PRELIMINARY STUDY OF THE FOCAL PROPERTIES OF THE PYRGOS, 1993 EARTHQUAKE (NW PELOPONNESE - GREECE)

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A B S T R A C T

An earthquake with M_s=5.2 occurred on March 26, 1993 (11:58 GMT) near the city of Pyrgos (NW Peloponnese) and caused considerable damage in the epicentral area. Based on the recordings at the seismological stations of the national Greek network (Geophysical Laboratory of Thessaloniki University and National Observatory of Athens), the main shock and its strongest foreshocks and aftershocks were located. The spatial distribution of the epicenters has an almost NW-SE trend of the active area. The focal depths are distributed from 4 to 26 Km and show a tendency for a NE dipping. The data indicate a fault trending NW-SE dipping to NE, almost beneath the city of Pyrgos and parallel to the coast in this area. The fault plane solution of the mainshock shows a thrust fault with one of the nodal planes trending NW-SE and dipping to NE, in good agreement with the spatial distribution of the epicenters and the field observations of the macroseismic effects.

ΠΡΟΚΑΤΑΡΚΤΙΚΗ ΜΕΛΕΤΗ ΤΩΝ ΕΣΤΙΑΚΩΝ ΙΔΙΟΤΗΤΩΝ ΤΟΥ ΣΕΙΣΜΟΥ ΤΟΥ 1993 ΣΤΟΝ ΠΥΡΓΟ

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Π Ε Ρ Ι Λ Η Ψ Η

Ενας σεισμός με μέγεθος M_s=5.2 έγινε στις 26 Μαρτίου 1993 (11:58 GMT) κοντά στον Πύργο (ΒΔ Πελοπόννησος) και προκάλεσε σοβαρές βλάβες στην επικεντρική περιοχή. Με βάση τις αναγραφές στους σεισμολογικούς σταθμούς του μόνιμου Ελληνικού Εθνικού δικτύου (Εργαστήριο Γεωφυσικής ΑΠΘ και Εθνικό Αστεροσκοπείο Αθηνών), έγινε ο υπολογισμός των εστιακών παραμέτρων του κύριου σεισμού καθώς επίσης και των ισχυρότερων προσεισμών και μετασεισμών. Η χωρική κατανομή των επικέντρων ορίζει μάλλον καλά μια ΒΔ-ΝΑ διεύθυνση της ενεργού ζώνης. Τα μακροσεισμικά αποτελέσματα που παρατηρήθηκαν ενισχύουν αυτή την παρατήρηση. Τα δεδομένα αυτά δείχνουν ότι πρόκειται για ένα ρήγμα ΒΔ-ΝΑ διεύθυνσης το οποίο κλίνει ΒΑ, βρίσκεται σχεδόν κάτω από τον Πύργο και η διεύθυνση του είναι παράλληλη προς τις ακτές στην

περιοχή. Ο μηχανισμός γένεσης του κύριου σεισμού δείχνει ότι πρόκειται για ανάστροφη διάρρηξη και είναι σε πολύ καλή συμφωνία με την κατανομή των μετασεισμών και τις παρατηρήσεις των μακροσεισμικών αποτελεσμάτων.

INTRODUCTION

The area affected by the mainshock of March 26, 1993 and its foreshocks and aftershocks is located in the easternmost part of the seismogenic source of Zante (Papazachos, 1990). This source is characterized by high seismic activity and thrust faulting, as a result of the subduction of the Mediterranean oceanic lithosphere under the Aegean continental lithosphere. The maximum observed magnitude in this source is equal to 7.0, but all the shocks which occurred in a distance of 30Km around the epicenter of the mainshock of March 16, 1993, had magnitudes less or equal to 5.7 (Comninakis and Papazachos, 1986; Papazachos and Papazachou, 1989). It means that the strong ($M_s \geq 6.0$) shallow earthquakes in this source are distributed in the off shore area, while beneath the mainland only earthquakes of moderate magnitude occur. Nevertheless, considerable damage has been reported in the past by earthquakes having their foci near urban areas.

