: physics, chemistry, geology, engineering and even philosophy" (Bullen, 1947). Recent trends in seismology confirm this traditional definition and earthquake prediction research as well as seismic risk and hazard evaluation research are multdisciplinary subjects and they involve the coupling of the knowledge from many fields of science.

It is now well known that strain is released in the form of large earthquakes, only after it has been built up over time and theoretical results combined with laboratory tests and field observations have shown that earthquakes do not occur "suddenly". The object of this thesis is to investigate different existing prominant hypotheses and models in earthquake prediction research as well as seismic risk and hazard analysis, in order to evaluate their results for the active tectonic regimes of Greece and China. The hypotheses which will be examined are: the Seismic Quiescence hypothesis of Wyss and Habermann (1988) , the Seismolap hypothesis of Zschau (1995, 1996), the Extensive Dilatancy Anisotropy hypothesis of Crampin (1978), as well as the earthquake source models of Brune (1970, 1971) and Madariaga (1976).

A plethora of investigations concerning seismicity patterns, have shown that main shocks are in some cases preceeded by foreshock activity (Jones, 1984, Shibazaki and Matsu'ura, 1995, Console and Murru, 1996, Bowman, 1997) and in some cases by seismic quiescence (Wyss, 1997). Continuous or transient aseismic slip has also been observed for many faults that have reached the Earth's surface and silent or slow earthquakes have been observed at long periods (McGuire, 1996) so that quiescences may serve as constraints for models of creep events along faults (Kato et al., 1997).

For this reason, the existence of the phenomenon of seismic quiescence prior to crustal main shocks, as defined by the hypothesis of Wyss and Habermann (1988) and also as defined by the Seismolap hypotheses of Zschau (1995), is tested with the earthquake catalogs of China and Greece. Both hypotheses investigate the phenomenon of precursory seismic quiescence, however each one approaches the detection of this quiescence with different methods. In this respect the Z value method of Wyss investigates seismic quiescence within the seismogenetic volume using a declustered earthquake catalog, while the Seismolap method of Zschau investigates quiescence in larger volumes around the epicenter of the main shock , using a clustered catalog.

In addition to the seismicity pattern investigations, seismological, ground deformation and electomagnetic investigations have also detected crustal instabilities before strong earthquakes (Leary and Malin, 1984, Fraser Smith et. al., 1990, Johnson and McEvilly, 1995) and the hypothesis of extended dilatancy anisotropy (EDA) has been proposed and tested in the laboratory as well as in the field (Crampin, 1978, Scholtz et al., 1973, Scholtz, 1998).

According to the EDA hypothesis most of the Earth's crust is pervaded by fluid filled cracks that are alligned by the local stress field. The implications of this hypothesis for earthquake prediction research is that by monitoring the geometrical orientation and behaviour of the fluid filled craks in a fault zone, one is infact monitoring the local stress field.

This anisotropy in the physical properties of the Earth's crust has been revealed so far by mainly observing a time delay in the propagation between the horizontal components of the shear (S) wave, as it propagates through the fluid filled cracks, which is proportional to the crack geometry.

The Gulf of Corinth in Central Greece is the most seismically active continental region of Europe and since 1995 it has been employed as the European test site for earthquake precursors and crustal activity. In this framework, several investigations concerning measurements of many different physical properties of the crust have been performed. The seismological data from local earthquakes and also results from magnetotelluric soundings are compared with continuous GPS observations and the existing anisotropy in the Gulf is interpreted by the presence of fluid filled cracks and the EDA hypothesis is applied in order to extract information regarding the state of stress in the region.

Further on, seismic hazard and risk investigations in Greece consider that the determination of earthquake source parameters and scaling relations, provides valuable information concerning the safety of structures because parameters of design-base earthquakes are often calculated by various regional empirical relations. For this reason, appropriate earthquake source models must be chosen and the results must be evaluated by comparing them with other independent results. The cicular fault models of Brune (1970, 1971) and of Madariaga (1976), that are most commonly used in seismology, are applied to short period data from the first digital network that was installed in Greece in 1995 and the results are compared with other results from independent investigations.

