ΠΡΑΚΤΙΚΑ ΤΗΣ ΑΚΑΔΗΜΙΑΣ ΑΘΗΝΩΝ

ΣΥΝΕΔΡΙΑ ΤΗΣ 16ΗΣ ΟΚΤΩΒΡΙΟΥ 1986

ΠΡΟΕΔΡΙΑ **ΚΩΝΣΤΑΝΤΙΝΟΥ ΤΡΥΠΑΝΗ**

ΣΕΙΣΜΟΛΟΓΙΑ.— **Difference in the Transition Pattern from Brittle to Ductile Deformation in the Northern and Southern Half of the Greater Area of Greece,** *by A. G. Galanopoulos**.

ABSTRACT

Drawing the seismic activity change against overlapping depth steps, 10 km wide, is a competent method for showing differences in the ability of deformation at various levels of the earth's crust and upper mantle. Drawings made separately for the northern and southern half of the greater area of Greece reveal marked differences in the thickness of their brittle and ductile layers. In the brittle layer the seismic activity is decreasing with increasing depth; in the ductile layer the seismic process is reversed, i.e. the seismic activity is increasing with increasing depth.

In the northern subregion the brittle layer extends down to a depth of 15 km. Below this level there is apparently a transition zone 15 km thick. A ductile layer that follows is relatively thin; it reaches the 40 km depth. In the southern subregion the brittle layer is not well expressed in drawings showing the activity in terms of strong shocks ($M_s \geqq 5\ 1/2$). This probably indicates that in the southern subregion the upper layer does not have the ability of large deformation and/or the barriers or asperities of the fault-planes are relatively small. Consequently, the southern subregion does not suffer from very shallow shocks, which are generally more destructive, as much and often as the northern half of the region. The ductile layer in the subduction region seems to extend from 25 or 30 to 45 km depth.

Although the seismic activity in the northern subregion ends at the level of about

* Α. Γ. ΓΑΛΑΝΟΠΟΥΛΟΥ, **Διαφορὰ στὸν τρόπο μεταβάσεως ἀπὸ τὴν εὔθραυστο στὴν εὐήλατο παραμόρφωση στὸ βόρειο καὶ νότιο ἥμισυ τοῦ Ἑλληνικοῦ χώρου.**

65 km depth and in the southern subregion is occurring down to the depth of 160 km and eventually below it, the earthquake potential is relatively greater in the northern half of the region (56% in shocks and 74% in seismic energy observed in the whole region). This, obviously, is not compatible with the assumed origin of the regional stress field from the convergence and collision of Eurasia and Africa plates. Mantle convection is most probably the origin of the dominating stress regime.

INTRODUCTION

It is believed that the earthquake occurrence is intimately related to the mechanical properties of the focal volume and /or the barriers or asperities of the fault-planes and the stress pattern to which are subject. This being the case, a regional change in the mechanical properties and deformation ability at various levels of the earth's crust and mantle might be reflected in a vertical profile of the related seismic activity (Galanopoulos, 1974).

Considering that the southern half of the greater area of Greece (33° N 43°, 17° E 30°) is admittedly a subduction area, the tectonic structure and the stress field might considerably differ from those inherent in the northern half of the region. Although the subduction area associated with the Hellenic arc is not exactly bounded on the north by the 38th parallel, the expected difference in the seismotectonic zone can not be masked in a fair extent by a transition zone from one half to the other. Guided by this reasoning an attempt was made to reveal the expected difference in the pattern of the seismic efficiency at various levels of the earth's crust and upper mantle in the northern and southern half of the greater area of Greece.

DATA USED

The data used for the outlined purpose cover the period 1971-1983. During this period the configuration of stations in Greece remained stationary and the type of recording devices did not change. In addition, since 1971 the seismic entries in the regional catalogues of the International Seismological Centre (ISC) are adequately homogeneous. All location data and focal depths were taken from these catalogues.

Surface wave magnitudes smaller than 6 3/4 were derived from a calibration formula using the number of the reporting stations and the distance out to which the related shocks were registered. The greater magnitudes were taken from Pasadena reports. The 4 1/2 M_S was adopted as threshold magnitude (Suzuki and Ito, 1980; Galanopoulos and Makropoulos, 1981).

It was previously shown (Galanopoulos, 1967) that in active regions with short return periods, such as Greece, even a short sample period is good enough to reveal with a high degree of reliability the rate, let alone the pattern of strain energy release. The data with $M_S \geqq 5$ 1/2 was taken from tables published in 1977 (Galanopoulos, 1977) and 1985 (Galanopoulos, 1985).

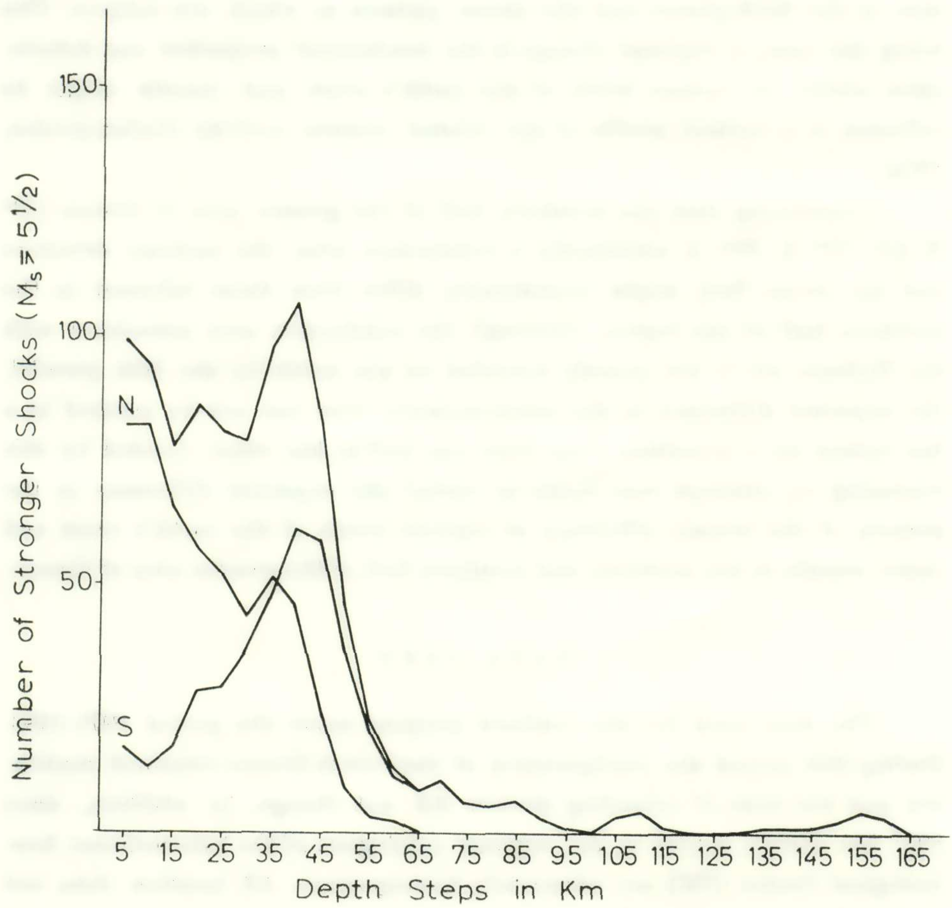

Fig. 1. Number of strong shocks ($M_S \geqq 5$ 1/2) occurred at various levels of the Earth's crust and upper Mantle during the period 1971-1983.

The remaining data was taken from unpublished catalogues of the author.

