The seismotectonic regime in Greece

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Summary. — Evidence is presented which favours the theory that the earthquake activity in the area of Greece should be ascribed to horizontal currents flowing off to the side of the secondary sedimentary arc, from a minor mantle current rising under the primary volcanic arc of the Southeastern section of the Dinaric Alps.

Riassunto. — Vengono portate testimonianze in favore della seguente teoria: l'attività sismica in Grecia si deve attribuire a correnti orizzontali che scorrono ai margini dell'arco sedimentario secondario, provenienti da da una corrente minore del mantello che ha origine al di sotto dell'arco vulcanico primario della sezione sud-orientale delle Alpi Dinariche.

According to Geologists (Aubouin (²)), the mountain ranges of Greece, viz. the southeastern section of the Dinaric Alps, known under the name "Hellenides"., consist of four main units, i.e. of the eastern inner zones (eugeoanticline-eugeosyncline) and the western outer zones (miogeoanticline-miogeosyncline). The Alpine orogenesis started in the upper Cretaceous proceeded successively from the eastern inner zones to the western outer zones of the Alpine geosyncline, being bordered on a common foreland (Apulian ridge) with the Appenines and a common hinterland (Rhodopian massif) with the Balkans.

After the Alpine folding and overthrusting of the surface layers, viz. at the end of Miocene started a dislocation of the Eastern Mediterranean which created large fault zones running in two prevailing directions: *NNW-SSE* and *WSW-ENE*. Seismological and Geological studies reveal the following features: on the faults along the fracture zone running in *WSW-ENE* direction, the motion is right-lateral and downthrow is on the North side. On the faults along the other zone, running in *NNW-SSE* direction, the motion is left-lateral, and downthrow is on the southwest side (Aki [1]). In the case of intermediate shocks, the motion along the same fault zones seems to be opposite (Hodgson and Wickens [11]).

A careful investigation of the earthquake history of Greece over the 250-year interval, 1710-1959, revealed that 642 earthquake foci were active in the area limited by 34° and 42° latitudes and 19° and 29° longitudes during the period considered. Of the 642 active foci which released shocks of magnitude $\geqslant$ 4.7 in the Greek area 389 foci were active only once, 203 foci were active 2 to 5 times, 29 foci 6 to 10 times and 21 foci were active more than 10 times (Galanopoulos [7]). In the interval 1960-1963 the number of earthquake foci which released shocks of magnitude $\geqslant$ 4.7 in the area of Greece increased by 146. Thus the number of earthquake foci which were active in the area of Greece during the period 1710-1963 total 788. The vast majority of these foci, i.e. 620 of them, were active in the period 1951 to 1963. This shows that in active regions, such as Greece, even a short interval is good enough to reveal with a high degree of realability the pattern of strain release. In view of this and of the fact that the strain accumulated in any region might be releaved either suddenly by almost one major shock or gradually by a series of minor shocks, one might get a more realistic idea about the "quake ability" of a seismic region from the distribution of the earthquake foci being denoted by the "cumulative magnitudes", which correspond to the sum of the strain energy released from each one in a given period. The advantage of this Technique is that it is very simple and devoid of any assumption.

A map showing the distribution of the earthquake foci denoted by the cumulative magnitudes allows to see immediately in which regions the time of recurrence of strong shocks is relatively short. Areas with a thin population of earthquake foci of minor importance do not indicate that these are not subject to strong shocks, but merely that the time of recurrence of strong shocks in these regions is probably very long. This holds especially for the borders of the cratons, i.e. of the forelands and hinterlands and of the intermediate crystalline masses. The clustering and the delineation of the earthquake foci, on the other hand, permit to draw some conclusions about the trend or the continuation of the deep seismotectonic lines which lack of surface expression. To the best of my knowledge no other kind of mapping of the earthquake activity allows such a conjecture.

