LITHOSPHERIC STRESS STATE IN THE AREA OF GREECE AS INFERRED FROM TIDAL TRIGGERING OF EARTHQUAKES

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ABSTRACT

The tidal triggering effect is manifested in the difference of the number of events occurring during the phases of tidal compression and tension. This difference reflects the stress state and mechanical instability in a particular volume of the lithosphere. A detailed study of earthquake occurrence times versus tidal phases is undertaken for the area of Greece, limited by 34-42° N. and 19-28° E. The triggering effect connected with tidal deformations is investigated and interpreted in terms of lithospheric stress state.

ΟΙ ΛΙΘΟΣΦΑΙΡΙΚΕΣ ΤΑΣΕΙΣ ΣΤΗΝ ΠΕΡΙΟΧΗ ΤΗΣ ΕΛΛΑΔΑΣ ΟΠΩΣ ΠΡΟΚΥΠΤΟΥΝ ΑΠΟ ΜΕΛΕΤΗ ΤΗΣ ΠΑΛΙΡΡΟΙΑΚΗΣ ΠΡΟΚΛΗΣΗΣ ΤΩΝ ΣΕΙΣΜΩΝ

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ΠΕΡΙΛΗΨΗ

Το φαινόμενο της παλιρροιακής πρόκλησης σεισμών εκδηλώνεται στη διαφορά του αριθμού των σεισμών που γίνονται στην διάρκεια των φάσεων παλιρροιακής συμπίεσης και εφελκυσμού. Αυτή η διαφορά αντανακλά την κατάσταση του πεδίου των τάσεων και της μηχανικής αστάθειας σε ένα συγκεκριμένο όγκο της λιθόσφαιρας. Επιχειρείται μιά λεπτομερής μελέτη των χρόνων γένεσης των σεισμών σε σχέση με τις παλιρροιακές φάσεις στην περιοχή της Ελλάδας (34-42° N, 19-28° E). Μελετάται το φαινόμενο της πρόκλησης των σεισμών από παλιρροιακές μεταμορφώσεις και επιχειρείται η σύνδεσή του με την κατάσταση του πεδίου των λιθοσφαιρικών τάσεων.

INTRODUCTION

Tensosensitivity and vibrosensitivity are fundamental properties of crustal rocks. Tensosensitivity is manifested in deformations (Beresnev,I.A. and Nikolaev,A.V., 1990; Nikolaev,A.V. and Verestschagina,G.M., 1991), in wave-velocity changes connected with earth tides and background tectonic processes. Vibrosensitivity is dispayed in seismic and acoustic emission variations induced by storm microseisms and by the artificial vibrations generated by seismic vibrators (Longman,1959). It appears also in the specific influence of underground nuclear explosions and strong earthquakes on seismicity as remote as 1500 Km and even more (Nikolaev and Nikolaev, 1992). So it is clear that the fine structure of seismicity may be affected by earth tides. There have been several attempts to study these effects, but as far as we know their results are rather contradictory and unstable both spatially and temporally. This study is oriented towards the regularities of seismicity's fine structure associated with earth tides (Nikolaev and Nikolaev, 1993; Rukunov, et al., 1979). Earth tide stresses may be considered as a periodical loading of the Earth's crust which interferes with the background tectonic stress field. The background process may be connected with the process of preparation of a strong earthquake, creep or weak seismicity. Taking into account that the majority of earthquake sources is a result of movement along the fault plane one may consider three main types of fracture: normal fault, strike-slip fault and thrust. The earthquake triggering process depends on the slow background changes of the stress field and on the comparatively short variations of earth tide stresses. Depending on the earth tide phase, tidal forces can act both towards the geodynamic process or be opposed to it. Thus it can either stimulate or suppress the triggering effect. At the very end of the preparation process of a strong earthquake even a very small stress change may trigger the earthquake and this quantity can be a tidal stress which interferes positively with the regional stress field in the area of the impending earthquake. Hence the character of tidal stresses acting at the moment a strong earthquake occurs corresponds to the character of stress released by it. Therefore the study of tidal phases in relation to the earthquake occurrence times allows us in principle to solve the inverse problem; to find the character of stresses acting in the individual earthquake source as well as the tendency and character of the stress field prevailing during a certain time interval in a certain volume of the Earth's crust.

