3. ΦΥΣΙΚΗ ΤΟΥ ΕΣΩΤΕΡΙΚΟΥ ΤΗΣ ΓΗΣ

3. PHYSICS OF THE EARTH'S INTERIOR

SEISMOTECTONICS OF THE AEGEAN AREA

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ABSTRACT

Reliable fault plane solutions for the shallow and intermediate depth earthquakes, for the period 1964 - 1991, as well as new seismicity data are used to resume the contemporary knowledge on the seismotectonic framework of the Aegean and the surrounding area. The parameters of the focal mechanisms are compiled in two catalogues, for the shallow and the intermediate depth events, and are here presented. In addition, an updated catalogue of all the intermediate depth earthquakes ($h \geq 70$ Km) of the Aegean area, of the period 1964-1989, recorded by at least 26 stations is used to reexamine the shape of the Benioff zone in southern Aegean. The new data confirm and fill in gaps of our previous knowledge. The subduction along the Hellenic arc is playing the role of a buffering system for the geodynamic stability of the broader Aegean area. The slab is subducting at a low angle (14°) up to depths of 100 Km and then steepens its dip to 38°. Along the outer part of the Hellenic arc low angle thrust faults are observed which produce a compressional deformation pattern. The compression is performed at an azimuth of 214° at a mean rate of 6 mm/yr. As we go away from the trench and proceed to greater depths (40-100 Km) pull forces are acting at the slab. As a result down dip extension is observed within the slab at a rate of 8 mm/yr. However, within the slab a component of nearly horizontal compression parallel to the strike of the Hellenic arc also occurs at a rate of 21 mm/yr. This compressional velocity is rather hard to be explained with simple kinematic models. In the Aegean sea and the surrounding land areas the principal stress axes show that the region is dominated by extension which takes place in an about N-S direction at a rate of about 5 mm/yr. The faster extension rates are observed in the Northern Anatolia and in the Northern Aegean trough where the westward motion of the Turkish plate is perturbed with the N-S extension of the Aegean. This leads to E-W compression which reduces from 22 mm/yr in Northern Anatolia to 16 mm/yr in the Northern Aegean trough. This E-W compression is compensated by N-S extension which reduces from 19 mm/yr to 8 mm/yr in the same sense. Along the zone of thrusting that runs the western coastal regions and the zone of extension that dominates the mainland of Greece, there is a rather narrow suture zone that shows E-W extension at a mean rate of 1.6 mm/yr.

ΣΥΓΧΡΟΝΕΣ ΑΠΟΨΕΙΣ ΓΙΑ ΤΗ ΣΕΙΣΜΟΤΕΚΤΟΝΙΚΗ ΤΗΣ ΠΕΡΙΟΧΗΣ ΤΟΥ ΑΙΓΑΙΟΥ

Παπαζάχος,Β., Κυρατζή,Α. και Παπαδημητρίου,Ε.

ΠΕΡΙΛΗΨΗ

Στην παρούσα εργασία χρησιμοποιούνται αξιόπιστοι μηχανισμοί γέννεσης για σεισμούς επιφανείας και ενδιαμέσου βάθους, της χρονικής περιόδου 1964-1991, καθώς και άλλα σεισμολογικά στοιχεία για να δοθεί το σεισμοτεκτονικό πλαίσιο του Αιγαίου και των γειτονικών περιοχών. Δίδονται δύο κατάλογοι με τις παραμέτρους των μηχανισμών γένεσης για τους σεισμούς επιφανείας και ενδιαμέσου βάθους αντίστοιχα. Επιπροσθέτως, ένας κατάλογος σεισμών ενδιαμέσου βάθους της περιόδου 1964-1989, με αριθμό παρατηρήσεων ≥ 26, χρησιμοποιείται για την επανεξέταση της γεωμετρίας της ζώνης Benioff. Τα καινούργια δεδομένα επιβεβαιώνουν ή συμπληρώνουν την προηγούμενη γνώση μας σχετικά με τη σεισμοτεκτονική του Αιγαίου. Φαίνεται οτι η κατάδυση της πλάκας στο νότιο Αιγαίο παίζει πρωτεύοντα και ρυθμιστικό ρόλο στη γεωδυναμική του όλου συστήματος. Η πλάκα βυθίζεται με μικρή γωνία κλίσης (14°) μέχρι το βάθος των 100 Km περίπου και για μεγαλύτερα βάθη η γωνία κλίσης αυξάνει σε 38°. Κατά μήκος του Ελληνικού τόξου παρατηρούνται ανάστροφα ρήγματα μικρής κλίσης τα οποία δημιουργούν συμπιεστικό πεδίο παραμόρφωσης με ταχύτητα 6 mm/yr. Καθώς απομακρυνόμασθε από την τάφρο και αυξάνει το βάθος των εστιών (40-100 Km), εφελκυστικές δυνάμεις αναπτύσσονται πάνω στην καταδυόμενη πλάκα (slab pull-forces). Αυτό έχει ως αποτέλεσμα η καταδυόμενη λιθόσφαιρα να επεκτείνεται με ρυθμό 8 mm/yr. Παράλληλα όμως αναπτύσσεται και μιά συνιστώσα σχεδόν οριζόντιας συμπίεσης, παράλληλα με το Ελληνικό τόξο, με ρυθμό 21 mm/yr. Στην ηπειρωτική Ελλάδα και Τουρκία η κατανομή των μέγιστων αξόνων τάσης φανερώνει την ύπαρξη εφελκυσμού, με διεύθυνση περίπου Β-Ν, με ταχύτητα παραμόρφωσης 5 mm/yr. Οι μεγαλύτερες ταχύτητες εφελκυσμού παρατηρούνται στην περιοχή του Β. Αιγαίου και της Β. Ανατόλιας. Στο χώρο αυτό η πρός δυσμάς κίνηση της Τουρκικής πλάκας επηρεάζεται από τον εφελκυσμό του Β. Αιγαίου. Ετσι το πεδίο παραμόρφωσης χαρακτηρίζεται απο συμπίεση διεύθυνσης Α-Δ με ταχύτητα 22 mm/yr στην Β. Ανατόλια και 16 mm/yr στο Β. Αιγαίο. Η συμπίεση αυτή αντισταθμίζεται απο εφελκυσμό με ταχύτητα 19 mm/yr στην Ανατόλια που ελαττώνεται σε 8 mm/yr στο Β. Αιγαίο. Μεταξύ της εξωτερικής συμπίεσης που διατρέχει τις δυτικές ακτές και του εφελκυσμού της ηπειρωτικής Ελλάδας υπάρχει μια στενή ζώνη 'επαφής' που παρουσιάζει εφελκυσμό με διεύθυνση Α-Δ με ταχύτητα της τάξης των 1.6 mm/yr.