The delineation of the earthquake epicentres in the area of Greece indicates that the Northern Anatolian dextral shear fault system continues through the Trikkeri-Canal fault into the Gulf of Patras and the

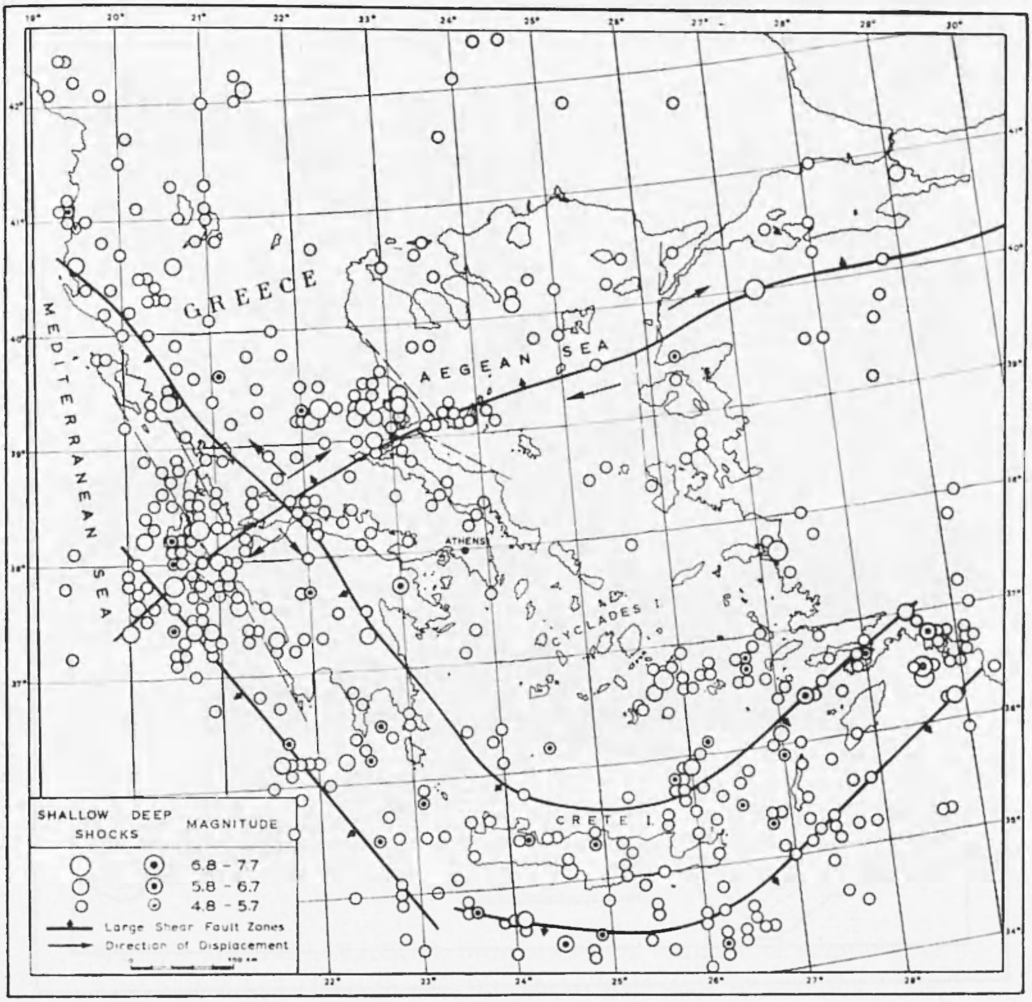

Fig. 1 – Seismotectonic map showing the large conjugate fault-system which presumably is responsible for the major part of the earthquake activity in the area of Greece and the distribution of the earthquake foci during the period 1951-1964.

shear fault zone of Cephalonia-Zante (s. Fig. 1). As known, the Cephalonia fault zone entertains one of the two permanent centres of higher earthquake activity being assessed in the area of Greece (Galanopoulos (7)). Additional corroborative evidence for the extension of the Northern Anatolian fault system into Greece is the migration of earth-