The whole set of data for the entire region (33° N 43°; 17° E 30°) and subregions (33.1° N 38°, 17°E30° and 38.1°N43°, 17°E30°) was arranged per depth and magnitude (see Tables I, II, III and IV, V, VI). Assuming a 5 km inaccuracy in the focal depth determination, the range of focal depths was taken equal to 10 km overlapping (0-10, 6-15, 11-20, 16-25, 21-30... km). The seismic magnitudes were arranged in steps of 1/4 magnitude unit.

To interpret the Tables, the number of stronger events ($M_s \geq 5\ 1/2$) as well as the seismic energy for the whole region and the two subregions were plotted against the above defined depth steps (see Fig. 1 and 2). The seismic energy was calculated by the Gutenberg-Richter's formula (1956):

$$\text{Log } E = 11.8 + 1.5\ M_s$$

The number of medium size shocks (4 1/2 - 5 1/4 M_s) with the shorter recurrence rates and the corresponding seismic energy were plotted separately (see Fig. 3 and 4).

DISCUSSION

In the first drawing, depicting the seismic activity expressed in number of shocks, there is a striking difference in their decrease pattern related to the northern and southern subregions. In the northern half of the region, N, the number of shocks decreases abruptly in the upper brittle layer down to a depth of about 15 km. Below the depth level of 15 km the decreasing slows down to a depth of 30 km; there is a small increase between 30 and 35 km, and from the depth level of about 40 km the number of shocks decreases again abruptly down to a 55 km depth. The seismic activity stops finally at the depth level of about 65 km.

In the southern half of the region, S, the seismic activity remains almost constant down to the depth of 15 km; below this level it starts increasing with increasing depth, possibly as result of the transition from brittle to ductile deformation (Boatwight, 1985), down to a depth of 40 or 45 km. Beneath this level it desreases rather abruptly down to a depth of 60 to 65 km, but it remains decreasing down to a depth of about 160 km.

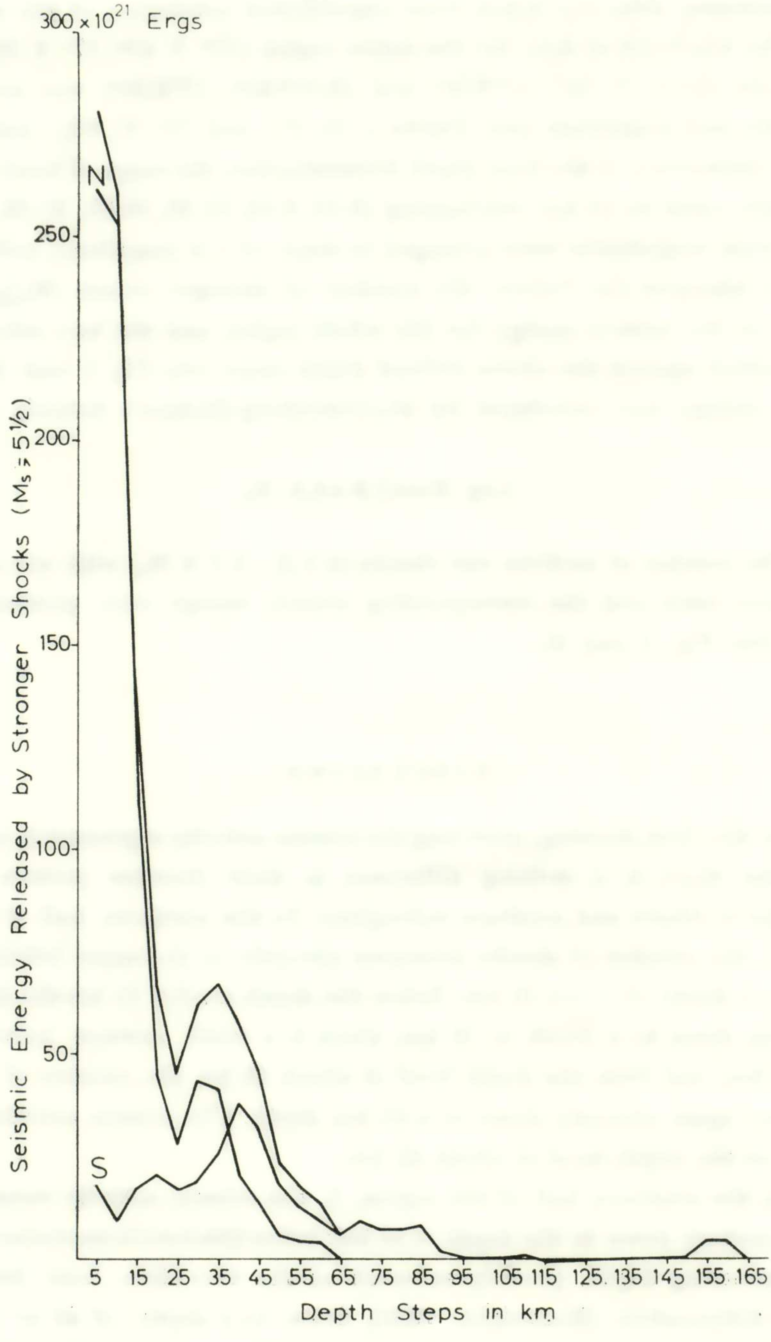

Fig. 2. Seismic energy released in strong shocks ($M_S \geqq 5$ 1/2) at various levels of the Earth's crust and upper Mantle during the period 1971-1983.

The pattern of seismic activity change for the whole region lumps the differences of the previously described patterns and shows at the depth interval of 15 to 30 km the existence of a transition zone from the brittle to ductile layer. Temperature and water are both eligible to transform the crust from brittle to ductile structure. Water contained in rocks has two competing effects. One is an embrittling effect, and the other is the effect of enhancing ductility. Hydraulitic weakening promotes recrystallization of rock forming minerals at moderate temperature and pressures. In this water softening regime, the weakend crystals deform plastically by dislocation-propagated slip. The transition from brittle to ductile behaviour in the earth is supposed to take place at shallow depths of a few kilometers. None the less, due to the embrittling effect of fluids, the transition depth is greatly deepened, and and the transition from brittleness to ductility appears to occur in the mid-crust (Yukutake, 1985).

For the whole region the ductile layer ends at a depth of about 40 km. The existence of a layer between ca. 30 and 50 km depth, which is distinctly different from other layers above and below it, was revealed at first sight by plotting the recurrence curves for seven ranges of focal depths that fit the seismic mangitude data ($M_S \geqq 5$ 1/2) for the major area of Greece (34° N 42°, 19°E29°) over the period 1961-1970 (Galanopoulos and Ekonomides, 1974). This gives much credit to the existence of a layer with different mechanical properties allowing the release of the most part of the strain energy accumulated at the depth range of 30 to 50 km in the form of minor shocks. Below the depth level of 50 km the pattern of deformation ability is similar to that holding for the southern subregion.