There are algorithms available for the calculation of earth tide characteristics for every geographical point and every time moment. The Longman's algorithm (Yaramanci et al., 1988) has been used in this study. It is evident that the real structure of tidal deformations has complex structure as a result of lateral inhmogeneities of lithosphere. So the calculated values should be considered as strongly generalized and smoothened ones. The technique was applied in the following manner. The region limited by 34-42° N and 19-28° E was separated into small windows 0.5x0.5 degrees. The catalogue of Greek earthquakes with $M > 4$ which occurred in the period 1900-1985 (Comninakis and Papazachos, 1986; Montlhy Bulletins of the National Observatory of Athens and of Geophysical Laboratory of the University of Thessaloniki) was used to study the tidal triggering effect. The total number of events is more than three thousands.

Fig. 1 shows the map of earthquake distribution. Two numbers are shown in each window. The upper one N corresponds to the earthquakes that happened during the phase of compression and the lower one, N durring the phase of tension of the modulus of the tidal vector. The difference between these numbers, N_+-N_-, may be considered as a concequence of the tidal triggering effect if it is statistically confident. From the statistical point of view, more informative is the characteristic of the normalized difference, $(N_+-N_-)/2\sigma$, where σ is the standard deviation of the mean value $(N_+-N_-)/2$. For the binomial distribution of N_+ and N_-, the standard deviation is given by $\sigma = (p\,q(N_+ + N_-))^{0.5}$, where p and q are the probability for every event to occur during the phase of tidal compression and tidal tension respectively. If the earthquake occurrence times are independent on the tide phase, $p=q=0.5$. So we can verify the hypothesis of nonrandom difference $N_+ - N_-$. If the modulus of the normalized value $(N_+-N_-)/2\sigma$ is significant, equal to 1.5 and more, this must be considered as a manifestation of the tidal triggering effect.

