SOURCE PROPERTIES OF THE 21 DECEMBER 1990 GOUMENISSA EARTHQUAKE IN NORTHERN GREECE

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A B S T R A C T

The spatial, time and magnitude distribution of aftershocks as well as the fault plane solution and the macroseismic field of the strong earthquake (M_s=6.0) which occurred on 21 December 1990 in Northern Greece are investigated. The spatial distribution of aftershocks as well as the fault plane solution and the isoseismal lines of the main shock show that this earthquake is due to a normal fault which strikes in a N54°E direction and dips to the south. The focal properties of this earthquake are in accordance with the extension in the back-arc Aegean region.

ΜΕΛΕΤΗ ΤΗΣ ΣΕΙΣΜΙΚΗΣ ΔΡΑΣΤΗΡΙΟΤΗΤΑΣ ΤΗΣ 21 ΔΕΚΕΜΒΡΙΟΥ 1990 ΣΤΗΝ ΚΕΝΤΡΙΚΗ ΜΑΚΕΔΟΝΙΑ-ΒΟΡΕΙΑΣ ΕΛΛΑΔΑΣ

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Π Ε Ρ Ι Λ Η Ψ Η

Μελετήθηκαν η χωρική, χρονική και κατά μέγεθος κατανομή των μετασεισμών καθώς επίσης ο μηχανισμός γένεσης και τα μακροσεισμικά δεδομένα του ισχυρού σεισμού μεγέθους M_s=6.0 ο οποίος έγινε την 21 Δεκεμβρίου 1990 στη Βόρεια Ελλάδα. Η χωρική κατανομή των μετασεισμών, ο μηχανισμός γένεσης και ο χάρτης των ισοσείστων καμπυλών του κυρίου σεισμού, έδειξαν ότι το κύριο σεισμογενές ρήγμα είναι ένα κανονικό ρήγμα με διεύθυνση N54°E το οποίο βυθίζεται προς το Νότο. Τα αποτελέσματα των εστιακών παραμέτρων των σεισμών της ακολουθίας της Γουμένισσας είναι σε συμφωνία με το εφελκυστικό πεδίο των τάσεων του εσωτερικού μέρους του τόξου του Αιγαίου.

INTRODUCTION

On 21 December 1990 (06h 57m 44s) an earthquake of surface wave magnitude M_s=6.0(M_L=5.5) occurred in central Macedonia (Northern Greece). The epicentre of the earthquake (φ=40.9°N , λ=22.4°E) was located near the village of Goumenissa about 50km northwest of Thessaloniki. This earthquake was not preceded by recorded foreshocks but it was followed by numerous aftershocks.

The largest aftershock occurred on December 24 (02h 34m 06s) with local magnitude M_L=3.9. The main shock caused serious damage in the epicentral area near the Greek-Yugoslavian border. A woman was killed in the city of Edessa and several people were injured .

A small number of shocks with magnitudes up to 5.3 occurred in the area of Goumenissa, which is an area with low seismicity, during the period 1955-1980 (Comninakis and Papazachos, 1986). The most recent nearest strong event in this area occurred about 50km north from the epicental area on March 8, 1931 and had a surface wave magnitude equal to 6.7 .

In the present paper, the spatial, time and magnitude distribution of the aftershocks of the 21 December 1990 earthquake as well as its focal properties are studied. For this purpose, instrumental and macroseismic data have been used. Such studies are of interest because of their potential contribution to the understanding of the earthquake generation.

SPATIAL, TIME AND MAGNITUDE DISTRIBUTION OF AFTERSHOCKS

In order to achieve reliable epicentre location, the arrival times of the longitudinal and the shear waves (when it was possible) of the earthquakes of the sequence at the seismological stations of Greece and neighbouring countries have been used. For such location of the main shock and its aftershocks, the HYPO 71 (revised) computer program (Lee and Lahr 1975) has been used with a three layer crustal model above a half space (d_1=1.5 km, v_1=5.0 km/sec, d_2=17 km, v_2=6.0 km/sec, d_3=12.5 km, v_3=6.6 km/sec and v_n=7.9 km/sec) suggested by Panagiotopoulos and Papazachos (1985) .

In order to use the best of the available information concerning the location of the earthquake foci of this sequence we finally used the focal coordinates only for the earthquakes with local magnitude $M_L \geq 2.9$, for which the standard error in the estimation of epicentre (ERH), the standard error in the estimation of focal depth (ERZ), the root mean square error of the time residuals (RMS), and the number of station readings used in locating the epicentres (N.O.) satisfied the following conditions: ERH≤3km, ERZ≤3km, RMS≤0.6sec and N.O.≥10, respectively.

