

ΑΝΑΚΟΙΝΩΣΕΙΣ ΜΗ ΜΕΛΩΝ

ΣΕΙΣΜΟΛΟΓΙΑ.—**Variation of the Annual Strain Release Pattern in the Region of Greece, by N. D. Delibasis and A. G. Galanopoulos***. Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Μ. Κ. Μητσοπούλου.

INTRODUCTION

It was previously asserted (Galanopoulos, 1963) that both maps of earthquake efficiency in Greece, constructed for the periods 1710 - 1959 and 1841 - 1959, show in general the same trend of isoenergetical contours. Both maps reveal that the main part of the earthquake energy released in the area of Greece comes from two well developed centres of higher seismic activity, located along the large fault zone bordering the western and southern coasts of Greece.

In the centre situated along the western coast of Greece the earthquake activity rises rapidly towards the middle region of the centre, and culminates between the islands of Cephalonia and Zante and the entrance to the Gulf of Patras. The middle region of the centre situated in the southeastern Aegean Sea covers the area between Rhodes, Karpathos and Kos.

Now it was thought that a set of similar maps constructed for one year period could reveal some details about the variation in the distribution of the seismic centres, and in turn these could possibly throw some light on the rheological behaviour of the Alpine folding in the area of Greece. To test the resolving power of the proposed method four maps showing the strain release pattern for 1958 through 1961 were constructed for the time being.

METHOD APPLIED

For mapping the annual strain release the method described in the previous paper (Galanopoulos, 1963) was in general applied. At the first step the total strain release, i.e. the sum of the square roots of the earthquake energies for each one-degree quadrangle (1° lat. 1° long.) was calculated from $S = \sum_j E_j^{1/2}$, in which the summation extends over all earthquakes of magnitude $\geq 4^{3/4}$ having occurred in the corresponding cell. The individual strain release was computed from the formula :

$$\log E^{1/2} = 5.9 + 0.75M,$$

* Ν. Δ. ΔΕΛΗΜΠΑΣΗ καὶ Α. Γ. ΓΑΛΑΝΟΠΟΥΛΟΥ, Μεταβολὴ τοῦ σχεδίου ἑτησίας ἐκλύσεως ἑλαστικῶν τάσεων εἰς τὸν ἑλληνικὸν χῶρον.

where M is the magnitude on the Richter scale and E is the released seismic energy in ergs. Where the epicentre was situated on the borderline between two adjacent square degrees or at the middle point of four square degrees, the individual strain release, expressed in $10^{11}(\text{ergs})^{1/2}$ units, was divided equally among them. At the second step the cumulative strain release of four adjacent square degrees was further summarized and divided by four. Then the weighted mean of the four cells was inserted in the center of the quadrangle formed by the cells considered. The procedure was successively applied over the entire region. Thus a new grid system of square degrees with averaged strain release values was formed. Now the distance between two successive weighted means denoting the annual strain release — i.e. the cumulative «*rebound displacement*» after Ritsema (1954) or the «*tectonic flux*» after Amand (1956) — in each square degree was divided by contours graded in levels of 5 per cent of the unit.

It was thought that the general accuracy of locations of earthquakes occurred in the area of Greece does not permit, for the time being, the use of cells of smaller size. The difference in the area of the cells due to difference in latitude, amounting to about $8\frac{1}{2}$ per cent from 34° N to 42° N, was not considered important for the reliability of the strain release pattern owing to smoothing process applied. The data used were taken from the «*Seismological Institute Bulletin*» published by the National Observatory of Athens for years 1958 through 1961.

DISCUSSION

It is a fact that the frequent occurrence of earthquakes in Greece allows the distribution of seismic zones to be defined very accurately by the strain release patterns. The annual patterns of strain release in the area of Greece for years 1958 through 1961 show very small variations in the distribution of seismic zones. In general the annual strain release patterns are very similar to the average patterns previously found for the periods 1710 - 1959 and 1841 - 1959 (s. Fig. 1 and 2).