Method and Results

The thesis comprises six papers. In papers **I, II** and **III** we investigate the Seismolap and Z-value hypotheses of seismic quiescence in Greece and China, in papers **IV** and **V** we investigate the Extensive Dilatancy Anisotropy (EDA) hypothesis in the Gulf of Corinth, Central Greece and in paper **VI** we investigate different earthquake source models when determining source parameters and scaling relations for Greek earthquakes.

In paper **I,** we test the Seismolap hypothesis as proposed by Zschau (1995) with the Greek earthquake catalog issued by the Institute of Geodynamics of the National Observatory of Athens (NOA) since 1964, for the strongest crustal main shocks that have occured in the last 25 years. The Seismolap hypothesis proposes that seismic quiescence should be observed over large distances (i.e., 100 km for a magnitude 6 earthquake) and such observations were made prior to the Spitak earthquake in Armenia , the Loma Prieta earthquake in California, the Kobe earthquake in Japan, and the Aigio earthquake in Greece (Zschau, 1996). In the Greek earthquake catalog, Seismolap detected quiescence anomalies within 150 km of the epicentral region, prior to 15 of the 21 strongest crustal main shocks ranging in magnitudes from M_L=5.6 to M_L=6.6. The quiescence ranged between 1 and 2 years for this short magnitude range and it was clearly associated with the main shocks since no other significant seismic activity occured in the investigated region during the anomaly duration.

A well documented case of a prediction based on seismicity rate decrease in Greece is that by Papadimitriou and Papazachos (1985) for the Ms=6.7 earthquake, in Kefalonia island (37.97 ^{0} N - 20.25^0 E) on January 17th, 1983, one of the strongest events in the Greek earthquake catalog. This was one of the first events that was examined by the Seismolap method and Figure 1 shows the anomaly that corresponds to this event as presented by Chouliaras et al. (1997) and also in paper **I**. One can clearly see that the probability of an event occurrence in the investigated area around the epicenter of the impending earthquake begins to increase around the middle of 1981, reaches a maximum just a few days before the main shock and drops abruptly at the time of the main shock. In the same figure one can see that no other significant events (M>5)

occured in the vicinity of the investigated area and also that the seismicity rate shows a clear decrease which begins almost half year before the main shock.

In paper **II** we investigate the hypothesis of precursory seismic quiescence as proposed by Wyss and Habermann (1988) to examine the seismic quiescence situation in Greece using NOA's earthquake catalog and the z-value method as described by Wyss et al. (1997).

For the sake of comparison with Seismolap at this point, we use the Z-value method for the region of Kefalonia prior to the 1983 main shock and the results are shown in Figures 2 and 3. Figure 2 shows the cumulative number curve of the area containing the epicenter of the main shock and Figure 3 shows the Z-value distribution just prior to the main shock. It is evident from Figure 1 that an absence of seismicity for a period of 6 years, only 1 event from 1977 to 1983, preceded the Ms=6.7 event. Further on the quiescence anomaly as mapped in Figure 3 indicates that the top Z-value of 8.54 is only a few kilometers from the epicentre of the main shock and also that the NE-SW trend of the anomaly across the island, agrees well with the aftershock distribution of earthquakes as shown by Scordilis et al. (1985).

The results of paper **II** mainly concern the current seismic quiescence in Greece, and for this reason the quiescence regime on January 1st, 1999 is presented and three regions with seismic quiescence are outlined, where seismic activity is also expected based on the the area's previous seismic behaviour. On February 3rd, 1999 this manuscript was submitted to the "Journal of Seismology " and on February 7th 1999, an earthquake swarm with an Ms=5.2 main event struck at 39.01 ^{0} N - 23.17 ^{0} E , followed by 9 more strong events with Ms>4 within one hour of the main shock. This area was presented in paper **2** as a candidate centered at 39.24 ^{0} N, 23.06 ^{0}E since it exhibited an absence of seismicity for more than three years prior to 1999.