Table (1) provides information on the shocks which occurred in the epicentral area between 21 December 1990 and 16 March 1991 and have $M_L \geq 2.9$. This table includes dates, origin times, local magnitudes, epicentral coordinates, focal depths and the quantities D_{min}, RMS, ERH, ERZ and N.O. for the twenty largest shocks of the sequence. The epicentres of these shocks are shown on the map of fig. (1).

It is seen that the epicentre distribution has a NE-SW trend which is in fairly good agreement with the trend of the fault which produced the main shock as shown by the fault plane solution and the trend of the isoseismal lines. The main shock is located at the southern end and the largest aftershock, which followed the main shock in 67 hours, near to the northern end of the epicentral area. The average focal depth of the shocks on table (1) is 3.0km with a standard deviation of 2.3km. The mean standard errors of the epicentres, ERH, and of the focal depths, ERZ, are 1.4 ($\pm$0.3)km and 1.8 ($\pm$0.4)km, respectively.

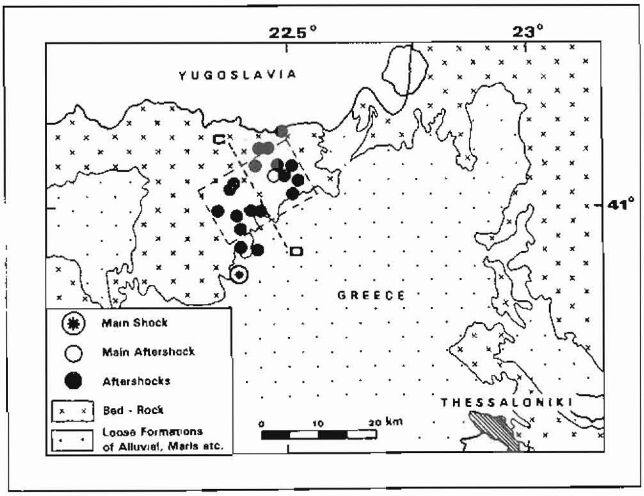

Fig.1. Distribution of the epicentres of the aftershocks with local magnitude M$\geq$2.9 .

Table 1. Information on the best located aftershocks of the seismic sequence.

Date	Or. time	Lat N	Lon E	h	M_L	No	Dmin	RMS	ERH	ERZ
901221	065744.4	40.90	22.40	12.0	5.4	68	7.0	0.6	1.1	1.1
901221	080057.7	40.94	22.43	2.8	3.6	34	3.0	0.6	1.4	1.5
901221	102810.2	41.00	22.36	3.2	3.1	29	5.0	0.6	1.2	1.9
901221	135253.6	41.03	22.38	7.1	3.5	21	8.0	0.5	1.8	1.8
901221	161948.7	40.99	22.39	1.3	3.7	46	47.0	0.6	1.2	2.1
901221	210448.0	40.94	22.40	5.0	3.4	24	2.0	0.6	1.8	1.4
901222	002626.3	41.00	22.42	3.0	2.9	18	44.0	0.4	1.5	1.7
901222	042852.8	41.10	22.44	1.6	3.1	26	16.0	0.5	1.4	1.7
901222	224046.6	41.06	22.47	0.5	3.4	32	12.0	0.5	1.3	1.9
901223	010503.1	41.05	22.52	2.0	3.4	24	14.0	0.5	1.5	2.0
901224	023405.7	41.06	22.49	1.0	3.9	39	13.0	0.5	1.1	2.0
901225	190337.2	41.07	22.48	4.5	3.1	19	14.0	0.4	1.3	1.4
901226	130625.3	40.97	22.40	6.9	3.2	19	1.0	0.5	2.0	1.4
901231	045847.1	41.00	22.44	5.2	3.3	22	6.0	0.5	1.8	1.2
910103	081408.4	41.07	22.43	0.5	2.9	22	12.0	0.4	1.2	2.4
910128	100113.0	41.13	22.49	0.5	3.5	41	23.0	0.6	1.3	2.3
910128	105809.8	41.07	22.51	0.7	3.2	29	16.0	0.6	1.5	2.5
910226	050759.4	41.04	22.38	6.5	2.9	18	9.0	0.7	1.6	2.2
910303	100907.3	41.03	22.51	0.5	3.5	52	12.0	0.6	1.2	2.0
910316	134246.1	41.10	22.45	1.9	3.0	19	16.0	0.5	1.5	2.3

The length of the main cluster of the aftershocks area, which has a NE-SW trend on the map in fig. (1), is about 15 km. Papazachos (1989) suggested the formula :

$$\mathrm{Log}L = -1.85 + 0.51M_s \qquad (1)$$

for the length, L, of the aftershock area along the strike of the faults in the area of Greece. For M_s=6.0, this formula gives L=16 km which is in good agreement with the length of the aftershock area in the present case.