The southeastern centre of maximum strain release in 1958 (s. Fig. 3) is not connected with the western centre; but appears at the normal place, between the islands Kos, Karpathos and Rhodes, with a well expressed tongue over the middle Crete. The activity in this centre culminated on June 30, 1958,

with the occurrence of an intermediate shock of $M = 6$ (36.5° N, 27.4° E). The western centre, between Cephalonia and Zante, shows a very clear tendency to extend southwestwards of Zante Island. Two tongues from the

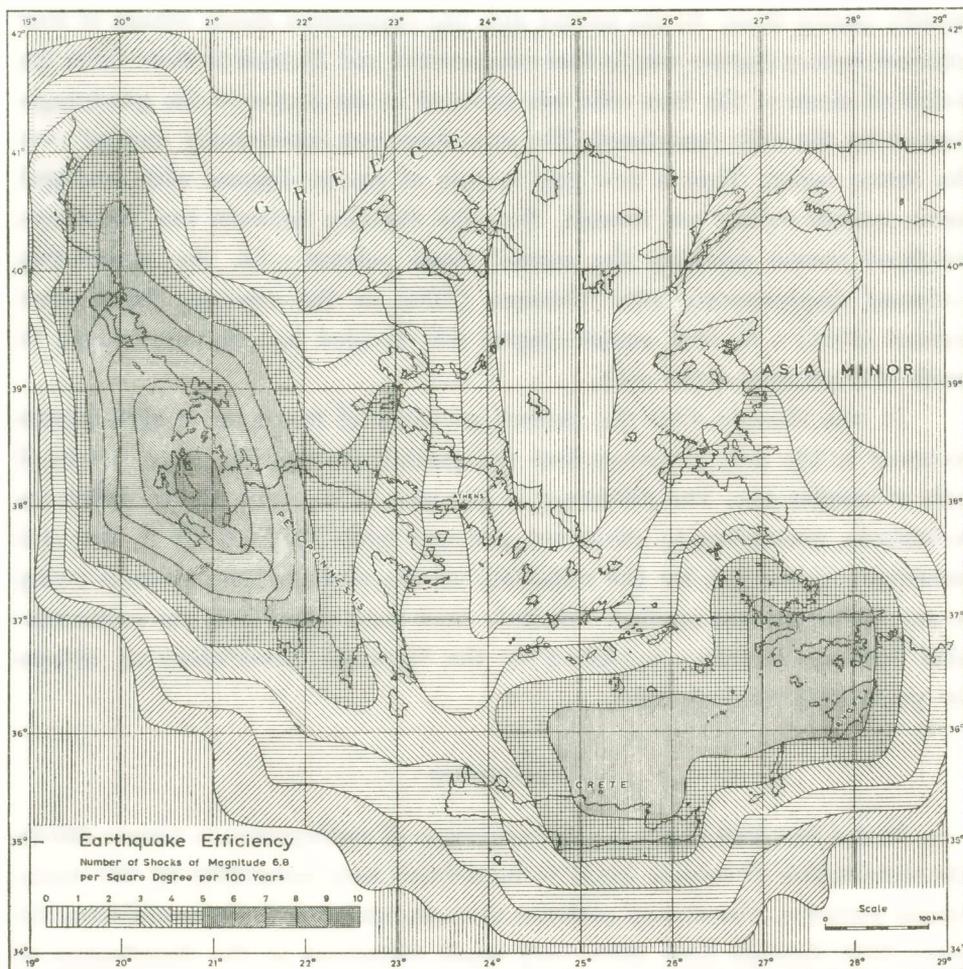


Fig. 1. — Earthquake efficiency in Greece derived from earthquake data over the period 1710 - 1959.

western centre licked up the tips of Kassandra and Sithonia peninsulae and the western coast of Greece. The maximum of the seismic energy released in this centre is due to a shock of magnitude $6\frac{1}{2}$, on August 25, 1958 (37.8° N, 20.5° E). The secondary centre at the boundary of Greece-Albania shifted

on April 3, 1958, by a shock of magnitude 5.7 (41° N, 20° E) one degree northwards, at the latitude of the Ochrida and Prespa Lakes. The strain release in