INTRODUCTION

The Aegean and the surrounding area, situated along the Africa - Eurasia plate boundary, has been a region of intense seismic activity and has attracted the attention of many geophysicists. Destructive shallow earthquakes with M_s values up to 7.5, and intermediate depth earthquakes, with even larger magnitudes (≈8.0), have repeatedly struck many sites.

In brief, the most prominent features of tectonic origin are (figure 1), from south to north, the **Mediterranean Ridge**, a compressional submarine accretionary prism of material which extends from the Ionian Sea to Cyprus and follows the trend of the Hellenic arc, the **Hellenic trench** with a maximum water depth of 5Km, the Hellenic arc, which consists of the outer sedimentary arc and the inner volcanic arc, and finally the **back-arc Aegean** area, which includes the Aegean Sea, the mainland of Greece, Albania, south Yugoslavia, south Bulgaria and western Turkey.

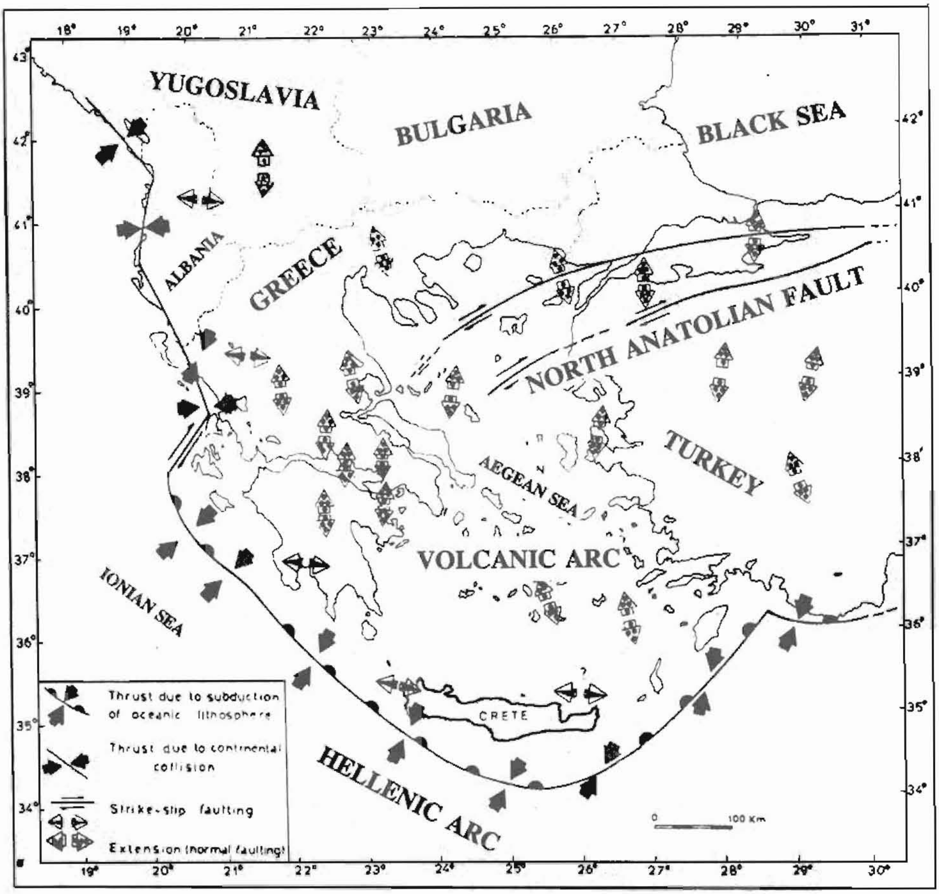

Fig.1. The main tectonic features of the broader Aegean area.

The kinematics of the area are controlled by the westward motion of Turkey and the southwestward motion of the southern Aegean both relative to Eurasia. The westward motion of Turkey relative to Eurasia is related to the collision between Arabia and Eurasia in the area of Caucasus and eastern Turkey. Most of the westward motion of Turkey is accommodated on the North and East Anatolian strike slip fault systems (McKenzie, 1978; Taymaz et al., 1991; Kiratzi, 1991; 1993). The thickened crust in eastern Turkey can provide the buoyancy force that drives Turkey westwards. The Aegean area is dominated by extension as the southern Aegean Sea moves in a nearly southwest direction relative to Eurasia. This extension is thought to be driven principally by the "roll -back" of the subducting slab beneath the southern Aegean (McKenzie, 1978; LePichon, 1982), as it sinks into the mantle with a component of velocity normal to its surface.

In the present paper, the active tectonis of the Aegean sea and the surrounding coastal regions are re-examined in an attempt to update our knowledge with the results of new data both in the distribution of the seismicity as well as in the distribution of the focal mechanisms. A contribution of the present paper is the publication of two catalogues with the parameters of the most reliable fault plane solutions of shallow and intermediate depth earthquakes and the use of one catalogue of intermediate depth events ($h \geq 70$ Km), of the period 1964-1989. These data in connection with our previous own work and the work of others are used to give a present day picture of the geodynamics of the broader Aegean area and to discuss about problems that need further clarification.

