PLATE TECTONICS IN THE AREA OF GREECE AS REFLECTED IN THE DEEP FOCUS SEISMICITY *

BY

A. G. GALANOPOULOS

Abstract. Deep focus seismicity in the southern Aegean Sea along two belts, two hundred kilometers wide, trending N 60° E and N 30° W, was projected on the median vertical planes; the planes are perpendicular to each other and to the strike of the Hellenic Island arc and run across the large zones of positive and negative gravity anomalies in the concave and convex side of the arc. From the slopes of the African plate in the two cross-sections, as reflected in the deep focus seismicity, it was found that the true dip of the African plate is nearly 20°; the strike of the plate is N 58° W. The direction of maximum slope being perpendicular to the strike is N 32° E. Calculation was confirmed by plotting deep focus seismicity along the direction of maximum slope of the African plate.

The dip of the African plate found from the two cross-sections in the southern Aegean Sea is of the same order of magnitude with that found tentatively for the whole area bounded by the 19° and 29° Meridians and the 34° and 42° Parallels. From the small slope of the African plate under the Hellenic Island arc one might dare to speculate that the underthrusting of the lithospheric slab in the eastern Mediterranean is much younger in comprison to that observed under the Calabrian Island arc in the western Mediterranean and / or the margin of the plate in the eastern area is comparatively lighter, i. e. hotter.

There is further evidence that disruption of the African plate in two segments along the Cretan furrow might account much better for the anomalous distribution of hypocentres of intermediate earthquakes in the area of Greece. It is assumed that underthrusting and tearing of the African plate beneath the Eurasian was accomplished by a compression acting from southwest due to the opening of the Atlantic in Jurassic and Upper Cretaceous.

INTRODUCTION

In an attempt to study the «Space and Time Variations of Strain Release in the Area of Greece» (DELIBASIS and GALANOPOULOS, 1965) the foci of earthquakes with $M \geqslant 4^3/_4$ occurred between the Meridians of 19° E and 29° E and the Parallels of 34° N and 42° N during the period

* Α. Γ. ΓΑΛΑΝΟΠΟΥΛΟΥ.— Ἡ τεκτονικὴ τῶν πλακῶν εἰς τὴν περιοχὴν τῆς Ἑλλάδος ὡς κατοπτρίζεται εἰς τὴν σεισμικότητα βάθους.

1841 - 1959 were projected on two median vertical planes running parallel to the 24° E Meridian and 38° N Parallel. The two cross-sections tentatively constructed allowed at that time to make the following remarks:

«For the present, the intermediate shocks appear to occur between the Meridians of 20.0° E and 28.0° E with a clear increase of the focal depth from west to east. The distribution of the foci of the intermediate shocks suggests the existence of a boundary surface dipping between the meridians of 20.2° E and 28.0° E from a depth of 100 km to a depth of 200 km».

«The foci of the intermediate shocks appear to occur between the Parallels 34.0° N and 40.0° N, but their majority is expressdly confined between the Parallels 34.0° N and 38.0° N. If we disregard the focal depth of 170 km appeared at the lattitude 34.0° N, the distribution of the intermediate foci marks a wedge plunging 200 km deep at the 36.5° N latitude. The two surfaces of the wedge dipping from a depth of 130 km at the latitude 34.5° N, and 80 km at the latitude 40.0° N, towards the depth of 200 km at the latitude 36.5° N, show the same inclination. It is interesting to note that the cusp of the wedge is at the 36.5° N Parallel close to which the active volcanoes of Santorin and Nisyros are situated».

In a recent analysis of the seismicity and fault-plane solutions in the Mediterranean area, D. P. McKENZIE (1970) was led to suggest the existence, in the eastern Mediterranean, of two small, rapidly moving plates. The first, named the Aegean plate, comprises the Aegean Sea, part of mainland Greece, Crete, Rhodes and western Turkey. The second — the Turkish plate — includes most of Turkey and Cyprus. In terms of theories of plate tectonics, the relatively high earthquake activity in the area of Greece — about 2 percent of the earthquake energy released in the world — is directly related to movements along the boundaries between these subplates and the main plates which flank them to the north (Eurasian Plate) und south (African Plate). Morphologically the Aegean subplate is marked to the south and west by the Hellenic Trough and to the north by the Saros Graben (GALANOPOULOS, 1965); its eastern margin is rather uncertain. It is difficult to identify plate boundaries clearly. The distribution of intermediate depth earthquakes under the Aegean Sea is very complicated (TOKSÖZ, 1971).

The extension of the North Anatolian shear fault-zone through the Saros Graben, the Trikkeri-Canal fault into the Gulf of Patras and the shear fault-zone of Cephalonia - Zante was first suggested in 1965 (GALANOPOULOS, 1965). Exceptionally intense earthquake activity in the northern Aegean Sea in 1967, March 4 (39.2° N, 24.6° E; M = 6 $^{1}/_{2}$) and 1968, February 19 (39.4° N; 25.0° E: M = 7 $^{1}/_{2}$) substantiated the suggestion.

From an analysis of the seismicity of the Mediterranean basin CAPUTO and his associates (1970) were led to the conclusion «that the African plate is wedged under the Euro-Asiatic plate with a slope of approximately 58° in the Lipari region and 35° in the Aegean region». The analysis of the seismicity in the Aegean region was based on a list of earthquakes covering the period 1961 - 1969. According to V. KARNIK (1972), the dip angle of the seismic interface is about 30°; estimation is based on intermediate-depth shocks data over the observation period 1901 - 1970. Depth distribution of the earthquake foci over the period 1841 - 1959 had previously revealed that the dip of the African plate under the Hellenic Island arc is much more gentle, i.e. a low-angle (~20°) thrust occurs. This is in accordance with the theory, that the oceanic lithosphere, because of its strength, is unlikely to bend sharply (KANAMORI, 1971).

DATA AND METHOD APPLIED

Like so many other geological problems, the determination of the slope of the African plate leans heavily on personal opinion. None the less, it was thought worth while to check the discrepancy in the dipping of the African plate by using first I.S.C. data of the most recent period, 1964 - 1968; the period includes 4 - years accurate data of the National Seismological Stations Network recently established in Greece.

All data between the Meridians 19° E and 29° E and the Parallels 34° N and 42° N were projected on a vertical plane along the 24° Meridian. Although the new data cover merely a 5 - year period, the pattern of the space distribution of the earthquake foci is very alike to that found in 1965.

If we disregard a few focal depths of small shocks, one might be allowed to speculate that the Aegean subplate having the form of a wedge overthrusts the African plate as well as the Eurasian one (s. Fig. 1). As reflected in the deep focus seismicity, the Eurasian plate plunges downward to the Aegean sublate at an angle of about 15° or 5° smaller than the relatively colder, i.e. heavier African plate. Apparently the two plates approach each other under the south Aegean volcanic arc, at the apex of the Aegean wedge, between 36° N and 37° N Parallel.

