

The reliability of reported depths of some earthquake sequences in Northwestern Greece (Epirus and Corfu Island) and the geodynamic situation of the area

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Abstract

The study of the earthquakes of the rectangle with coordinates 39° - 40° N 19° - 21° E is very important for a better understanding of the geodynamics of this area. In and near this zone, the subduction of the Aegean arc stops, and northward, going to the Albanian coast, the confrontation between the Adria microplate and the Albanian orogen is probably of collisional type. In this approach based on records of Greek seismological stations situated in this area as well as southern stations of the Albanian Seismological Network (ASN), the depth of the earthquakes of some sequences that occurred recently in this zone is carefully investigated. Some records of Southern Albanian seismological stations resulting from earthquakes with the same epicentral zone but reported with different depth are compared. The importance of detailed studies of this zone is stressed to shed light on the geodynamics of a key segment of the northwestern end of the Aegean arc.

Key words *microseismicity – earthquake sequence – hypocenter determination – focal depth – focal mechanism solution*

1. Introduction

It is well known that there are two ways of providing information about the present tectonics: 1) determining the accurate hypocentral location of earthquakes, and 2) using their fault plane solutions.

The area included in the rectangle with coordinates 39° - 40° N 19° - 21° E is seismically very active. This zone is dominated by a compressional stress field (thrust faulting) (McKenzie,

1978). According to Papazachos (1990), this tectonic unit takes part in the convergence of two continental lithospheres: the Apulian (Adriatic) lithosphere from the southwest and the front part of the Eurasian lithosphere (lithosphere of Albania and Central Greece) from the east. Some investigators are of the opinion that subduction does not continue north of Leukas Island (Aurox *et al.*, 1984; Sulstarova, 1987; Hatzfeld *et al.*, 1993; Hatzfeld *et al.*, 1995; Muço, 1995). Others are of a different opinion (Macropoulos and Burton, 1984) and assign great importance to the intermediate depth earthquakes resulting from some earthquake determinations in this area.

Careful seismic monitoring of this zone is of great interest because it is a key segment in the geodynamic situation of the Aegean and Southwestern Balkan peninsula.

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2. Seismic activity data

For the period 1900-1978 there are 35 earthquakes with $M_s \geq 4.5$ located within the coordinates $39^\circ\text{-}40^\circ\text{N}$ $19^\circ\text{-}21^\circ\text{E}$ (Macropoulos and Burton, 1981) (see fig. 1). Only 28 percent of them have a hypocentral depth greater than

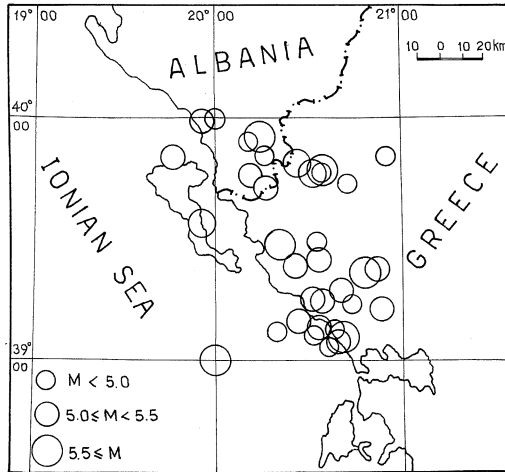


Fig. 1. The epicenters of the studied area for the period 1900-1978, $M_s \geq 4.5$.

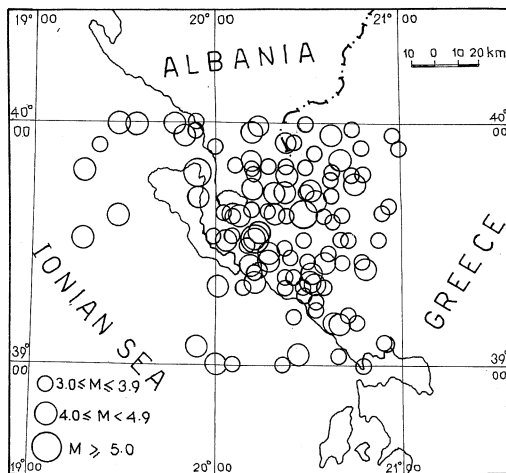


Fig. 2. The epicenters for the period 1979-1989, $M_L \geq 3.0$.