In paper **III** the Chinese earthquake catalog from 1970 till 1998, issued by the Chinese Seismological Bureau of Beijing, is used to investigate the hypothesis of precursory seismic quiescence as proposed by Wyss and Habermann (1988) within the seismogenetic volume, prior to the occurence of strong crustal earthquakes. The catalog, containing more than 160000 crustal events with M>2.0 and depths <50 km, is tested for homogeneity and completeness using the GENAS algorithm (Haberman, 1983) and the magnitude of completeness is found to be M_{COMP}=2.5. The earthquake catalog is subsequently declustered using the Reasenberg (1985) algorithm and

constants and then the Z-value gridding method (Wiemer and Wyss, 1994, Wyss et. al., 1997) is used and a search for seismicity rate changes with a grid spacing of 0.2^0 for all of China is performed.

The results indicate that the most significant quiescence, with the largest Z value of 9.8 is indeed observed prior to the largest earthquake in the catalog, that is a M=7.4 event which took place in 1985 in the western part of China, exhibiting a total absence of seismicity in the epicentral region for a period of 6 (six) years prior to the main shock. In addition to this precursory seismic quiescence, aseismic quiescence was also observed over the Japan subduction trench for a period of 8.2 years without a subsequent main shock and this conforms with similar observations in other parts of the world and it is most likely attributed to the phenomenon of creep events, "silent earthquakes" or volcanic collapse (Kato et al., 1997).

In papers **IV** and **V**, we have investigated the shallow and deep crustal structure of the Gulf of Corinth, respectively. In paper **IV**, seismological and magnetotelluric measurements were conducted in the western part of the Gulf and the results show the simultaneous presence of electric and seismic anisotropy in a coincident direction, which is also correlated well with the orientation of the local strain as is deduced from GPS measurements. The observation of shear wave splitting in a direction which has maximum electrical conductivity and which agrees with the orientation of the local stress field, can be interpreted by the presence of fluids in the upper crust which is in accordance with the EDA hypothesis.

In paper **V,** extensive magnetotelluric soundings around the central part of the Gulf of Corinth have provided a quite detailed tomography of the crust and upper mantle structure in the region surrounding the seismogenetic volume of the June 15, 1995, Ms=6.1 main shock that devestated the city of Aigio. These results indicate that the deep electrical anisotropy is also governed by the local stress field and that a significant conductivity anomaly exists at a depth of 9 to 12 km, having a 7 km thickness and conductivity values that can be interpreted by the presence of fluids in a ductile zone. This boundary seperates the brittle upper crust from the more ductile lower crust and a detachment mechanism between these two has recently been proposed as being responsible for the local seismicity (Rigo et al., 1996).

In paper **VI** digital seismic data from a regional network in Greece, are used to determine earthquake dynamic source parameters (seismic moment, fault dimensions,

stress drop, average displacement) and the scaling relations of these parameters with earthquake magnitude. The classic earthquake source models proposed by Brune (1970, 1971) and by Madariaga (1976) are used, in conjunction with the spectral fitting method of Scherbaum (1990), for crustal earthquakes from three differens seismic regions in Greece.

The computed seismic moments are found to be in good agreement with the centroid moment tensors (CMT) as they are determined by the global broadband networks and when comparing the results from the two source models, it is found that Brune's model gives lower stress drops whilst Madariaga's model gives a more accurate indication of the fault dimensions for Greek earthquakes. These results are in good agreement with the results of other investigations that used different methodologies such as Kulhanek and Meyer, 1979, Kim et al., 1984 and Stavrakakis et al., 1989.

Discussion and Conclusions

Earthquake prediction research deals with the problem of determining three parameters, and their relative errors, that are essential in forecasting an impending earthquake, namely, the location of the earthquake, it's magnitude and the time of it's occurrence. For this reason most investigations have focused on the monitoring of the state of stress in earthquake prone areas using different methods and techniques, in order to detect anomalous changes and establish their association with the earthquake generation process through different physical models and hypotheses.

Of the most prominent hypotheses that are currently investigated due to their promising results, are the precursory seismic quiescence hypothesis and the extensive dilatancy anisotropy hypothesis. These hypotheses have developed physical models that have so far accounted for the observations, however neither method has been able to determine all three prediction parameters independantly, prior to the occurrence of a srong earthquake.