This seismic sequence started on February 10, 1993 with a shock of magnitude M_s=4.1. Four days later another strong event of M_s=4.6 occurred. The seismic activity continued until the end of February and then declined. Two days before the occurrence of the mainshock the area reactivated. It is remarkable that two foreshocks with magnitudes 4.9 and 4.6, respectively, occurred 15 minutes and 2 minutes before the mainshock. Strong foreshock activity just before the mainshock has been also observed in the past. During the present century at least in four seismic sequences the mainshock preceded by a strong foreshock ($M_s \geq 4.5$) which occurred in a time interval of 22 hours to 7 hours before the mainshock (Comninakis and Papazachos, 1986).

Numerous fore- and aftershocks were recorded by the stations of the telemetry seismological network of the University of Thessaloniki and of the Seismological Institute of the National Observatory of Athens. Hence, a significant number of recordings was available for an accurate epicenter determination. Although a regional seismological network is not the most proper one for studying thoroughly a seismic sequence, it is believed that the data presented below are accurate, since the reliability of the epicenter determination was checked by the pattern of the macroseismic data. The spatial distribution of the events located in the present study is in good agreement with the fault plane solution determined using the first onsets of P wave arrivals at long and short period instruments.

SPATIAL DISTRIBUTION OF EARTHQUAKE FOCI

The seismological stations of the Greek national telemetry network, whose data have been used in this paper, are denoted by triangles in the map of Figure 1. In the same map the epicentral area is also marked by a square. From this figure, it is seen, that the azimuthal distribution of the stations around the epicentral area is rather satisfactory. The records at these stations were used to determine the focal parameters of the events of the seismic sequence, while for the mainshock and the two large foreshocks, the S-P arrival time differences found from the record of an SMA-1 accelerometer installed in Pyrgos (in a distance about 5km from the epicenters) were additionally used.

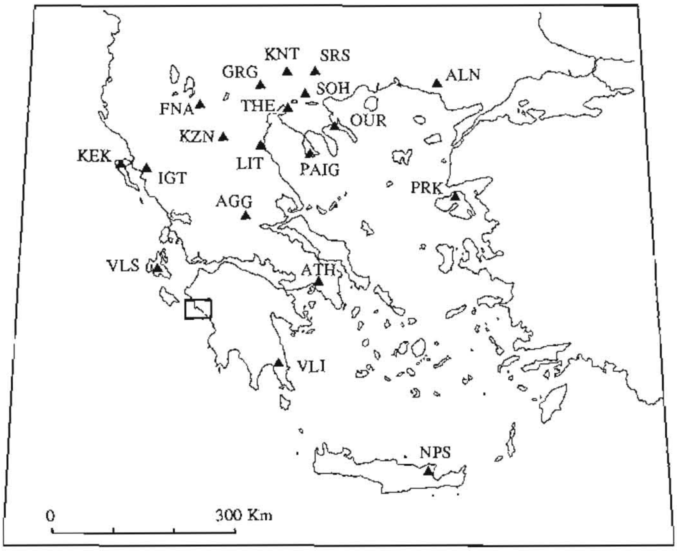

Fig.1. The sites of the stations of the permanent National Greek telemetry network whose data were used in the present study. The area studied is marked by a square.

The determination of the focal coordinates was made using the program HYPO 71 (revised), (Lee and Lahr, 1975). A crustal model consisting of two layers above a half space, that is, a granitic and a basaltic layer above the mantle, was used. This model is a modification of the model proposed by Panagiotopoulos and Papazachos (1985) for the broader Aegean area. The modification is based on the data of the October 16, 1988 seismic sequence which took place in a distance of 30 Km NW of the Pyrgos area (Karakostas et al., 1993). The difference between the two models concerns the thickness of the crust which is larger in the area of NW Peloponnese (Makris, 1978; Panagiotopoulos and Papazachos, 1985). The P-wave velocities and the thicknesses of the layers of the model used in the present study, are the following: v_g=6.0Km/sec, d_g=29Km, v_b=6.6Km/sec, d_b=19Km, v_n=7.9Km/sec.

The epicenters of all the earthquakes of the seismic sequence which were recorded by the Greek Seismological network were determined. It was observed that the errors in the epicenter and depth determination were larger in the case when less than

10 P- and S- wave arrivals were used, resulting in a scattering of the epicenters in comparison with the epicenters of the shocks with more arrivals. Thus, the focal coordinates determined using 10 or more P- and S- wave arrivals were considered accurate and only these were subsequently used to define the seismogenic volume.