In the second drawing, showing the seismic activity in terms of seismic energy (see fig. 2), the ability of deformation at various levels of the earth's crust follows the same pattern in the whole region and the northern subregion. There are, however, two small differences between this pattern and the pattern of the earthquake frequency. The seismic energy culminates at the depth range of 5-10 km and the transition from brittle to ductile deformation seems to be rather abrupt. The energy corresponding to the 36% and 52% of the shocks occurring in the upper portion of the crust (0-20 km) is about 67% and 81% for the whole region and northern subregion, respectively. This indicates that large earthquakes tend indeed to nucleate near the base of the brittle layer (Bollinger, 1985). However, this does not happen

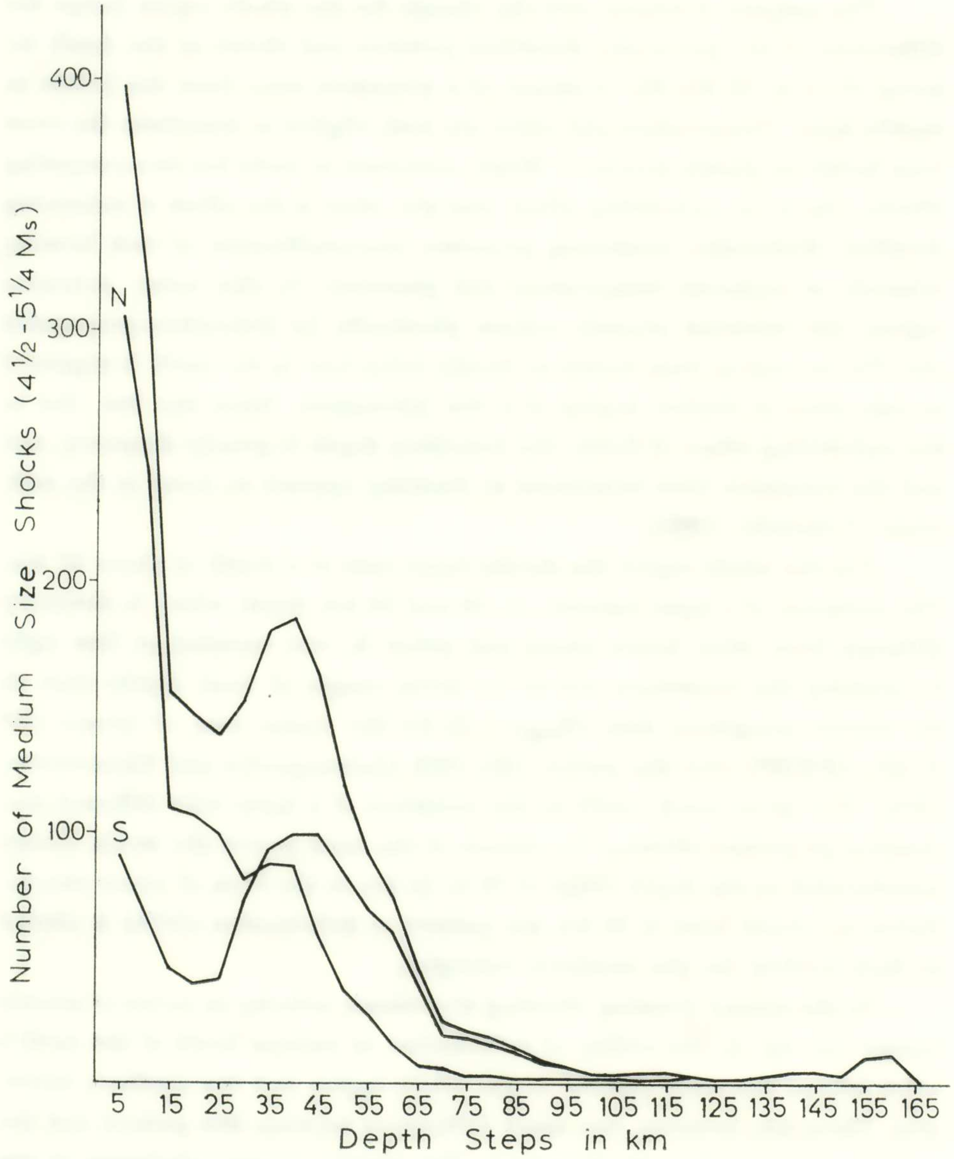

Fig. 3. Number of medium size shocks (M_s=4 1/2 - 5 1/4) occurred at various levels of the Earth's crust and upper Mantle during the period 1971-1983.

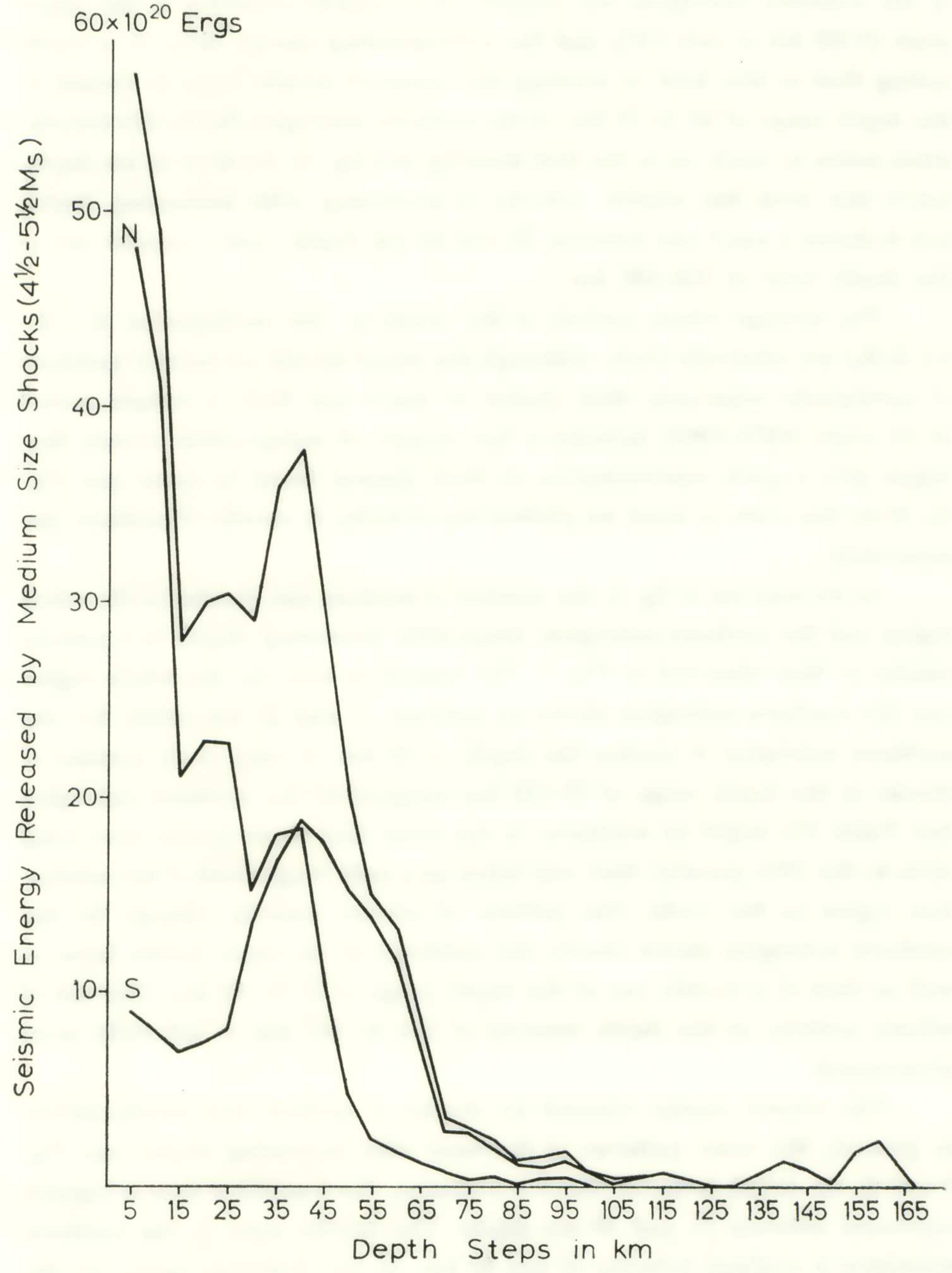

Fig. 4. Seismic energy released in medium size shocks (M_S=4 1/2 - 5 1/4) at various levels of the Earth's crust and upper Mantle during the period 1971-1983.

in the southern subregion; the number of the shocks occurring in the upper crust (0-20) km is only 15% and the corresponding energy 24%. It is worth noting that in this kind of drawing the assumed ductile layer is limited to the depth range of 25 to 35 km. In the southern subregion the ductile deformation seems to reach, as in the first drawing (see fig. 1), the 40 or 45 km depth; below this level the seismic activity is decreasing with increasing depth, but it shows a small rise between 70 and 85 km depth, and a smaller one at the depth level of 155-160 km.