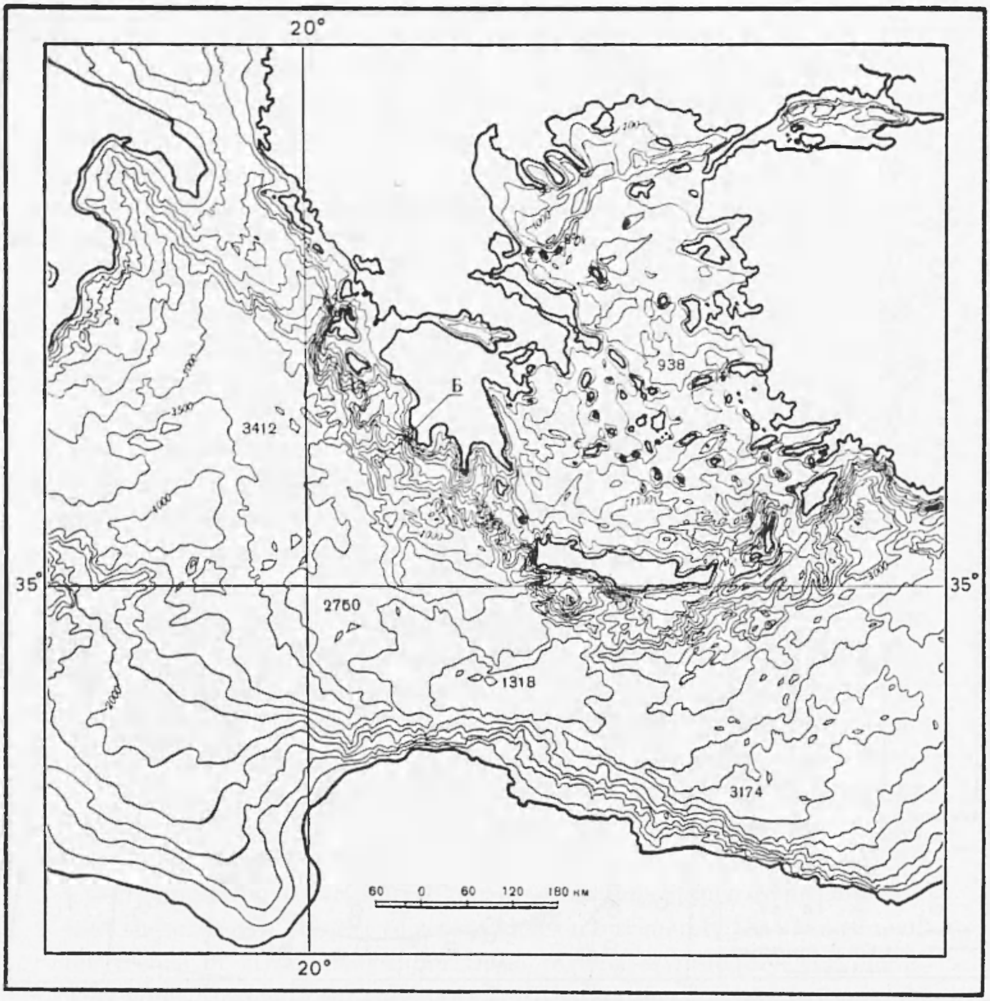

Fig. 2 – Bathymetric chart showing the principal features of the submarine topography of the Eastern Mediterranean, after O. B. Michailof (12).

quake foci along the big dextral fault zone and the Eastward offset of Cephalonia, Central Greece, Magnesia and Mysia (Northern part of Asia Minor) over a distance of about 20 km in reference to Zante, Peloponnesus, Euboea and Lesbos, respectively. The large shocks of

March 18, 1953, in Asia Minor and August 9-12, 1953, on Cephalonia, as well as those of Thessaly (1954, April 30-1955, April 19 and 21-1957 March 8) and the recent activity in the Northern Sporaden (1965,