Figure 2 is an epicentral map of all the accurately determined epicenters of the sequence for which information is given in Table I. Open and black circles show the epicenters of the foreshocks and aftershocks, respectively. The epicenter of the main shock is shown by a larger circle including a triangle.

Table 1. Information on the focal parameters of the events of the sequence.

Date	Or. time	Lat. φ°N	Lon. λ°E	Depth km	Mag. M_s	No	RMS sec	ERH km	ERZ km
93 03 25	05:44:08.3	37.67	21.42	18.3	4.5	25	0.41	1.9	1.5
93 03 26	11:45:15.0	37.66	21.46	23.7	4.9	27	0.78	3.9	3.4
93 03 26	11:56:13.2	37.75	21.43	21.0	4.7	23	0.57	3.7	3.1
93 03 26	11:58:16.6	37.66	21.47	19.5	5.2	15	0.55	4.7	3.6
93 03 26	12:26:30.7	37.65	21.47	23.1	4.5	24	0.51	3.3	2.9
93 03 26	12:38:05.8	37.73	21.37	23.3	3.9	13	0.42	4.3	5.0
93 03 26	12:49:13.6	37.66	21.50	18.8	4.7	20	0.56	3.5	2.6
93 03 26	18:47:00.4	37.64	21.43	12.9	3.9	10	0.56	4.0	3.5
93 03 27	06:16:44.1	37.66	21.43	8.3	3.7	10	0.70	6.2	4.3
93 03 27	06:51:02.3	37.66	21.47	18.5	4.3	22	0.39	1.8	1.4
93 03 27	08:10:08.8	37.70	21.41	17.3	3.7	11	0.44	2.8	2.5
93 03 27	09:16:59.4	37.66	21.50	9.1	4.1	14	0.76	4.2	4.0
93 03 27	09:21:53.5	37.67	21.49	13.1	4.0	14	0.97	5.7	4.9
93 03 27	18:55:53.8	37.64	21.50	6.0	3.9	16	0.79	4.4	4.0
93 03 28	03:31:25.0	37.69	21.40	15.9	3.6	10	0.66	4.6	3.9
93 03 28	22:57:06.7	37.65	21.47	22.7	4.0	17	0.78	5.2	5.6
93 03 29	02:23:28.1	37.65	21.40	10.1	3.8	12	0.63	3.9	3.5
93 03 29	03:27:11.8	37.68	21.39	14.6	3.9	17	0.81	4.3	3.5
93 03 29	11:57:05.0	37.69	21.44	21.2	4.0	14	0.49	4.8	4.9
93 03 29	13:11:47.9	37.69	21.44	22.3	4.0	14	0.54	3.7	4.0
93 03 29	22:47:19.0	37.72	21.41	25.9	4.3	21	0.41	2.4	2.5
93 03 30	02:59:25.1	37.68	21.51	18.3	4.1	15	0.62	3.6	3.0
93 03 30	04:24:11.2	37.71	21.43	24.4	4.2	19	0.57	3.3	3.6
93 03 30	10:24:56.4	37.65	21.46	18.2	4.4	18	0.58	2.9	2.3
93 03 30	10:43:06.4	37.65	21.46	23.5	4.1	21	0.66	4.1	4.1
93 03 30	16:17:32.1	37.67	21.43	26.4	4.1	21	0.66	3.9	4.2
93 03 30	19:08:56.4	37.69	21.44	24.9	4.5	21	0.68	4.7	5.1
93 03 31	00:25:34.0	37.71	21.46	24.0	4.0	11	0.59	7.9	9.4
93 03 31	14:56:45.9	37.71	21.46	12.6	3.9	12	0.52	4.4	3.8
93 04 01	01:04:52.9	37.67	21.45	16.4	3.9	13	0.70	4.4	3.6
93 04 03	21:11:09.1	37.71	21.51	21.8	4.3	20	0.77	4.8	5.4
93 04 09	14:26:21.2	37.69	21.46	4.2	3.7	10	0.49	3.3	3.7

These data define fairly well a NW-SE trending aftershock zone. The length of this zone is about 10 km which is in fairly good agreement with a fault capable to produce an earthquake of magnitude M_s=5.2, according to the formula proposed by Papazachos

(1989) for the broader Aegean area:

$$\log L = -1.85 + 0.51 M_s \quad (1)$$

where L is the length of a fault produced by an earthquake having magnitude equal to M_s.