The average return periods of the medium size earthquakes (4 1/2 - 5 1/4 M_s) are relatively short. Although the minor shocks are mostly members of earthquake sequences, that cluster in space and time, a sample period of 13 years (1971-1983) includes a fair sample of independent events that might give a good representation of their general trend in space (see Fig. 5). With this view in mind we plotted the activity in shocks of medium size separately.

As we may see in fig. 3, the number of medium size shocks for the whole region and the northern subregion drops with increasing depth in a pattern similar to that observed in Fig. 1. The transition zone for the whole region and the southern subregion shows up between 15 and 25 km, while for the northern subregion it reaches the depth of 30 km. A very small number of shocks at the depth range of 70-120 km assigned to the northern subregion (see Table VI) might be «outliers», in the sense that these shocks were lying close to the 38th parallel, that was taken as a very rough limit of the subduction region on the north. The pattern of seismic activity change for the southern subregion shows clearly the existence of an upper brittle layer as well as that of a ductile one at the depth range of 25 to 45 km. The rise of seismic activity at the depth interval of 155 to 160 km is naturally more pronounced.

The seismic energy released by shocks of medium size shocks shows, in general, the same patterns of decrease with increasing depth (see Fig. 3 and 4). In detail, however, there is a nuance; the transition zone is vaguely expressed between 15 and 30 km depth. The ductile layer in the northern subregion is confined between 30 and 40 km. In the drawings made for the whole region and the southern subregion the delineation of the ductile layer is that previously found (see Fig. 3 and 4), i.e. at the depth range of 30-40 km and 25-45 km, respectively.

CONCLUSION

Summing up the brittle layer is well expressed in all drawings made for the northern subregion; it extends down to the depth of 15 or 20 km and eventually below it. In the subduction region, i.e. the southern subregion

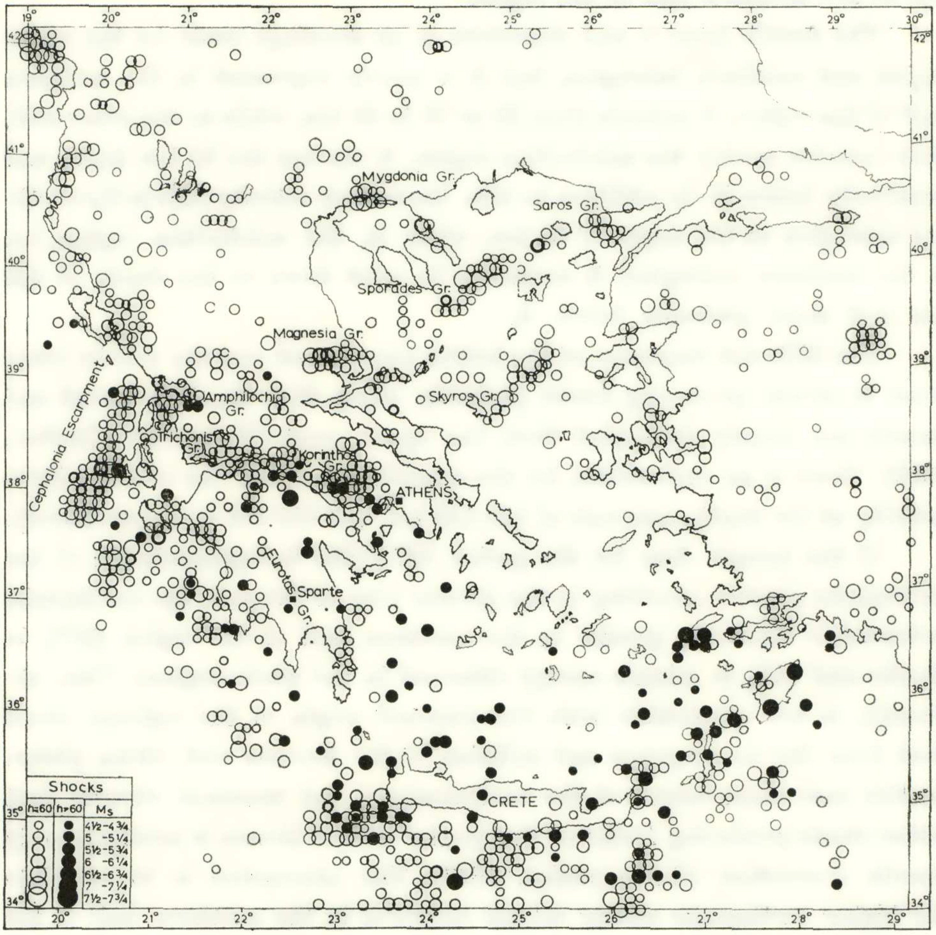

Fig. 5. Distribution pattern of shallow and intermediate focal depth earthquakes with $M_s \geq 4$ 1/2 in the major area of Greece during the period 1971-1983. Note the striking delineation of the Cephalonia escarpment and the Neogene-Quaternary Grabens (Saros, Sporades, Skyros, Mygdonia, Magnesia, Korinthos, Trichonis, Amphilochia etc.) contrasting with the amazingly long-lasting seismic quiescence of Eurotas graben structure dated from 464 B.C. (Destruction of Sparte).

the brittle layer is delineated only in drawings depicting seismic activity change in terms of medium size shocks (4 1/2 - 5 1/4 M_s). This probably indicates that in the southern subregion the upper layer does not have the ability of large deformation and/or the barriers or asperities of the fault planes are relatively small. Consequently, the southern subregion does not suffer from very shallow shocks, which are generally more destructive, as much and often as the northern half of the region.

The ductile layer is well expressed in all drawings made for the whole region and southern subregion, but it is poorly expressed in the northern half of the region; it extends from 25 or 30 to 40 km, while in the other half, that includes mostly the subduction region, it reaches the 45 km depth and eventually below it. In addition to this, the seismic activity ends in the northern subregion at the depth of 65 km, while in the subduction region, i.e. in the southern subregion, it continues to exist down to the depth of 160 km and most probably below it.

The different responses of the brittle upper crust and the ductile lower crust to strain-producing forces probably imply that the lower crust and mantle are largely decoupled from the upper crust (Hearn and Clayton, 1986). There is no explanation for the consistent fall and rise of the seismic activity at the depth intervals of 125-130 km and 155-160 km, respectively.

