ΠΡΑΚΤΙΚΑ ΤΗΣ ΑΚΑΔΗΜΙΑΣ ΑΘΗΝΩΝ

ΣΥΝΕΔΡΙΑ ΤΗΣ 11$^{\text{ΗΣ}}$ ΝΟΕΜΒΡΙΟΥ 1971

ΠΡΟΕΔΡΙΑ ΣΠΥΡ. ΜΑΡΙΝΑΤΟΥ

ΣΕΙΣΜΟΛΟΓΙΑ.— **Space-time Seismicity of Greece,** *by A. G. Galanopoulos* [*]. Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Ἠλ. Μαριολοπούλου.

Summary: The space-time earthquake pattern found in this study indicates that successive major earthquakes are related to one another; there is a strong tendency the major shocks to progress in time from west to east and / or vice versa. If the evidence of migration of major earthquakes is strong enough to justify predictions is open to question until the next earthquake with M ⩾ 7 that may occur in the SW-segment of the area considered. The vast majority of the earthquake energy released in the SW-segment, and generally in the southern section of the investigated area, comes from the upper-mantle.

Introduction

Seismicity is determined primarily by shocks of about magnitude 7 and larger. Energy released by shocks of minor magnitude during a time interval long enough to include some major earthquakes is generally a small fraction of the energy released by the larger shocks (M ⩾ 7) in the same area.

In seismically active regions the stressfield is everywhere about the same. Large strain relief by earthquakes of about magnitude 7 and larger in a given space is followed by a redistribution of the near-by

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stresses and a relatively high stress concentration at the end of the dislocation (CHINNERY, 1963); this high stress concentration may result sooner or later to an overstress of the neighbouring regions, preferably those situated in the same fault system.

The redistribution of the near-by stresses and the following faulting is governed by numerous variables such as confining pressure, strain rate, strain history and lithology. In nature, these parameters may vary not only from one fault system to another but also along a single fault (SYLVESTER, 1970). However, there is a tendency in active regions the overstress and ultimately the faulting to occur over some period in the same direction. It follows a period of quiescence and then the process of strain release in large scale starts again usually from another point more close to the space of the initial failure of the previously terminated period.

It is generally recognized that shallow and deep earthquakes have a tendency to cluster in space and time (ISACKS et al., 1967). In addition to this clustering form, some investigators (VERE-JONES and others, 1964, 1966; UTSU, 1968, 1969) have found clustering of deep earthquakes with large separations in space and especially in time. Some others (FEDOTOV, 1965; MOGI, 1968 a, b and 1969 a, b) have found in seveval seismic zones linear trends of large earthquakes strong enough for inferring causal relationships between them. Space-time graphs of large earthquakes ($M \geqslant 7.7$) of the Alaska-Aleutian seismic zone display a clear pattern of successive linear sequences running from east to west or counterclockwise (KELLEHER, 1970). The same pattern of occurrence of major earthquakes ($M \geqslant 7$) appears to prevail in the area of Greece. The space-time earthquake pattern found in this study indicates that successive major earthquakes are related to one another. If the evidence of migration of major earthquakes in the area considered is strong enough to justify predictions is open to question until the next earthquake with $M \geqslant 7$ that may occur in the SW-segment of the area.

Space-time Graphs

All major earthquakes of about magnitude 7 and larger occurred between the meridians of 19° E and 31° E and the latitudes of 34° N and 42° N are listed in the following Table I; the list was compiled from

«Seismicity of the Earth» (GUTENBERG, B. and C. F. RICHTER, 1954), catalogues previously published by the author (GALANOPOULOS, 1965, 1967) and USCGS cards of preliminary determination of epicentres. The areal distribution of the major earthquakes is shown in the map (s. Fig. 1);