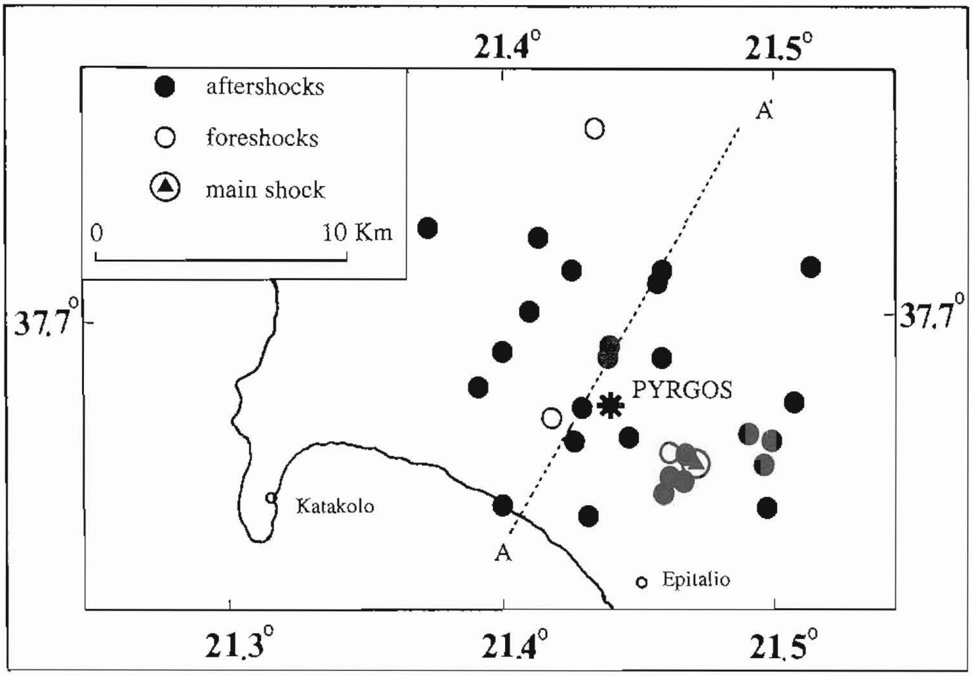

Fig.2. Distribution of the epicenters of the foreshocks (open circles), mainshock (circle including a triangle) and aftershocks (black circles) located using the data of the permanent telemetry networks of Greece.

A cross section vertical to the direction of the aftershock zone (AA', figure 2) is shown in Figure 3. It is observed that the focal depths of the earthquakes range from 4km to 26km. The focal depth of the mainshock is 20km, that is, it is located in the lower part of the aftershock zone. From this cross-section a NE dipping of the aftershock zone is observed with an angle about 70°.

MACROSEISMIC OBSERVATIONS

According to our field investigations both primary as well as secondary effects were observed mainly in the area between Pyrgos and Epitalio.

The damage in Pyrgos was observed mainly on brittle constructions, as low rise brittle houses made of bricks without considerable reinforcement. The old hospital which suffered great damage belongs also to this type of constructions. The damage on this type of constructions are more dependent on the amplitude of the strong ground motion than on its duration (Jennings, 1985). The high accelerations (a>40%g) recorded by the instruments of ITSAK support this result. Serious damage on reinforced concrete constructions were very few and concentrated at the area close to the hospital and the market. Light cracks and fall of plaster pieces were observed on many of the reinforced concrete buildings. The mean intensity for the area of Pyrgos was almost VII in MM scale. The same degree of damage was also observed at Epitalio, while the less damage (V in MM scale) were observed at Katakolo.