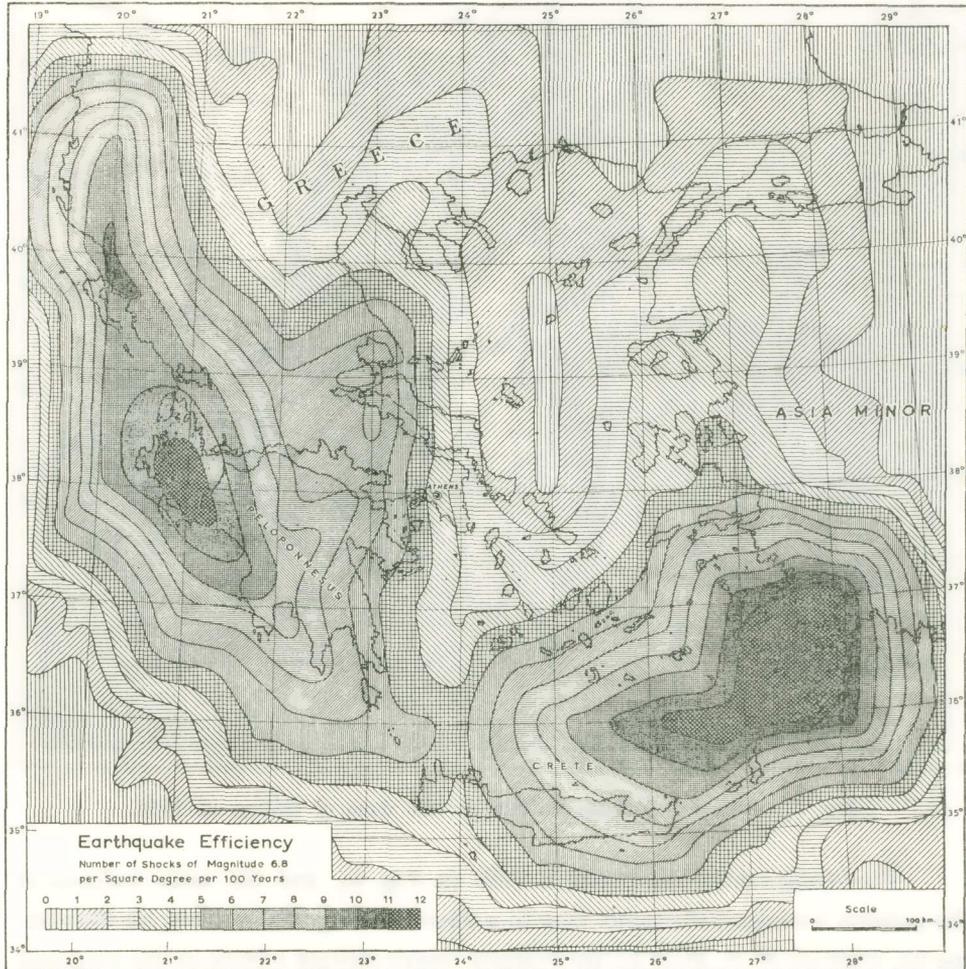


Fig. 2. — Earthquake efficiency in Greece derived from earthquake data over the period 1841 - 1959.

the main centres reached in 1958 a maximum $2\frac{1}{2}$ times higher than the average found for the same regions over the time interval 1841 - 1959. The Albania centre shows a strain release equal to $\frac{3}{4}$ of the annual average.