SEISMIC MOMENT RELEASE IN THE SEISMOGENIC SOURCES

The seismic moment rate release was calculated for each of the 68 seismogenic sources of the Aegean area, identified by Papazachos (1990). Using Molnar's (1979) formulation the seismic moment rate release was calculated for each source. Then, in order to have a value comparable with one another for every source, we calculated a normalized value for the seismic moment rate for an area of 10.000 Km^2.

Figure (2) shows the distribution of the normalized values of the seismic moment rate release for the seismogenic sources of shallow earthquakes and figure (3) shows the same for the sources of the intermediate depth earthquakes. The magnitudes shown in the index of these figures are calculated assuming a moment magnitude relation for the Aegean area (Papazachos et al., 1992). This is the magnitude, M_c, of the earthquake which could occur yearly per 10.000 Km^2, if all the seismic moment could be released by one earthquake. It is observed, that for the shallow earthquakes the corresponding cumulative magnitudes vary between 4.4 and 6.3. These values can be considered as good measures of relative seismicity of the seismogenic sources. In general, high shallow seismicity is observed: (a) along the convex side of the Hellenic arc but very close to the coast, with the highest value in its northwesternmost part (Cephalonia - Lefkada) where a transform fault has been identified (Scordilis et al., 1985; Kiratzi and Langston, 1991) (b) along a megazone which includes the western part of the northern Anatolian fault system, and the Serbomacedonian massif, (c) an area in central Greece which includes the seismogenic sources of the Patraikos - Corinthiakos Gulfs, the Evoikos and Maliakos Gulfs as well as the area of Thessalia. All other seismogenic sources have approximately the same but clearly higher seismicity than in the area with background seismicity.

From figure (3) it is seen that the seismic moment rate release is much higher for the external zone of intermediate depth earthquakes than it is for the internal zone. As a matter of fact the normalised annual magnitude of the occurrence of an earthquake is about the same for the zones of shallow seismicity and the external intermediate depth seismicity, along the Hellenic arc. This observation probably indicates that the collision (coupling) between the eastern Mediterranean lithosphere and the Aegean lithosphere is taking place on this slightly dipping belt.

THE FAULT PLANE SOLUTIONS OF THE AREA

Shallow earthquakes

Table I lists the parameters of the focal mechanisms of the shallow depth earthquakes ($h \leq 40$ km), of the Aegean area. This catalogue is updated from Papazachos,B. et al., (1991) and Papazachos,C. et al., (1992). Earthquakes with magnitude greater than 5.5 are included for the period 1964-1990 with some exceptions for some older events which produced surface expression of the fault. In each case in this catalogue, nodal plane 1 is considered to be the fault plane based on the existence of surface expression, if any, on the distribution of aftershocks, and on macroseismic data. In cases where no other evidence was available, the nodal plane with the smallest dip angle was arbitrarily chosen as the fault plane.

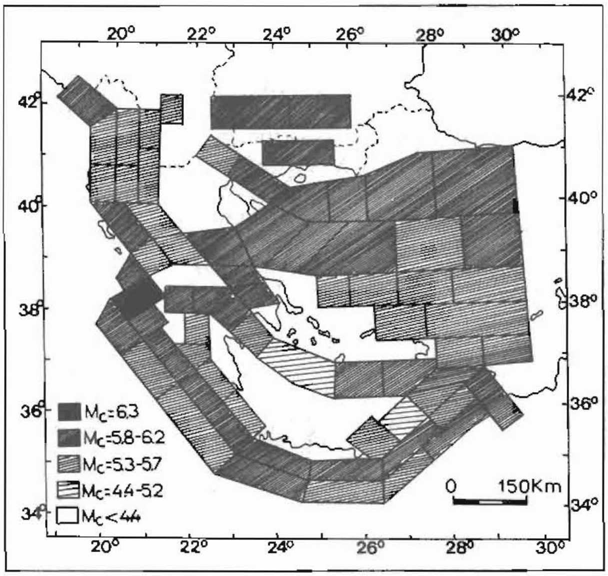

Fig.2. The distribution of the seismic moment rate release, normalised for an area of 10.000 Km^2, for the shallow earthquakes of the Aegean area.

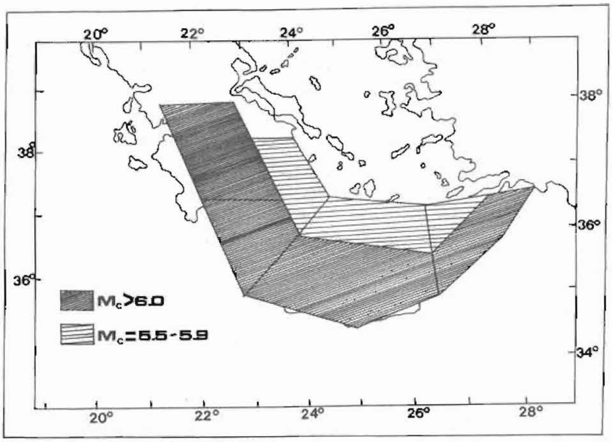

Fig.3. The same as in fig.2, for the intermediate depth earthquakes.

Figure (4) shows the fault plane solutions of the shallow earthquakes of the Aegean area, listed in Table I. An equal area lower hemisphere projection is used where the black quadrants denote compressional first onset, while the blank ones, denote dilatational one. The date of occurrence of the corresponding earthquake is also shown in the figure.