50 km. The deepest determination is 85 km. It should be noted that some of the earthquakes in the Albania-Greece border region with reported focal depth over 40 km (Macropoulos and Burton, 1981) are reported with focal depths of less than 20 km by other sources (Sulstarova and Koçaj, 1975).

The earthquakes of the period 1979-1989 are taken from the Seismological Monthly Bulletins of Athens Observatory (SMBAO) (fig. 2). From these earthquakes there are 26 cases which have depths exceeding 60 km.

The earthquakes of the period 1990-1992 are analyzed in detail in this paper. The data are also taken from SMBAO. We considered 6 earthquake sequences which are investigated in detail. These sequences are shown in table I.

3. Discussion on the focal depth

On the basis of the catalogue of Greece and surrounding area (Macropoulos and Burton, 1981), in their study, Macropoulos and Burton (1984) suggested that subduction is taking place even at the northwestern end of the Hellenic trench which includes the northwestern part of Greece, Corfu Island and the southwest coast of Albania.

From the data of SMBAO for the years 1990-1992, an impression could be created that going westward, from the land area to the sea, the depths of earthquakes tend to increase. We analyzed the sequence 2 of table I. The detailed data for this sequence are presented in table II and shown in fig. 3a. If we project the hypocenters of this sequence on the profile A-A' (which is nearly perpendicular to the coastline), fig. 3b is obtained. From this figure one could envision a subduction slab dipping to SW.

Thus, even if we consider reliable the earthquake depths of the sequences shown in table I, the subduction plane seemingly resulting from their spatial distribution dips the opposite way from subduction coming from the Hellenic trench.

On the other hand, are these epicenter determinations as reliable as to lead to the idea of active subduction in this area?

Table I. The sequences of earthquakes for the studied area, 1990-1992.

No.	Period of time	Number of earthquakes	M_L of main shock	Maximum focal depth (km)
1	November 10, 1990-December 22, 1990	12	4.2	72
2	March 15, 1991-March 19, 1991	26	4.4	130
3	May 6, 1992-May 8, 1992	5	4.6	60
4	June 14, 1992-July 9, 1992	12	4.8	43
5	November 13, 1992-November 24, 1992	6	3.4	63
6	December 16, 1992-January 3, 1993	8	4.3	141

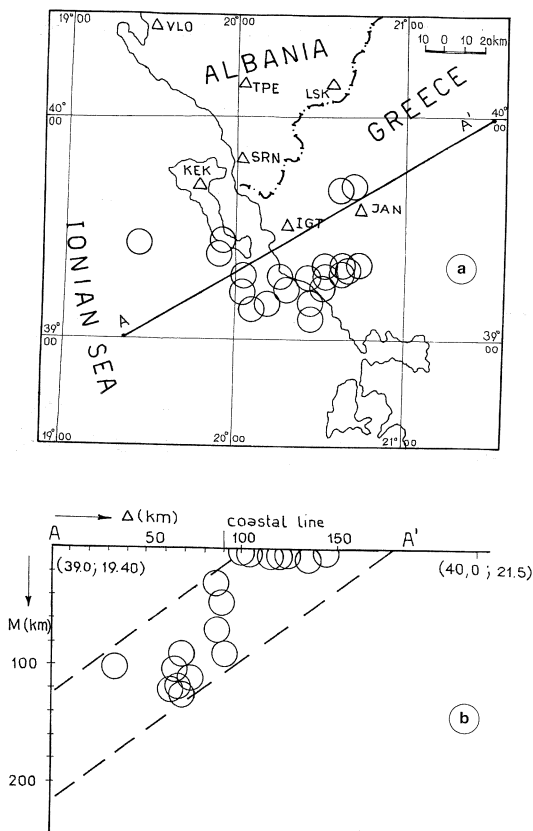


Fig. 3a,b. The epicenters of earthquakes of the sequence of March 1991 (see table II): a) the epicenters and profile A-A'; b) the depth distribution of the same hypocenters along A-A' profile.