Two different hypotheses and methodologies have recently attacked the problem of detecting seismic quiescence, by quantifying it's significance in time and space, namely Z-value (Wyss et al., 1997) and Seismolap (Zschau, 1995). The results from papers **I** , **II** and from figures 1,2 and 3, presented in this manuscript, using the Seismolap and Z-value method in Greece, show that significant quiescence anomalies are associated with

one of the largest crustal main shocks, for which another investigation had issued a prediction based on a seismicity pattern anomaly in that region prior to the main shock. For the January 17, 1983 M=6.7, main shock in Kefalonia, the Seismolap quiescence anomaly has a duration of 1.5 years and a spatial extent of 100 kilometers around the epicenter, whereas the Z-value quiescence anomaly has a 6 year duration and it's spatial extent is confined within the seismogenetic volume which is of the order of few tens of kilometers.

These differences in the spatial and temporal extent of the anomalies is attributed to the different methodologies involved since, Seismolap measures the absence of seismicity in cubical volumes of the order of 100-200 kilometers using a clustered catalog whereas, the Z-value method measures the absence of seismicity using a declustered catalog, in closely spaced grid points and investigates circular volumes with radii of the order of a few tens of kilometers, depending on the size of the seismogentic volume. In this respect Z-value is more efficient in localizing the anomaly within the source volume of the impending main shock .

It is also observed that because Seismolap uses a clustered catalog, in many cases "artificial" quiescence is observed upon completion of an aftershock sequence because the normal decrease in the seismicity rate is detected and is confused with quiescence as defined in the hypothesis. This unwanted effect is removed by the declustering of earthquake catalog which is done in the Z-value method and fewer false alarms are observed.

The homogeneity, completeness and duration of the earthquake catalog is crucial in detecting seismicity rate changes, since one establishes a "backround" seismicity for the area of investigation using statistical methods in order to quantify quiescence. For this reason we have used the Chinese earthquake catalog, that has a magnitude of completeness as low as M=2.5, to investigate seismic quiescence with the Z-value gridding method. The results mapped the most significant quiescence in the catalog with a duration of six years and associated this anomaly with the occurrence of the largest crustal main shock in China since 1980, with a magnitude of M=7.4.

Another interesting result from paper **III** that agrees with similar observations in other subduction zones, is the detection of absence of seismicity for a period of 8.2 years, without the occurance of a subsequent main shock. This phenomenon is not attributed to artificial causes but is a real effect and it is believed to be caused by "silent"

earthquakes or creep episodes in megathrust zones. In order to be able to identify these creep episodes and distinguish them from precursory seismic quiescence, we need to compare these observations with precise geodetic measurements which will reveal any crustal instabilities associated with these episodes.

In summary, seismic quiescence has been detected in this study in two earthquake catalogs, prior to two crustal main shocks and state of the art software now makes it now possible to investigate the spatial and temporal extent of quiescence with great accuracy using the Z-value method, which is proven superior to the Seismolap method in this respect. Nevertheless, the proposed relationship between the spatial and temporal extent of quiescence and the magnitude of the impending event has yet to be resolved by the few available observations and this relationship is under investigation thourough a real time study of the ongoing seismic quiescence situation in Greece and it's relation with future seismic activity, as described in paper **II.** In addition to this, the quiescence hypothesis may be applied in the detection of creep episodes or "silent" earthquakes in conjunction with geotedic measurements and in this sense the method could prove valuable in the monitoring of aseismic crustal deformation.

On the other hand, the extensive dilatancy anisotropy hypothesis has proposed a time dependent model and the detection of minute variations of strain in the vicinity of the impending earthquake by real time geophysical methods, can be of great value in predicting the temporal evolution of the earthquake nucleation process with greater accuracy. Combined magnetotelluric, GPS and seismological investigations in the seismically active Gulf of Corinth in Central Greece as presented in papers **IV** and **V**, show that the earth's upper crust is pervaded by electrically conductive fluid zones, which coincide with shallow and deep structural discontinuities that are created and are geometrically alligned by the local stress field. These observations confirm the extensive dilatancy anisotropy hypothesis with state of the art methods that are able to monitor the geometrical alignment of the microcracks that comprise the fault plane, as well as provide porosity estimates and in this way monitor crustal strain. Thus more refined multidisciplinary studies are encouraged, which will be able to image and monitor crustal strain under the extensive dilatancy anisotropy model, in multiparameter test sites around the world.