The area limited by the Parallels 36° N and 37° N is most characteristic for being the place of several sharp, local magnetic anomalies, and a nest of great intermediate earthquakes of magnitude 8 and over. All the great intermediate-depth earthquakes occur along a belt which

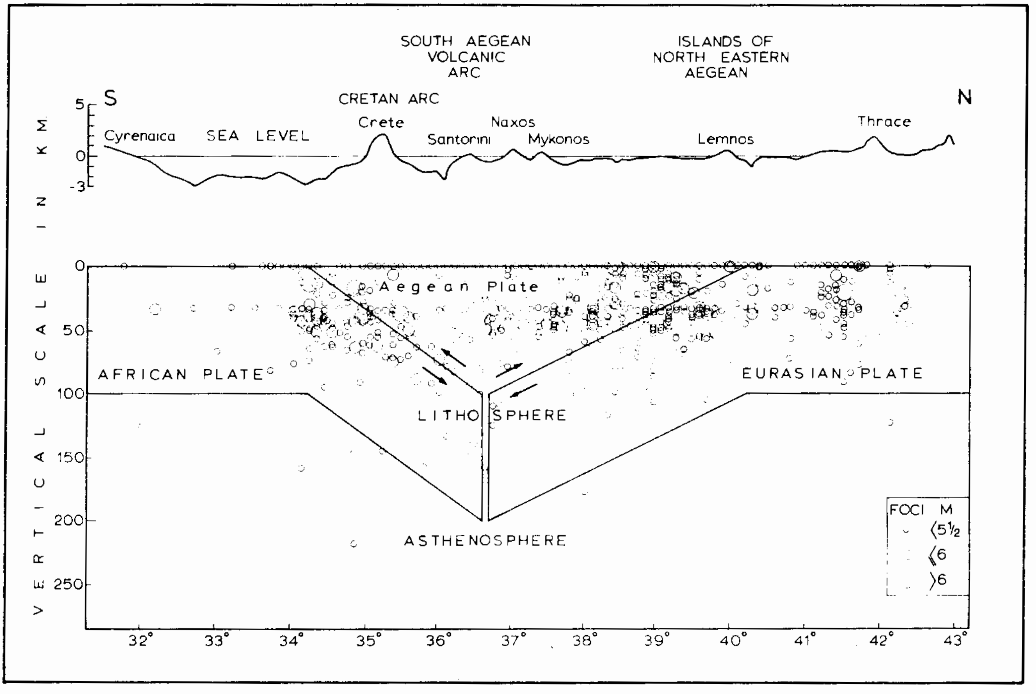

Fig. 1. Vertical cross-section of hypocentres of the earthquakes occurred between the Meridians of 19° and 29° E and the Parallels of 34° and 42° N during the period 1964 - 1968. All hypocentres are projected onto a vertical plane oriented parallel to 24° E Meridian.

is parallel too, but around 100 km inward of the Hellenic Trench (GALANOPOULOS, 1967).

In order to determine the true dip of the African plate we projected deep focus seismicity over the period 1903-1967 (s. Table 1) observed in the southern Aegean Sea along two belts, two hundred kilometers wide, on the median vertical planes; the planes, trending N 60° E and N 30° W, are perpendicular to each other and to the strike of the Hellenic Island arc and run across the large zones of positive and negative gravity anomalies in the concave and convex side of the arc (s. Fig. 2). A few focal depths of small shocks or old ones—when instrumentation was less sophisticated—deviated from the apparent trend of the lithospheric slab

TABLE I

List of intermediate-depth earthquakes occurred in the belts, that were used for the cross-sections AA′, BB′, CC′ and DD′ during the period 1903-1967. Data denoted by GR were taken from «Seismicity of the Earth and Associated Phenomena» (GUTENBERG and RICHTER, 1954); the others were compiled from «International Seismological Summary» and «Bulletin of the International Seismological Centre».

Date	Location	Depth	Magnitude
1962, May 1	38.2° N, 20.5° E	92	4 1/2
1943, Jan. 7	38 1/2° N, 20 1/2° E	100	5 1/2 GR
1967, March 13	38.3° N, 20.6° E	117	4
1966, Nov. 27	39.3° N, 20.9° E	76	3 1/2
1963, May 6	39.4° N, 20.9° E	105	5 1/4
1966, Sept. 9	38.8° N, 21.0° E	95	3
1963, April 30	39.6° N, 21.1° E	70	4 3/4
1967, May 4	39.8° N, 21.2° E	60	4 3/4
1966, April 12	37.8° N, 21.3° E	86	3 1/2
1967, May 1	39.3° N, 21.3° E	70	3 3/4
1966, May 8	38.9° N, 21.5° E	83	4 1/2
1966, March 13	38.7° N, 21.6° E	65	4 1/2
1967, May 3	39.4° N, 21.6° E	85	3 3/4
1967, Aug. 13	35.0° N, 21.8° E	219	3 3/4
1966, March 28	38.7° N, 21.8° E	71	4 1/4
1966, Jan. 30	38.9° N, 21.8° E	87	4
1963, Jan. 31	35.9° N, 21.9° E	62	5 1/4
1967, Sept. 14	36.0° N, 21.9° E	69	4 1/2
1966, July 13	37.6° N, 21.9° E	81	3 3/4
1926, Sept. 19	36° N, 22° E	80	6 1/4 GR
1967, Sept. 14	36.1° N, 22 0° E	83	5
1966, Jan. 17	38.1° N, 22.0° E	62	3 3/4
1967, Nov. 1	38.4° N, 22.0° E	80	3
1932, April 15	39 1/4° N, 22° E	100	5 1/2 GR
1961, Jan. 28	39.3° N, 22.0° E	89	5
1925, June 6	37 8° N, 22.1° E	120	6 1/2 GR
1966, Sept. 24	38.1° N, 22.1° E	71	4 3/4
1967, Jan. 5	38.9° N, 22.1° E	107	4 1/4
1967, May 4	39.9° N, 22.1° E	74	4
1965, March 31	38.5° N, 22.2° E	78	4 1/2
1966, July 31	35.7° N, 22.3° E	71	4
1966, June 6	38.0° N, 22.3° E	99	3 3/4
1965, March 9	38.5° N, 22.4° E	66	4
1962, Jan. 10	35.8° N, 22.5° E	87	5
1965, March 23	36.6° N, 22.5° E	141	4
1967, March 13	37.3° N, 22.5° E	79	4 1/2
1938, Sept. 18	38° N, 22 1/2° E	100	6 1/2 GR
1965, May 29	35.1° N, 22.6° E	59	4 1/2
1962, July 31	36.5° N, 22.7° E	109	5

TABLE I (cont.)

