THE STRAIN PATTERN OF THE AEGEAN FROM MICROEARTHQUAKE DATA

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A B S T R A C T

Since 1986, we conducted several microearthquake surveys to study the seismotectonics of the Aegean. We installed for periods of 6-8 weeks temporary networks of (25 to 85) portable stations. We located about 2500 earthquakes with a great accuracy, and computed about 330 focal mechanisms.

The shallow seismicity is mostly located along the trench and does not define a small number of active faults suggesting that most of the brittle deformation is distributed on multiple preexisting small faults.

Shallow focal mechanisms show a complex pattern. We observe reverse faulting along the trench, with P-axes trending ENE. In the Aegean we observe normal faulting. The T-axes trend N-S in the internal part but are parallel to the trench in the external part. The non-uniform strain suggests that one mechanism of internal deformation is gravity spreading.

ΠΑΡΑΜΟΡΦΩΣΗ ΣΤΟ ΧΩΡΟ ΤΟΥ ΑΙΓΑΙΟΥ ΜΕ ΔΕΔΟΜΕΝΑ ΜΙΚΡΟΣΕΙΣΜΩΝ

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Π Ε Ρ Ι Λ Η Ψ Η

Για τη μελέτη των σεισμοτεκτονικών ιδιοτήτων του χώρου του Αιγαίου πραγματοποιήθηκαν αρκετά πειράματα από το έτος 1986 στα οποία εγκαταστάθηκαν δίκτυα από 25 μέχρι 85 φορητούς σεισμογράφους για περιόδους 6-8 εβδομάδων. Υπολογίστηκαν με μεγάλη ακρίβεια οι εστιακές παράμετροι 2500 μικροσεισμών και περίπου 330 μηχανισμοί γένεσης.

Τα επίκεντρα των επιφανειακών σεισμών κατανέμονται κυρίως κατά μήκος της τάφρου του Ν.Αιγαίου, και η κατανομή τους δείχνει ότι η περισσότερη από την παραμόρφωση γίνεται σε προϋπάρχοντα μικρά ρήγματα. Οι μηχανισμοί γένεσης των επιφανειακών σεισμών δείχνουν μιά πολύπλοκη εικόνα. Παρατηρούνται ανάστροφα ρήγματα κατά μήκος της τάφρου με τους άξονες P να έχουν διεύθυνση ΑΒΑ. Στο εσωτερικό τμήμα του Αιγαίου παρατηρούνται κανονικά ρήγματα στα οποία ο άξονας T έχει διεύθυνση Β-Ν ενώ στο εξωτερικό τμήμα

της τάφρου ο άξονας T έχει διεύθυνση παράλληλη με αυτήν. Οι διαφορές αυτές στην διεύθυνση της παραμόρφωσης δείχνουν ότι ένα πιθανό αίτιο της παραμόρφωσης στο εσωτρικό μέρος του τόξου είναι η βαρυτική έλξη.

INTRODUCTION

The Aegean is a region of inhomogeneous deformation located between the African and the European lithospheric plates. The relative motion of the Aegean arc relative to Africa is in a SW direction at a rate of 7-10 cm/year (McKenzie, 1978; Le Pichon and Angelier, 1979). The Aegean has deformed intensely and rapidly since Pliocene time (Mercier et al., 1987; Angelier, 1979) and this deformation is not uniformly distributed.

Paleomagnetic results (Kissel and Laj, 1988) suggest that the Peloponnese has rotated 25° clockwise since Miocene time, and that parts of western Turkey have rotated 30° counterclockwise. GPS geodetic measurements conducted around Peloponnese and Evia (Billiris et al., 1991) confirm the important internal deformation and a slight rotation.

The seismicity and the associated focal mechanisms, which are related only to the brittle part of the deformation observed during a very short time compared to geological processes, is of moderate level, and therefore, because earthquakes are not recorded in many seismological stations, the control in the location, and especially in the depth, of some earthquakes is not very good.

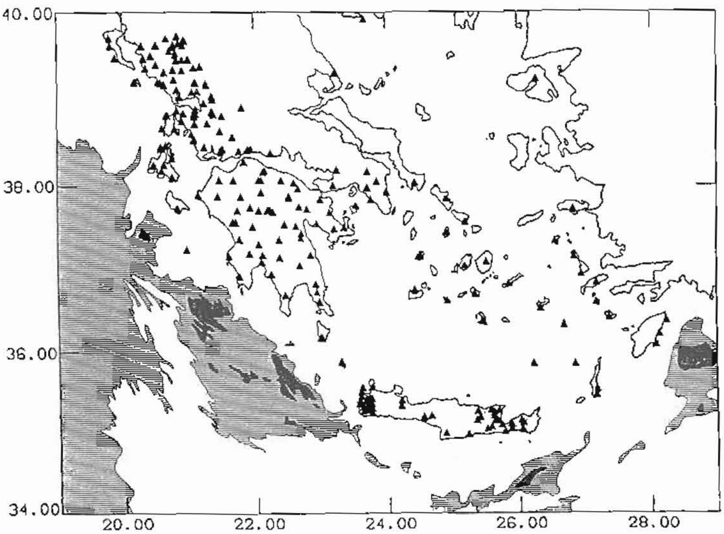

Fig.1. Locations of the stations installed for the 3 experiments during 1986-1989.