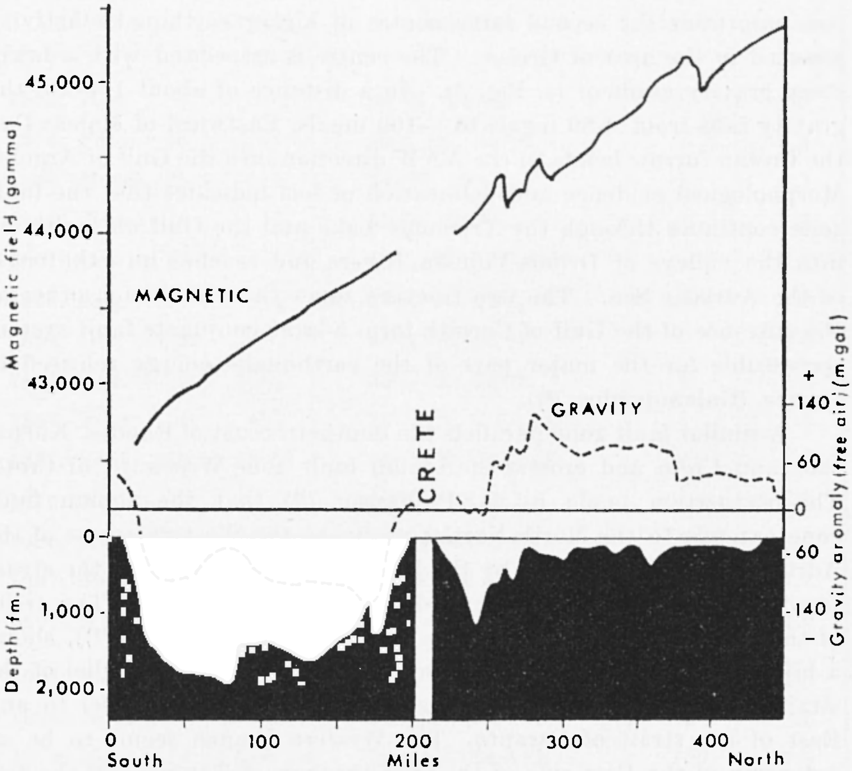

Fig. 3 – A North-South profile of magnetics, gravity, and bathymetry along the meridian 26° East from the African coast through Crete to the central part of the Aegean Province (N. Lat. 39°). After K. O. Emery et al. ([5]).

March 4 and 1967, March 9), form a striking example of migration of very active foci along the dextral shear fault zone in question. The offset of Cephalonia is pretty well evidenced by the sharp Eastward bending of the Ionian fault escarpment between Zante and Cephalonia (s. Fig. 2). This eastward bending is consistent with the prevailing almost horizontal maximum tension in S 27 °W direction in the area of Greece (Scheidegger ([14])). The average rate of displacement is presumed to be of the order of 1 to 2 mm per year. The association of the Ionian centre of higher earthquake activity with the end of the big shear fault zone and the sharp bending of the Ionian fault escarpment indicates the existing relationship among them.

The second large fault zone responsible for the earthquake activity observed in Greece is the Cretan furrow. The Eastern wing of the furrow entertains the second large centre of higher earthquake activity asserted in the area of Greece. The centre is associated with a fairly steep gravity gradient (s. Fig. 3). In a distance of about 100 km the gravity falls from +80 mgals to —100 mgals. Eastward of Maleas Cap the Cretan furrow bends to the *NNW* direction into the Gulf of Argolis. Morphological evidence and delineation of foci indicates that the fault zone continues through the Trichonis Lake and the Gulf of Ambrakia into the valleys of Drinos-Vojussa Rivers and reaches into the coast of the Adriatic Sea. The two fracture zones that cross each other at the entrance of the Gulf of Corinth form a large conjugate fault system responsible for the major part of the earthquake energy released in Greece (Galanopoulos ([8])).

A similar fault zone parallels the Southern coast of Rhodes, Karpathos and Crete and crosses the Ionian fault zone Westward of Crete. The postulation made by A. Philippson ([13]) that the Ionian fault zone extends to the North-Northwest up to the Western coasts of the Adriatic Sea is invalidated by the lack of earthquake foci in the structural trend considered Northward of the 38 °N parallel. The relief of the sea-bottom, as revealed by the isobaths (Michailof ([12])), shows a bifurcation of the Ionian fault zone Northward of the parallel of the strait Zante-Cephalonia. The Eastern branch trends parallel to and East of the strait of Otranto. The Western branch seems to be an extension of the East side of the Gulf through of Taranto. Of the two branches merely the Eastern one appears to be active.

The measurement of gravity in the Eastern Mediterranean revealed the existence of a large zone of positive isostatic anomalies (+100 mgals) in the Southern Aegean Sea and a long belt of negative isostatic anomalies (—140 mgals) bordering the island arc Kythera-Crete-Rhodes. According to V. Fleischer ([6]), the gravity anomalies in the Eastern Mediterranean indicate that "*the present morphology of this area has probably developed from an uplifting of the sea bottom of the Aegean Sea and a depression outside the island arc Khitera-Crete-Rhodes*". Taking into account this notion, the overriding of the sediments of the eugeosyncline furrow of Pindus over the miogeanticline ridge of Gavrovo-Tripolitza and the pattern of strain accumulation, viz. the distribution of the earthquake foci (Delibasis and Galanopoulos ([4])),

Table I – CATALOGUE OF MAIOR SHOCKS ($M \geqslant 7$) OCCURRED IN THE AREA OF GREECE SINCE 1800. MAGNITUDES PRIOR TO 1900 FROM MAXIMUM INTENSITY AND FELT AREA.