Starting firstly only from a visual impression of records of the Albanian Seismological Network, we tried to judge the reliability of the depths reported for these earthquake sequences. Let us carefully investigate two earthquakes of March 17, 1991, 04 h 24 min ($M_L = 4.0$) and 19 h 22 min ($M_L = 4.4$). The SMBAO determinations give a depth of 96 and 1 km for these two events respectively (see table II). But their records from some seismological stations of the Albanian Seismological Network in South Albania do not reflect such difference of focal depth (fig. 4a-c). Comparing these two earthquakes recorded in SRN, LSK and TPE station, it seems that both of them have the same characteristics of shallow earthquakes and the difference in their reported depths does not appear to be justified.

For the earthquakes of the sequences included in table I, with depths 100-140 km, the time difference between P and S wave onsets at the seismological station of Saranda (SRN) is 10-12 s. From a simple calculation, such time difference could account for only a hypocentral distance up to 100-120 km, and keeping in mind that the depth reported is of the same value, it means that the hypocenters of these earthquakes should be located directly below the site of the SRN station, which is not the case.

We determined the hypocentral coordinates of all these earthquakes using the interactive hypocenter location algorithm recommended by Herrman (1979), modified with a procedure

Table II. Earthquake parameters of sequence 2, March 1991.

No.	Y	M	D	Origin time and coordinates from SMBAO			M_L	Origin time and coordinates from this study			Origin time and coordinates from ISC											
				h	min	s		FO	LO	HO	h	min	s	FO	LO	HO						
1	1991	03	15	13	30	20.2;	39.24;	20.58;	1	4.3	13	30	19.1;	39.21;	20.56;	31	13	30	19.3;	39.27;	20.54;	10
2	1991	03	15	14	36	09.3;	39.19;	20.06;	107	3.0	14	36	09.1;	39.21;	20.48;	12	14	36	11.6;	39.21;	20.54;	10
3	1991	03	15	18	04	53.8;	39.15;	20.20;	114	3.0	18	04	53.6;	39.19;	20.58;	12	18	04	54.0;	39.20;	20.20;	10
4	1991	03	17	04	24	07.8;	39.25;	20.06;	96	4.0	04	24	08.5;	39.25;	20.48;	34	04	24	10.9;	39.28;	20.49;	25
5	1991	03	17	15	11	41.1;	39.40;	19.48;	102	3.6	15	11	51.2;	39.33;	20.45;	32	15	11	50.5;	39.24;	20.46;	17
6	1991	03	17	19	20	58.1;	39.25;	20.47;	1	3.2	19	20	56.7;	39.25;	20.54;	30						
7	1991	03	17	19	22	11.3;	39.21;	20.53;	1	4.4	19	22	10.4;	39.19;	20.48;	34	19	22	10.6;	39.31;	20.51;	10
8	1991	03	18	23	28	50.5;	39.28;	20.63;	1	3.8	23	28	50.9;	39.17;	20.64;	37						
9	1991	03	19	02	37	02.5;	39.20;	20.32;	66	4.0	02	37	02.0;	39.11;	20.62;	37						
10	1991	03	19	02	51	19.7;	39.36;	19.93;	121	4.2	02	51	25.4;	39.34;	20.55;	25	02	51	25.6;	39.28;	20.46;	10
11	1991	03	19	03	12	28.2;	39.41;	19.94;	130													
12	1991	03	19	03	39	03.3;	39.11;	20.12;	122													
13	1991	03	19	05	47	20.9;	39.24;	20.29;	75													
14	1991	03	19	06	23	54.2;	39.28;	20.64;	1	3.0	06	23	51.0;	39.27;	20.69;	31						
15	1991	03	19	11	52	02.8;	39.86;	20.66;	1	3.1	11	52	01.3;	39.82;	20.73;	36						
16	1991	03	19	21	37	03.8;	39.26;	20.62;	1	3.0	21	37	01.4;	39.31;	20.56;	35						
17	1991	03	20	01	58	34.3;	39.29;	20.70;	4	3.1	01	58	31.4;	39.30;	20.68;	37						
18	1991	03	20	04	45	38.6;	39.29;	20.59;	1	3.5	04	45	35.0;	39.24;	20.57;	19						
19	1991	03	20	21	41	31.2;	39.09;	20.48;	53	2.9												
20	1991	03	23	23	54	43.0;	39.25;	20.47;	1	2.8												
21	1991	03	25	13	31	02.6;	39.67;	20.71;	9	2.8												
22	1991	03	26	08	27	33.1;	39.37;	20.72;	1	2.9												