Date	Location		Depth	Magnitude
1927, July 1	36 $^3/_4$° N,	22 $^3/_4$° E	120	6 9 GR
1962, Aug. 28	37.8° N,	22.9° E	95	6 $^3/_4$
1903, Aug. 11	36° N,	23° E	100 - 150	8.3 GR
1931, June 30	36 $^1/_2$° N,	23° E	100 ±	5 $^1/_2$ GR
1948, Sept. 11	37° N,	23° E	100 - 110	6.5
1963, March 1	35.8° N,	23.1° E	156	4 $^1/_2$
1965, Febr. 26	35.1° N,	23.2° E	92	3 $^1/_2$
1926, Aug. 30	36 $^3/_4$° N,	23 $^1/_4$° E	100	7 GR
1954, Aug. 6	36 $^3/_4$° N,	23 $^1/_4$° E	100	5 $^1/_4$
1961, Aug. 27	35.6° N,	23.4° E	62	5 $^1/_2$
1961, Dec. 11	36.4° N,	23.4° E	69	5 $^1/_2$
1946, April 5	35 $^1/_4$° N,	23 $^1/_2$° E	100	6 GR
1967, April 4	35.6° N,	23.6° E	73	5 $^1/_2$
1964, July 17	38.0° N,	23.6° E	155	6 $^1/_4$
1966, March 27	38.0° N,	23.9° E	178	4 $^1/_2$
1963, Jan. 15	36.1° N,	24.0° E	100	5 $^1/_4$
1961, Oct. 3	35.4° N,	24 1° E	100	5
1964, May 18	36.9° N,	24.3° E	109	4 $^1/_4$
1930, March 6	35° N,	24 $^1/_2$° E	100	6 GR
1964, April 20	35.1° N,	24.5° E	68	4 $^1/_2$
1954, July 25	36.2° N,	24.5° E	100	4 $^1/_2$
1930, Febr. 14	35 $^3/_4$° N,	24 $^3/_4$° E	130	6 $^3/_4$ GR
1960, Sept. 23	35.3° N,	24.9° E	118	4 $^1/_2$
1923, Aug. 1	35° N,	25° E	150	6.7 GR
1923, Aug. 3	35° N,	25° E	150	5
1966, Sept. 2	35.5° N,	25 0° E	72	3 $^1/_4$
1935, Febr. 25	35 $^3/_4$° N,	25° E	80	6 $^3/_4$ GR
1957, June 23	35.7° N,	25.3° E	100	6 $^1/_4$
1918, July 16	35 $^1/_2$° N,	25 $^1/_2$° E	150	6 $^1/_2$ GR
1964, Dec. 31	35 8° N,	25.5° E	89	5 $^1/_2$
1911, April 4	36 $^1/_2$° N,	25 $^1/_2$° E	140	7 GR
1965, July 6	34.7° N,	25.6° E	61	4 $^1/_4$
1964, June 15	34.6° N,	25.7° E	62	4 $^1/_4$
1934, Nov. 9	36 $^3/_4$° N,	25 $^3/_4$° E	140	6 $^1/_4$ GR
1964, Aug. 17	35.3° N,	25.9° E	64	5 $^1/_2$
1966, April 12	35.9° N,	25 9° E	158	4 $^1/_4$
1934, Nov. 21	34° N,	26° E	60	5 $^3/_4$ GR
1961, Sept. 18	34.4° N,	26.0° E	62	5
1930, March 6	34 $^1/_2$° N,	26° E	130	5 $^3/_4$ GR
1943, June 27	35° N,	26° E	100	5 $^3/_4$ GR
1942, May 9	35 $^1/_2$° N,	26° E	100	5 $^3/_4$ GR
1964, July 18	36.1° N,	26 0° E	99	5
1965, Jan. 2	36.5° N,	26.1° E	59	3 $^1/_2$
1961, Jan. 7	35 4° N,	26 2° E	75	5 $^1/_2$
1963, March 5	36.1° N,	26.2° E	77	4 $^3/_4$
1966, Aug 18	36.2° N,	26.3° E	133	5
1967, Aug. 10	34.4° N,	26.4° E	74	3 $^3/_4$
1938, June 3	34 $^1/_2$° N,	26 $^1/_2$° E	120	5 $^3/_4$ GR
1953, Febr. 14	35 $^1/_2$° N,	26 $^1/_2$° E	100	5 $^3/_4$
1929, March 27	36 $^3/_4$° N,	26 $^1/_2$° E	120	5 $^3/_4$ GR
1965, June 10	36.4° N,	26.6° E	142	5

TABLE I (cont.)

Date	Location	Depth	Magnitude
1966, Sept. 6	36.7° N, 26.6° E	158	4 $^1/_2$
1954, Sept. 4	36.7° N, 26.7° E	130	4 $^3/_4$
1967, Aug. 28	36.7° N, 26.7° E	169	5
1958, May 27	36.8° N, 26.7° E	165	5 $^1/_2$
1936, April 28	36 $^3/_4$° N, 26 $^3/_4$° E	170	5 $^3/_4$ GR
1967, Dec. 5	36.5° N, 26.8° E	137	5 $^1/_4$
1967, May 15	34.4° N, 26.9° E	64	4 $^1/_2$
1966, Sept. 10	36.5° N, 26.9° E	146	4 $^1/_2$
1967, Jan. 16	36.6° N, 26.9° E	154	4
1965, May 7	36.7° N, 26.9° E	162	4 $^1/_2$
1965, Febr. 6	35.4° N, 27.0° E	71	5
1935, March 18	35 $^1/_2$° N, 27° E	130	6 $^1/_4$ GR
1961, Febr. 5	36.4° N, 27.0° E	72	5
1926, July 5	36 $^1/_2$° N, 27° E	150	5 $^1/_2$ GR
1942, June 21	36 $^1/_2$° N, 27° E	130	6 $^1/_4$
1966, Febr. 27	36.6° N, 27.2° E	79	5
1964, Sept. 24	34.3° N, 27.3° E	77	3 $^1/_4$
1958, June 30	36.4° N, 27.3° E	110	6 $^1/_2$
1966, Jan. 30	37.0° N, 27.3° E	70	3 $^1/_4$
1965, Jan. 9	36.0° N, 27.4° E	63	4 $^1/_4$
1965, Nov. 28	36.1° N, 27.4° E	73	6
1966, May 10	36.5° N, 27.4° E	94	3 $^1/_4$
1966, Oct. 29	34.7° N, 27.5° E	64	4 $^3/_4$
1944, May 27	36° N, 27 $^1/_2$° E	100	6 $^1/_2$ GR
1926, June 26	36 $^1/_2$° N, 27 $^1/_2$° E	100	8.3 GR
1943, Oct. 16	36 $^1/_2$° N, 27 $^1/_2$° E	110	6 $^1/_4$ GR
1944, Aug. 9	36 $^1/_2$° N, 27 $^1/_2$° E	100	5 $^1/_2$ GR
1964, April 25	35.5° N, 27.7° E	61	5 $^1/_4$
1966, Jan. 22	36.0° N, 27.7° E	92	3 $^1/_4$
1967, Sept. 10	35.5° N, 27.9° E	146	4
1964, Aug. 5	33.9° N, 28.0° E	82	4 $^1/_2$
1938, Jan. 16	36 $^1/_2$° N, 28° E	200	5 $^1/_2$ GR
1963, Febr. 16	36.7° N, 28.0° E	100	4 $^3/_4$
1960, Nov. 18	35.2° N, 28.1° E	246	5 $^1/_4$
1966, Febr. 8	36.2° N, 28.1° E	79	5
1966, Dec. 25	35.2° N, 28.2° E	61	4 $^1/_2$
1964, May 13	36.3° N, 28.2° E	82	4 $^1/_2$
1964, June 8	36.3° N, 28.3° E	62	4 $^1/_2$
1964, Oct. 13	36.9° N, 28.3° E	76	4 $^1/_4$
1967, Aug. 9	37.0° N, 28.4° E	64	4 $^1/_4$
1964, Aug. 25	34.3° N, 28.5° E	159	4 $^1/_4$
1964, Aug. 25	34.6° N, 28.6° E	95	5
1967, July 25	37.8° N, 28.6° E	75	4 $^1/_4$
1964, Dec. 18	35.6° N, 28.7° E	74	4