It is seen that thrust faulting is observed along the Dalmatian coast of Yugoslavia, Albania and western Greece, due to the collision of two continental lithospheres (Apulia - Eurasia), with no evidence of subduction. This zone of thrusting continues southern, along the coastal regions of northwestern Greece up to the island of Cephalonia. The recent activity that struck this area (January 1983 sequence) declared the existence of dextral strike-slip movement on NE-SW striking nodal planes (Scordilis et al., 1985; Kiratzi and Langston, 1991; Papadimitriou, 1993). This belt of dextral strike-slip faulting is considered as the westward termination of the Hellenic subduction zone. Along the convex side of the Hellenic arc, the motion of Africa relative to Eurasia causes the occurrence of low angle thrust faulting, with the shallow dipping plane considered as the fault plane (McKenzie, 1972, 1978; Papazachos et al., 1984a). The trend of the P axis is normal to the arc at its western part and keeping the same trend tends to become parallel to the arc at its eastern part.

In the mainland of Greece, as well as western Turkey, normal faulting is observed in mainly EW striking nodal planes. The study of the recent seismic sequences (Thessaloniki 1978, Magnesia 1980, Corinth 1981, Kalamata 1986) has shown that the normal faults are in most of the cases listric faults occuring at very shallow depths ($\leq$ 10 Km).

In the northern Aegean, the extension of the Aegean and the motion of the North Anatolian Fault are combined resulting in very complex tectonics. Thus, we have the existence of pure dip slip mechanisms and pure strike-slip ones in close proximity to each other.

Along the zone of thrusting that runs the western coastal regions of the broader Aegean area, and the zone of extension that dominates the mainland of Greece, there is a rather narrow zone that shows E-W extension (Papazachos et al., 1986). This zone is probably a suture zone between two different tectonic regimes.

Intermediate depth earthquakes

Table II lists the fault plane solutions of the intermediate depth events of the period 1961-1987 occurred in the southern Aegean area (from Kiratzi and Papazachos, 1992). It is seen that there are very few large recent intermediate depth events with known fault plane solutions. However, the past has shown that strong earthquakes have occurred there (M_s 8.0) (Papazachos and Comninakis, 1969, 1971; Comninakis and Papazachos, 1980; Papazachos and Papazachou, 1989; Papazachos 1990).

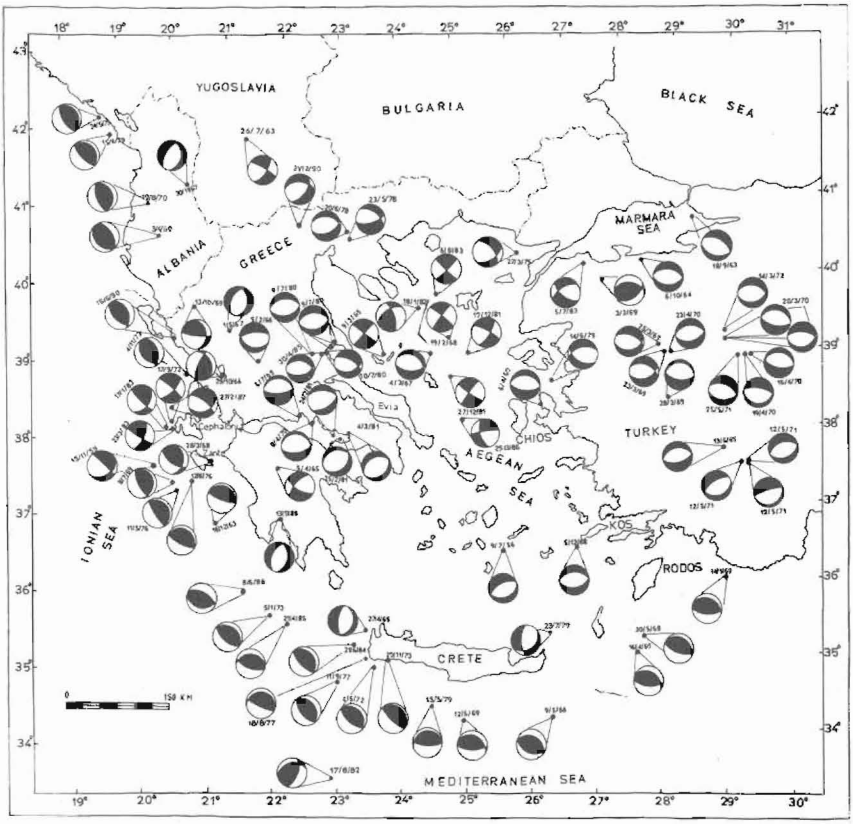

Fig.4. Lower hemisphere equal area projection of the fault plane solutions of the shallow earthquakes of the broader Aegean area. (Modified from Papazachos et al., 1992).

Table 1. Fault plane parameters for the shallow ($h \leq 40$Km) earthquakes of the Aegean and surrounding area for the period 1963-1990. Data for five older events are also included (Revised from Papazachos et al., 1992).