Date		Time	Location	Depth	Magnitude
1805, July	3	—	36 °N, 24 °E	i	7.6
1810, Febr.	16	—	$35^1/_2$ °N, 25 °E	i	8.2
1846, March	28	15	36 °N, 25 °E	i	8.1
1846, June	10	15	37 °N, 22 °E	n	7.2
1851, Oct.	12	—	$40^1/_2$ °N, $19^1/_2$ °E	n	7.1
1853, Aug.	18	$8^1/_2$	$38^1/_4$ °N, $23^1/_2$ °E	n	7.2
1856, Oct.	12	$^3/_4$	$35^1/_2$ °N, 26 °E	i	8.6
1863, Apr.	22	$20^1/_2$	$36^1/_2$ °N, 28 °E	i	8.5
1867, Febr.	4	$4^1/_4$	$38^1/_4$ °N, $20^1/_4$ °E	i	7.9
1867, Sept.	20	03:15	$36^1/_2$ °N, $22^1/_4$ °E	i	7.6
1874, Nov.	16	—	36 °N, 28 °E	n	7.3
1886, Aug.	27	$21^1/_2$	37 °N, $21^1/_4$ °E	i	8.4
1887, July	17	$7^3/_4$	36 °N, 26 °E	i	7.7
1897, May	28	$22^1/_4$	$37^1/_2$ °N, $20^1/_2$ °E	i	7.6
1903, Aug.	11	04:32:54	36.0 °N, 23.0 °E	100	8.3
1905, Nov.	8	22:06:12	40.0 °N, 24.0 °E	n	7.8
1910, Febr.	18	05:09:18	36.0 °N, 24.5 °E	150	7.0
1911, Apr.	4	15:43:54	36.5 °N, 25.5 °E	140	7.0
1912, Aug.	9	01:29:00	40.5 °N, 27.0 °E	n	7.75
1926, June	26	19:46:34	36.5 °N, 27.5 °E	100	8.3
1926, Aug.	30	11:38:12	36.8 °N, 23.3 °E	100	7.0
1947, Oct.	6	19:55:37	37.0 °N, 22.0 °E	n	7.0
1948, Febr.	9	12:58:15	35.5 °N, 27.0 °E	40	7.1
1953, March	18	19:06:14	40.0 °N, 27.3 °E	n	7.25
1953, Aug.	12	09:23:53	38.3 °N, 20.8 °E	n	7.1
1954, Apr.	30	13:02:37	39.0 °N, 22.0 °E	n	7.0
1956, July	9	03:11:40	37.0 °N, 26.0 °E	n	7.8
1957, Apr.	25	02:25:36	36.5 °N, 29.0 °E	n	7.1

the writer may hazard the theory that the earthquake activity in the area of Greece should be ascribed to horizontal currents flowing off to the side of the secondary sedimentary arc, from a minor mantle current rising under the primary volcanic arc of the Southeastern section of