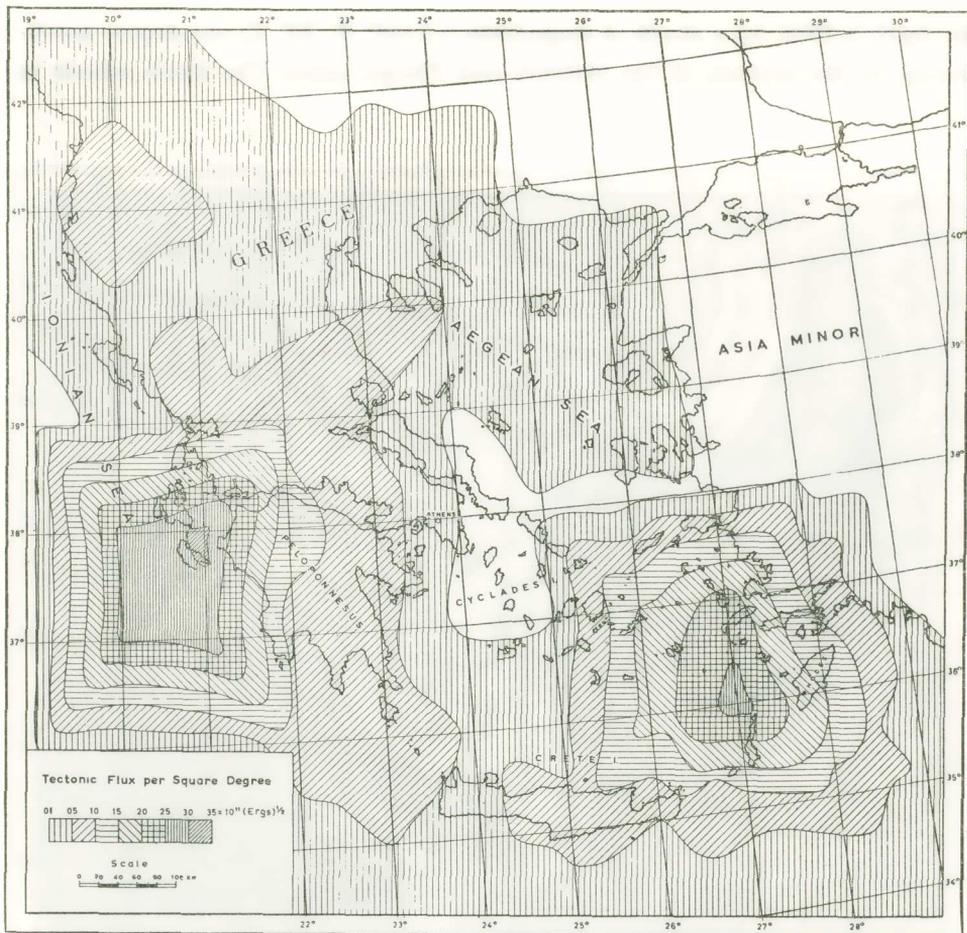


Fig. 3. — Strain - Release Pattern in the Area of Greece in 1958.

The strain release increased in 1959 (s. Fig. 4), but the main features of the pattern remained the same. Due to a shock of magnitude $\approx 6 \frac{3}{4}$ on November 15, 1959 (37.8° N, 20.5° E) the western centre shifted a little to the west and the south of Zante Island and the tectonic flux increased almost to the double, in comparison to that of the previous year. The northeastern tongue of the 1958 western centre split into a transient centre at the mouth of the Gulf of Salonica, but the strain release remained at the same level. The Salonica centre appeared on May 14, 1959 (40.0° N, 23.3° E) with two shocks of magnitude 5 - 5 $\frac{1}{4}$. The southeastern centre split up into two centres, one north-east of Rhodes Island appeared on April 25, 1959 (37.0° N, 28.5° E) with a

shock of magnitude 6.3, and the other over the middle Crete. The second centre appeared on May 14, 1959 ($35^{\circ} \frac{1}{4}$ N, $24^{\circ} \frac{3}{4}$ E) with a shock of magnitude $6 \frac{1}{2}$. In both centres the strain release reached a level about twice higher than the average. The Crete centre is connected with the Zante centre