Date	Origin Time	Epicentral Coordinates		Nodal plane 1			M_s	Ref
		Lat°N	Lon°E	strike°	dip°	rake°		
1928,Apr. 18	19:22:48	42.2	25.0	270	40	-90	7.0	24
1932,Sept.26	19:20:42	40.5	23.9	90	40	-90	7.0	24
1953,Mar. 18	19:06:16	40.0	27.4	250	70	-160	7.4	24
1956,July 09	03:11:40	36.7	25.8	65	40	-90	7.5	1
1959,Nov. 15	17:08:43	37.8	20.5	46	37	187	6.8	3
1963,July 26	04:17:12	42.0	21.4	322	73	-20	6.1	2
1963,Sep. 18	16:58:08	40.8	29.1	128	35	-78	6.3	23
1963,Dec. 16	13:47:53	37.0	21.0	296	16	101	5.9	3
1964,Oct. 06	14:31:23	40.3	28.2	100	40	-90	6.9	23
1965,Mar. 09	17:57:54	39.3	23.8	40	90	-6	6.1	2
1965,Apr. 05	03:12:55	37.7	22.0	226	57	-159	6.1	2
1965,Apr. 27	14:09:06	35.6	23.5	22	27	-81	5.7	5
1965,June 13	20:01:51	37.8	29.3	259	38	-90	5.6	4
1965,July 06	03:18:42	38.4	22.4	270	14	-90	6.3	2
1966,Feb. 05	02:01:45	39.1	21.7	103	23	-75	6.2	6
1966,May 09	00:42:53	34.4	26.4	295	40	90	5.8	2
1966,Oct. 29	02:39:25	38.9	21.1	335	27	132	6.0	6
1967,Mar. 04	17:58:09	39.2	24.6	98	54	-107	6.6	2
1967,May 01	07:09:02	39.5	21.2	2	36	-100	6.4	4
1967,Nov. 30	07:23:50	41.4	20.4	0	33	-107	6.3	6
1968,Feb. 19	22:45:42	39.4	24.9	217	86	175	7.1	7
1968,Mar. 28	07:39:59	37.8	20.9	354	34	137	5.9	6
1968,May 30	17:40:26	35.4	27.9	293	25	90	5.9	2
1968,Dec. 05	07:52:11	36.6	26.9	86	50	-90	5.9	2
1969,Jan. 14	23:12:06	36.1	29.2	282	25	95	6.2	2
1969,Mar. 03	00:59:10	40.1	27.5	268	53	108	6.0	23
1969,Mar. 23	21:08:42	39.1	28.5	70	46	-128	6.1	2
1969,Mar. 25	13:21:34	39.2	28.4	90	40	-105	6.0	2
1969,Mar. 28	01:48:29	38.5	28.5	281	28	-90	6.6	2
1969,Apr. 03	22:12:22	40.7	20.0	143	30	90	5.8	14
1969,Apr. 06	03:49:34	38.5	26.4	280	30	-90	5.9	2
1969,Apr. 16	23:21:06	35.2	27.7	301	30	109	5.5	2
1969,June 12	15:13:31	34.4	25.0	294	29	105	6.1	2
1969,July 08	08:09:13	37.5	20.3	353	18	116	5.9	3
1969,Oct. 13	01:02:31	39.8	20.6	340	30	160	5.8	6
1970,Mar. 28	21:02:23	39.2	29.5	280	30	-90	7.1	4
1970,Mar. 28	23:11:43	39.1	29.6	73	32	-109	5.5	8
1970,Apr. 08	13:50:28	38.3	22.6	278	20	-85	6.2	15
1970,Apr. 16	10:42:22	39.0	29.9	273	30	-99	5.7	8
1970,Apr. 19	13:29:36	39.0	29.8	102	23	-90	6.0	8
1970,Apr. 23	09:01:27	39.1	28.6	265	40	-83	5.6	8
1970,Aug. 19	02:01:52	41.1	19.8	343	20	90	5.4	2
1971,May 12	06:25:15	37.6	29.7	68	40	-90	6.2	4
1971,May 12	10:10:38	37.6	29.7	73	14	-90	5.6	4
1971,May 12	12:57:25	37.6	29.6	79	22	-72	5.7	4
1971,May 25	05:43:26	39.0	29.7	97	40	-101	6.1	8
1972,Mar. 14	14:05:47	39.3	29.5	101	40	-101	5.6	8

1972,May	04	21:39:57	35.1	23.6	308	18	90	6.5	9
1972,Sep.	17	14:07:15	38.3	20.3	45	68	186	6.3	3
1973,Jan.	05	05:49:18	35.8	21.9	306	30	82	5.6	8
1973,Nov.	04	15:52:13	38.9	20.5	348	40	109	5.8	6
1973,Nov.	29	10:57:44	35.2	23.8	316	10	90	6.0	8
1975,Mar.	27	05:15:08	40.4	26.1	68	55	-145	6.6	23
1976,May	11	16:59:45	37.4	20.4	335	14	106	6.5	3
1976,June	12	00:59:18	37.5	20.6	297	20	90	5.8	6
1977,Aug.	18	09:27:41	35.3	23.5	270	12	114	5.6	10
1977,Sep.	11	23:19:19	34.9	23.0	320	30	90	6.3	4
1978,May	23	23:34:11	40.7	23.2	227	49	-64	5.8	11
1978,June	20	20:03:21	40.8	23.2	278	46	-70	6.5	11
1979,Apr.	15	06:19:41	42.0	19.0	318	12	90	7.1	12
1979,May	15	06:59:23	34.6	24.5	253	17	65	5.7	10
1979,May	24	17:23:18	42.2	18.8	330	22	90	6.3	12
1979,June	14	11:44:45	38.8	26.6	262	41	-108	5.9	23
1979,July	23	11:41:55	35.5	26.4	61	35	-40	5.5	21
1980,July	09	02:10:20	39.3	22.9	82	42	-79	5.6	13
1980,July	09	02:11:57	39.3	22.9	81	40	-90	6.5	13
1980,July	09	02:35:52	39.2	22.6	81	40	-90	6.1	13
1981,Feb.	24	20:53:37	38.2	23.0	264	42	-80	6.7	23
1981,Feb.	25	02:35:54	38.2	23.1	241	44	-85	6.4	23
1981,Mar.	04	21:58:07	38.2	23.3	230	45	-90	6.4	23
1981,Dec.	19	14:10:51	39.2	25.2	37	67	-166	7.2	16
1981,Dec.	27	17:39:13	38.9	24.9	216	79	175	6.5	23
1982,Jan.	18	19:27:25	39.8	24.4	233	62	-173	7.0	23
1982,Aug.	17	22:22:20	33.7	22.9	246	31	125	6.4	3
1983,Jan.	17	12:41:30	38.1	20.2	60	47	174	7.0	17
1983,Mar.	23	23:51:05	38.2	20.3	31	69	174	6.2	3
1983,July	05	12:01:27	40.3	27.2	248	70	-155	6.1	18
1983,Aug.	06	15:43:52	40.0	24.7	48	83	178	6.8	19
1984,June	21	10:43:46	35.4	23.3	322	16	114	6.2	3
1985,Apr.	21	08:49:42	35.7	22.2	269	36	71	5.6	22
1985,Apr.	30	18:14:13	39.3	22.8	77	50	-105	5.8	23
1986,Mar.	25	01:41:35	38.4	25.1	261	84	27	5.5	22
1986,June	8	04:55:01	36.1	21.6	109	34	86	4.9	22
1986,Sep.	13	17:24:34	37.1	22.2	200	50	-81	6.0	20
1987,Feb.	27	27:23:35	38.5	20.3	46	37	-155	5.6	22
1990,June	16	02:16:21	39.3	20.6	329	39	102	5.3	22
1990,Dec.	21	06:57:45	41.0	22.4	265	46	-54	5.9	25
1992,Nov.	18	21:10:42	38.3	22.4	80	59	-95	5.9	26