were properly ignored in the determination of the plates slope (s. Fig. 3).

From the slopes of the African plate in the two cross-sections, as reflected in the deep focus seismicity, it was found that the true dip of the African plate is nearly 20°; the strike of the plate is N 58° W. The direction of maximum slope being perpendicular to the strike is N 32° E. This is in accordance with the northeastward, gentle dipping of

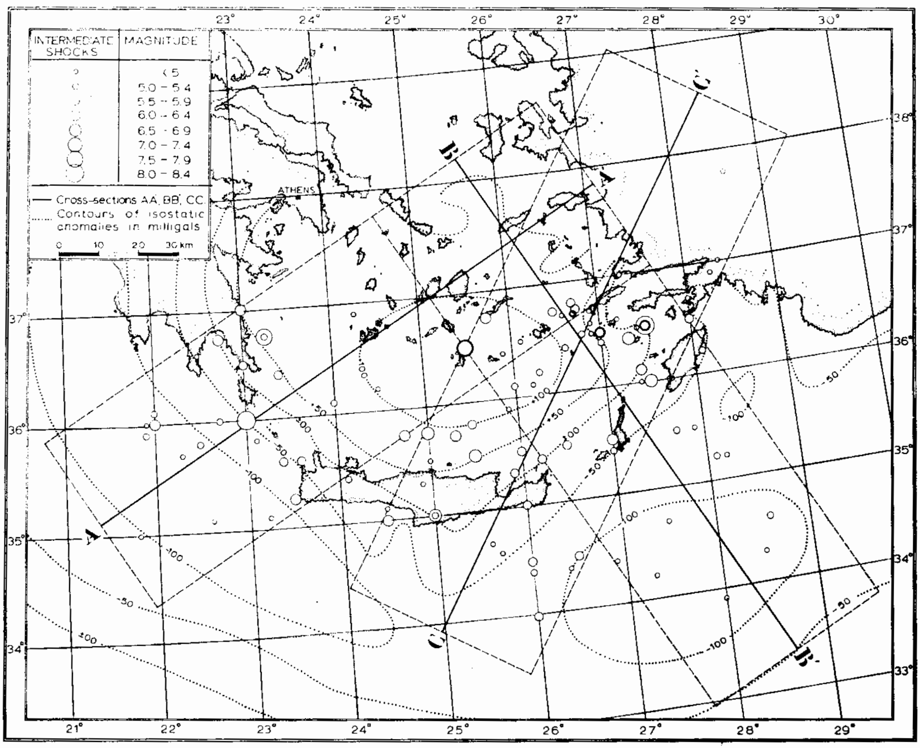

Fig. 2. Areal distribution of epicentres of intermediate-depth earthquakes occurred in the southern Aegean Sea, along the belts AA', BB' and CC', during the period 1903 - 1967. Gravity contours after ARTEMIEV (1963).

the African plate indicated in the fault-plane solutions (McKENZIE, 1970; NICHOLS, 1971). Calculation was confirmed by plotting deep focus seismicity along the direction of maximum slope of the African plate (s. Fig. 4).

The dip of the African plate found from the two cross-sections in the southern Aegean Sea is of the same order of magnitude with that found tentatively for the whole area bounded by the 19° and 29° Meridians and the 34° and 42° Parallels. From the small slope of the African plate under the Hellenic Island arc one might dare to speculate that the underthrusting of the lithospheric slab in the eastern Mediterranean is much younger in comparison to that observed under the Calabrian

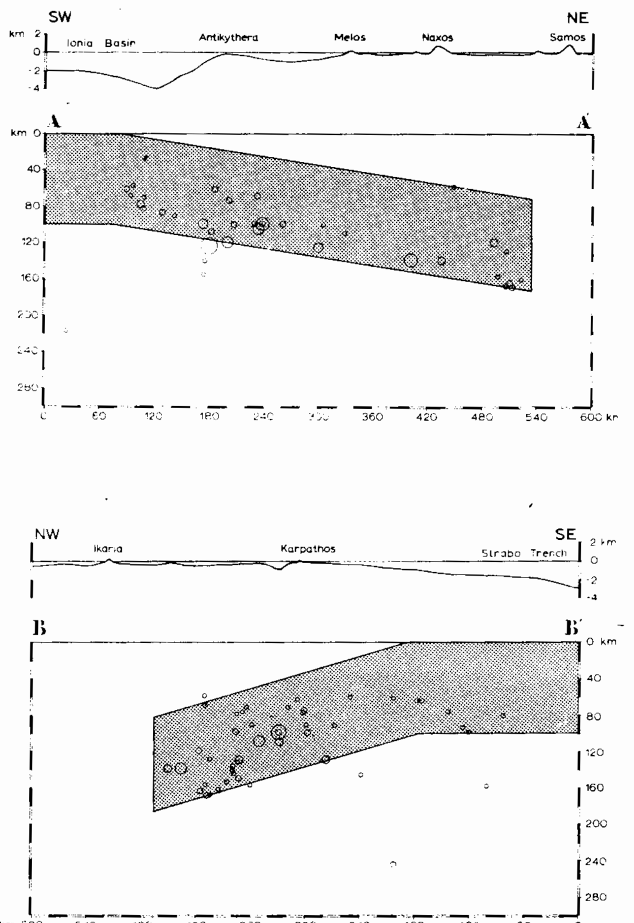

Fig. 3. Vertical sections oriented perpendicular to each other and to the Hellenic Island arc showing distribution of hypocentres of intermediate-depth earthquakes from 1903 through 1967. Hypocentres are projected from distances within ± 100 km of each section. Symbols are the same as for Fig. 2.