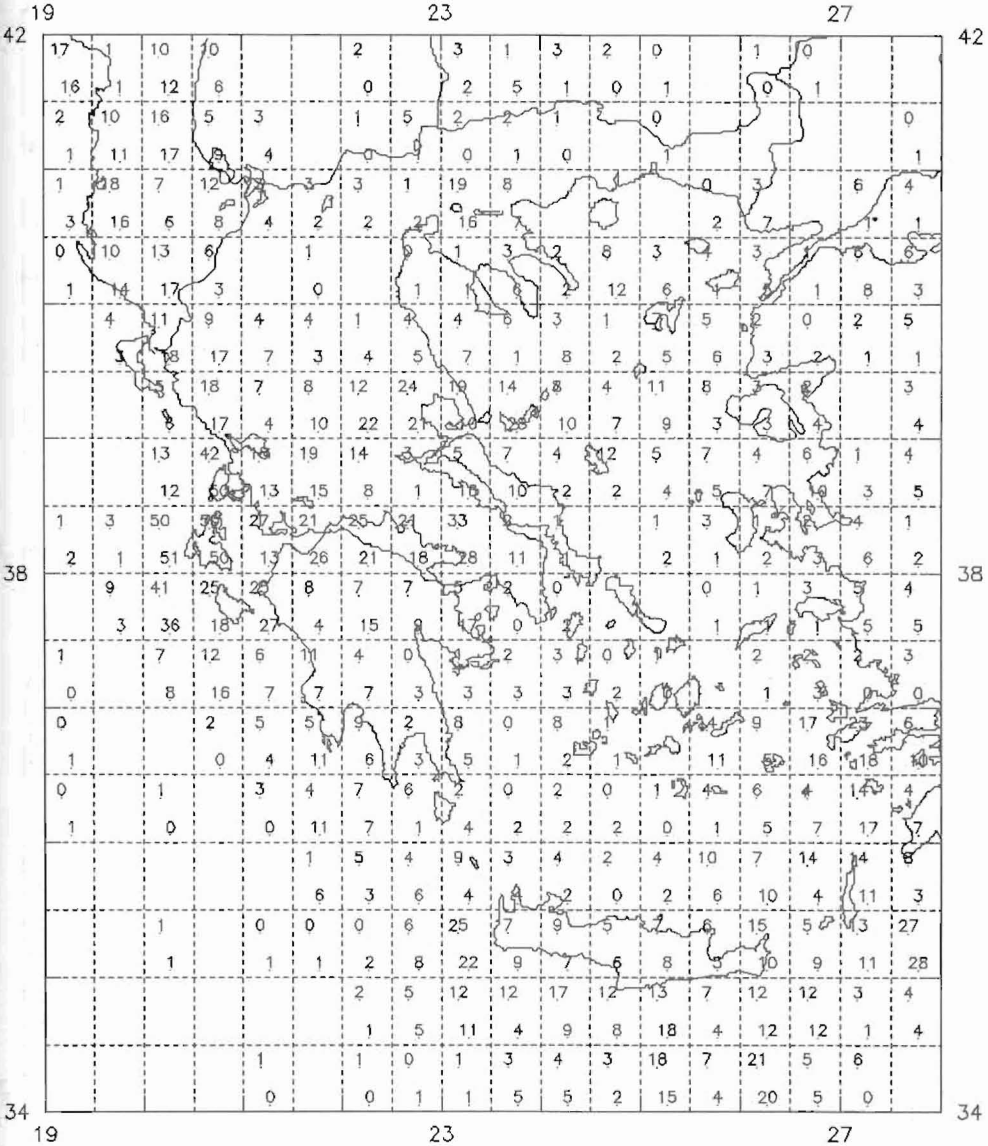

Fig.1. The map of number of the earthquakes occurred during tidal phases of compression (top) and tension (bottom).

Fig.2 shows the map of normalized differences $(N_+ - N_-)/2\sigma$. 47% of the whole region displays the domination of compression, and 44% the domination of tension. The highest value, 2.6, is observed towards the south from Skyros island. In this particular case the hypothesis of tidal influence on the triggering of the events must be accepted with a probability of more than 0.994.