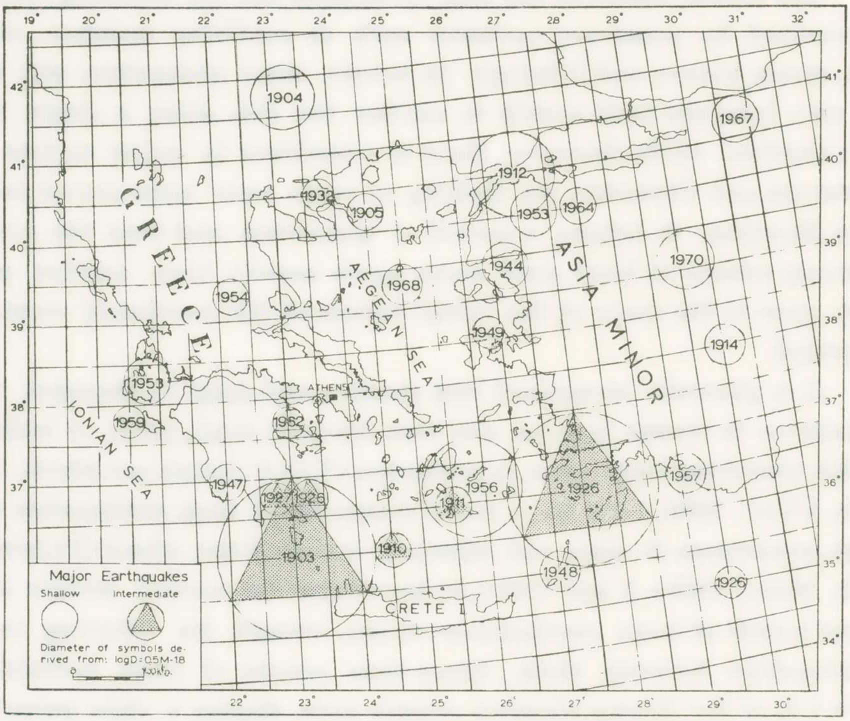

Fig. 1. Areal distribution of epicentres of major shocks (M ⩾ 7) occurred since 1900.

the size of the symbols is equal to the average circular size of the aftershock region of a shallow earthquake with the same magnitude (UTSU, 1961).

Seismic data can be easily examined for space-time patterns by plotting the epicentres against longitude and latitude and the year of occurrence of the respective shocks. Space-time graphs constructed for the area outlined above demonstrate that the number of major shocks and the energy released by them are equally distributed in the two sections bounded by the meridian of 25° E. The distribution of the same shocks is also equal in the two sections bounded by the parallel of 38° N, but the energy released in the southern section is about 5 times the energy released in the northern section.

Most of the energy released in the southern section comes from intermediate focal depth ; the energy released by crustal shocks in the southern section is about 1/8 the energy released by mantle shocks. Mantle processes in substantial scale are confined to the southern section; large mantle shocks do not occur in the northern section. The energy released by mantle shocks is almost equally divided between the eastern and western section, i.e. in the SW-and SE-segment. (s. Fig. 2).

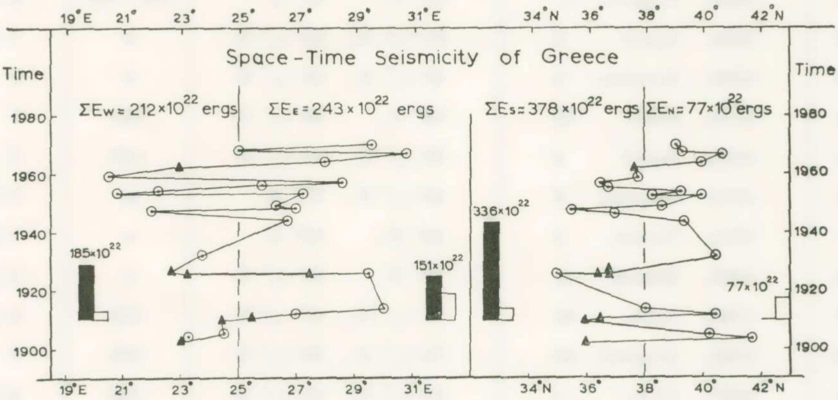

Fig. 2. West - to - east and north - to - south migration of epicentres of major shocks ($M \geqslant 7$). Open circles denote crustal shocks and solid triangles shocks of focal depth between 100 and 150 km. Insert : solid and open rectangles represent energy released by mantle and crustal chocks, respectively.

Most of the energy released by crustal shocks comes from the eastern section ; the energy released in the eastern section by shallow shocks is about 3 times the energy released in the western section. The energy of the shallow shocks in the northern section is about 2 times the energy in the southern section. In more detail, the crustal energy in the four segments: NE, SE, NW and SW is, respectively, about 53, 39, 24 and 3 units ($= 10^{22}$ ergs). The relatively high percentage of the crustal energy released in the NE-segment combined with the lack of major mantle shocks suggests that the strain-producing forces in this area are very shallow. The evidence is corroborated by frequent surface expression of the active faults associated with major earthquakes.