If the sample data for the period 1971-1983 is representative of the earthquake process occurring in the greater area of Greece*, the earthquake potential is relatively greater in the northern half of the region (56% in shocks and 74% in seismic energy observed in the whole region). This, obviously, is not compatible with the assumed origin of the regional stress field from the convergence and collision of the Eurasia and Africa plates. In this case main source of the compressional and tensional stresses that act as strain-producing forces on the greater area of Greece is most probably mantle convection (Galanopoulos, 1967). The alternative is to associate the higher earthquake energy release observed in the northern half of the

*It is interesting to note, that according to Bath's Table III (Bath, 1983), the number of total magnitudes with $M \geqq 7$, equivalent to the corresponding total energy for 1918-1977 and $1^\circ \times 1^\circ$ blocks, centered at the coordinates given, is 42 for the northern half (38° N 42°, 19.5° E 28.5°) and 28 for the southern half (33.5° N 37.5°, 19.5° E 28.5°) of the area of Greece.

region with the existing evidence (Galanopoulos, 1981; Scholz et al., 1986), that intraplate faults with longer recurrence times have higher frictional strenghts than plate boundaries.

ACKNOWLEDGEMENTS

The author is much indebted to Mrs. N. Galanopoulos-Skordopoulos for drawing the graphs and Miss Maria Dailiana for typing the paper.

ΠΕΡΙΛΗΨΗ

Διαφορά στὸν τρόπο μεταβάσεως ἀπὸ τὴν εὔθραυστο στὴν εὐήλατο παραμόρφωση στὸ βόρειο καὶ νότιο ἥμισυ τοῦ Ἑλληνικοῦ Χώρου.

Πιστεύεται ὅτι ἡ γένεση τῶν σεισμῶν ἔχει στενὴ σχέση πρὸς τὶς μηχανικὲς ἰδιότητες τῶν ἑστιακῶν ὄγκων καὶ/ἢ τῶν ἐμποδίων ἢ προεξοχῶν τῶν ἐπιφανειῶν τῶν ρηγμάτων, ὡς καὶ πρὸς τὸν τρόπο κατανομῆς τῶν τάσεων ποὺ ἀσκοῦνται ἐπ' αὐτῶν. Μὲ αὐτὸ τὸ δεδομένο εἶναι λογικὸ οἱαδήποτε μεταβολὴ εὐρείας κλίμακας στὶς μηχανικὲς ἰδιότητες καὶ στὴν ἱκανότητα παραμορφώσεως τῶν πετρωμάτων σὲ διάφορες στάθμες τοῦ γηΐνου φλοιοῦ καὶ τοῦ ἀνώτερου μανδύα νὰ ἐμφανίζεται σὲ κατακόρυφο τομὴ τῆς σεισμικῆς δράσεως.

Λαμβάνοντες ὑπ' ὄψη ὅτι τὸ νότιο ἥμισυ τοῦ Ἑλληνικοῦ χώρου εἶναι κατὰ τὸ πλεῖστον χῶρος συγκλίσεως καὶ ἐφιππεύσεως τοῦ Αἰγαίου τεμάχους ἐπὶ τῆς Ἀφρικανικῆς πλάκας, ἡ τεκτονικὴ δομή του καὶ τὸ πεδίο τῶν τάσεων ποὺ ἀσκεῖται σ' αὐτὴ πρέπει νὰ διαφέρουν σημαντικὰ ἀπὸ τὰ ἀντίστοιχα τεκτονικὰ στοιχεῖα ποὺ ἐπικρατοῦν στὸ βόρειο ἥμισυ τοῦ εὐρύτερου Ἑλληνικοῦ χώρου (33° Ν 43°, 17° Ε 30°). Ἂν καὶ τὸ βόρειο ὅριο καταδύσεως τῆς Ἀφρικανικῆς πλάκας δὲν ὁρίζεται ἀκριβῶς ἀπὸ τὸν 38° παράλληλο, ἡ ἀναμενόμενη διαφορὰ στὸ σεισμοτεκτονικὸ καθεστὼς δὲν μπορεῖ νὰ καλυφθεῖ ἀπὸ ἐνδεχόμενη προέλαση τῆς ζώνης Benioff βορείως τοῦ 38° παραλλήλου, ἢ/καὶ ἄλλες ἀνωμαλίες στὴν ἔκταση τῆς βυθιζόμενης στὴν Ἑλληνικὴ τάφρο βόρειας παρυφῆς τῆς Ἀφρικανικῆς πλάκας. Μὲ αὐτὸ τὸ σκεπτικὸ ἐγένετο ἀπόπειρα ἀποκαλύψεως τῆς πιθανῆς διαφορᾶς στὴν τεκτονικὴ δομὴ τοῦ βορείου καὶ νοτίου τομέα ἀπὸ τὰ ἀντίστοιχα σχέδια μεταβολῆς τῆς σεισμικῆς δράσεως συναρτήσει τοῦ ἑστιακοῦ βάθους.

Στὸ βόρειο ἥμισυ τοῦ Ἑλληνικοῦ χώρου τὸ εὔθραυστο ἐπιφανειακὸ στρῶμα φθάνει μέχρι βάθους 15 χιλμ. Στὸ στρῶμα αὐτὸ ἡ σεισμικὴ δράση μειώνεται ταχέως ὅσον αὐξάνει τὸ βάθος. Κάτωθεν τοῦ βάθους τῶν 15 χιλμ. φαίνεται νὰ ὑπάρχει μεταβατικὸ στρῶμα ποὺ φθάνει σὲ βάθος 30 χιλμ. Στὸ στρῶμα αὐτὸ ἡ σεισμικὴ δράση δὲν φαίνεται νὰ παρουσιάζει αἰσθητὴ μεταβολὴ μὲ τὸ βάθος. Στὸ εὐήλατο στρῶμα ποὺ ἀκολουθεῖ ἡ σεισμικὴ δράση αὐξάνει μὲ τὸ βάθος. Τὸ στρῶμα αὐτὸ εἶναι σχετικῶς λεπτό· ἐκτείνεται μέχρι βάθους 40 χιλμ. περίπου. Στὸ νότιο ἥμισυ τοῦ Ἑλληνικοῦ χώρου τὸ εὔθραυστο στρῶμα δὲν διαγράφεται σαφῶς στὴ χαρτογράφηση τῆς σεισμικῆς δράσεως ποὺ ἐκδηλώνεται μὲ σεισμοὺς μεγέθους 5 1/2 καὶ ἄνω. Ὁ ἀριθμὸς τῶν σεισμῶν ποὺ συμβαίνουν στὰ πρῶτα 20 χιλμ. τοῦ γηΐνου φλοιοῦ εἶναι μόλις 15% καὶ ἡ ἀντιστοιχοῦσα ἐνέργεια 24% περίπου. Στὸ βόρειο τομέα οἱ ἀντίχροιχοι ἀριθμοὶ εἶναι 52% καὶ 81%. Αὐτὸ πιθανῶς ὑποδηλώνει ὅτι στὸ νότιο ἥμισυ τὸ ἀνώτερο στρῶμα δὲν ἔχει ἱκανότητα συγκεντρώσεως μεγάλων ἐλαστικῶν τάσεων, ἢ/καὶ τὰ κλεῖθρα ἢ οἱ προεξοχὲς τῶν ρηξιγενῶν ἐπιφανειῶν εἶναι σχετικῶς μικρές. Ἑπομένως, τὸ νότιο ἥμισυ δὲν ὑποφέρει ἀπὸ σεισμοὺς πολὺ μικροῦ βάθους -ποὺ εἶναι γενικῶς περισσότερο καταστρεπτικοί- τόσο πολὺ καὶ τόσο συχνὰ ὅσο τὸ βόρειο ἥμισυ τοῦ Ἑλληνικοῦ χώρου.