In addition to the above studies which focused on earthquake prediction research, paper **VI** is a first attempt at using three component, short period, digital data from

Greek earthquakes to determine their dynamic source parameters and the scaling relations between them, using spectral analysis methods. Two prominant earthquake source models were adapted in the analysis, namely Brune's model and Madariaga's model for comparison purposes and it was found that although Brune's source model desribes better the stress drops of Greek earthquakes, Madariagas model describes better the fault dimensions when compared with the results of other studies. Further on, the scaling relations between magnitude, and the other source parameters that have been found, can provide further information in seismic hazard studies that concern the Greek area.

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References

Bowman, J., R., 1997. A seismic precursor to a sequence of Ms 6.3-6.7 midplate earthquakes in Australia. Pure Appl. Geophys., 149, 61-78.

Brune, J., N., 1970. Tectonic stress and the spectra of seismic shear waves from earthquakes. J. Geophys. Res., 75, 4997-5009.

Brune, J., N., 1971. Correction. J. Geophys. Res., 76, 5002.

Bullen, 1947. An introduction to the theory of seismology. Cambridge University Press.

Console, R. and M. Murru, 1996. Probability gain due to foreshocks following quiescence tested by synthetic catalogs. Bull. Seismol. Soc. Am., 86, 911-913.

Chouliaras, G., Zschau, J., Drakatos, G., Latousakis, J. and G. N. Stavrakakis, 1997. Application of the Seismolap method in Greece. Presented at the 29th General Assembly of the IASPEI, August 18-28, 1997, Thessaloniki, Greece, Abstracts, pp142.

Crampin, S., 1978. Seismic wave propagation through a cracked solid: Polarization as a possible dilatancy diagnostic, Geophys. J. R. astr. Soc., 53, 467-496, 1978.

Fraser Smith, A. C., Bernardi, A., McGill, P. R.., Ladd, M., E., Heliwell, R., A. and O. G. Villard Jr., 1990. Low frequency magnetic field measurements near the epicenter of the Ms 7.1 Loma Prieta earthquake. Geophys. Res. Lett., 17, 1465-1468.

Habermann, R., E., 1983. Teleseismic detection in the Aleutian Island arc. J. Geophys. Res., 88, 5056-5064.

Johnson M. J. S. and T. V. McEvilly, 1995. Parkfield seismicity: fluid-driven? J. Geophys. Res., 100, 12937-12950.

Jones, L., M., 1984. Foreshocks (1966-1980) in the San Andreas system, California. Bull. Seismol. Soc. Am., 74, 1361-1380.

Kato, N., Ohtake, M. and Hirasawa, T., 1997. Possible mechanism of precursory seismic quiescence : Regional stress relaxation due to preseismic sliding. Pure Appl. Geophys., 150 (2) 249-267.

Kim, W., Kulhanek, O., and K., Meyer, 1984. Source process of the 1981 Gulf of Corinth earthquake sequence from body-wave analysis. Bull. Seismol. Soc. Am., 74, 459-477.

Kulhanek, O., and K., Meyer, 1979. Source parameters of the Volvi-Langadhas earthquake of June 20, 1978 dedeuced from body wave spectra at station Uppsala and Kiruna. Bull. Seismol. Soc. Am., 68, 1289-1294.

Latousakis, J. and Drakatos, G., 1994. A quantitative study of some aftershock sequences in Greece. Pure Appl. Geophys., 143(4), 603-616.

Leary P. C. and P. Malin, 1984. Ground deformation events preceeding the Homestead Valley earthquakes. Bull. Seismol. Soc. Am., 74, 1799-1817.

Madariaga, R., 1976. Dynamics of an expanding circular fault. Bull. Seismol. Soc. Am., 66, 636-666.

McGuire A., 1996. Time-domain observations of a slow precursor to the 1994 Romance transform earthquake. Science, 274, 82-85.

Papadimitriou, E., E. and Papazachos B., C., 1985. Evidence for precursory seismicity patterns in the Ionian islands (Greece). Earth. Pred. Res., 3, 95-103.

Reasenberg, P., A., 1985. Second-order moment of Central California Seismicity. 1969-1982. J. Geophys. Res., 90, 5479-5495.