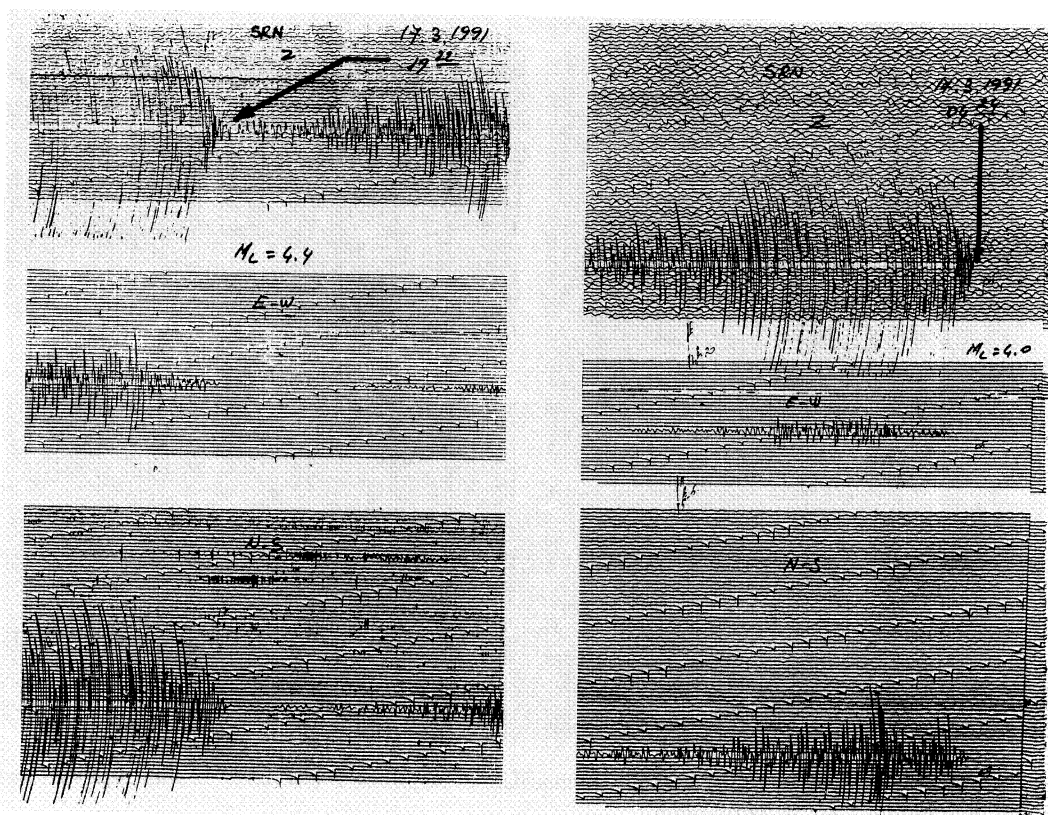


Fig. 4a. The comparison of records of two earthquakes of sequence 2 (see table I) with reported depth respectively 96 and 1 km in SRN station.

for more accurate depth determination (Muço, 1992). The velocity model used for the crust is a single layered model, with a constant crustal thickness of 40 km and a linear increasing step: $V = 5.0 + 0.016 H$ for crustal P_g phases and $V = 8.1 + 0.012 H^*$ for phases generated under the Mohorovicic discontinuity ($H^* = H - 40$) (Muço, 1992). Our determinations for the sequence of March 1991 shows depths different from those obtained by SMBAO.

Analyzing 22 earthquakes of the sequence of March 1991 (see table II), it is observed that in 11 cases with $H \geq 40$ km (reported by SMBAO), the Janina station (JAN) is not included in the hypocenter determination, while from the other 11 cases with $H < 40$ km, only in two of them

is JAN absent. In the localization procedure of SMBAO, also the Igumenitsa station (IGT), of the Thessaloniki Seismological Network and the South Albanian seismological stations: SRN, TPE, LSK, VLO, KBN, BERA, were not considered. In this case, it is well known that the hypocenter determination with a network not surrounding the true epicenter can easily produce inaccurate parameters.