Στὸ νότιο τμῆμα τοῦ Ἑλληνικοῦ χώρου, ὅπου ἡ Ἀφρικανικὴ πλάκα εἰσχωρεῖ σὲ βάθος 160-180 χιλμ., τὸ εὐήλατο στρῶμα φαίνεται νὰ ἐκτείνεται μεταξὺ 25 ἢ 30 καὶ 45 χιλμ. Ἡ ὕπαρξη τοῦ στρώματος αὐτοῦ στὸν Ἑλληνικὸ χῶρο (34° N 42°, 19° E 29°) ἐπισημάνθηκε πρὸ δωδεκαετίας περίπου μὲ καμπύλες συσσωρευτικῆς συχνότητας ἀπὸ σεισμικὰ δεδομένα τῆς περιόδου 1961-1970. Τὸ γεγονὸς αὐτὸ ἐνισχύει τὴν ἄποψη ὅτι οἱ μηχανικὲς ἰδιότητες τοῦ εὐήλατου στρώματος ἐπιτρέπουν τὴν ἀπελευθέρωση τοῦ μεγαλύτερου μέρους τῶν ἐλαστικῶν τάσεων, ποὺ συγκεντρώνονται στὴν περιοχὴ βάθους 30 ἕως 50 χιλμ. περίπου, ὑπὸ μορφὴ σχετικῶς μικροτέρων σεισμῶν.

Ἂν καὶ ἡ σεισμικὴ δράση στὸ βόρειο ἥμισυ τοῦ Ἑλληνικοῦ χώρου σταματᾶ οὐσιαστικῶς σὲ βάθος 65 χιλμ. περίπου, καὶ στὸ νότιο ἥμισυ ἐξακολουθεῖ νὰ ὑπάρχει μέχρι βάθους 160 χιλμ. καὶ ἐνδεχομένως κάτωθεν αὐτοῦ, τὸ σεισμικὸ δυναμικό, ὅπως φαίνεται ἀπὸ τὰ δεδομένα τῆς περιόδου 1971-1983, εἶναι σχετικῶς μεγαλύτερο στὸ βόρειο ἥμισυ τοῦ Ἑλληνικοῦ χώρου (56% σὲ σεισμοὺς μεγέθους 4 1/2 καὶ ἄνω, καὶ 74% σὲ σεισμικὴ ἐνέργεια ποὺ παρατηρεῖται στὸν εὐρύτερο χῶρο.) Ἐὰν τὸ χρησιμοποιηθὲν δεῖγμα εἶναι ἀντιπροσωπευτικὸ τοῦ σεισμικοῦ καθεστῶτος ποὺ ἐπικρατεῖ στὸν εὐρύτερο Ἑλληνικὸ χῶρο, τὸ καθεστὼς αὐτὸ δὲν συμβιβάζεται μὲ τὴν εἰκαζόμενη προέλευση τοῦ πεδίου τῶν ἀσκουμένων τάσεων ἀπὸ τὴν σύγκλιση καὶ σύγκρουση τῶν πλακῶν Εὐρασίας καὶ Ἀφρικῆς. Στὴν περίπτωση αὐτή, κύρια πηγὴ τῶν συμπιεστικῶν καὶ ἐφελκυστικῶν τάσεων ποὺ ἀσκοῦνται στὸ χῶρο αὐτὸ θὰ εἶναι μᾶλλον ὑπόγεια ρεύματα μεταφορᾶς.

TABLE Ia

Seismic Data Arranged per Depth (0-10, 11-20, 21-30........km) and Magnitude for the Greater Area of Greece(33^oN43^o, 17^oE30^o) over the Period 1971-1983

M_s / h in km	5 1/2	5 3/4	6	6 1/4	6 1/2	6 3/4	7	7 1/4	7 1/2	N≥5 1/2	ΣE
5	41	26	8	10	7	3	2	1	1	99	281.06
15	19	18	19	10	9	2	–	1	–	78	130.00
25	24	23	19	14	1	–	–	–	–	81	45.37
35	40	17	20	14	7	–	–	–	–	98	67.44
45	42	22	6	7	6	–	–	–	–	83	46.14
55	10	6	2	2	3	–	–	–	–	23	17.63
65	2	3	2	–	1	–	–	–	–	8	5.84
75	2	2	–	–	2	–	–	–	–	6	7.86
85	2	–	–	3	1	–	–	–	–	6	8.27
95	1	–	–	–	–	–	–	–	–	1	0.11
105	1	2	–	–	–	–	–	–	–	3	0.65
115	–	1	–	–	–	–	–	–	–	1	0.27
125	–	–	–	–	–	–	–	–	–	–	–
135	1	–	–	–	–	–	–	–	–	1	0.11
145	1	–	–	–	–	–	–	–	–	1	0.11
155	–	2	1	–	1	–	–	–	–	4	4.72
Total	186	122	77	60	38	5	2	2	1	493	
ΣE	20.46	32.94	48.51	90.00	134.90	42.05	39.90	94.62	112.20		615.58

TABLE Ib

Seismic Data Arranged per Depth (≤ 5, 6-15, 16-25........km) and Magnitude for the Greater Area of Greece (33°N43°, 17°E30°) over the Period 1971-1983

M_s / h in km	5 1/2	5 3/4	6	6 1/4	6 1/2	6 3/4	7	7 1/4	7 1/2	N≥5 1/2	ΣE
≤ 5	15	12	5	4	2	2	1	1	-	42	105.22
10	41	19	10	9	10	2	1	1	1	94	261.22
20	19	26	22	14	4	1	-	-	-	86	66.58
30	23	16	19	15	6	-	-	-	-	79	62.62
40	54	23	11	12	6	-	-	-	-	106	58.38
50	19	15	6	2	3	-	-	-	-	45	23.57
60	6	2	1	1	3	-	-	-	-	13	13.98
70	2	4	2	-	2	-	-	-	-	10	9.66
80	2	-	-	2	1	-	-	-	-	5	6.77
90	2	-	-	1	-	-	-	-	-	3	1.72
100	-	-	-	-	-	-	-	-	-	-	-
110	1	3	-	-	-	-	-	-	-	4	0.92
120	-	-	-	-	-	-	-	-	-	-	-
130	-	-	-	-	-	-	-	-	-	-	-
140	1	-	-	-	-	-	-	-	-	1	0.11
150	1	1	-	-	-	-	-	-	-	2	0.38
160	-	1	1	-	1	-	-	-	-	3	4.45
Total	186	122	77	60	38	5	2	2	1	493	
ΣE	20.46	32.94	48.51	90.00	134.90	42.05	39.90	94.62	112.20		615.58

T A B L E IIa

Seismic Data Arranged per Depth (0-10, 11-20, 21-30........km) and Magnitude for the Sourthern Half of the Greater Area of Greece(33.1°N38°, 17°E30°) over the Period 1971-1983

M_s / h in km	5 1/2	5 3/4	6	6 1/4	6 1/2	6 3/4	7	7 1/4	7 1/2	N≥5 1/2	ΣE
5	10	2	2	-	2	1	-	-	-	17	18.41
15	3	3	7	1	3	-	-	-	-	17	17.70
25	7	7	9	6	-	-	-	-	-	29	17.33
35	20	10	10	5	2	-	-	-	-	47	25.80
45	26	21	3	5	4	-	-	-	-	59	32.12
55	10	5	1	2	2	-	-	-	-	20	13.18
65	2	3	2	-	1	-	-	-	-	8	5.84
75	2	2	-	-	2	-	-	-	-	6	7.86
85	2	-	-	3	1	-	-	-	-	6	8.27
95	1	-	-	-	-	-	-	-	-	1	0.11
105	1	2	-	-	-	-	-	-	-	3	0.65
115	-	1	-	-	-	-	-	-	-	1	0.27
125	-	-	-	-	-	-	-	-	-	-	-
135	1	-	-	-	-	-	-	-	-	1	0.11
145	1	-	-	-	-	-	-	-	-	1	0.11
155	-	2	1	-	1	-	-	-	-	4	4.72
Total	86	58	35	22	18	1	-	-	-	220	
ΣE	9.46	15.66	22.05	33.00	63.90	8.41	-	-	-		152.48