Rigo, A., Lyon-Caen, H., Armijo, R., Deschamps, A., Hatzfeld, D., Makropoulos, K., and P. Papadimitriou , 1996. A microseismic survey in the Western part of the Gulf of Corinth (Greece): implications for large scale normal faulting mechanisms. Geophys. J. Int., 126, 663-688.

Scherbaum, F., 1990. Combined inversion of the Three-dimensional Q structure and source parameters using microearthquake spectra. J., Geophys. Res., 95, 12423-12438.

Scholtz. C., H., Sykes, L. R. and Y. P. Aggarwal, 1973. Earthquake prediction : A physical basis. Science, 181, 803-810.

Scholtz, C., H., 1998. Earthquake and friction laws. Nature, 391, 37-41.

Scordilis, E., M., Karakaisis, G., F., Karakostas, B., G., Panagiotopoulos, D., G., Comninakis, P., E. and B., C., Papazachos, 1985. Evidence for transform faulting in the Ionian Sea: The Cephalonia Island Earthquake sequence of 1983. Pure Appl. Geophys., 123, 388-397.

Shibazaki, B. and M. Matsu'ura, 1995. Foreshocks and pre-events associated with the nucleation of large earthquakes. Geophys. Res. Lett., 22, 1305-1308.

Stavrakakis, G., Drakopoulos, J, Latousakis, J., Papanastasiou, D. and G. Drakatos.,Specral characteristics of the 1986 September 13 Kalamata (Southern Greece) Earthquake. Geophys. J. Int., 98, 149-157.

Wiemer and Wyss, 1994. Seismic quiescence before the Landers (M =7.5) and Big Bear (M=6.5) 1992 earthquakes. Bull. Seismol. Soc. Am., 84, 900-916.

Wyss, M., 1997. Nomination of precursory seismic quiescence as a significant precursor. Pure Appl. Geophys., 149, 79-113.

Wyss, M., Console, R. and M. Murru. Seismicity rete change before the Irpinia (M=6.9) earthquake. Bull Seismol.Soc. Am., 87(2) 318-326.

Wyss, M. and Haberman R., E., 1988. Precursory seismic quiescence. Pure Appl. Geophys., 126, 319-332.

Zschau, J., 1995. Seismolap : A quantification of seismic quiescence and clustering. IUGG, XXI General Assembly, Abstract A389.

Zschau, J., 1996. Seismolap-Ein Schritt in Richtung Erdbebenvorhersage. Geowissenschaften 11, 11-17.