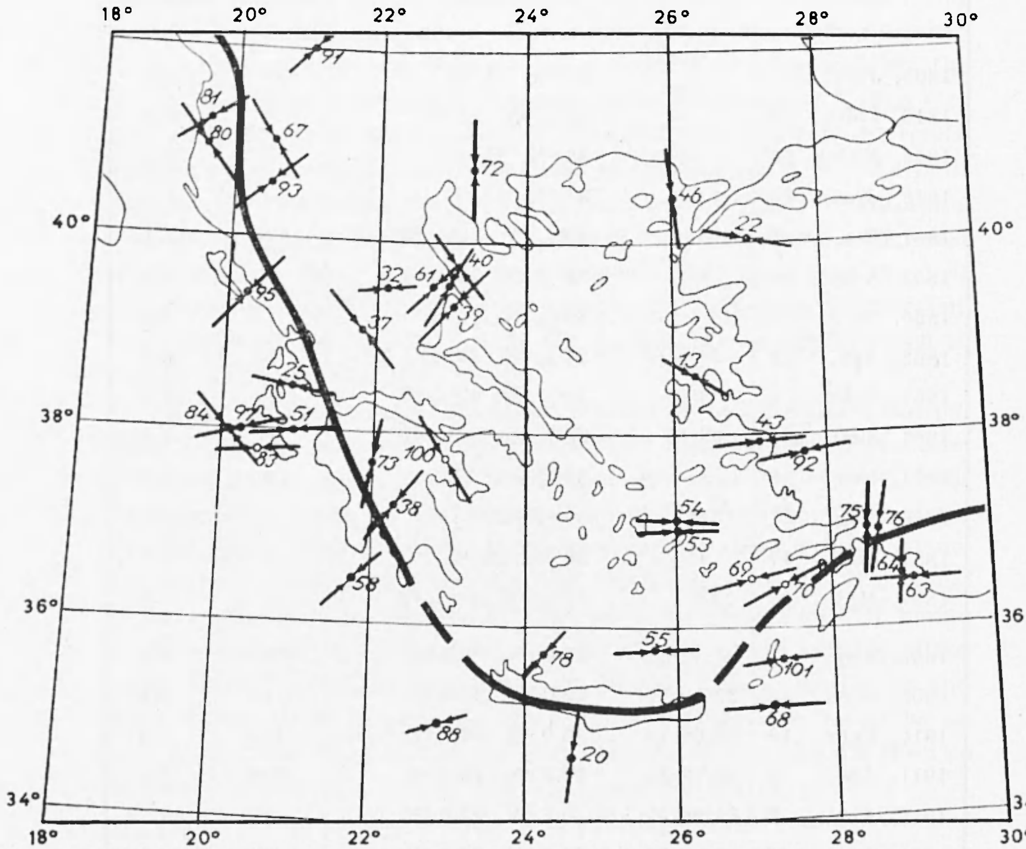

Fig. 4 – Pressure direction in the area of Greece, as determined by Livin Constantinescu et al. (3). Numbers are the identification numbers of earthquake mechanism solutions in the Constantinescu's catalogue. The long heavy line represents the general trend of the Alpine folding.

the Dinaric Alps. The stress pattern at the foci of about two scores of Greek earthquakes (s. Fig. 4), as revealed from the fault-plane solutions (Constantinescu et al. (3)), the association of the majority of the foci of major shocks (M ⩾ 7) with the primary volcanic arc (s. Fig. 5 and 6), and the fact that the earthquake volume of the major shocks extends to depths far below the Moho-discontinuity (Galanopoulos [9]) give evidently a fair support to the theory. The theory is in harmony with the suggestion made by J. B. Hersey [10] "*that vertical movements*