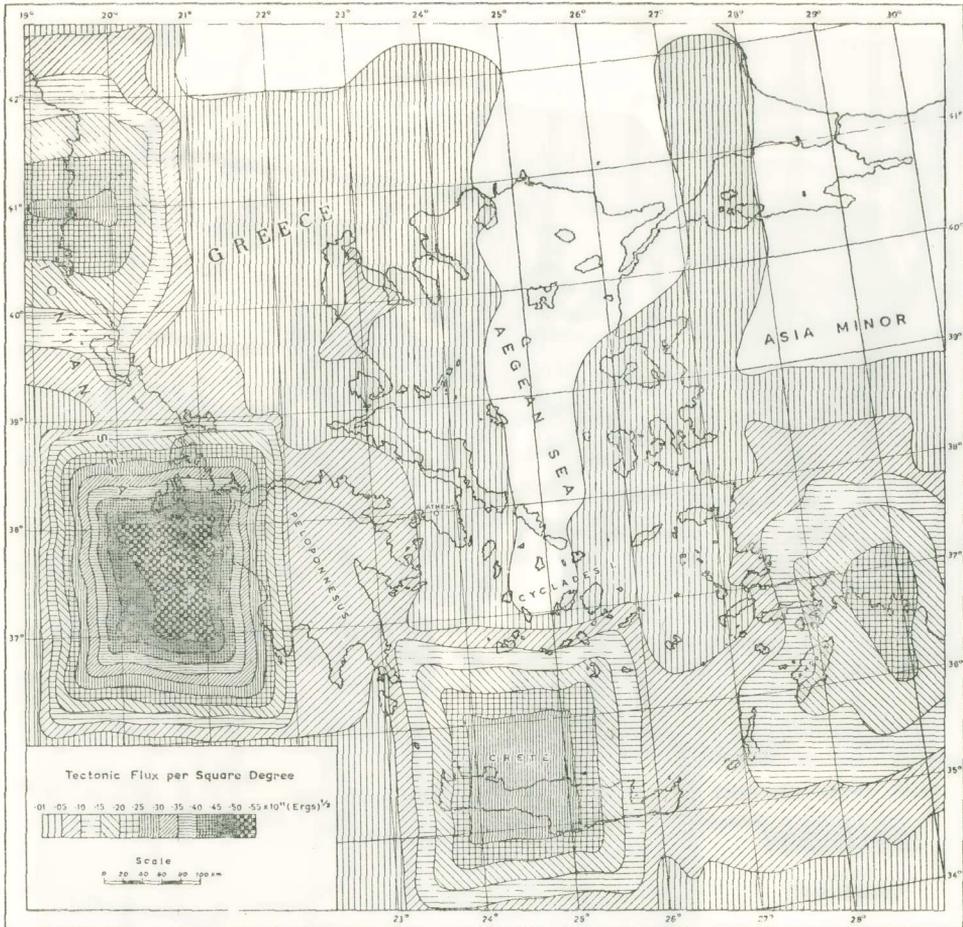


Fig. 4.— Strain - Release Pattern in the Area of Greece in 1959.

by a narrow bridge. The secondary centre of Albania remained at the same place but the tectonic flux, owing to two shocks of magnitude ≥ 6 on August 17, 1959 (41° N, $19^{\circ} \frac{1}{2}$ E) and on September 1, 1959 (41.0° N, 19.6° E), developed a maximum $3 \frac{1}{2}$ times higher than the level of the previous year.

The gulf of lower earthquake activity in the northern Aegean Sea is well defined by two peninsulae of one level higher strain release on both sides of the gulf considered.

The strain release pattern in 1960 (s. Fig. 5) shows a southeastern centre with two secondary maxima, one north of Rhodes Island and the other in

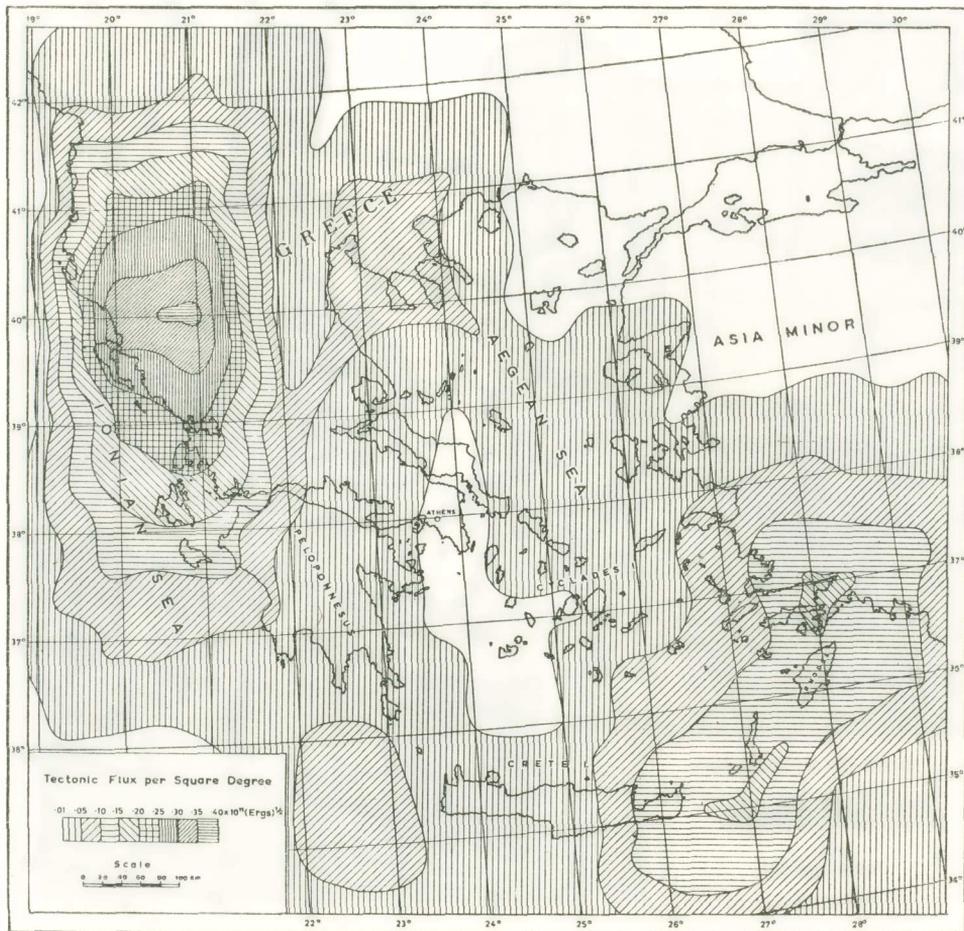


Fig. 5.— Strain - Release Pattern in the Area of Greece in 1960.