Island arc in the western Mediterranean and/or the margin of the plate in the eastern area is comparatively lighter, i.e. hotter.

The eastern Mediterranean crust is closer to continental crust, while the western Mediterranean crust is closer to oceanic. In the eastern Mediterranean the total crustal thickness is estimated at 22 - 24 km, mostly composed of a low-velocity, thick sedimentary structure (WOODSIDE and BOWIN, 1970; ALLAN and MORELLI, 1971). Another marked difference is in the direction of the seismic zone dipping; in the Lipari region the seismic zone dips NNW (PETERSCHMITT, 1956; CAPUTO et. al., 1970), i.e. perpendicular to the zone dipping observed in the Aegean region (NNE). In the Tyrrhenian Sea continental crust seems to be pushed down under an oceanic one (CAPUTO et. al., 1972), and the inclined seismic zone reaches depths of 480 km; in the Aegean Sea the seismic

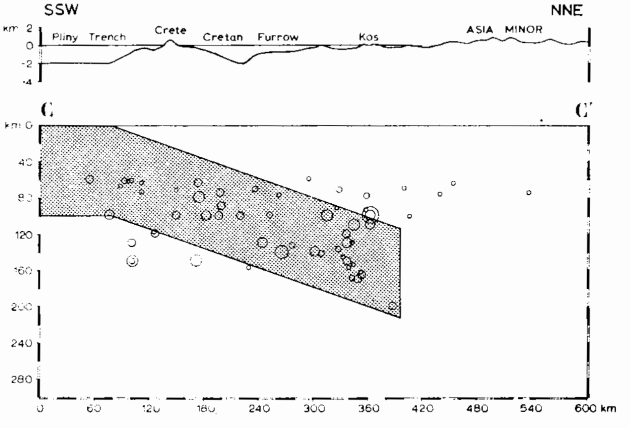

Fig. 4. Vertical section oriented parallel to the direction of maximum slope of the lithospheric slab showing distribution of hypocentres of intermediate-depth earthquakes from 1903 through 1967. Hypocentres are projected from distances within ± 100 km of the section. Symbols are the same as for Fig. 2.

zone dips gently and reaches depths of about 200 km. In the Calabrian arc magnetic anomalies are considerably greater in amplitude than those measured in the Aegean volcanic arc (ALLAN and MORELLI, 1971). Another feature of the Hellenic arc is a maximum gravity gradient of 1.5 mgal/km between a minimum of—180 mgal free-air anomaly a few kilometers south-east of the Strabo Trench and a value of + 120 mgal about 200 km north-west of this point, at the Island of Augo in the Aegean Sea (ALLAN and MORELLI, 1971).

DISCUSSION AND REMARKS

It is necessary to state at first that the seismic evidence so far is not compelling for any plate model of the eastern Mediterranean; in view of this and of the theoretical difficulties of causing continental crust to sink (McKENZIE, 1969), the model of the Aegean subplate overthrusting the European plate in the Saros Graben is open to revision. Nevertheless, it should be kept in mind, that there is the possibility the Saros Graben to be a remnant of the Middle Jurassic oceanic crust (SMITH, 1971).

The earthquake fault-plane solutions of McKENZIE (1970) show that «the Aegean plate is moving towards the south-west relative to the Euro-

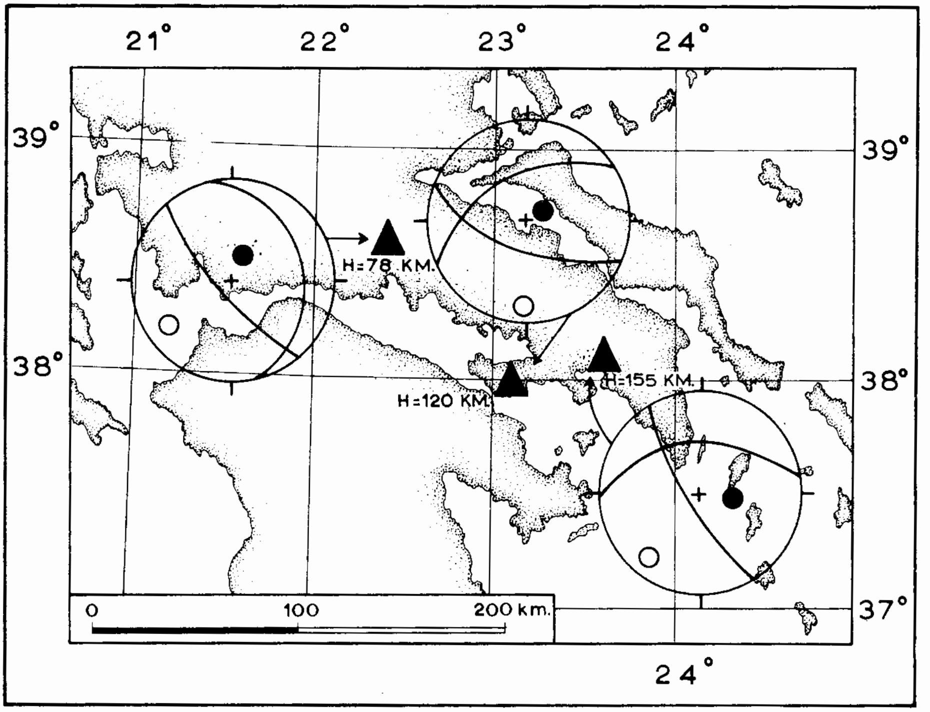

Fig. 5. Fault-plane solutions of three intermediate-depth earthquakes in the eastern part of mainland Greece after WICKENS and HODGSON (1967) and McKENZIE (1970). The focal mechanisms are shown as equal-area projections of the lower focal hemisphere. The open circles are the axes of compression, P, and the closed circles are the axes of tension, T.

pean plate, producing extension and strike slip on the boundary between them». According to McKENZIE, this suggests that the Saros Graben has been produced like the East African Rift «by extension of the crust, associated with the large basic intrusions». Part of the Saros Graben has an associated magnetic anomaly (ALLAN and MORELLI, 1971).