In this case, we consider that the length of the aftershock area is the length of the main cluster because all the shocks at the northern part of the aftershock area have very shallow foci, and the focal depth of the foci at the southern part increased gradually from NW to SE. On the other hand, the main shock, which is the deeper one, occurred at the southern end of the aftershock area. Plots of the earthquakes foci onto several vertical planes have been made in order to find any evidence for the dip direction of the aftershock zone. The best results were obtained when the plot was made in a NW-SE direction (fig. 2), that is, in a direction normal to the elongation of the aftershock area of the main cluster in fig. (1).

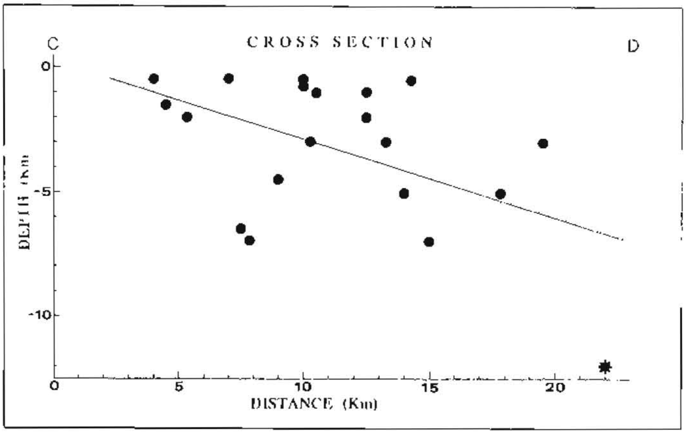

Fig.2. Cross section of the earthquake foci along the line CD of figure (1).

It has been shown (Mogi, 1962) that the number of aftershocks per day, n, decreases with the time, t, according to a relation

$$n = n_1 t^{-p} \qquad (2)$$

The parameter p is of physical significance because it depends on properties of the material in the focal region. Figure (3) shows the time variation of the frequency of aftershocks studied in the present paper. The data are fitted by a relation of the form (2) with p=0.74 and n_1=24.55 . This p-value is relatively small in comparison with the representative value 1.13 for the area of Greece (Papazachos, 1974). This is probably due to the low temperature of the material in the focal region (Ouchi, 1982).

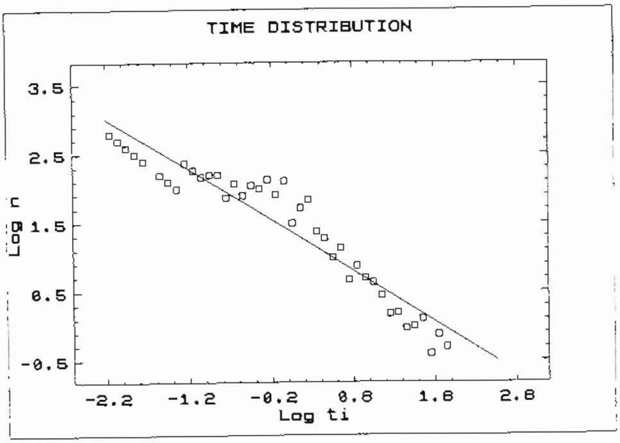

Fig.3. The logarithm of the aftershock frequency (shocks with $M_L \geq 1.1$ day-1) as a function of the logarithm of time (in days).

It is well known that the Gutenberg and Richter relation between the cumulative number of shocks, N, and their magnitudes holds also for aftershocks. Figure (4) shows the cumulative frequency distribution for the aftershocks of the main shock of 21 December 1990. The period covered is from the origin time of the main shock until March 26, 1991. The data are fitted by the relation :

$$\text{LogN} = 4.79 - 1.17M \tag{3}$$

and the completeness is for local magnitude equal to or larger than 2.1. It is seen that the b-value for aftershocks (1.17) is in agreement with the mean b-value (1.08) for aftershocks from the seismic sequences of the area of Greece (Karakaisis 1984).