the east of Crete, i.e. south of Kasos and Karpathos. The strain release at the two highs dropped in 1960 close to the level of the annual average rate ($0.12 \times 10^{11} (\text{ergs})^{1/2}$). The 1959 well expressed high southwestwards of Zante and the secondary high across the Albania coast at the 41° latitude disap-

peared and another high developed one degree southwards of Prespa Lake. The strain released in the new high of the western centre reached on May 26, 1960, due to a shock of magnitude $6 \frac{1}{2}$ (40.6° N, 20.6° E), a level 3 times higher than the average. The transient centre in the Gulf of Salonica shifted on July 13, 1960, over the Chalcidike (40.6° N, 23.4° E) in the form of an axe arising from the large western centre. The strain released in the Chalcidike centre, in spite of two shocks of magnitude $5 \frac{1}{4}$ and $5 \frac{3}{4}$, remained at the same level. A transient centre at the level of one half of the annual maximum average rate appeared on December 28 - 29, 1960, with two shocks of magnitude $5 \frac{1}{4}$ in the west of Crete, southwards of Peloponnesus (35.0° N, 22.3° E; 35.5° N, 22.6° E). However, this new centre was not large enough to connect the two main features of the strain release pattern.

The southeastern centre of higher strain release shifted in 1961 (s. Fig. 6) to the southeastern coast of Rhodes Island. An intermediate shock of magnitude $6 \frac{1}{2}$ on May 23, 1961 (36.8° N, 28.7° E) raised the tectonic flux in the Rhodes centre to a level about two times higher than the average. The western centre, in spite of two shocks of magnitude $5 \frac{1}{4}$ and $5 \frac{1}{2}$ on January 7, 1961 (37.6° N, 20.8° E) and on July 19, 1961 (37.8° N, 20.1° E) respectively, is vaguely expressed in the level of $\frac{3}{4}$ of the average, but due to a shock of magnitude $5 \frac{3}{4}$ on October 2, 1961 (37.0° N, 22.0° E) is well connected with the Rhodes centre. A large transient centre developed between Chios and Dardanelia in the place of the normal northern tongue of the southeastern centre. Due to a shock of magnitude $5 \frac{1}{2}$ on November 28, 1961 (39.5° N, 26.3° E) the strain release in the transient centre reached a level equal to the annual average found for the region. A secondary centre, separated from the main western centre, is vaguely outlined in Albania, northwestwards of Ochrida Lake. In spite of a shock of magnitude $5 \frac{1}{2}$ on June 22, 1961 (42.4° N, 19.3° E), the strain release in this centre remained 3 times lower than the annual average. The small secondary centre in the channel of Trikkeri, evolved after an intermediate shock of magnitude $5 \frac{1}{4}$ on January 28, 1961 (39.3° N, 22.0° E), is hardly expressed in the level of one half of the annual average. The gulf of the lower earthquake activity is well developed between the northeasterly large extension of the western centre and the Chios-Dardanelia centre.