1.Shirokova (1972), 2.McKenzie (1972), 3.Papadimitriou (1992), 4.Papazachos et al. (1991b), 5.Lyon-Caen et al. (1988), 6.Anderson and Jackson (1987), 7.Kiratzi et al. (1991a), 8.McKenzie (1978), 9.Kiratzi and Langston (1989), 10.Taymaz et al. (1990), 11.Soufleris and Stewart (1981), 12.Boore et al. (1981), 13.Papazachos et al. (1983), 14.Ritsema (1974), 15.Liotier (1989), 16.Papazachos et al. (1984b), 17.Kiratzi and Langston (1991), 18.Dziewonski et al. (1984), 19.Rocca et al. (1985), 20.Papazachos et al. (1988), 21.Ekstrom and England (1989), 22.NEIS, 23.Taymaz et al. (1991), 24.Papazachos et al., (1992), 25. Panagiotopoulos, et al., (1993). 26. Karakaisis et al., (1993).

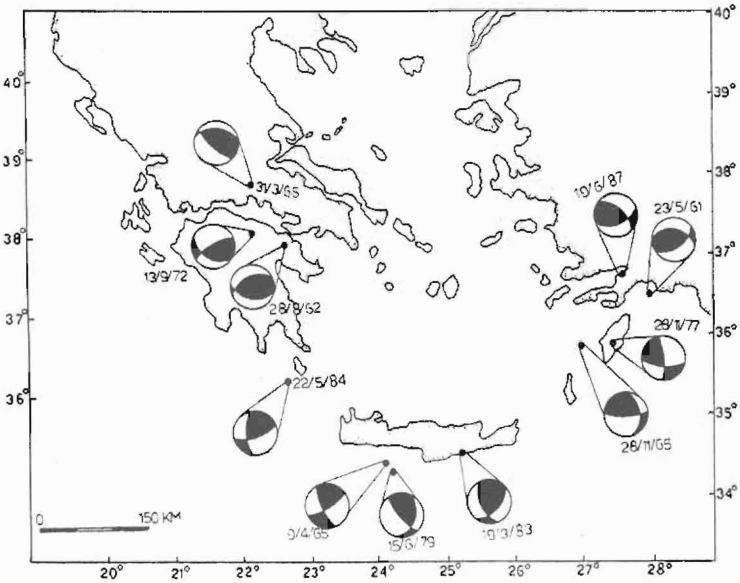

Fig.5. Lower hemisphere equal area projection of the fault plane solutions of the intermediate depth earthquakes of the southern Aegean area. (From Kiratzi and Papazachos, 1992).

Figure (5) shows the focal mechanisms listed in Table II. All solutions show high angle reverse faulting with a considerable strike-slip component. The earthquake with the largest known focal depth ever observed in this area is the one which occurred on April 10, 1976 with M_s=4.3, epicentral coordinates 37.31°N,24.94°E and focal depth 183 Km (Comninakis and Papazachos, 1980).

THE GEOMETRY OF THE BENIOFF ZONE

In order to define the geometry of the Benioff zone with new data we collected all the earthquakes that occurred in the southern Aegean area for the period 1964 - 1989. The data for the period 1964-1979 are from Comninakis and Papazachos (1980). For the period 1965-1989 are from the bulletins of the International Seismological Centre (ISC). Only the intermediate depth earthquakes ($h \geq$ 70Km) were collected and only those that were recorded by at least 26 stations. In this way we believe we use the most reliable data set.

The distribution of these earthquakes is shown in figure (6). Different symbols are used to denote different magnitude and depth ranges. Plots of the depth versus distance, (not shown here), showed that the slope of the Benioff zone equals 38° as it was previously defined (Papazachos 1990, Papazachos et al., 1991). A delineation of earthquake foci was also observed in the western part of the Hellenic arc, in a NNE-SSW trend, up to the area of Magnesia suggesting that the Hellenic arc is assymetrical in its shape.