T A B L E IIb

Seismic Data Arranged per Depth (≤ 5, 6-15, 16-25......km) and Magnitude for the Southern Half of the Greater Area of Greece ($33.1^{o}N38^{o}$, $17^{o}E30^{o}$) over the Period 1971-1983

M_s / h in km	5 1/2	5 3/4	6	6 1/4	6 1/2	6 3/4	7	7 1/4	7 1/2	$N \geq 5$ 1/2	ΣΕ
≤ 5	2	2	1	-	1	1	-	-	-	7	13.35
10	8	1	2	-	2	-	-	-	-	13	9.51
20	6	6	11	3	2	-	-	-	-	28	20.81
30	14	7	8	7	-	-	-	-	-	36	18.97
40	27	17	6	6	5	-	-	-	-	61	38.09
50	14	14	4	2	2	-	-	-	-	36	17.94
60	6	2	-	1	2	-	-	-	-	11	9.80
70	2	4	2	-	2	-	-	-	-	10	9.66
80	2	-	-	2	1	-	-	-	-	5	6.77
90	2	-	-	1	-	-	-	-	-	3	1.72
100	-	-	-	-	-	-	-	-	-	-	-
110	1	3	-	-	-	-	-	-	-	4	0.92
120	-	-	-	-	-	-	-	-	-	-	-
130	-	-	-	-	-	-	-	-	-	-	-
140	1	-	-	-	-	-	-	-	-	1	0.11
150	1	1	-	-	-	-	-	-	-	2	0.38
160	-	1	1	-	1	-	-	-	-	3	4.45
Total	86	58	35	22	18	1	-	-	-	220	
ΣΕ	9.46	15.66	22.05	33.00	63.90	8.41	-	-	-		152.48

TABLE IIIa

Seismic Data Arranged per Depth (0-10, 11-20, 21-30........km) and Magnitude for the Northern Half of the Greater Area of Greece (38.1°N43°, 17°E30°) over the Period 1971-1983

M_s / h in km	5 1/2	5 3/4	6	6 1/4	6 1/2	6 3/4	7	7 1/4	7 1/2	N≥5 1/2	ΣΕ
5	31	24	6	10	5	2	2	1	1	82	262.65
15	16	15	12	9	6	2	-	1	-	61	112.30
25	17	16	10	8	1	-	-	-	-	52	28.04
35	20	7	10	9	5	-	-	-	-	51	41.64
45	16	1	3	2	2	-	-	-	-	24	14.02
55	-	1	1	-	1	-	-	-	-	3	4.45
65	-	-	-	-	-	-	-	-	-	-	-
75	-	-	-	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-	-	-	-
105	-	-	-	-	-	-	-	-	-	-	-
115	-	-	-	-	-	-	-	-	-	-	-
125	-	-	-	-	-	-	-	-	-	-	-
135	-	-	-	-	-	-	-	-	-	-	-
145	-	-	-	-	-	-	-	-	-	-	-
155	-	-	-	-	-	-	-	-	-	-	-
Total	100	64	42	38	20	4	2	2	1	273	
ΣΕ	11.00	17.28	26.46	57.00	71.00	33.64	39.90	94.62	112.20		463.10

T A B L E IIIb

Seismic Data Arranged per Depth ($\leq$ 5, 6-15, 16-25......km) and Magnitude for the Northern Half of the Greater Area of Greece ($38.1^{o}N43^{o}$, $17^{o}E30^{o}$) over the Period 1971-1983

M_s / h in km	5 1/2	5 3/4	6	6 1/4	6 1/2	6 3/4	7	7 1/4	7 1/2	N$\geq$5 1/2	ΣE
$\leq$ 5	13	10	4	4	1	1	1	1	-	35	91.87
10	33	18	9	9	8	2	1	1	1	82	252.34
20	13	20	10	11	2	1	-	-	-	57	45.14
30	9	9	11	8	6	-	-	-	-	43	43.65
40	27	6	5	6	1	-	-	-	-	45	20.29
50	5	1	2	-	1	-	-	-	-	9	5.63
60	-	-	1	-	1	-	-	-	-	2	4.18
70	-	-	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-	-	-
100	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-
120	-	-	-	-	-	-	-	-	-	-	-
130	-	-	-	-	-	-	-	-	-	-	-
140	-	-	-	-	-	-	-	-	-	-	-
150	-	-	-	-	-	-	-	-	-	-	-
160	-	-	-	-	-	-	-	-	-	-	-
Total	100	64	42	38	20	4	2	2	1	273	
ΣE	11.00	17.28	26.46	57.00	71.00	33.64	39.90	94.62	112.20		463.10

T A B L E IVa

Seismic Data Arranged per Depth (0-10, 11-20, 21-30........km) and Magnitude for the Greater Area of Greece(33^oN43^o, 17^oE30^o) over the Period 1971-1983

M_s / h in km	4 1/2	4 3/4	5	5 1/4	N ≥ 4 1/2	ΣE
5	161	108	71	57	397	5.72
15	62	31	26	36	155	2.78
25	39	29	27	44	139	3.09
35	44	53	36	47	180	3.64
45	45	44	41	32	162	2.93
55	39	20	14	18	91	1.48
65	13	13	9	10	45	0.83
75	5	6	7	2	20	0.31
85	5	4	4	-	13	0.13
95	1	1	1	3	6	0.18
105	2	1	1	-	4	0.04
115	1	1	1	1	4	0.08
125	1	-	-	-	1	0.00
135	-	2	-	1	3	0.07
145	2	-	1	1	4	0.08
155	3	1	5	1	10	0.17
165	-	-	1	1	2	0.07
Total	423	314	245	254	1236	
ΣE	1.52	2.73	4.90	12.45		21.60

T A B L E IVb

Seismic Data Arranged per Depth ($\lesssim$ 5, 6-15, 16-25.........km) and Magnitude for the Greater Area of Greece(33^{o}N43^{o}, 17^{o}E30^{o}) over the Period 1971-1983

M_s / h in km	4 1/2	4 3/4	5	5 1/4	N $\gtrsim$ 4 1/2	ΣE
$\lesssim$ 5	75	41	32	21	169	2.30
10	123	80	50	57	310	4.93
20	42	32	32	40	146	3.03
30	47	40	30	36	153	2.88
40	43	54	40	48	185	3.78
50	43	28	25	23	119	2.03
60	25	19	13	17	74	1.35
70	9	6	6	3	24	0.35
80	4	7	6	1	18	0.24
90	3	2	1	2	8	0.15
100	1	1	1	1	4	0.08
110	2	-	2	-	4	0.05
120	1	1	-	1	3	0.05
130	-	1	-	-	1	0.01
140	-	1	1	2	4	0.13
150	3	-	-	-	3	0.01
160	2	1	6	2	11	0.23
Total	423	314	245	254	1236	
ΣE	1.52	2.73	4.90	12.45		21.60