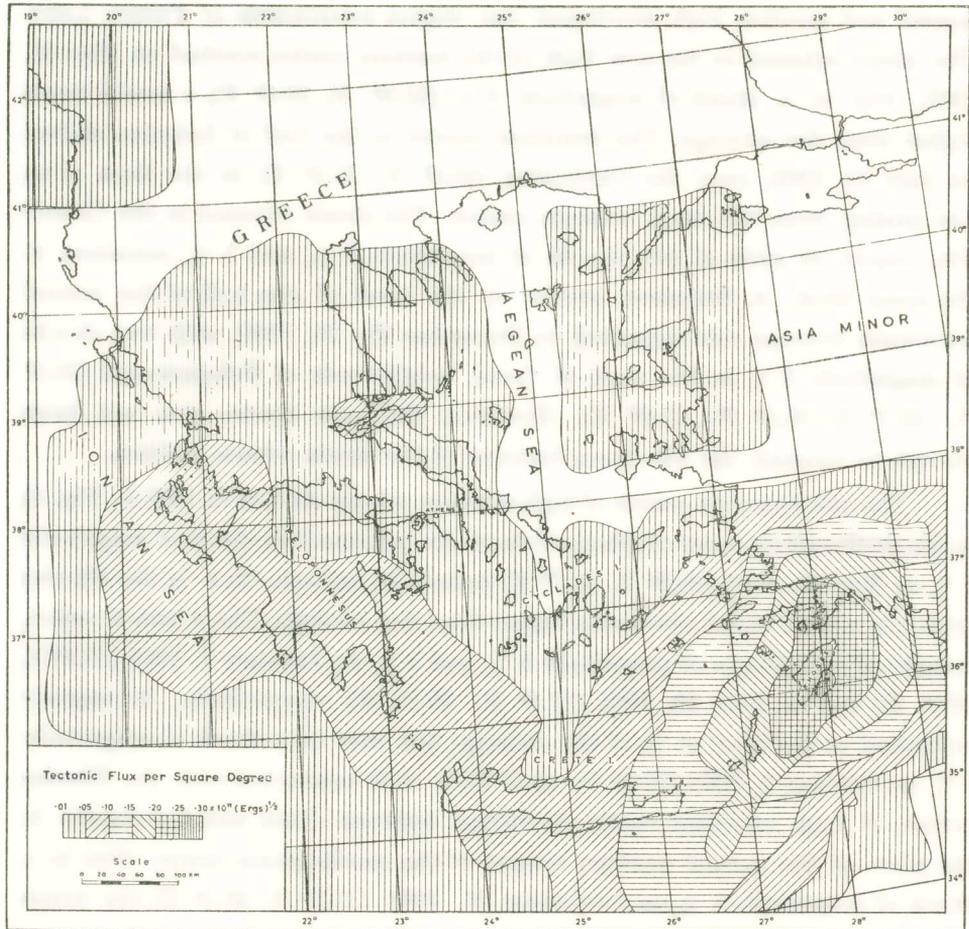


Fig. 6.— Strain - Release Pattern in the Area of Greece in 1961.

CONCLUSION

It is out of question that the dynamic representation of seismic activity in four successive years —which are available for the present time— do not cover a time interval long enough to reveal the law, if any, of the shift of the earthquake centres along the large fault zone, which marks the marginal geosyncline being now in the course of development in the eastern Mediterranean. However, the existence of two permanent centres in the western and southeastern coasts of Greece makes fairly clear that the forces responsible for the strain accumulation in the area of Greece are more active in the region

of Zante-Cephalonia-Leukas, as well as in the region of Kos, Karpathos and Rhodes. From the set of strain release maps available it seems that the two permanent centres from time to time stretch out long tongues which soon develop secondary or transient centres. At the same time the activity in the permanent centres slows down. In general the maps of annual strain release seem to bear a qualitative resemblance to weather maps, the variations and changes in the annual strain release patterns reflecting the deformation and flow of matter in the upper mantle, where convection may occur.

ACKNOWLEDGMENTS

The research reported in this document has been sponsored by the AIR FORCE OFFICE OF SCIENTIFIC RESEARCH under Contract AF 61(052)-803 through the European Office of Aerospace Research (OAR), United States Air Force, as part of the Advanced Research Projects Agency's Project VELA UNIFORM.

The authors would like to express their sincere thanks to Dr. B. Papazachos for reading critically the manuscript of this paper.

ΠΕΡΙΛΗΨΙΣ

Είς τὴν προηγουμένην ἐργασίαν τοῦ Α. Γαλανοπούλου (1963) ἀνεπτύχθη μία νέα μέθοδος ἀπεικονίσεως τῆς σεισμικῆς δράσεως δι' ἰσοενεργητικῶν καμπυλῶν, ἐπὶ τῇ βάσει δὲ τῆς μεθόδου ταύτης κατεσκευάσθησαν δύο χάρται τῆς σεισμικῆς δυναμικότητος τοῦ Ἑλληνικοῦ Χώρου διὰ τὰς περιόδους 1710 - 1959 καὶ 1841 - 1959. Ἀπὸ τὴν διάταξιν τῶν ἰσοενεργητικῶν καμπυλῶν εἰς ἀμφοτέρους τοὺς χάρτας τούτους ἀπεδείχθη ὅτι τὸ μεγαλύτερον μέρος τῆς σεισμικῆς ἐνεργείας, ἡ ὁποία ἐλευθεροῦται εἰς τὸν Ἑλληνικὸν Χῶρον κατὰ τετραγωνικὴν μοῖραν εἰς 400 ἔτη προέρχεται ἀπὸ δύο μόνιμα σεισμικὰ κέντρα ἐντόνου δράσεως, τὰ ὁποῖα εὐρίσκονται κατὰ μῆκος τῆς μεγάλης ρηξιγενεοῦς ζώνης, ἣτις περιβάλλει τὰς δυτικὰς καὶ νοτίους ἀκτὰς τῆς Ἑλλάδος. Εἰκάζεται ὅτι ἡ ζώνη αὕτη εἶναι παράλληλος πρὸς τὸν ἄξονα ἐνὸς νέου περιφερικοῦ γεωσυγκλίνου, τὸ ὁποῖον εὐρίσκεται ἐν ἐξελίξει ἐν τῇ Ἀνατολικῇ Μεσογείᾳ, ἀπὸ τὴν παρουσίαν δὲ εἰς τὴν ζώνην ταύτην δύο μόνιμων κέντρων ἐντόνου σεισμικῆς δράσεως συμπεραίνεται ὅτι αἱ ὀρογενετικαὶ δυνάμεις, αἱ ὁποῖαι εἶναι ὑπεύθυνοι διὰ τὴν συσσώρευσιν ἐλαστικῶν τάσεων εἰς τὸν Ἑλληνικὸν Χῶρον, εἶναι περισσότερον ἐνεργοὶ εἰς τὴν περιοχὴν Ζακύνθου - Κεφαλληνίας - Λευκάδος καὶ εἰς τὴν νοτίαν περιοχὴν τοῦ Αἰγαίου τὴν ὀριζομένην ἀπὸ τὰς νήσους Κῶ, Ρόδον καὶ Κάρπαθον.