THE FAULT PLANE SOLUTION OF THE MAIN SHOCK

Long-period P and SH waves recorded by the World Wide Standard Seismograph Network (WWSSN) at teleseismic distances are in

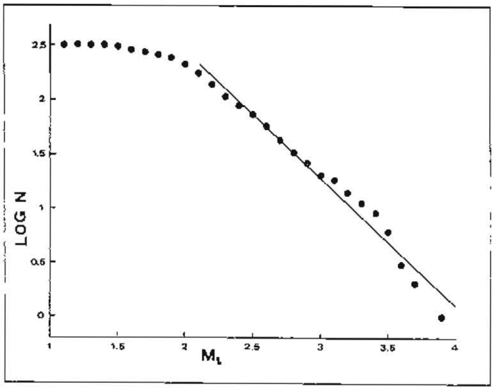

Fig.4. The cumulative frequency-magnitude relation for the aftershocks.

verted simultaneously to determine the centroid depth, far-field source time function, seismic moment, and source mechanism (strike, dip and rake), using the inversion technique by Nabelek (1984). To avoid the strong effects of the upper mantle and the core, the stations are limited to the epicentral distance range of 30° and 90° for P waves and 30° to 70° for SH waves. The data were hand digitized and interpolated at four and two samples per second for P and S waves, respectively. The seismograms are equalized to a common instrument magnification and epicentral distance. The crustal structure around the source is assumed to be a half-space. The P- and S- wave velocities and the density of the half-space are : 6.8 Km/sec, 3.7 Km/sec and 2.8 gr/cm^3, respectively. The half-space velocities were estimated by the use of local seismicity data (Scordilis, 1985).

The earthquake source parameters are estimated by matching the observed seismograms with theoretical ones in a least-squares sense using the procedure discussed by Nabelek (1984, 1985). The overall matching gives a dip slip normal faulting (54/47/257) with a centroid depth of 16 Km (Fig. 5). The seismic moment is 1.7x10^{25} dyn cm, and the duration of the source is about 4 sec. The strike of the fault plane is in good agreement with the spatial distribution of the aftershocks and the direction of the maximum axis of the isoseismals. The azimuth (153°) of the axis T (maximum tension) is in agreement with the regional stress field (Papazachos et al., 1991).

First onsets of long period instrumentation were used additionally, to determine the fault plane solution of the main shock of this sequence. The data were taken from a questionnaire that was answered by seismologists at the seismological stations all over the world. The data were plotted on an equal area projection of the lower hemisphere of the focal sphere, and a velocity equal to 6.8 Km/sec was assumed for the compressional waves at the focus of the earthquake (Fig. 6). Triangles and circles represent dilatations and compressions respectively. The solution obtained is in excellent agreement with the one obtained by the inversion technique.

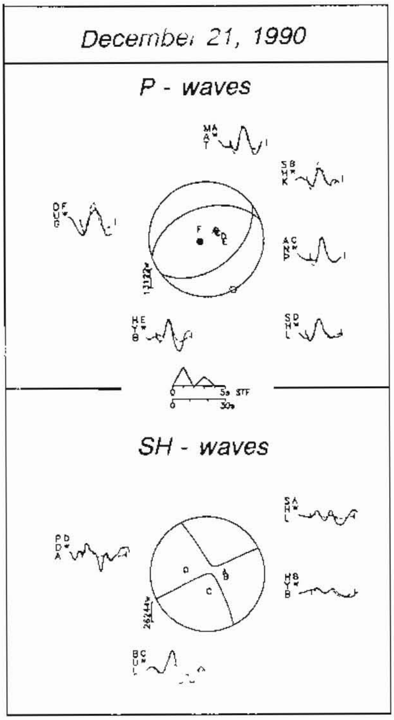

Fig.5. Observed (solid) and synthetic (dashed) long-period seismograms for the 1990 December 21, earthquake. P-waves are shown on the top and SH-waves on the bottom. In the middle portion of each half of the figure, the nodal planes of the direct P and SH waves are shown on lower-hemisphere,equal-area projections. Letters indicate the position of each station. Amplitude scales for both the P and SH waves are shown near the focal spheres. The far-field source-time function and the time scale is drawn in the middle of the figure.

MACROSEISMIC FIELD

Three main sources of macroseismic data have been used to compile the isoseismal maps of the main shock. First, the data published in the monthly bulletins of the National Observatory of Athens and the Seismological Institute of Skopje, second the data provided to us by the Geophysical Institute of the Bulgarian Academy of sciences and third the data send from the IZISS (Skopje). Moreover, few observations were collected from field investigations by a team of seismologists of the Geophysical

Laboratory of the University of Thessaloniki.