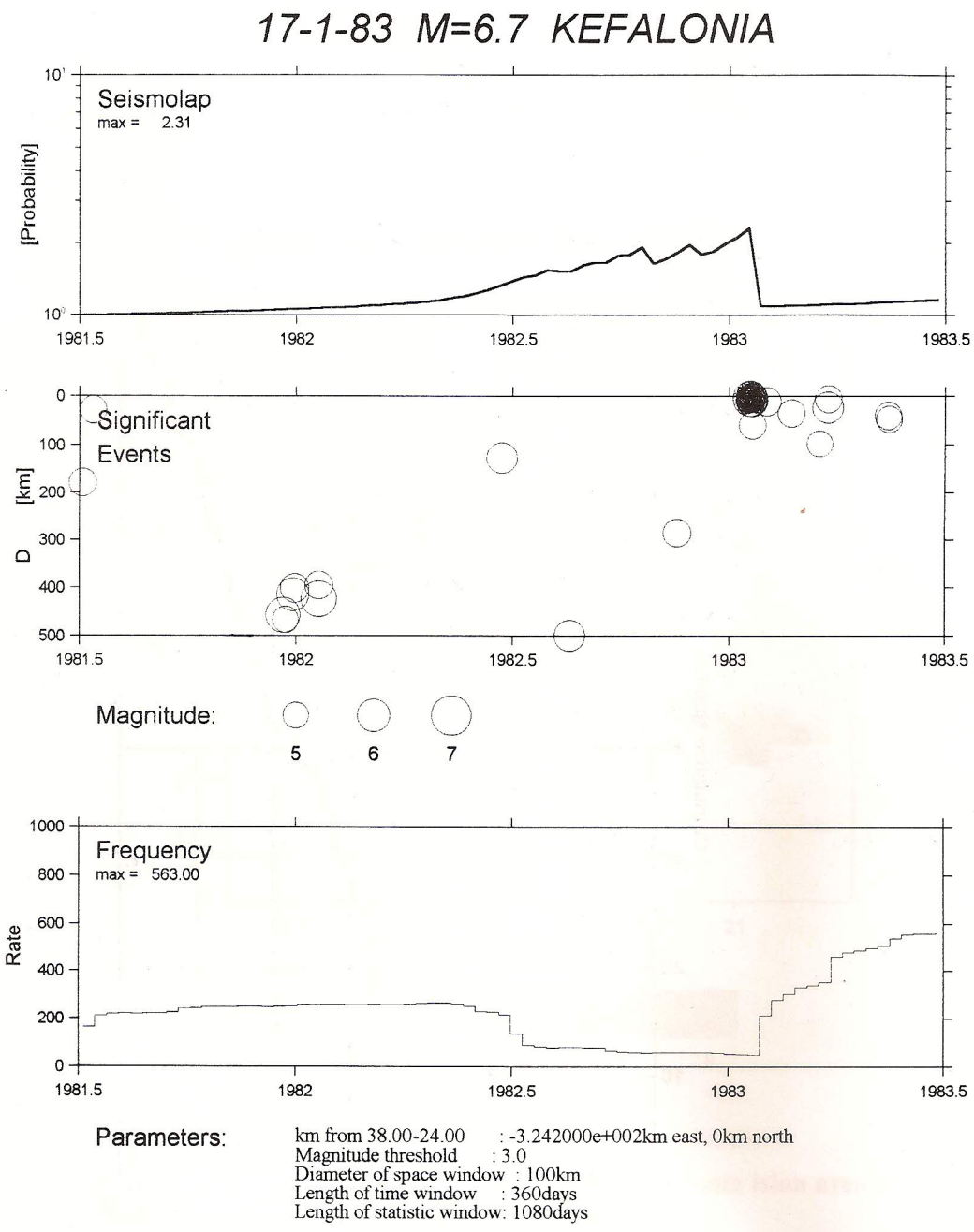

Figure 1. Seismolap results for the 17-1-1983 main shock in Kefalonia. Top figure shows the Seismolap value expressed as 1/Probability versus time.