It is worth noting that volcanics located to the north of the Saros Graben (Western Thrace, Thrace, Rhodope, Western Macedonia) exhibit relatively low K_2O/SiO_2 (G. PARASKEVOPOULOS, personal communication) in comparison to those encountered just to the south of the Graben (Orthrys, St. Eustratios, Lemnos, Imbros, Lesbos, Chios, Karaburun, Izmir). The occurrence of some shocks of intermediate focal depth on the northern boundary of the Aegean subplate makes the suggestion weak; neither the East African Rift nor the Middle Oceanic Ridges are associated with intermediate earthquakes. In addition to this, the fault-

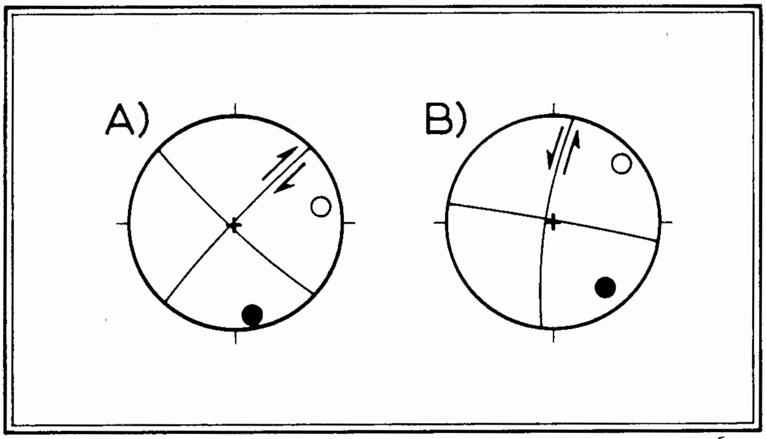

Fig. 6. Fault-plane solutions of two major shallow earthquakes in northern (A) and southern (B) Aegean Sea after DELIBASIS and DRAKOPOULOS (1973) and WICKENS and HODGSON (1967). Focal mechanisms and symbols are shown as in Fig. 5.

plane solutions in the eastern Mediterranean are very complicated (McKENZIE, 1970) and the evidence from them is not compelling especially when the conditions for well-defined nodal plane solutions are not fullfilled (STEVENS and HODGSON, 1968).

On the other hand, even solutions considered reliable and well determined do not happen always to be consistent with the orientation and dip of the seismic zone. As a striking example we cite the fault-plane solutions of three earthquakes belonging to a very narrow region of Greece (s. Fig. 5); 1962 August 28 (38.0° N, 23.1° E; h = 120 km, M=6 3/4), 1964, July 17 (38.1° N, 23.6° E; h = 155 km, M = 6 1/4) and 1965, March 31 (38.6° N, 22.4° E; h = 78 km, M = 6 1/2). The first and most reliable solution is given by WICKENS and HODGSON (1967), the others two by McKENZIE (ISACKS and MOLNAR, 1971). The depths of 120 km and 78 km assigned respectively to the 1962 and 1965 earthquakes are revised to 95 km and 45 km in the «International Seismological Summary» (1968) and the «Bulletin of the International Seismological Centre» (1968). The solutions are similar in respect to indicating extensional stress parallel to the dip direction of the African plate.

The fault - plane solutions of the two recent, largest earthquakes ($M \geqslant 7\frac{1}{2}$) occurred in the southern and northern Aegean Sea in 1956, July 9 (36.7° N, 25.8° E ; h = normal) and 1968, February 19 (39.4° N, 25.0° E ; h = 7 km) are similar (s. Fig. 6) ; in both cases the extensional stresses are aligned approximately parallel to the direction of underthrusting inferred from the slablike zone of intermediate-depth hypocentres and approximatelly perpendicular to the alignment of the active volcanoes in the southern Aegean Sea. The dip of the inclined zone, about 15° to the south, is of the same order of magnitude to that inferred from the distribution of intermediate-depth hypocentres beneath Peru (ISACKS and MOLNAR, 1971). The difference in the two solutions is merely in the sense of the relative motion between the two sides of the fault ; in the northern Aegean Sea the motion is right-handed (DELIBASIS and DRAKOPOULOS, 1973), in the southern area left-handed (WICKENS and HODGSON, 1967). The solutions are consistent with a general southwestward movement of the Aegean subplate relative to Eurasia and Africa. The solutions might be considered reliable and well determined, since they meet fairly well the requirements set up by STEVENS and HODGSON (1968). In both solutions the number of the push-pull observations are nearly hundred or over ; the score 79. It is worth noting that both earthquakes were accompanied by a tsunami ; the 1956 tsunami occurred in the southern Aegean Sea was very destructive (GALANOPOULOS, 1957).

From the two vertical cross-sections across the Hellenic arc it was found that the African plate is dipping N 32° E. If there was a single slab dipping N 32° E, in a cross-section along the strike of the slab the zone of subcrustal shocks should extend all along to about the same depth. With this in mind we constructed the N 58° W vertical cross-section (s. Fig. 7). Curiously, at first glance the cross-section shows two successive slablike zones of intermediate-depth hypocentres dipping southeast at the same angle, of about 19°. A pronounced minimum in the shallow and subcrustal seismicity between the two zones supports the view.

If this happens indeed, the existence of the first slab could be interpreted as a remnant of the Middle Jurassic oceanic crust. The apparent bending of the plate starts at the Sub-Pelagonian zone that contains mafic and ultramafic rocks associated with cherts of the Middle Jurassic age. It was theorized (SMITH, 1971), that some of the ophiolite-chert sequences could represent «slices of oceanic crust and mantle thrust up onto the continent during part of the Alpine orogeny». If this holds, the Sub-Pelagonian zone might mark the near-by existence of a former plate margin that vanished into the mantle (DERCOURT, 1970). In that case, the complete detachment of the sinking lithosphere might account for the existing evidence of two parallel seismic planes (KANAMORI, 1971).