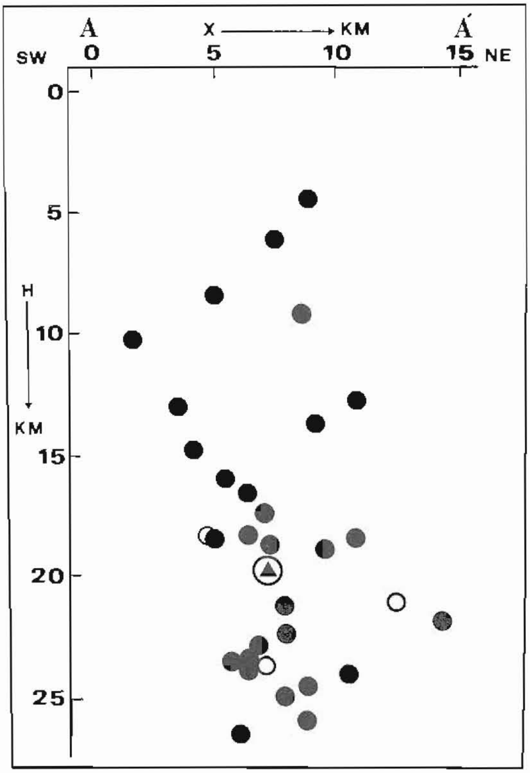

Fig.3. A cross section on a vertical plane perpendicular to the trend of the distribution of the epicenters of the aftershocks.

At the northern part of the prefecture (around Amalias) the damage was not considerable. According to our discussions, the majority of the damaged houses were already affected by the 1988 Killini earthquake (Karakostas et al., 1993) and were not well repaired. The greater degree of damage for this area was observed at the village of Geraki, while at the villages of Chavari, Krioneri, Prodromos, Analipsi and Peristeri only few number of houses were damaged. The town of Amalias did not suffer any considerable damage. At the area of Agia Anna a displacement of tiles on the roof of a church was observed. Some failures were also observed on the walls of two buildings opposite to the church.

At the area of Olympia less damage was observed on the top of the entrance of the museum, which may be associated to torsional effects on the construction.

At the area northeastern of Pyrgos landslides were observed to previously marked surfaces at Ampelonas and at the monastery of Kremasti. The towns of Ampelonas and Agios Ioannis were suffered also some damage to brittle houses.

FAULT PLANE SOLUTION

The first onsets of long and short period P-wave arrivals were used to determine the fault plane solution of the mainshock. Although the magnitude of this event was small, an adequate number of data was available for this determination. Figure 4 is an equal area projection of the lower hemisphere of the focal sphere. A value equal to 6.8 Km/sec was assumed for the longitudinal waves at the focus of the earthquake. Dilatations and compressions represented by triangles and circles, respectively. The data are well distributed azimuthally helping in constraining the nodal planes rather well.

The fault plane solution suggests a thrust faulting. The nodal plane trending 300° NW-SE is in good agreement with the trend of the aftershock zone. Its dip is 66°, which also agrees with the distribution of earthquake foci shown in figure 3.

The P-axis is almost horizontal with a 63° trend, that is, perpendicular to the trend of the Hellenic arc in this area, in good agreement with the regional stress pattern (Papazachos et al., 1991).

Table II summarises all the parameters of the fault plane solution of the main shock.

Table 2. The parameters of the fault plane solution of the mainshock.

Plane A			Plane B			P		T	
φ°	δ°	λ°	φ°	δ°	λ°	φ°	δ°	φ°	δ°
300	66	42	190	53	149	63	07	161	46

DISCUSSION

A question arises immediately after the occurrence of a strong earthquake, especially when it affects urban areas. The question is if a stronger earthquake will follow or not. It is well known that it is quite difficult to answer this question. Nevertheless, it is possible to have some evidence concerning the evolution of the seismic activity. The spatial distribution of the aftershocks is one strong evidence among others.