It is important to note that even during temporary seismic investigation of this zone, no events resulted with a depth of more than 30 km. This is the case of a six-week detailed monitoring of this zone (King *et al.*, 1983) and also a two-year microearthquake survey in the Steno dam site which takes part of this region

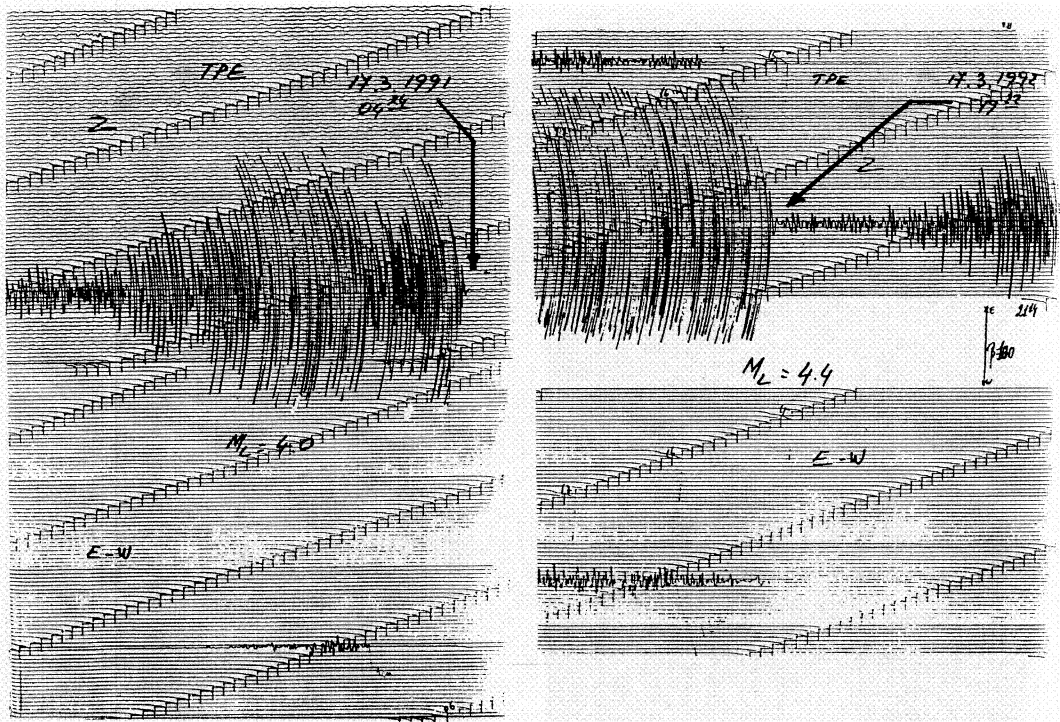


Fig. 4b. The comparison of records of two earthquakes of sequence 2 (see table I) with reported depth respectively 96 and 1 km in TPE station.

(Kiratzi *et al.*, 1987). From microseismic investigation of Epirus it is reported that there are no intermediate depth earthquakes in the period 1984-1989 (Hatzfeld, 1993; Hatzfeld *et al.*, 1993, 1995).

4. Fault solutions

The mapping of the data shows that the earthquakes of this zone do not occur on a single fault or a small number of major faults and it is difficult to say to what fault the earthquakes of this zone belong (figs. 1, 2 and 3a,b).

Our study is extended to the focal mechanism solutions of the considered area, which showed evidence for both normal and thrust faulting (McKenzie, 1972; King *et al.*, 1983;

Papazachos *et al.*, 1991). From 30 focal mechanism solutions for the earthquakes from 1964 to 1988 (Muço, 1992, 1994) a dominance of compressional stress is quite clear (the generalized vector has a strike 262° (WSW-NNE)). Figure 5 shows the generalized compressional and tensional stress vector and the focal mechanism solutions for the earthquakes of the above mentioned period, with $M_s \geq 5.0$.

Very interesting results are provided on this subject by Hatzfeld *et al.* (1995). The directions of *P* and *T* axes for Epirus in their study (Hatzfeld *et al.*, 1995) are almost the same as in our study.