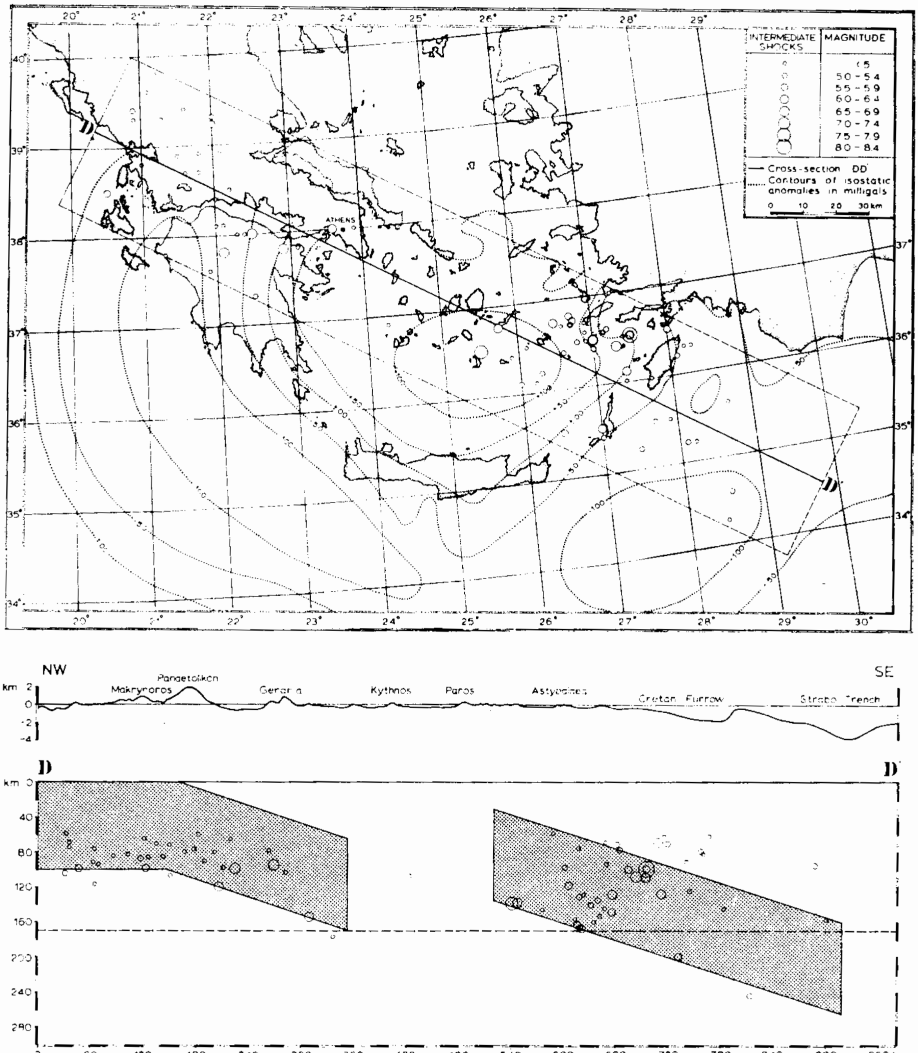

Fig. 7. Areal distribution of epicentres (above), and vertical section oriented parallel to the strike of the lithosperic slab (below) showing distribution of hypocentres of intermediate-depth earthquakes from 1903 through 1967. Hypocentres are projected from distances within ± 100 km of the section.

However, an assumption of this kind is invalidated in the present case by the low-angle thrusting; the low-angle thrusting of the oceanic lithosphere beneath the continental lithosphere is reasonably assumed to take place at an early stage. In that case, the two parallel seismic planes can not reflect past-episodes of lithospheric sinking. The existence of a second slab stumbles also on the evidence derived from the previous cross-sections. In addition to this, the second slab appears to dip anomalously towards the Hellenic trough, i. e. opposite to what is generally observed beneath the island-arc structures. We are therefore forced to accept that the depth of the slab along the cross-section DD′is practi-

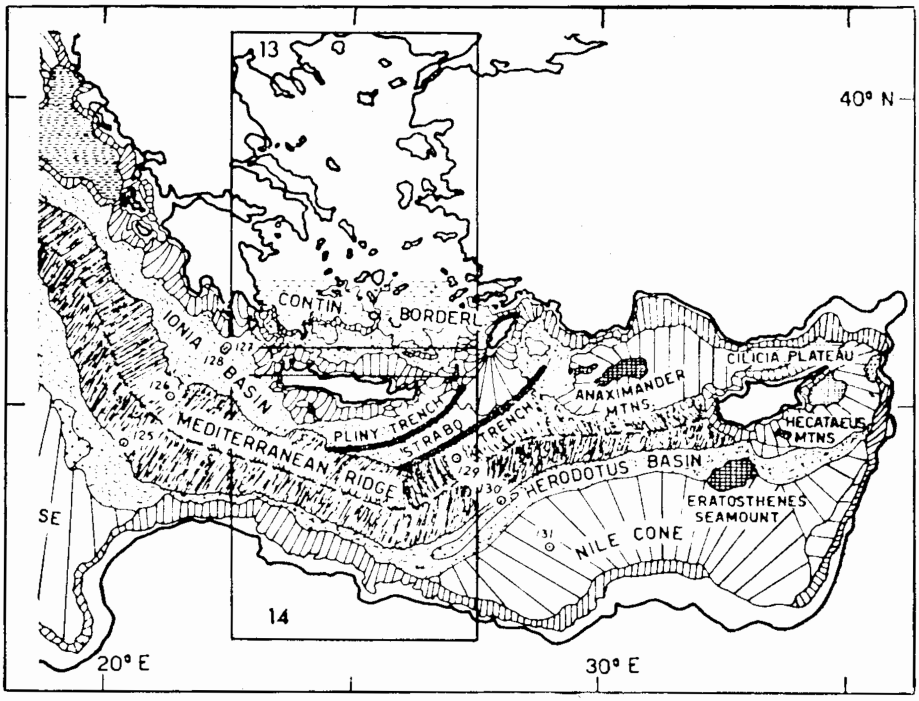

Fig. 8. Physiographic provinces of Eastern Mediterranean extracted from ALLAN and MORELLI (1971).

cally the same, considering the limits of error of focal determination (± 25 km). The existence of a focus at a depth of about 150 km (GUTENBERG and RICHTER, 1954) beneath the Ionian Sea (1942, May 21; 37 $^1/_2$° N, 20 $^1/_2$° E, M = 5 $^1/_2$) is much in favour of the second notion.

Another puzzle is the appearance of subcrustal activity in going along the strike of the plate, from the continental to oceanic side, well beyond the Pliny Trech (GALANOPOULOS, 1968). A line of epicentres appears to coincide with the Mediterranean Wall (RYAN et al., 1970). It seems that southeast of Crete and Rhodes the decoupling of the sinking lithosphere from the lithosphere beneath the ocean basin starts much far to the south at the Strabo Trench (s. Fig. 8).

Because earthquakes are few in number at depths below 100 km, discrimination between the two possibilities is quite uncertain. If the first case is correct, the complex system of underthrusting inferred from the two slablike zones of intermediate - depth hypocentres beneath the Hellenic Island arc should be ascribed to a contortion of the African plate.

In general, beneath the Aegean Sea the intermediate earthquakes fall in a pattern that does not fit a simple model of a continuous inclined

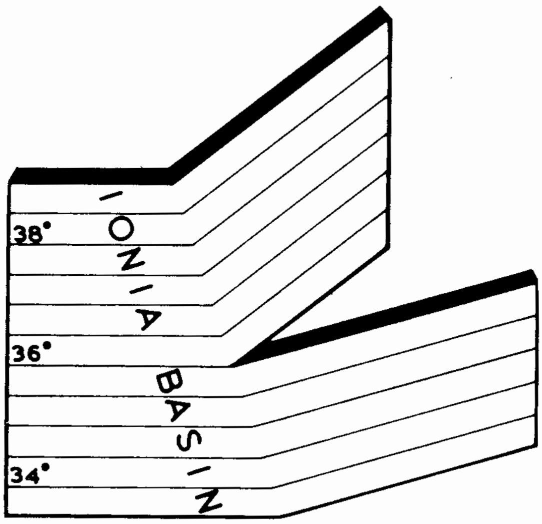

Fig. 9. Postulated plate tectonics in the area of Greece.

seismic zone dipping from the trench beneath the volcanoes (NINKOVICH and HAYS, 1971). A northward underthrusting of the African lithospheric shield, causing a northward dipping seismic «Benioff Zone» is not compatible with the pattern of spatial distribution of intermediate - depth earthquakes in the eastern Mediterranean (GALANOPOULOS, 1968). It is worthnoting that the hypocentral diseribution in the Cyprus area shows about the same picture (maximum slope of lithospheric slab about 25^0; direction of maximum slope N 72^0 E).

