THE APRIL-AUGUST 2002 MOLDOVA NOUĂ EARTHQUAKES SEQUENCE AND ITS SEISMOTECTONIC SIGNIFICANCE*

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Starting with 19 April 2002, a series of crustal earthquakes occurred near the Romanian – Serbian border, South of the Banat seismic region, into the Danube seismogenic zone. Until the end of August 2002, the stations of the Banat seismic network recorded 70 earthquakes ($1.8 \leq M_D \leq 4.8$) with the epicenters clustered within a small area, elongated in North-South direction and located near the town of Moldova Nouă. In this time interval, two main-shocks occurred, on 24 May 2002 ($M_D = 4.8$) and on 2 August 2002 ($M_D = 4.6$). Significant damages (Io = VI-VII MSK) were reported in the epicentral (Moldova Nouă) area. Temporal distribution of the earthquakes indicates at least three stages of strain release. The focal mechanisms derived from P first-motion polarities, obtained for the first time for the Moldova Nouă area, exhibit: i) a dominant normal faulting (23 May 2002, $M_D = 3.8$) and ii) a strike-slip faulting with a large normal component (for the two largest events). The fault plane oriented N–S and dipping around 60º to the West is practically identical for all three events. The sequence appears to have occurred on the southern segment of the Oraviţa Fault.

Key words: Danube seismogenic zone, Banat Seismic Network, focal mechanism solutions, Oraviţa Fault, macroseismic intensities, seismotectonics.

INTRODUCTION

The 2002 Moldova Nouă earthquake sequence occurred in the southern part of the Banat region, one of the most seismically active regions of Romania. Two seismogenic zones have been identified in this area (Radulian *et al.*, 2000): i) the Banat seismogenic zone in the North and ii) the Danube seismogenic zone in the South.

The sequence studied in the present paper is located in the western part of the Danube Zone, near the town of Moldova Nouă (Fig. 3), into a small depression filled with young sediments (Neogene and Quaternary aged). The high earthquake potential of this zone is supported by many crustal earthquakes with $M_w \geq 4.1$, Io ≥ VI MSK (Oncescu *et al.*, 1999), which occurred within two main sub-zones: Moldova Nouă–Oraviţa–Reşiţa in the west and Herculane Spa–Mehadia–Orşova in the east. Since 1894 the Moldova Nouă–Dognecea area has been seismically quiescent, at least for $M_w \geq 4.1$ (Table 1).

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Table 1

Historical earthquakes (I_o≥VI MSK) occurred in the Danube Seismogenic Zone between 984 and 2002 (after Oncescu *et al.*, 1999 and Romplus, www.infp.ro)

No.	Date d	m	y	Origin-time hh	mm	ss.s	Lat °N	Long °E	Depth (km)	Mw	I max (MSK)	Area
1	28	9	1879	15	30	0.0	44.80N	21.50E	9.9*	4.7	7	Ro/Yu border
2	10	10	1879	15	45	0.0	44.70N	21.60E	9.9*	5.3	8	Moldova Nouă
3	10	10	1879	18	30	0.0	44.70N	21.60E	9.9*	4.7	7	Moldova Nouă
4	10	10	1879	19	30	0.0	44.70N	21.60E	9.9*	4.7	7	Moldova Nouă
5	11	10	1879	1	0	0.0	44.70N	21.60E	9.9*	4.7	7	Moldova Nouă
6	11	10	1879	2	45	0.0	44.70N	21.60E	9.9*	5.3	8	Moldova Nouă
7	11	10	1879	10	45	0.0	44.70N	21.60E	9.9*	4.7	7	Moldova Nouă
8	17	10	1879	2	53	0.0	44.70N	21.60E	9.9*	4.7	7	Moldova Nouă
9	20	10	1879	10	45	0.0	44.70N	21.70E	9.9*	4.7	7	Moldova Nouă
10	22	12	1879	4	3	0.0	44.70N	21.60E	9.9*	4.7	7	Moldova Nouă
11	23	2	1880	21	30	0.0	44.50N	21.60E	9.9*	4.7	7	Moldova Nouă
12	1	3	1880	2	45	0.0	44.70N	21.60E	9.9*	4.7	7	Moldova Nouă
13	13	4	1880	12	20	0.0	44.60N	21.60E	9.9*	4.7	7	Moldova Nouă
14	19	12	1894	21	30	0.0	45.00N	21.70E	9.9*	4.7	7	Oravița
15	31	8	1909	21	21	29.0	45.10N	21.80E	20.0	4.4	6	Anina
16	11	10	1910	11	52	9.0	44.90N	22.40E	7.0	4.3	6	Herculane Spa
17	16	4	1912	4	30	0.0	45.20N	21.90E	9.9*	4.1	6	Dognecea
18	24	3	1922	12	21	50.0	45.00N	22.00E	9.9*	4.1	6	Bozovici
19	31	5	1927	22	58	15.0	44.90N	21.70E	16.0	4.4	6	Sasca
20	20	6	1943	1	0	0.0	45.00N	23.00E	9.9*	5.2	6	Baia de Aramă
21	18	7	1991	11	56	0.0	44.90N	22.40E	12.0	5.6	7-8	Herculane Spa

The recent seismic activity in the area (1996–2002) is characterized by two spatial clusters in the Moldova Nouă – South Danube zone, on the Oravița Fault System, and in the Herculane Spa–Orşova area, on the Cerna–Jiu Fault System (Oros, 1998, 2003; Oros, Nițoiu, 2000a, 2001).