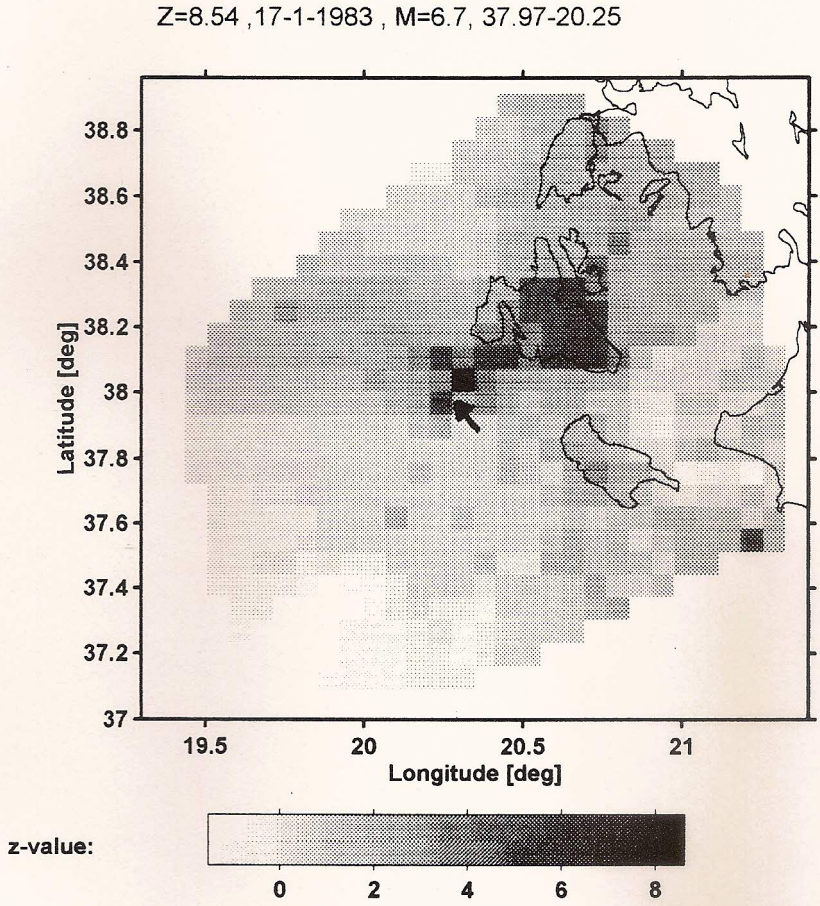

Figure 3. Z-value contour map around the Kefalonia islan area prior to the main shock(indicated by the arrow).

1977-1983, only 1 event !

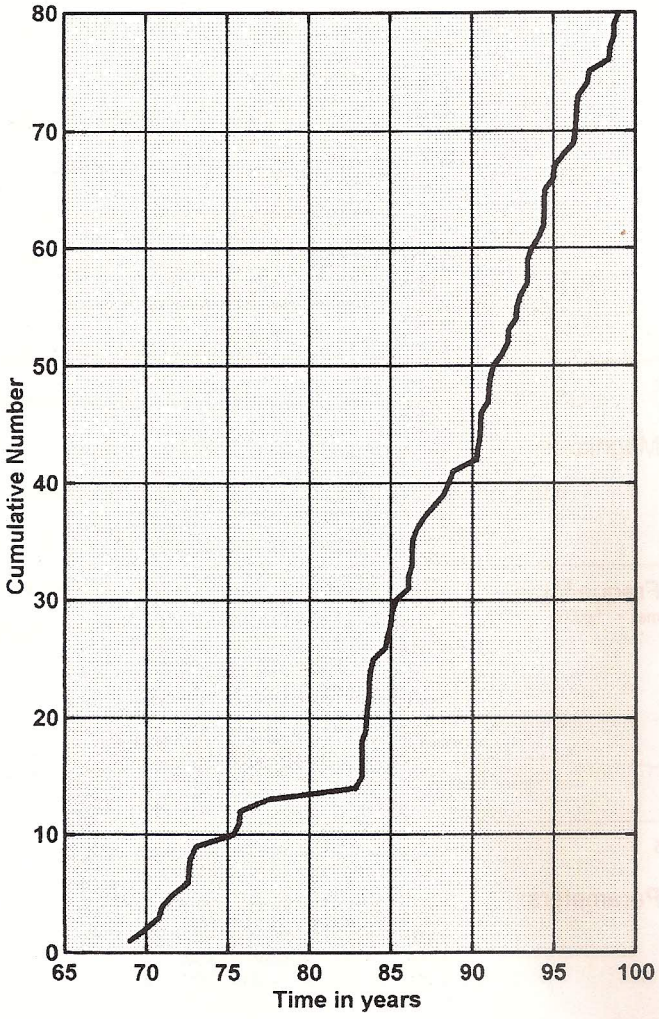

Figure 2. Cumulative number of earthquakes versus time, at the epicenter of the main shock.

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Abstract
The main aim of this investigation is to evaluate the most well known hypotheses and models in earthquake prediction research. For this reason we investigate the "localized" seismic quiescence hypothesis using the Z value griding method as well as the recently introduced Seismolap hypothesis of "extended" seismic quiescence.

The results indicate that precursory seismic quiescence has preceded crustal main shocks in China and Greece and also that aseismic quiescence can be attributed to "silent earthquakes " such as creep events in subduction zones. The application of the Z-value method in investigating the recent seismic quiescence regime in Greece has given indications of three areas in Greece where significant quiescence is observed and which also are candidate areas for strong earthquakes according to their previous seismic history.

Recently, the Gulf of Corinth in Central Greece has been appointed as an official multiparameter site for earthquake prediction research by the European Council and in this framework, magnetotelluric and seismological investigations revealed the presence of fluids in the Earth's crust that are mainly responsible for the observed seismic and electromagnetic anisotropy which correlates well with the local stress field as revealed from GPS measurements. In addition, the spectral fitting method was used on digital short period data from this region in order to obtain dynamic source parameters from local earthquakes and also to determine scaling relations using two different earthquake source models.

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