Δι' ένα περαιτέρω έλεγχο τῆς αξιοπιστίας τῆς ἀνωτέρω σεισμικῆς εἰκόνας, οἱ συγγραφεῖς παρουσιάζουν εἰς τὴν παροῦσαν ἐργασίαν σειρὰν ὁμοίων χαρτῶν μὲ ἰσο-ενεργητικὰς καμπύλας διὰ διαδοχικὰ ἔτη. Οἱ χάρται οὗτοι ἐμφανίζουν ὠρισμένας λεπτομερείας εἰς τὴν ἀπὸ ἔτους εἰς ἔτος μεταβολὴν τῆς θέσεως τῶν σεισμικῶν κέντρων, αἱ ὁποῖαι ἀποκαλύπτουν τὴν ρεολογικὴν συμπεριφορὰν τῆς Ἀλπικῆς πτυχώσεως εἰς τὸν Ἑλληνικὸν Χῶρον. Ἀπὸ τὴν σειρὰν χαρτῶν ἐτησίως σεισμικῆς δράσεως, τὴν ὁποῖαν παρουσιάζουν οἱ συγγραφεῖς διὰ τὴν περίοδον 1958 - 1961, φαίνεται ὅτι ἀπὸ τὰ δύο πρωτεύοντα σεισμικὰ κέντρα, τὰ λειτουργοῦντα μονίμως εἰς τὸν Ἑλληνικὸν Χῶρον, ἐκτείνονται ἀπὸ καιροῦ εἰς καιρὸν ἐπιμήκεις γλῶσσαι, αἱ ὁποῖαι ταχέως ἐξελίσσονται εἰς δευτερεύοντα ἢ προσωρινὰ σεισμικὰ κέντρα ἐντόνου δράσεως. Κατὰ τὸν χρόνον τοῦτον ἡ σεισμικὴ δρᾶσις εἰς τὰ μόνιμα κέντρα εὐρίσκεται ἐν ὑφέσει. Μετὰ τὴν ἐξαφάνισιν τῶν δευτερευόντων κέντρων ἡ σεισμικὴ δρᾶσις ἀναζωπυροῦται κατὰ μῆκος τῆς ρηξιγενοῦς ζώνης, ἡ ὁποῖα φιλοξενεῖ τὰ δύο μόνιμα σεισμικὰ κέντρα. Γενικῶς οἱ χάρται ἐτησίως ἐκλύσεως ἐλαστικῶν τάσεων ἐν τῷ Ἑλληνικῷ Χώρῳ δεικνύουν ποιοτικὴν ὁμοιότητα πρὸς τοὺς χάρτας καιροῦ, φαίνεται δὲ ὅτι ἀντικατοπτρίζουν τὸ σχέδιον ροῆς ὑπογείων ρευμάτων μεταφορᾶς, τὰ ὁποῖα φαίνεται νὰ ἀναπτύσσονται εἰς τὸν ἀνώτερον μανδύαν, ὅπως καὶ οἱ ἰσοπορικοὶ χάρται ἴσης ἐτησίως μεταβολῆς τῶν γεωμαγνητικῶν στοιχείων, οἱ ὁποῖοι—ὡς πιστεῦεται γενικῶς—ἀντικατοπτρίζουν τὸ σχέδιον ροῆς τῶν κυκλοφορούντων εἰς τὸν πυρῆνα τῆς Γῆς ἡλεκτρικῶν δινορευμάτων.

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