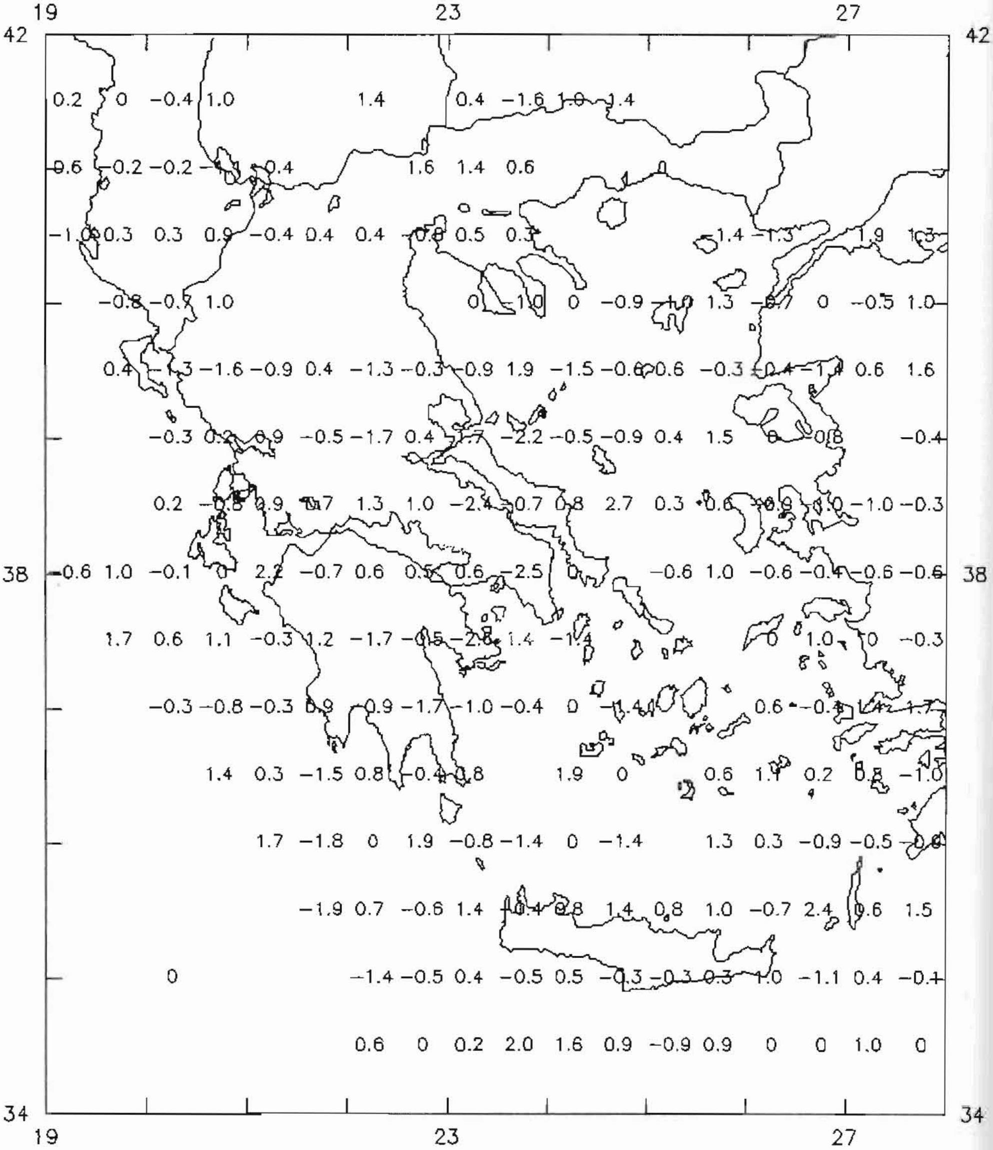

Fig.2. The map of normalized differences $(N - N)/2\sigma$.

The following main regularities of spatial distribution of $(N_+ - N_-)/2\sigma$ are seen: the areas characterized by similar response of the tidal deformation are clustered and form rather large areas stretching up to 200-400Km. This regularity may be considered as an independent indication of the nonrandom character of the $N_+ - N_-$ difference. Fig.3 shows the spatial distribution of the normalized difference versus the phase of tidal modulus.