Most of the focal mechanisms are for earthquakes of relatively large magnitude and therefore located either along the trench or in the northern Aegean Sea (Papazachos et al., 1984, 1991). There are computed using polarity data (McKenzie, 1972, 1978) or body wave modelling (Taymaz et al., 1990,1991; Kiratzi et al., 1991). However it is not possible to infer, from teleseismically computed mechanisms, a continuous strain pattern for the whole Aegean region.

The installation of a dense local seismological network above a region (with a spacing between stations of about the same order as the depth of the earthquakes) allows one to record many earthquakes of small magnitude and to study very accurately the seismicity and fault plane solutions.

During the years 1986-1989, we installed a network of 45 to 85 portable stations (Fig. 1) over the Peloponnese, the South Aegean Sea and the Epirus (Hatzfeld et al., 1990, 1992). The earthquakes were located after conducting numerous tests to insure the reliability of the locations (to be better than 10 or 20 km).

SEISMICITY

We located a total amount of about 2500 earthquakes of magnitude ranging from -0.2 to 5.2 (Fig. 2). But this seismicity map does not represent a global picture of the brittle deformation within the Aegean because of the short time duration of each of the experiment and of the inhomogenous distribution of stations.

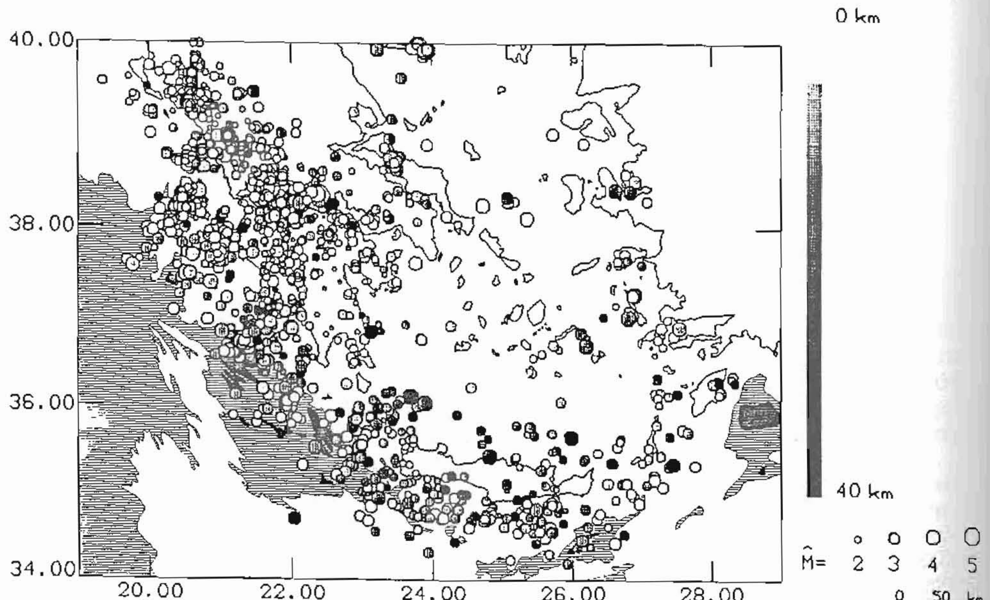

Fig.2. Seismicity map of the 1976 earthquakes located with an accuracy better than 20 km during the 3 experiments.

The seismicity is spread over most of the Aegean area, but most earthquakes are located along the Hellenic trench from Corfu to Rhodos. Along the arc the earthquakes are located north of the trench and very few reliably located earthquakes are located south of it. It is therefore likely that the convergence between Africa and Aegean occurs not far from the Hellenic trench. Earthquakes are spread over wide areas in Epirus or in Peloponnese (located in continental Greece). This diffuse seismicity could be associated with the difference in the type of convergence observed south and north of the Ionian islands. The convergence rate would be higher South of the Ionian islands where we observe an active subduction, but north of them the convergence between Apulia and Aegean would be slower because of continental collision. The sea of Crete is almost free of earthquakes. This lack of seismic activity is surprising, because this area is supposed to be undergoing important extensional strain beginning in Pliocene time (Le Pichon and Angelier, 1979).