TABLE I

Major earthquakes of about magnitude 7 and larger occurred between the meridians of 19° E and 31^0 E and the latitudes of 34^0 N and 42^0 N since 1900.

No	Date	Location	Focal depth	Magnitude
1	1903, August 11	36^0 N, 23^0 E	100 - 150	8.3
2	1904, April 4	$41\,^3/_4{}^0$ N, $23\,^1/_4{}^0$ E	n	$7\,^1/_2$
3	1905, Novem. 8	$40\,^1/_4{}^0$ N, $24\,^1/_2{}^0$ E	n	7
4	1910, Febr. 18	36^0 N, $24\,^1/_2{}^0$ E	150	7
5	1911, April 4	$36\,^1/_2{}^0$ N, $25\,^1/_2{}^0$ E	140	7
6	1912, August 9	$40\,^1/_2{}^0$ N, 27^0 E	n	$7\,^3/_4$
7	1914, Octob. 3	38^0 N, 30^0 E	n	7.1
8	1926, March 18	35^0 N, $29\,^1/_2{}^0$ E	n	6.9
9	1926, June 26	$36\,^1/_2{}^0$ N, $27\,^1/_2{}^0$ E	100	$8\,^1/_4$
10	1926, August 30	$36\,^3/_4{}^0$ N, $23\,^1/_4{}^0$ E	100	7
11	1927, July 1	$36\,^3/_4{}^0$ N, $22\,^3/_4{}^0$ E	120	6.9
12	1932, Sept. 26	$40\,^1/_2{}^0$ N, $23\,^3/_4{}^0$ E	n	6.9
13	1944, Octob. 6	39.4^0 N, 26.7^0 E	n	7.2
14	1947, Octob. 6	37^0 N, 22^0 E	28	7
15	1948, Febr. 9	$35\,^1/_2{}^0$ N, 27^0 E	40	7.1
16	1949, July 23	38.6^0 N, 26.3^0 E	n	6.9
17	1953, March 18	40^0 N, $27\,^1/_4{}^0$ E	n	7.2
18	1953, Aug. 12	38.3^0 N, 20.8^0 E	n	$7\,^1/_4$
19	1954, April 30	39.3^0 N, 22.2^0 E	n	7
20	1956, July 9	36.7^0 N, 25.8^0 E	n	7.8
21	1957, April 25	36.5^0 N, 28.6^0 E	53	7.1
22	1959, Novem. 5	37.8^0 N, 20.5^0 E	n	6.9
23	1962, Aug. 28	37.7^0 N, $23\ 0^0$ E	120	6.9
24	1964, Octob. 6	40.0^0 N, 28.0^0 E	n	7
25	1967, July 22	40.7^0 N, 30.8^0 E	n	7.2
26	1968, Febr. 19	39.3^0 N, 25.0^0 E	n	7.1
27	1970, March 28	39.1^0 N, 29.6^0 E	n	7.4

Discussion and Conclusion

The distribution of major shocks in the area considered outlines space-time patterns that display a clear tendency the major earthquakes to progress in time from west to east and/or vice versa. The tendency is particularly clear in the linear sequences of major shocks in the periods 1910 - 1914, 1926 - 1927, 1953 - 1957 and 1959 - 1967. The observed number of linear trends is obviously larger than that expected from the accidental occurrence of the events. Another tendency, but less well expressed, is the major shocks to progress in time from north to south and/or vice versa (s. Fig. 2).