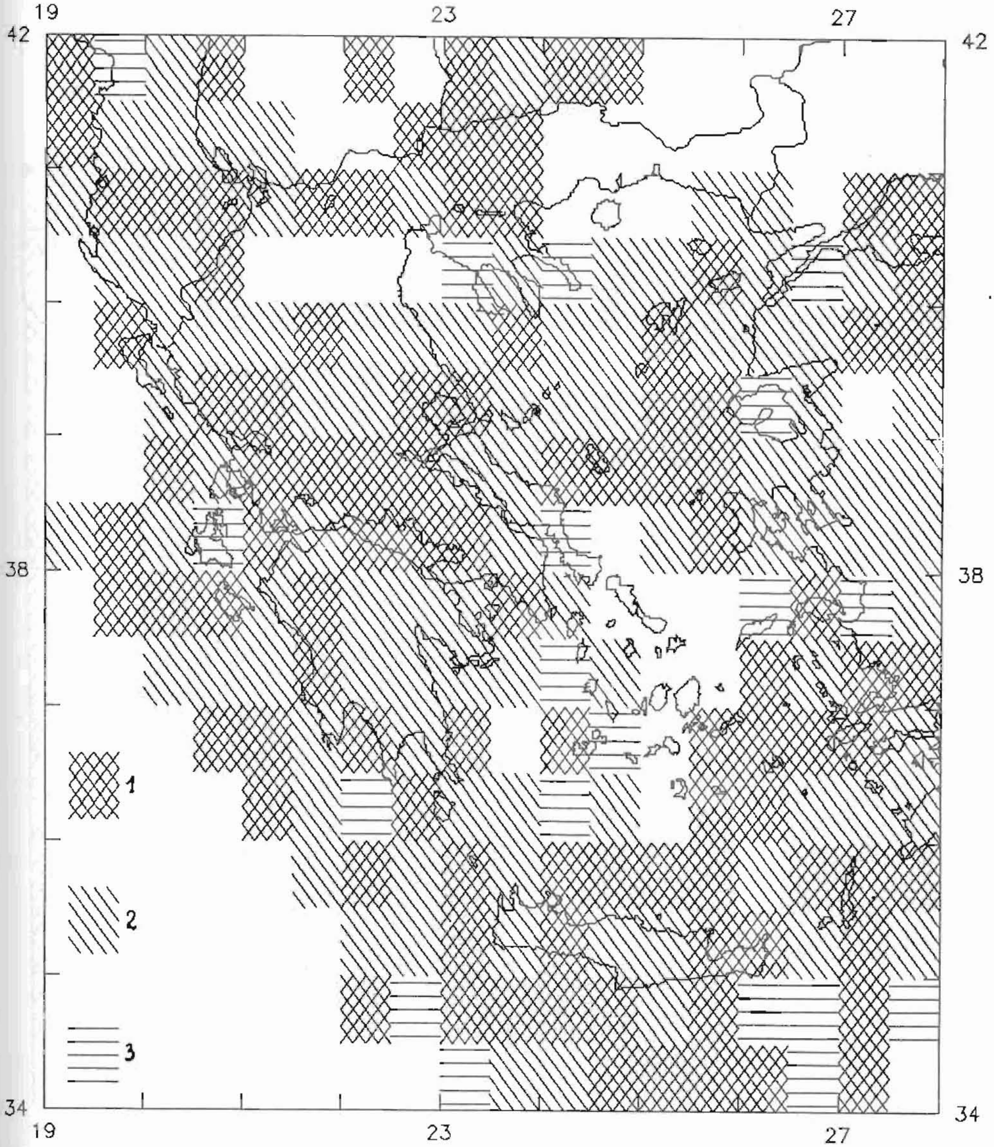

Fig.3. The map of general stress state: 1) compression, 2)tension, 3) neutral.

Fig.4 shows the spatial distribution of the normalized differences versus the phase of vertical component of the tidal deformation. The main feature of this map is rather similar to that seen in the Fig.3. Meanwhile the map of $N_+ - N_-$ versus the horizontal component of the tidal deformation, shown in the Fig.5, is more chaotic, but the western part of the Hellenic arc is expressed very clearly.