The seismicity reveals no clear evidence of individual faults, but we observe clusters of earthquakes from places to places where strong earthquakes of magnitude greater than 6 have occurred in the past 20 years (the Ionian islands, the Gulf of Patras, the Gulf of Corinth), but also around the Kythira strait, which has not experienced any strong earthquake since the last century. Therefore it is likely that the brittle part of the deformation (as far as small earthquakes are concerned) is not localized on single major active faults, but instead is distributed on many small faults along the Hellenic arc.

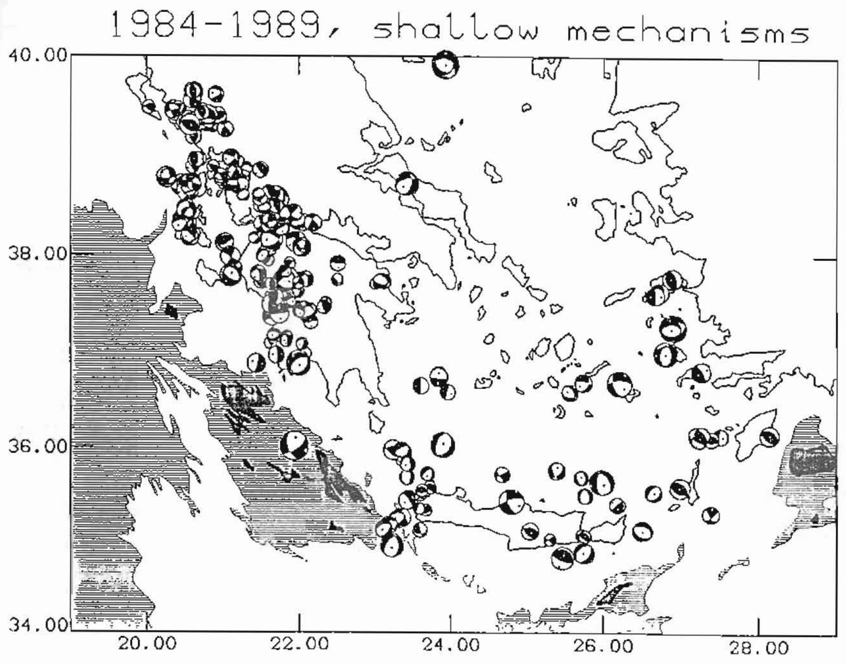

Fig.3. Focal mechanisms computed during 1986-1989.

Crustal seismicity is observed within the whole crust from the surface to the Moho, although most of the seismicity belong to the upper crust. Therefore the brittle-ductile transition is not clearly defined, at least by earthquakes of this range of magnitude.

FOCAL MECHANISMS

We computed about 330 focal mechanisms based on a minimum of 8 polarities and a maximum gap between P-waves first motion of 180°.

Figure 3 shows the complex pattern observed from the Albanian border to Turkey. In the northern Aegean, Evia, Attiki and the Eastern Dodecanese islands, the focal mechanisms show mostly N-S extension. Along the Hellenic arc, both in continental Greece or along the trench, we observe reverse faulting with P-axes trending roughly NE-SW. Around the Ionian islands the pattern is more complex, and we observe also some strike-slip faulting, with P-axes trending NW-SE. This is probably related to the strike-slip zone observed west of Kefalinia (Scordilis et al., 1985). In a more internal position, within the Aegean, we observe again normal faulting.

In order to get a smooth pattern of the strain in the area, we determine and plot the horizontal projection of the shallowly (<45°) dipping P- and T-axes. This could represent the response of the brittle part of the crust to the whole deformation of the lithosphere.

Fig. 4a and 4b show the horizontal projection of the shallowly plunging P- and T-axes, respectively. P-axes are located mostly along the Hellenic arc, and most of them are trending roughly perpendicular to the trench. This reverse faulting is consistent with the underthrusting of Africa beneath Aegean. The trend of P-axes rotates slightly from NE-SW, around the Ionian islands, to NNE-SSW around Crete. The T-axes trend N-S in Epirus and in northern Peloponnese, NW-SE in southern Peloponnese and around the Kythira strait, and E-W in northern Crete or southern Dodecanese. This pattern of deformation is consistent with neotectonic observations (Mercier et al., 1987; Angelier, 1979). This rotation of the trend of T-axes suggests that the strain pattern is not uniform along the arc, and therefore some internal deformation should occur within the Aegean.