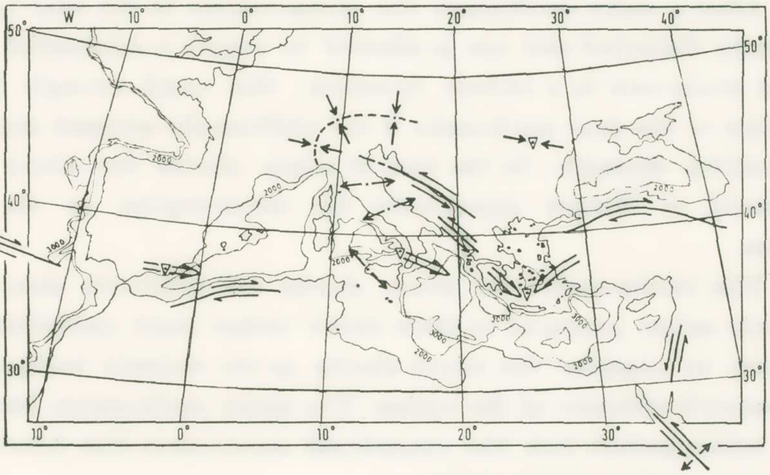

Fig. 3. The seismotectonic stress field in the Mediterrannean area (from RITSEMA, 1969).

The pattern of migration of major shocks in the area of Greece is consistent with the distribution of the horizontal components of maximum pressure obtained in the focal mechanism studies of earthquakes of Greece and Asia Minor. According to A. R. RITSEMA (1969), the overall picture of pressure stresses in the area of Greece suggests that material drifts into the southern basin of the Aegean sea from both the ENE and NW (s. Fig. 3). In general, «the present-day stress field as reflected by the mechanism of European earthquakes seems to have an about West - East or WNW-ESE direction».

The difference in the degree of tendency of seismicity migration in the west-to-east and north-to-south direction is fairly understood if we take into considetation that the energy release in the eastern and western section is about equal ; on the contrary, the energy released in the southern section is about 5 times the energy released in the northern section. However, in both cases the space-time earthquake patterns show rather clear that the occurrence of major shocks is not random as this may happen in the case of minor shocks.

After a major earthquake the stress-regime in the near-by regions is greatly disturbed and one is allowed to expect a substantial increase in the strain-rate in a certain direction ; this could strongly influence the time of the next earthquake if the additionally stressed area is close to breaking strength. In the case of minor shocks the strain relief is too small to disturb appreciably the stress-regime in the near-by regions

The return periods of minor shocks are relatively short and the «seismic noise» produced by them shows rather small oscillations allowing one to consider the minor shocks as the «seismic background» or the «seismic climate» of the region. The major earthquakes due to their long return periods look like exceptional occurrences that determine the «seismic weather» of the region.

If the tendency of retrograde shift of epicentres of major earthquakes afore mentioned constitutes a law for the investigated area, then the next earthquake with $M \geqslant 7$ should be expected in the SW-segment of the area.

ΠΕΡΙΛΗΨΙΣ

Χρονολογικὴ χαρτογράφησις τῶν ἐπικέντρων τῶν μεγάλων σεισμῶν ποὺ συνέβησαν εἰς τὸν Ἑλληνικὸν χῶρον ἀπὸ τοῦ 1900, συναρτήσει τοῦ Γεωγραφικοῦ Μήκους καὶ Πλάτους, ἀποκαλύπτει διαδοχικὰς σειρὰς μεταναστεύσεως τῶν ἐπικέντρων τῶν μεγάλων σεισμῶν ἐκ Δυσμῶν πρὸς Ἀνατολὰς καὶ ἀντιστρόφως. Ἡ τάσις μεταναστεύσεως τῶν ἐπικέντρων τῶν μεγάλων σεισμῶν ἀπὸ Βορρᾶ πρὸς Νότον, καὶ ἀντιστρόφως, εἶναι ὀλιγώτερον σαφής. Ἐὰν αἱ εὑρεθεῖσαι τάσεις γραμμικῆς μεταναστεύσεως τῶν ἐπικέντρων τῶν μεγάλων σεισμῶν εἶναι ἀρκούντως ἰσχυραί, ὥστε νὰ συνιστοῦν νόμον διὰ τὸν ἐξετασθέντα σεισμικὸν χῶρον, τότε ὁ προσεχὴς μεγάλος σεισμός, μεγέθους 7 ἢ μεγαλυτέρου, πρέπει ν' ἀναμένεται εἰς τὸν νοτιοδυτικὸν τομέα. Ἡ σεισμικὴ ἐνέργεια ποὺ ἐκλύεται εἰς τὸν νοτιοδυτικὸν τομέα, καί, γενικώτερον, εἰς τὸ νότιον τμῆμα τοῦ Ἑλληνικοῦ χώρου, προέρχεται κατὰ τὸ πλεῖστον ἀπὸ τὸν ἀνώτερον μανδύαν.

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