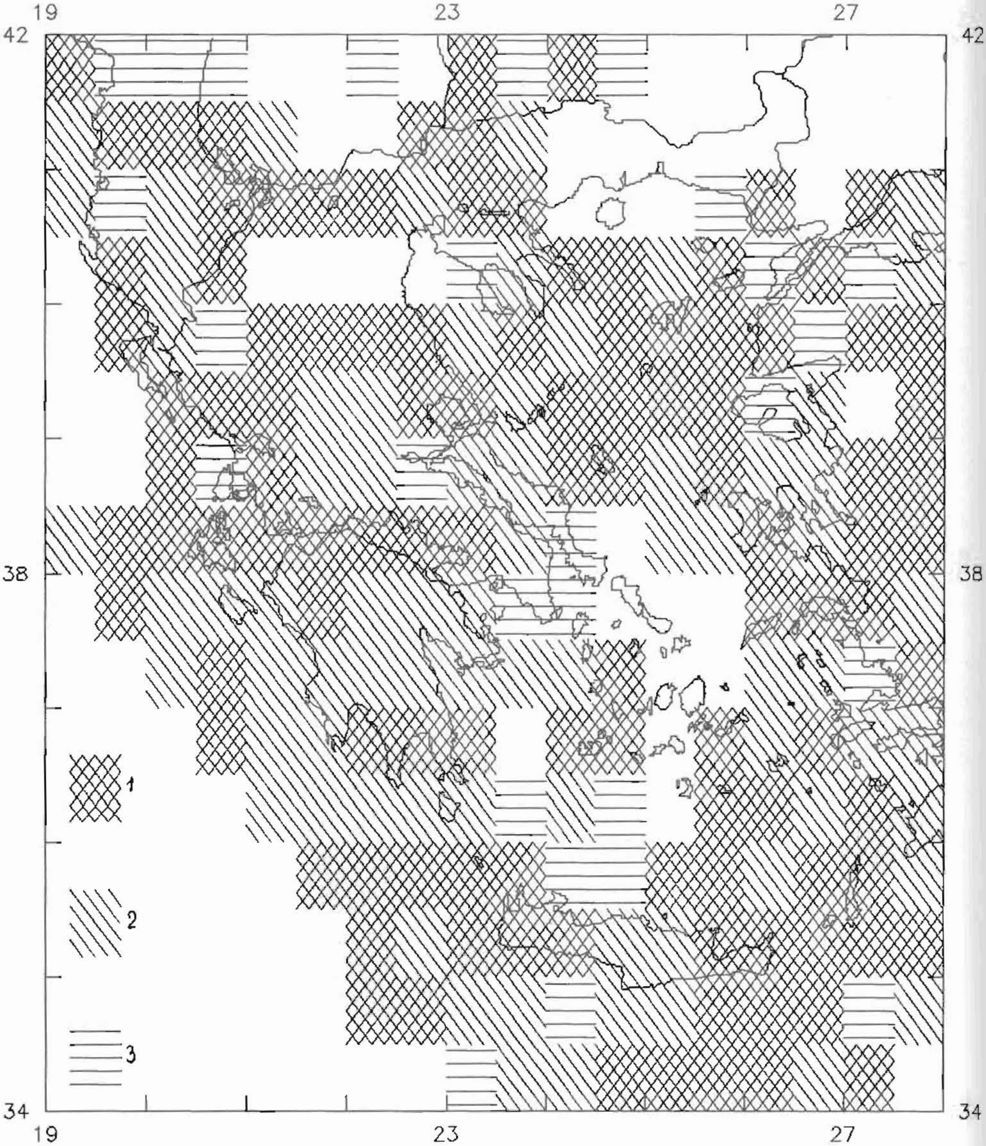

Fig.4. The map of the state of vertical stress: 1) compression, 2) tension, 3) neutral.

General compresssion is observed in Crete, central Aegean, eastern Dodecanese, Corinthiakos Gulf, nothern Macedonia, Attica western and southern Peloponnesus, eastern Ionian (Fig.3). General tension dominates in northern Aegean, southern Albania, Ionian, central Peloponnesus, western Turkey (Fig.3).