CONCLUSION

Installing a dense network of portable stations over the Aegean, we recorded and located a significantly large number of small magnitude earthquakes. Because these earthquakes are of small magnitude, they do not break the whole brittle part of the crust. The preexisting faulting, inherited from previous tectonic episodes, as local heterogeneities can be important. In order to make significant interpretation of the observations, we take first some precautions: 1) one earthquake or one cluster may not be related to regional strain, thus it is necessary to smooth

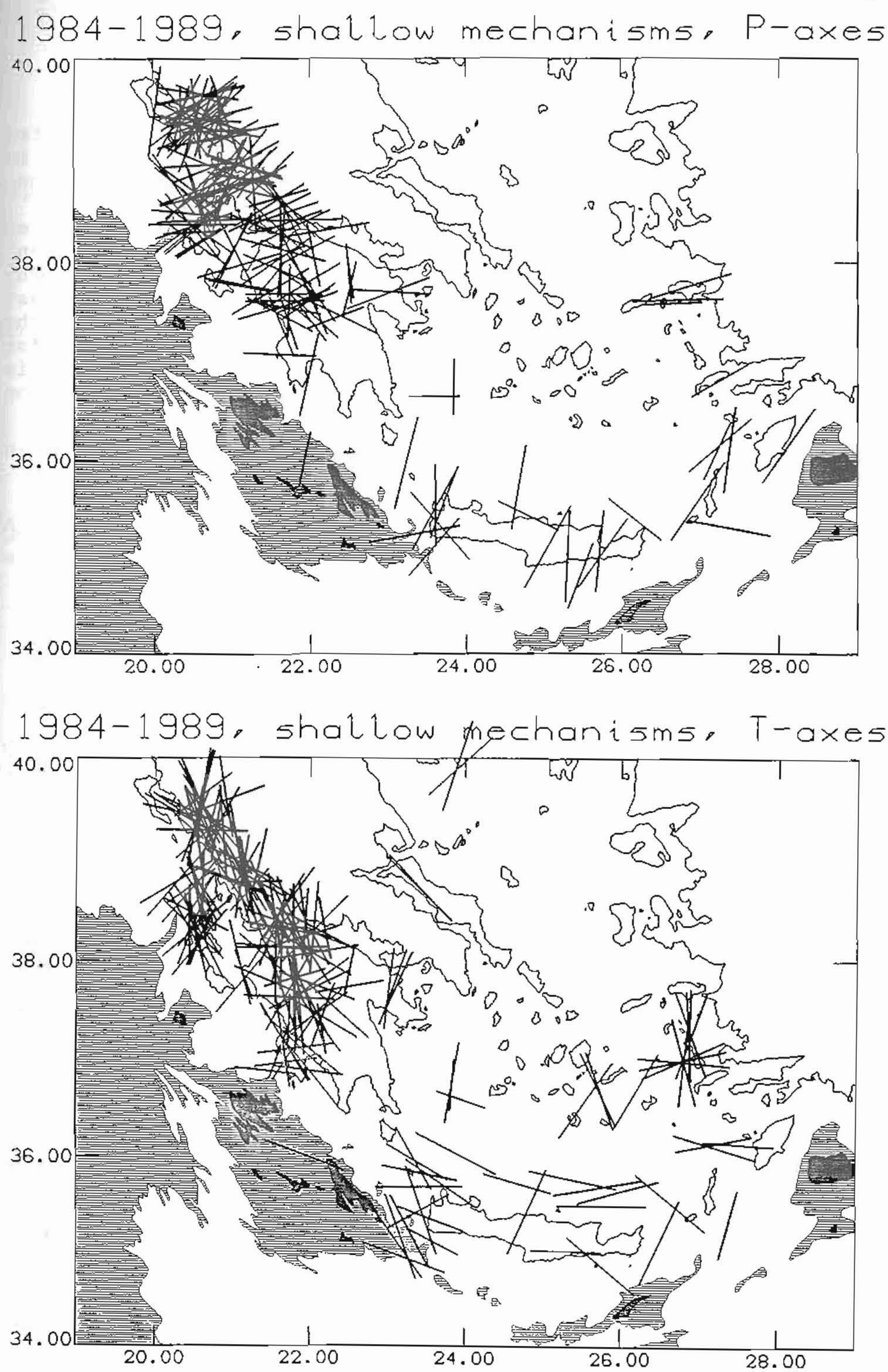

Fig.4. Horizontal projection of the shallow (<45) dipping axes, a) P-axes, b) T-axes.

the observations and to interpret only observations over an area of several km wide, 2) microearthquake observations should be consistent with strong earthquake observations, in the regions where we have both.

Our observations show that most of the seismicity is located along the Hellenic arc and the inferred deformation is consistent with the SW convergence of Aegean relative to Africa. The differences in the trend of the P-axes along the trench suggest that internal deformation takes place within the Aegean. The non-uniform extension that we observe behind the arc is also consistent with tectonic observations and with paleomagnetic results and suggest that the mechanism of internal deformation is similar of that of a gravity nappe (Merle, 1989).

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