As one can see, the stress pattern in Epirus and Corfu Island zone is quite similar to the Albanian coast where a continental collision between Adria microplate and Albanian orogen is taking place (Muço, 1992, 1994, 1995).

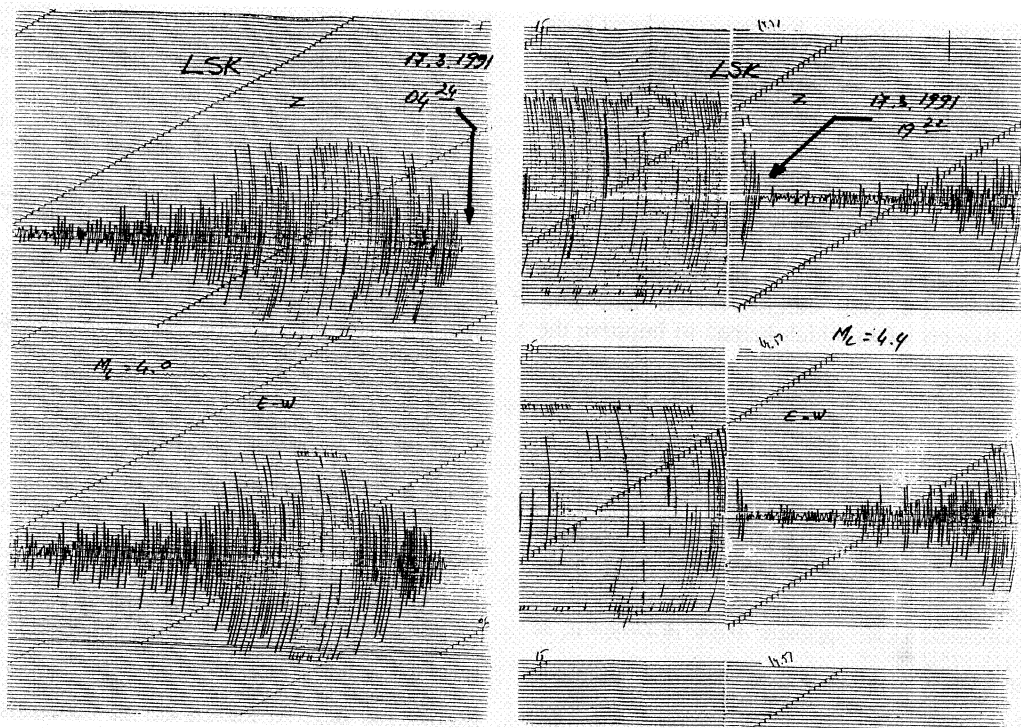


Fig. 4c. The comparison of records of two earthquakes of sequence 2 (see table I) with reported depth respectively 96 and 1 km in LSK station.

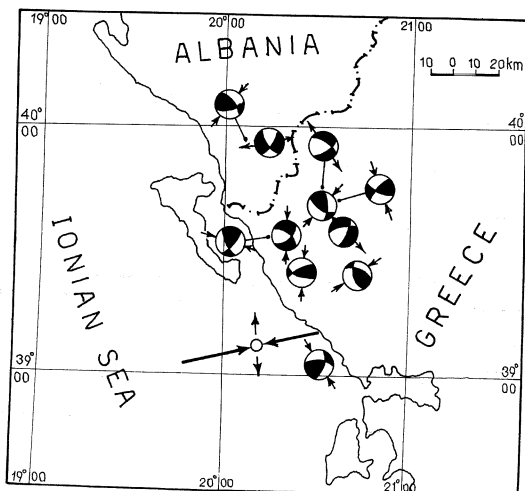


Fig. 5. Focal mechanism solutions for earthquakes of studied zone, 1964-1988, $M_s \geq 5.0$.

5. Some conclusions

1) Our opinion is that the earthquake depths reported for some recent sequences which occurred in the zone with coordinates 39° - 40° N 19° - 21° E are not reliable.

2) The focal mechanism solutions of earthquakes of this zone are similar to the Albanian coastal part where a continental collision is probably the case.

3) The recent seismological evidence does not support the hypothesis that a subduction zone is present from the gulf of Ambrakia to Corfu Island.