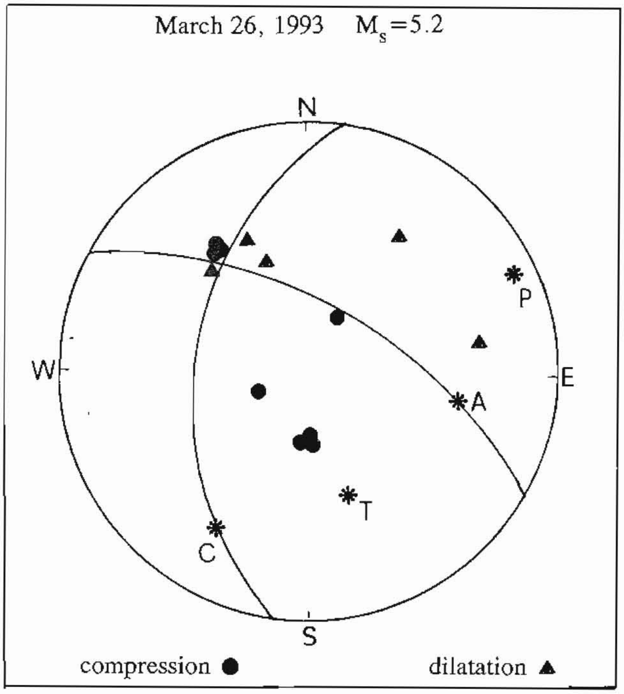

Fig.4. The fault plane solution of the March 26, 1993 M_s=5.2 mainshock. Triangles and circles represent dilatations and compressions respectively

The present study shows that it is possible to define very quickly and accurately the seismogenic volume using the recordings at the seismological stations of the Greek national telemetric network and a reliable crustal model valid for the area. We think that these data are not so accurate as those derived by a local network, but they have the main advantage that they can be processed very quickly.

The reliability of the results is supported by the field observations of the macroseismic effects and the fault plane solution. A NW-SE trending of the seismogenic volume was clearly observed, in agreement with the fault plane solution of the mainshock.

The area strongly affected extends from the city of Pyrgos to Epitalio village, which define a line with a NW-SE direction with a length of about 10 Km. The small epicentral distance from the town of Pyrgos was a factor of the observed damage. However, not only the epicentral distance but also the type of faulting is responsible for that. According to McGarr, (1984) thrust faulting has stronger affects than the normal one.

Further work, based on data derived from local network could be very useful for a more detailed investigation of this sequence, but it is believed that its general characteristics which were deduced in the present study will remain the same.

ACKNOWLEDGMENTS

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REFERENCES

Comninakis,P.E. and Papazachos,B.C., (1986). A catalogue of earthquakes in Greece and surrounding area for the period 1901-1985. "Publ. Geophys. Lab., Univ. Thessal.", 1, pp. 167.

Jennings,P.C., (1985) Ground motion parameters that influence structural damage, In R. Scholl and J.L. King [:editors] Strong ground motion simulation and earthquake engineering applications., EERI, I1-I5.

Karakostas,B.G., Scordilis,E.M., Papaioannou,Ch.A., Papazachos,B.C. and Mountrakis,D., (1993). Focal properties of the October 16, 1988 Killini earthquake (western Greece). "2nd Congr. Hellenic Geophys. Union", (this volume).

Lee,W.H.K. and Lahr,J.C., (1975). HYPO71 (revised): a computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes. "U.S.G.S. Open File Rep.", 75-311.

Makris,J., (1978). The crust and upper mantle of the Aegean region from deep seismic soundings. "Tectonophysics", 46, 269-284.

McGarr,A., (1984). Scaling of ground motion parameters, state of stress and focal depth. "J. Geophys. Res.", 89, 6969-6979.

Panagiotopoulos,D.G. and Papazachos,B.C., (1985). Travel times of P_n waves in the Aegean and the surrounding area. "Geophys. J. R. astron. Soc.", 80, 165-176.

Papazachos,B.C., (1989). Measures of earthquake size in Greece and surrounding area. "1st Congr. Hellenic Geophys. Union", 438-447.

Papazachos,B.C., (1990). Seismicity of the Aegean and surrounding area. "Tectonophysics", 178, 287-308.

Papazachos,B.C. and Papazachou,C.B., (1989). Earthquakes in Greece. "Ziti Publ.", pp. 356.

Papazachos,B.C., Kiratzi,A.A. and Papadimitriou,E.E., (1991). Regional focal mechanisms for earthquakes in the Aegean area. "Pure Appl. Geophys.", 136, 405-420.