T A B L E Va

Seismic Data Arranged per Depth (0-10, 11-20, 21-30........km) and Magnitude for the Southern Half of the Greater Area of Greace (33.1°N38°, 17°E30°) over the Period 1971-1983

M_s / h in km	4 1/2	4 3/4	5	5 1/4	N ⩾ 4 1/2	ΣE
5	40	28	21	2	91	0.90
15	22	8	7	8	45	0.68
25	11	9	10	10	40	0.81
35	24	25	22	22	93	1.82
45	30	24	26	19	99	1.77
55	21	18	11	19	69	1.38
65	9	12	9	8	38	0.71
75	5	4	6	2	17	0.27
85	5	4	3	-	12	0.11
95	1	1	1	2	5	0.13
105	1	1	1	-	3	0.03
115	1	-	1	1	3	0.07
125	-	-	-	-	-	0.00
135	-	2	-	1	3	0.07
145	2	-	1	1	4	0.08
155	3	1	5	1	10	0.17
165	-	-	1	1	2	0.07
Total	175	137	125	97	534	
ΣE	0.63	1.19	2.50	4.75		9.07

T A B L E Vb

Seismic Data Arranged per Depth ($\leq$ 5, 6-15, 16-25......km) and Magnitude for the Southern Half of the Greater Area of Greece (33.1°N38°, 17°E30°) over the Period 1971-1983

h in km \ M_s	4 1/2	4 3/4	5	5 1/4	N $\geq$ 4 1/2	ΣΕ
$\leq$ 5	23	12	11	1	47	0.46
10	29	19	14	5	67	0.79
20	13	8	9	9	39	0.74
30	20	19	9	15	73	1.35
40	27	26	23	23	99	1.91
50	27	20	17	19	83	1.54
60	16	17	11	15	59	1.16
70	6	4	6	2	18	0.27
80	4	6	4	1	15	0.19
90	3	2	1	1	7	0.10
100	-	1	1	1	3	0.08
110	2	-	2	-	4	0.05
120	-	-	-	1	1	0.05
130	-	1	-	-	1	0.01
140	-	1	1	2	4	0.13
150	3	-	-	-	3	0.01
160	2	1	6	2	11	0.23
Total	175	137	125	97	534	
ΣΕ	0.63	1.19	2.50	4.75		9.07

T A B L E VIa

Seismic Data Arranged per Depth (0-10, 11-20, 21-30........km) and Magnitude for the Northern Half of the Greater Area of Greece (38.1°N43°, 17°E30°) over the Period 1971-1983

h in km \ M_s	4 1/2	4 3/4	5	5 1/4	N $\geq$ 4 1/2	ΣE
5	121	80	50	55	306	4.82
15	40	23	19	28	110	2.10
25	28	20	17	34	99	2.28
35	20	28	14	25	87	1.82
45	15	20	13	11	59	1.03
55	18	2	5	1	26	0.23
65	4	1	-	2	7	0.12
75	-	2	1	-	3	0.04
85	-	-	1	-	1	0.02
95	-	-	-	1	1	0.05
105	1	-	-	-	1	0.00
115	-	1	-	-	1	0.01
125	1	-	-	-	1	-
135	-	-	-	-	-	-
145	-	-	-	-	-	-
155	-	-	-	-	-	-
165	-	-	-	-	-	-
Total	248	177	120	157	702	
ΣE	0.89	1.54	2.40	7.69		12.52

TABLE VIb

Seismic Data Arranged per Depth (≲ 5, 6-15, 16-25......km) and Magnitude for the Northern Half of the Greater Area of Greece (38.1°N43°, 17°E30°) over the Period 1971-1983

M_s / h in km	4 1/2	4 3/4	5	5 1/4	N ≳ 4 1/2	ΣE
≲ 5	52	29	21	20	122	1.84
10	94	61	36	52	243	4.14
20	29	24	23	31	107	2.29
30	27	21	11	21	80	1.53
40	16	28	17	25	86	1.87
50	16	8	8	4	36	0.48
60	9	2	2	2	15	0.19
70	3	2	-	1	6	0.08
80	-	1	2	-	3	0.05
90	-	-	-	1	1	0.05
100	1	-	-	-	1	0.00
110	-	-	-	-	-	-
120	1	1	-	-	2	0.01
130	-	-	-	-	-	-
140	-	-	-	-	-	-
150	-	-	-	-	-	-
160	-	-	-	-	-	-
Total	248	177	120	157	702	
ΣE	0.89	1.54	2.40	7.69		12.52

REFERENCES

Bath M., Earthquake Frequency and Energy in Greece. *Tectonophysics,* Vol. 95, pp. 233-252, 1983.

Boatwright J., Characteristics of the Afrerschock Sequence of the Borah Peak, Idaho, Earthquake Determined from Digital Recordings of the Events. *Bull. Seism. Soc. Am.»,* Vol. 75, No. 5, pp. 1265-1984, 1985.

Bollinger A. G., Seismic Geology. Presidential Address. *Bull. Seism. Soc. Am.,* Vol. 75, No. 5, pp. 1473-1477, 1985.

Galanopoulos G. A., The Seismotectonic Regime in Greece. *Ann. di Geof.,* Vol. XX, No. 1, pp. 109-119, 1967.

Galanopoulos G. A. and A. Economides, On the Ability of Deformation at Various Levels of the Earth's Crust and Upper Mantle in the Area of Greece. *Ann. Geol. des Pays Hellén.,* Vol. 26, pp. 402-409, 1974.

Galanopoulos G. A., On the Difference in the Seismic Risk for Normal and Tall Structures at the Same Site. *Publ. Seism. Lab. Univ. Athens,* pp. 1-33, 1977.

Galanopoulos G. A., The Damaging Shocks and the Earthquake Potential of Greece. *Ann. Géol. d. Pays Hellén.,* Vol. XXX, No. 2, pp. 647-724, 1981.

Galanopoulos G. A. and K. C. Makropoulos, On the Accuracy of the m_b-Determination from the Number of the Reporting Stations. Lowering of the Magnitude Threshold and Difference in the Index of Seismic Hazard and Seismic Risk in the Area of Greece. *Proceedings, 2nd. Intern. Symp. on the Analysis of Seismicity and on Seism. Hazard,* pp. 574-601, 1981.

Galanopoulos G. A., On the Earthquake Activity Occurring per Month in Greece. *Prakt. Acad. Athens,* Vol. 60, pp. 152-180, 1985.

Gutenberg B. and C. F. Richter, Magnitude and Energy of Earthquakes. *Ann. di Geof.,* Vol. 9, pp. 1-15, 1956.

Hearn M. T. and R. W. Clayton, Lateral Velocity Variations in Southern California. II. Results for the Lower Crust from P_n Waves. *Bull. Seism. Soc. Am.,* Vol. 76, No. 2, pp. 511-520, 1986.

Scholz H. C., Aviles A. C., and G. S. Wesnouski, Scaling Differences Between Large Interplate and Intraplate Earthquakes. *Bull. Seism. Soc. Am.,* Vol. 76, No. 1, pp. 66-70. 1986.

Suzuki Z. and A. Ito, A Note on the Georgaphical Distribution of Detectability of ISC Data. *Sci. Rep. Tohoku Univ. Ser. 5, Geoph.,* Vol. 26, Nos. 3,4, pp. 93-99, 1980.

Yukutake T., A Review of Studies on the Electrical Resistivity Stucture of the Crust in Japan. *Earthquake Pred. Res.,* Vol. 3, Nos. 3, 4, pp. 345-364, 1985.