In view of this data the author has the feeling that disruption of the African plate in two segments along the Cretan Furrow, as depicted in Figure 9, might account much better for the anomalous distribution of hypocentres of intermediate earthquakes in the area of Greece. Similar plate model has originally advanced for the Honshu area by

ISACKS and MOLNAR (1971). It is assumed that underthrusting and tearing of the African plate beneath the Eurasian was accomplished by a compression acting from south-west due to the opening of the Atlantic in Jurassic and Early Cretaceous.

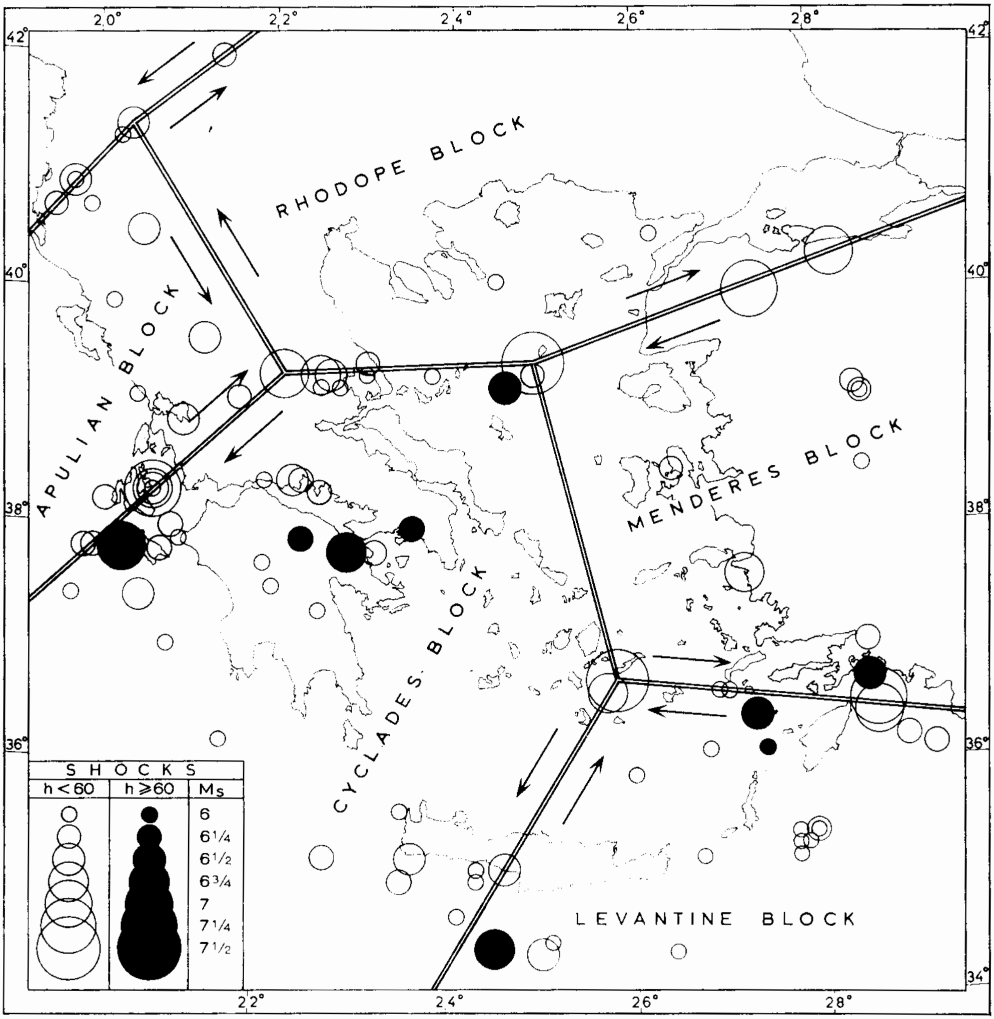

Fig. 10. Boundaries and junctions of old rigid blocks marked by geomorphology, surface geology and epicenters of major and large shocks supposedly results of interaction of adjacent blocks over the period 1950 - 1972.

The model may account for the N 32° E direction of maximum slope of the underthrusting plate, the northeast-southwest trend of linear magnetic anomalies of several hundred gammas observed in the

Aegean Sea (RYAN et al., 1970), the very high subcrustal activity along the Cretan Furrow and the relatively high K_2O/SiO_2 that exhibit volcanics encountered in the eastern (Dodecanese) and particularly the northeastern margin of the Aegean Sea (NINKOVICH and HAYS, 1971; NICHOLS, 1971).

It is tempting to theorize that due to the squeezing out exerted by the tearing apart of the African plate asthenosphere material is still upwelling along the arcuate suture marked by the southern Aegean volcanic arc. The proposed interpretation of the Aegean volcanism does not contradict VAN BEMMELEN'S concept, «that the Low Velocity layer underneath the Mediterranean belt is splitting up into a low-density fraction of basaltic magma and a high-density crystalline residue» (VAN BEMMELEN, 1971). A surficial load not fully compensated at depth might account for the existence of the large zone of positive isostatic anomalies (+ 100 mgal) in the southern Aegean Sea. This is in disagreement with FLEISCHER'S notion (1964) that «the present morphology of the area has probably devedoped from an uplifting of the sea bottom of the Aegean Sea». According to VAN BEMMELEN (1971), «The geology, the geomorphology and its highly positive gravity anomalies of the Cycladean region indicate rather that this is an actually subsiding crustal area».

It must be reminded that the plate model suggested in the present paper for the area of Greece is in accordance with the existing stress-field as reflected by the mechanism of the European earthquakes. According to R. RITSEMA (1969), «The Aegean Sea sector resembes a «Verschluckungszone» for material drifting in from NW and ENE». The possibly small northward movement of the African plate during the past 10 My seems to have played a minor role in the process of block, plate or arc movements in the eastern Mediterranean (RITSEMA, 1971).

An alternative scheme that could account for the observed seismicity in the area of Greece is that marked by the boundaries of the cratons or the crystalline masses and the delineation of the epicentres of major and large shocks (s. Fig. 10). It is needless to say that none of the proposed models really imposes itself as conclusive.

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