The highest degree of intensity was VII in the Modified Mercalli scale and was assigned for the areas of Aridaia and

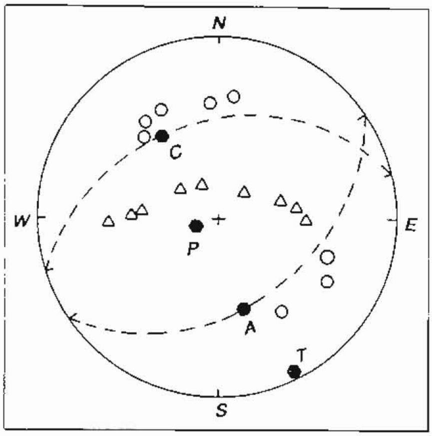

Fig. 6. Fault plane solution of the main shock of the sequence based on the first onsets of long period P waves.

northern Pella as well as for the area of Gevgelja (S. Yugoslavia). For the city of Edessa (which was the largest strongly affected city), located at a distance of ≈40 Km from the epicenter, the mean intensity was VI, with "islands" of higher intensities VI+ - VII. These high intensities were related to the local site conditions and the topography of these areas (Lekidis et al., 1991).

It is important to note that the great number of the seriously damaged constructions were one or two stories brittle masonry structures with shear walls. This type of constructions are normally affected by the high accelerations tending to experience the motions as static loads. Damages were also observed at reinforced concrete constructions mainly to those without infill walls (Pilotis constructions), which were located at soft deposits with depth 10-15m at Edessa (Lekidis et al., 1991).

For the area of Aridaia, 7% of the total number of constructions were suffered serious damages and 7% were characterized beyond repair, while for the area of Gevgelja very serious damages were observed at 18% of the masonry constructions and at 3% for the reinforced concrete buildings. The same numbers for the area of Valandovo are 2% and 0%, respectively.

Figure (7) shows the map of the synthetic isoseismals based on "grouped" intensities following the methodology proposed by Papazachos C. (1992). The original macroseismic map was separated into radial sectors of ten degrees each one and for every sector the macroseismic information with the same degree of intensity were grouped. This resulted to a data set of intensities with values the weighted mean of the initial group.

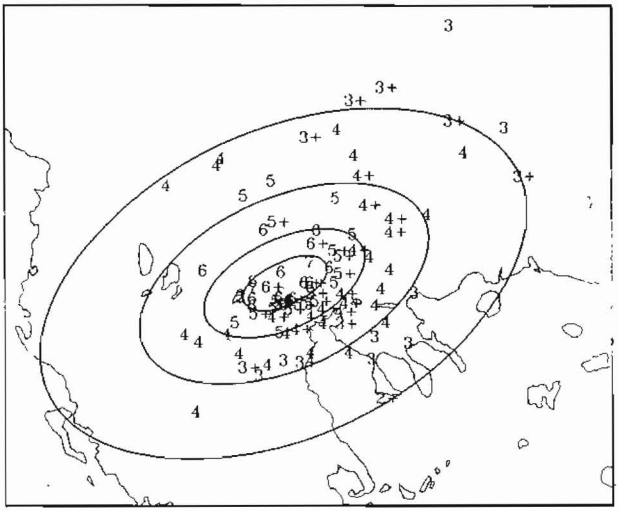

Fig.7. Synthetic isoseismals based on "grouped" intensities of the 21 December, 1990 main shock.

The grouped intensities are also shown on the map of fig.(7) together with the synthetic isoseismals determined by the methodology proposed by Papazachos C. (1992). The trend of the isoseismals shows a good correlation with the focal mechanism, while the elaboration of the macroseismic data gave results comparable with the ones from the instrumental data. Thus the macroseismic focal depth was found equal to 12Km and the macroseismic magnitude equal to 6.0.

DISCUSSION

The seismic sequence investigated in the present paper occurred in central Macedonia of northern Greece which is a part of the back-arc Aegean area. The 1990 seismic sequence in Goumenissa (40.9°N, 22.4°E) was preceded by a seismic sequence which occurred in Thessaloniki region (40.7°N, 23.3°E) in 1978.

The fault plane solution of the main shock shows that the T-axes are almost horizontal and trend in an about N-S direction. An extensional tectonics in the N-S direction, is also indicated by fault plane solutions of other strong earthquakes in the back-arc Aegean region (Papazachos and Comninakis, 1976; McKenzie, 1978; Papazachos et al., 1979, 1982, 1983; Jackson et al., 1982). On the other hand, geological studies and analysis of recent tectonic deformation in central Greece have shown an extensional phase during the middle Pleistocene-Recent as a result of expansion in the back-arc Aegean area (Mercier, 1977; Lemeille, 1977; Pavlides et al., 1990). In addition, latest studies for active crustal deformation in the Aegean area (Papazachos C. and Kiratzi, 1992; Papazachos C. at al., 1993) have shown that the deformation in central Macedonia is expressed as extension in a N162°E direction with a rate of 12.4 mm/yr which is in good agreement with the results of the presented paper.

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