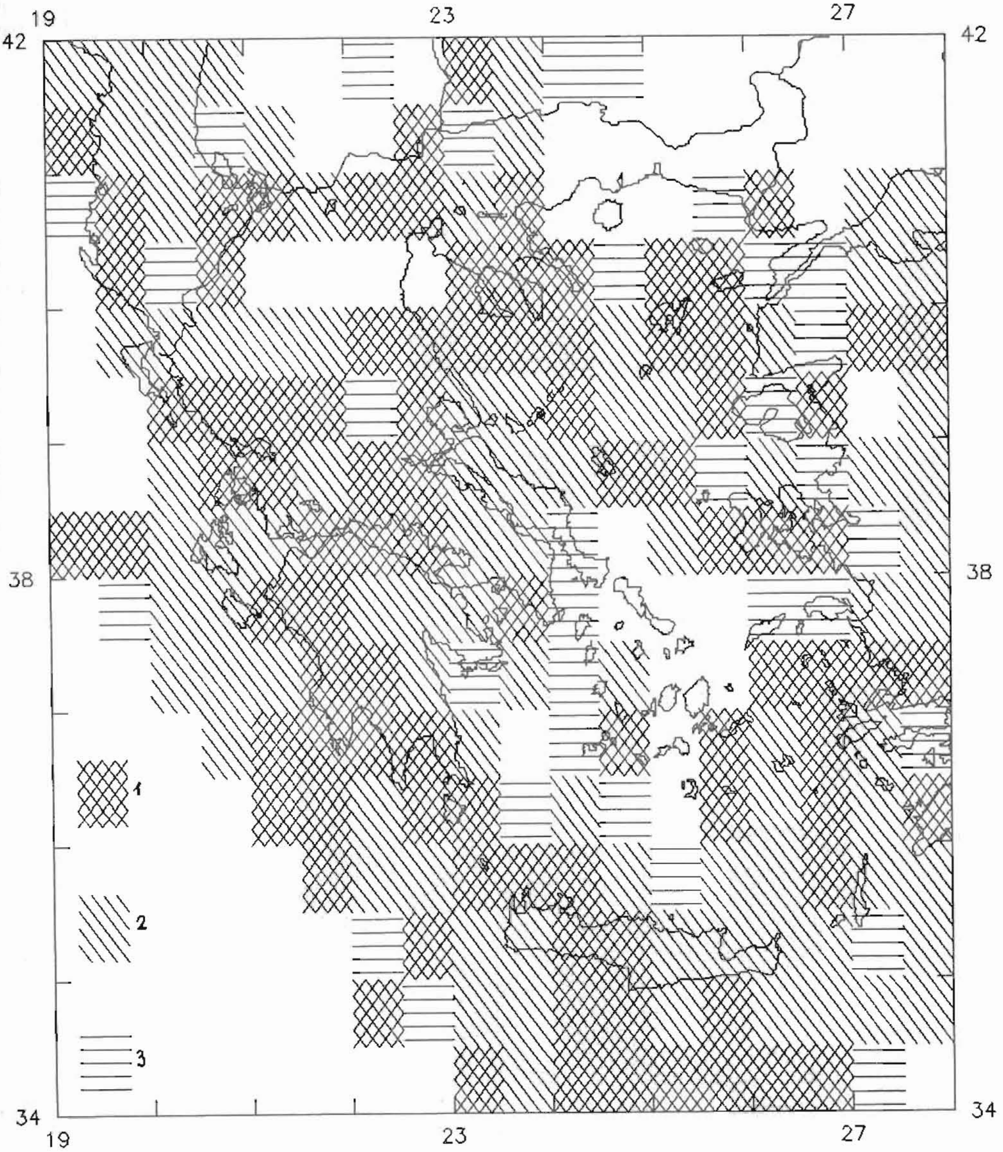

Fig.5. The map of the state of horizontal stress: 1) compression, 2) tension, 3) neutral.

Vertical compression is observed in the Ionian, Patraikos Gulf, southern Peloponnesus, western and eastern Crete, western Turkey, northern Aegean and northern Macedonia. Vertical tension prevails in Peloponnesus, central Crete, Lesbos, west coast of Peloponnesus (Fig.4).

Horizontal compression dominates in Macedonia, northern Ionian, Corinthiakos Gulf, west coast of Peloponnesus, south coast of Crete, northern Aegean, Albania. Horizontal tension prevails in Cephalonia, western and eastern Crete, western Turkey (Fig.5).

Generally the stress field is very complicated: compression prevails in the outer parts of the Hellenic arc, and tension prevails in the inner part of the Hellenic arc. In our opinion this method may be very helpful for stress field monitoring using small seismicity and for earthquake prediction.

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REFERENCES

Beresnev,I.A. and Nikolaev,A.V., (1990). Study of long vibro-signal propagation across the geophysical medium. Izv. Akad.Nauk USSR, Fizika Zemli, 1.86-98 (in Russian).

Comninakis,P.E. and Papazachos,B.C., (1986). A catalogue of earthquakes in Greece and the surrounding area of the period 1901-1985. Publ. No.1, Geoph.Lab. Univ. of Thessaloniki, pp. 167.

Longman,I.M. Journal Geophysical Research, 1959.Vol. 64.n.12, p.2351-2355.

Nikolaev,A.V., and Verestschagina,G.M., (1991). On the inducing of the earthquakes by the earthquakes. Dokl.Akad.Nauk. USSR, 318/2, 320-324.

Nikolaev,A.V. and Nikolaev,V.A., (1992). Earth tides triggering of earthquakes. 2nd International Conference on Continental Earthquakes. Abstracts. Beijing. 201.

Nikolaev,A.V. and Nikolaev,V.A., (1993). Correlation between aftershocks of strong earthquakes and the tidal phases as indicator of lithospheric stress state. Doklady (Reports) Akadem. Nauk. Russia. (in the press).

Rukunov,L.N., Khavroshkin,O.B. and Tsyplakov,V.V., (1979). Temporal variations fo high-frequency seismic noises. Izv.Akad.Nauk USSR, Fizika Zemli, 11.72-77 (in Russian).

Yaramanci,U., Zschau,J., Westerhaus,M. (1988). Tidal Tilt Admittance at Mudurnu Valley, Turkey, Anhang zum DFG Gesamtbericht uber das Vorhaben Geodatisch-Geophysikalische Untersuchungen im seismoaktiven Bereich der nord-anatolischen Storzone. 1,26.