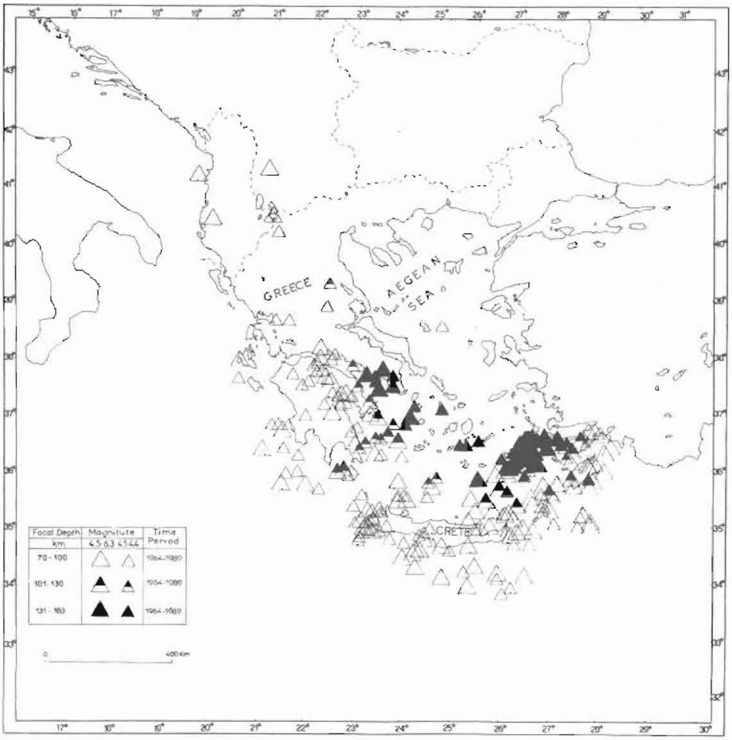

Fig.6. Distribution of the intermediate depth earthquakes, of the period 1964-1989 recorded by at least 26 stations.

Kiratzi and Papazachos (1992) using moment tensor analysis found that it is the A axes that follow the direction of the Benioff zone (and hence the subducted slab) and not the T axes. This observation has been previously supported by Papazachos (1990), Papazachos et al., (1991) and differs from the results of Isacks and Molnar (1971), Taymaz et al., (1990), who state that the T axes are aligned down-dip of the subducting lithosphere.

ACTIVE SEISMIC DEFORMATION IN THE AEGEAN AREA

Deformation caused by the shallow seismicity

Papazachos et al., (1992) calculated the active crustal deformation for the 26 seismic zones of the broader Aegean area, and the results are summarized in figure (7). It is seen that along the coastal region of Albania, Yugoslavia, and western

Table 2. Fault plane solutions of the indermediate depth earthquakes of the southern Aegean (from Kiratzi and Papazachos, 1992).

Date	Φ^o_N	λ^o_E	M_s	h(Km)	Strike°	Dip°	Rake°	REF
1. May 23, 1961	36.6	28.5	6.4	70	270	35	115	R
2. Aug 28, 1962	37.8	22.9	6.8	95	241	51	58	M
3. Mar 31, 1965	38.6	22.4	6.8	78	286	17	60	P
4. Apr 9, 1965	34.9	24.2	6.1	51	63	76	157	T
5. Nov 28, 1965	36.1	27.4	6.0	73	350	30	162	P
6. Sept 13,1972	38.0	22.4	6.3	75	235	76	48	K
7. Nov 28, 1977	36.1	27.8	5.8	85	103	46	24	E
8. June 15,1979	34.8	24.2	5.6	40	150	75	70	T
9. Mar 19, 1983	35.0	25.3	5.7	67	44	51	139	T
10.May 22, 1984	36.1	22.8	5.3	73	75	66	142	H
11.June 19,1987	36.8	28.1	5.5	60	316	54	137	E

R: Ritsema (1974)
M: McKenzie (1972)
P: Papazachos et al. (1991)
T: Taymaz et al., (1990)
K: Karacostas (1988)
E: Ekstrom and England (1989)
H: CMT Harvard determination

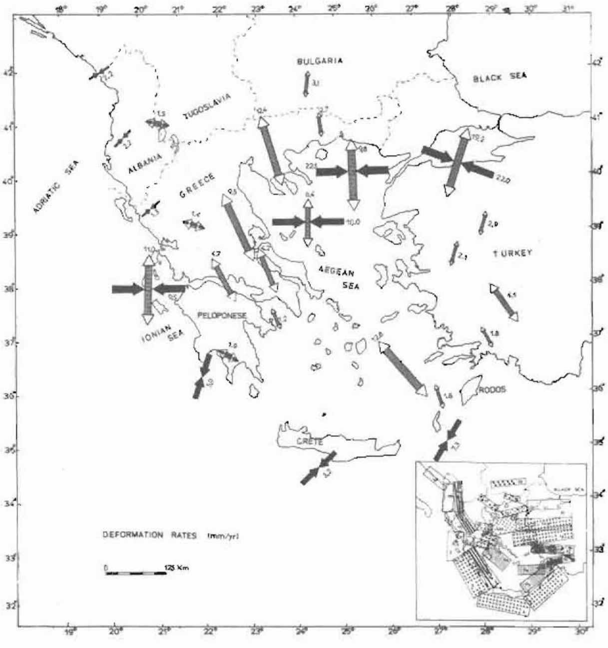

Fig.7. Rates of active crustal deformation in the Aegean and the surrounding area (Papazachos et al., 1992).

Greece the deformation is taken up by compression in a direction perpendicular to the coast line (N47°E) at a rate of about 2 mm/yr. In the Cephalonia island the deformation is taken up as N-S extension at a rate of 11 mm/yr compensated by E-W compression at a rate of 10 mm/yr. In this area the dextral strike slip motion has a rate of 2 mm/yr. Along the convex side of the Hellenic arc the upper crust is compressed at a rate of about 6 mm/yr in a direction N34°E, that is, in agreement with the motion of Africa relative to Eurasia. In the Aegean Sea and the surrounding lands the seismic deformation is taken up by an almost N-S extension at an average rate of 5 mm/yr. The dextral strike-slip motion in Northern Anatolia is 16 mm/yr. In the North Aegean trough the deformation is controlled by the westward movement of the North Anatolian Fault and of the extension of the Aegean area. Thus, the deformation is taken up by E-W compression at a rate of 16 mm/yr and by N-S extension at a rate of 8 mm/yr.