4) We emphasize the importance of accurate hypocenter determination and especially of focal depth, because some doubtful cases could easily lead to a quite untrue geodynamic situation of the region.

It is very important that the considered zone be investigated in more detail because this is a key segment in the northwestern edge of the Aegean arc.

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REFERENCES

- AUROUX, C., J. MASCLE and S. ROSSI (1984): Geologia del Margine Ionico dalle Isole Strofadi a Corfu (Estremità Settentrionale dell'Arco Ellenico), *Mem. Soc. Geol. It.*, **27**, 267-286.
- HATZFELD, D. (1993): Geodynamics of the Aegean: a microseismotectonic approach, *Annali di Geofisica*, **36** (2), 215-228.
- HATZFELD, D., K. MACROPOULOS and P. HATZIDIMITRIOU (1993): The intermediate depth seismicity related to Hellenic subduction, in *Proceedings of the 2nd Congress of the Hellenic Geophys. Union, Florina, Greece, 5-7 May*, 388-396.
- HATZFELD, D., J. KASSARAS, D. PANAGIOTOPOULOS, D. AMORESE, K. MAKROPOULOS, G. HARAKAISIS and O. COUTANT (1995): Microseismicity and strain pattern in Northwestern Greece, *Tectonics*, **14** (4), 773-785.
- HERRMAN, R.B. (1979): Fasthypo-a hypocenter location program, *Earthquake Notes*, **50**, 64-83.
- KING, G.C.P., A. TSELENTIS, J. GOMBERG, P. MOLNAR, S.W. ROECKER, H. SINVAL, C. SOUFLERIS and J.M. STOCK (1983): Microearthquake seismicity and active tectonics of Northwestern Greece, *Earth Planet. Sci. Lett.*, **66**, 279-288.
- KIRATZI, A.A., E.E. PAPADIMITRIOU and B.C. PAPAZACHOS (1987): A microearthquake survey in the Stenodam site in Northwestern Greece, *Annales Geophysicae*, **5B**(2), 161-166.
- MACROPOULOS, K.C. and P.W. BURTON (1981): A catalogue of seismicity in Greece and adjacent areas, *Geophys. J. R. Astron. Soc.*, **65**, 741-762 and Microfiche Gj 65/1.
- MACROPOULOS, K.C. and P.W. BURTON (1984): Greek tectonics and seismicity, *Tectonophysics*, **106**, 275-304.
- MCKENZIE, D.P. (1972): Active tectonics of the mediterranean Region, *Geophys. J. R. Astron. Soc.*, **30**, 109-185.
- MCKENZIE, D.P. (1978): Active tectonics of the Alpine-Himalayan belt: the Aegean Sea and Surrounding Region, *Geophys. J. R. Astron. Soc.*, **55**, 217-254.
- MUÇO, B. (1992): Features of Albanian earthquakes and role of underground water in their generation, *D. Sc. Thesis*, Seismological Center, Tirana, Albania, pp. 210 (in Albanian).
- MUÇO, B. (1994): Focal mechanism solutions for Albanian earthquakes for the years 1964-1988, *Tectonophysics*, **23**, 311-323.
- MUÇO, B. (1995): The collision between Adria and Albanian orogen on the light of focal mechanism solutions, in *Proceedings of 10th European Conference on Earthquake Eng., Vienna, September, 1994* (Duma, Editor, Balkema, Rotterdam), vol. **1**, 37-41.
- PAPAZACHOS, B.C. (1990): Seismicity of the Aegean and surrounding area, *Tectonophysics*, **178**, 287-308.
- PAPAZACHOS, B.C., A. KIRATZI and E. PAPADIMITRIOU (1991): Regional focal mechanisms for earthquakes in the Aegean Area, *Pageoph.*, **136** (4), 405-420.
- SULSTAROVA, E. and S. KOÇIAJ (1975): Catalogue of Albania, Seismological Center, Academy of Sciences, Tirana, Albania (in Albanian).
- SULSTAROVA, E. (1987): The field of recent tectonic stresses on the Alpin-Mediterranean region and Focal Mechanism Solutions for Balkan area, *Bul. Shk. Gjeol.*, **2**, 135-152 (in Albanian).

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