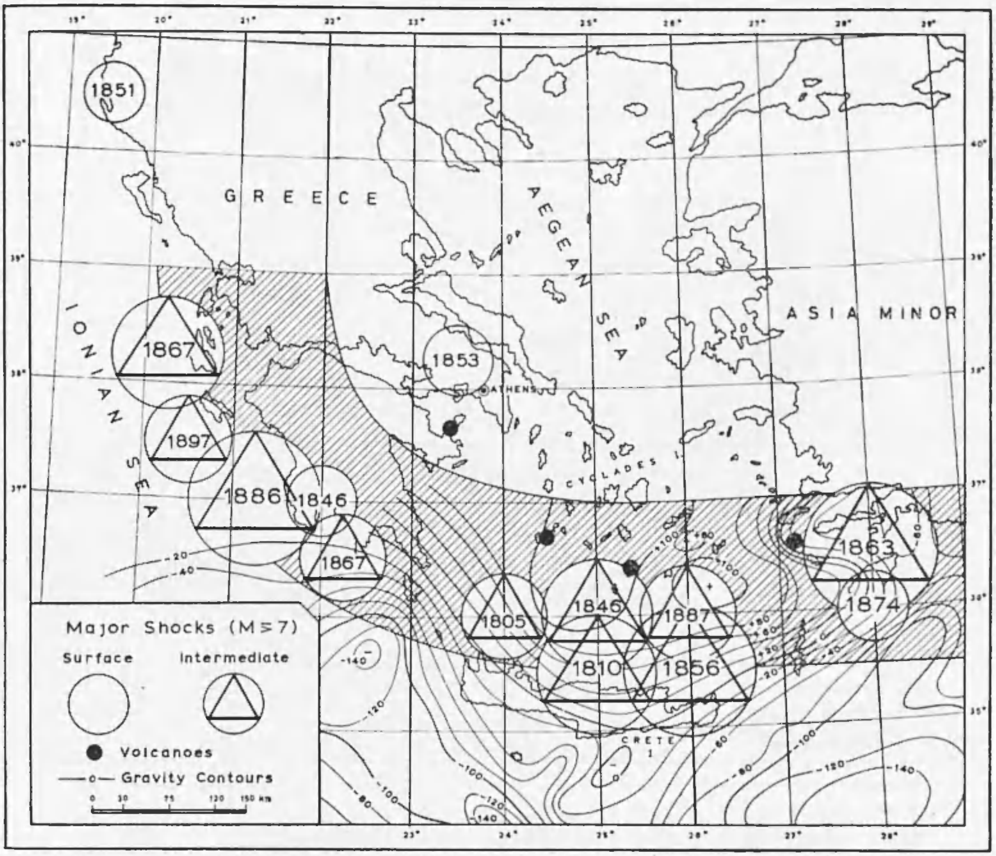

Fig. 5 – Distribution of the earthquake foci of major shocks (M ⩾ 7) occurred in the area of Greece since 1800 to 1900. Gravity contours after V. Fleischer [6].

of the earth's mantle, in addition to horizontal shearing stress, might better characterize Mediterranean tectonics than horizontal shears alone". The spread of low mantle-velocities and "cobblestone areas" i.e. areas of many small blocks of fractured material, found so far in the Eastern Mediterranean seem to give a fairly strong support to the suggestion that "*upwardmoving mantle assimilates some of the crustal* *rock, and causes other parts to move laterally under gravitational forces* ".

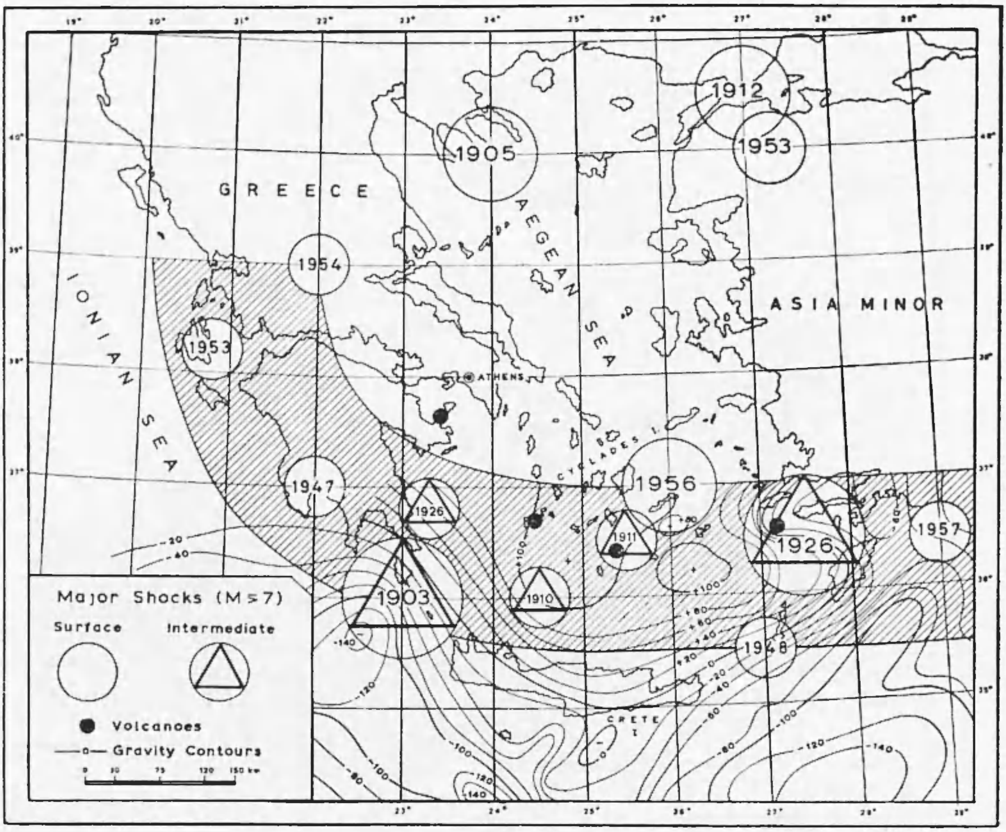

Fig. 6 – Distribution of the earthquake foci of major shocks (M ⩾ 7) occurred in the area of Greece since 1901 to 1966. Gravity contours after V. Fleischer ([6]).

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