The vertical crustal thickening along the compressional zones ranges from 0.2 to 0.5 mm/yr with an average of 0.3 mm/yr and the vertical crustal thinning in the extensional area ranges from 0.1 to 2.4 mm/yr with an average equal to 0.8 mm/yr.

Deformation of the descending slab

Kiratzi and Papazachos (1992) thoroughly investigated the deformation caused by the intermediate depth seismicity of the southern Aegean area. This was performed using a moment tensor analysis and information from recent and historical earthquakes. The results are graphically illustrated in figure (8). It is seen that the deformation of the subducting lithosphere is taken up by extension along the down dip direction of the Benioff zone at a rate of 8 mm/yr. This extension is mainly attributed to the

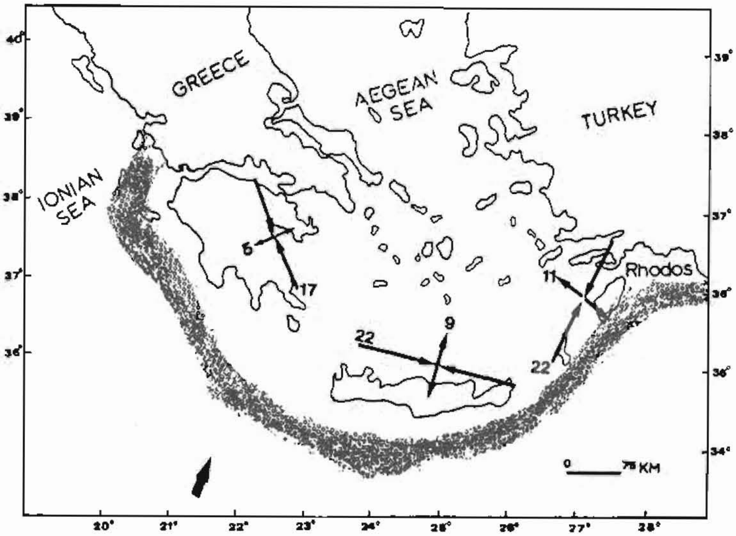

Fig.8. Rates of sub-crustal deformation in the southern Aegean Benioff zone (Kiratzi and Papazachos, 1992).

gravitational forces acting on the descending slab. Parallel to the trend of the Hellenic arc we have the occurrence of compression that occurs at a rate of 21 mm/yr. Kiratzi and Papazachos (1992) believe that this compression is the by-product of the extension observed down the dip of the Benioff zone. This deformation pattern is in very good agreement with the results of Hatzfeld et al. (1990).

DISCUSSION AND CONCLUSIONS

Reliable fault plane solutions show that the distribution of stress and of the seismic velocities in the Aegean area and the surrounding lands follow some clear patterns. The kinematics of the deformation is controlled by three factors: The westward motion of Turkey relative to Eurasia, the continental collision between NW Greece-Albania and the Apulia-Adriatic platform in the west, and finally the presence of the Hellenic subduction zone to the south. Along the coastal regions of Albania and western Greece coastal shortening occurs at a rate of about 2 mm/yr. Central Greece and western Turkey are dominated by normal faulting as it is clearly seen from the fault plane solutions. In the North Aegean Trough, the focal mechanisms declare strike slip motion on NNE-SSW nodal planes or alternatively they declare nearly N-S extension. In this area the extension of the Aegean is perturbed by the westward motion of the Turkish plate along the North Anatolian Fault. This dramatic difference between the N-S slip vectors on the normal faults in central Greece and the NE trending slip vectors on the strike-slip faults in the North Aegean Trough that led McKenzie and Jackson (1983, 1986) to postulate that block rotations about a vertical axis occurred in central Greece. In fact, the same authors believe that the Turkey - Eurasia motion cannot connect with the Hellenic Trench system without block rotations occurring in central Greece. The present rate of extension in the mainland of Greece, central Aegean and western Turkey is estimated to be about 5 mm/yr while the compression along the Hellenic arc is estimated to be about 6 mm/yr (Papazachos et al., 1992). The seismicity in the region of Crete is related to the N-S convergence between Africa and Eurasia (about 10 mm/yr at this longitude, Chase 1978; DeMetts et al., 1990) and to the extension within the Aegean province. The results show that the extension in the Aegean, as it is determined from seismic observations, is not faster than the convergence between Africa and Europe as it is suggested by others (Jackson and McKenzie, 1988a, b; Ekstrom and England, 1989; Main and Burton, 1989). The extension is very fast only in the North Aegean area and further east in the North Anatolian Fault, but the overall extension rate is less than 10 mm/yr. In fact, the continental shortening in NW Greece and Albania does not allow the rotation of the western margin of this region to be rapid enough to accomodate the distributed E-W right lateral shear produced by the continuation of the North Anatolian Fault into the Aegean. This leads to E-W shortening in the northern Aegean at a rate of 16 mm/yr which is compensated by N-S extension at a rate of 8 mm/yr as the southern Aegean margin can move easily over the Hellenic subduction zone.

The length and the time over which these present day rates of extension and convergence have been operating is still not clear. The length of the seismically active part of the subducting slab is about 300 Km. If we assume that this part of the slab has been thrust into the mantle with the convergence rate estimated from plate motions (1cm/yr, Chase 1978) then we end up with an age for the subduction of about 30 Myr, in agreement with Spakman et al. (1988). On the other hand the faster compression rates calculated by Jackson and McKenzie (1988a) that are of the order of 50-60 mm/yr along the Hellenic Trench would yield an initiation of the subduction about 5 Myr ago. If we accept that the subduction started 13 Myr ago (LePichon and Angelier, 1979), then we would expect a rate of convergence of the order of about 2 cm/yr, which is much more likely to occur. At any rate we still cannot be positive since there is no doubt that the strain has varied spatially over the time (Mercier et al., 1989).

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