The Alpine basement nappes, locally covered by Neogene intramountain depressions, characterize the regional structure. The faults system oriented NNE–SSW and dipping to the west dominates the regional tectonics. The most important crustal faults are: Oravița Fault (OF) and Cerna–Jiu Fault System (CJFS) (Fig. 1).

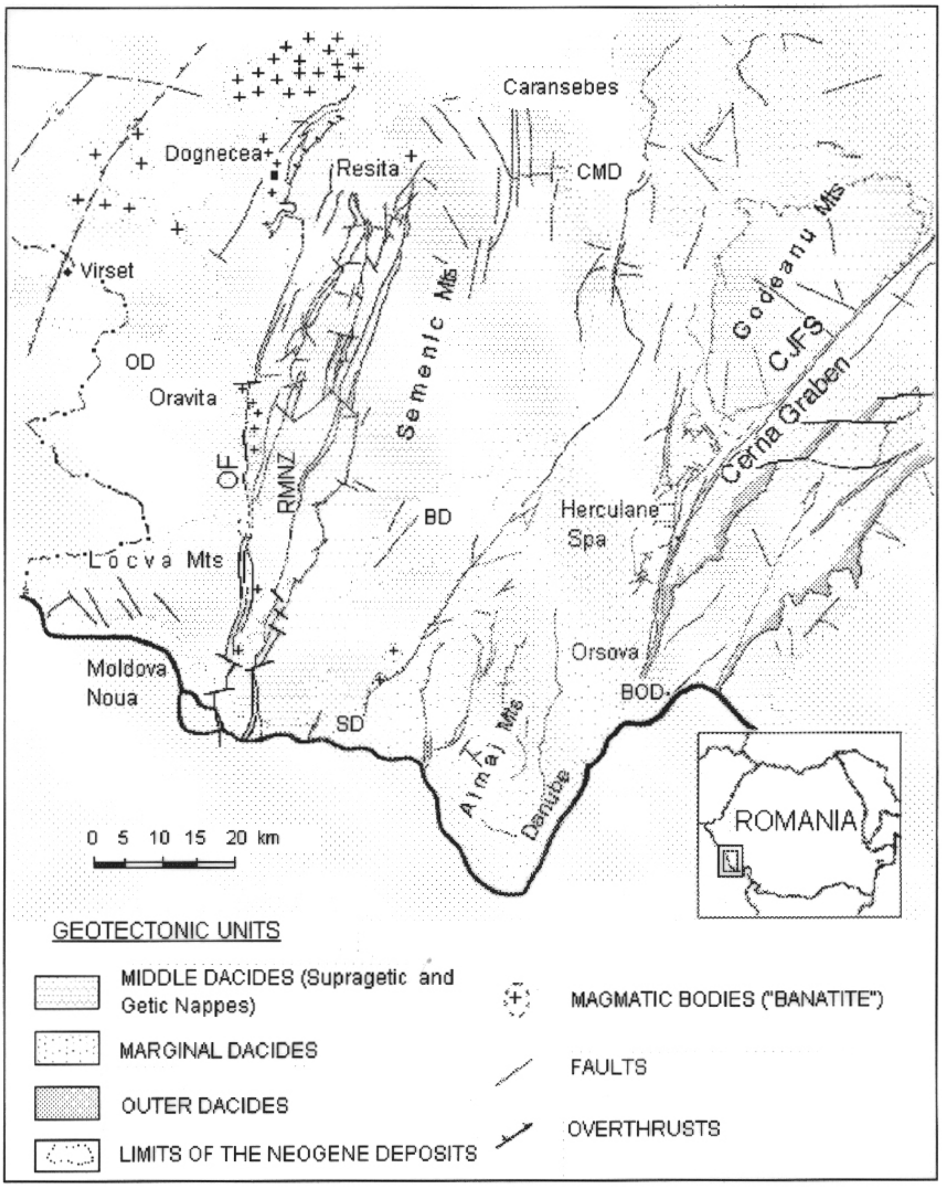


Fig. 1 – Geological map of the Danube Seismogenic Zone (compiled after the Geological Map of Romania, Reşiţa Sheet, 1968; Mutihac and Ionesi, 1974; Sandulescu, 1984). OF, Oravita Fault; CJSF, Cerna-Jiu Fault System; CMD, Caransebeş-Mehadia Depression; BOD, Bahna-Orşova Depression; SD, Sicheviţa Depression; BD, Bozovici Depression; OD, Oraviţa Depression.

The present paper analyzes the 2002 Moldova Nouă earthquake sequence in relation with tectonics (Dimitrescu, 1995; Geological map of Romania, 1968; Săndulescu, 1984), tectonic stress field (Radulian *et al.*, 2000) and historical seismicity (Oncescu *et al.*, 1999; Zsiros *et al.*, 1988). The main aim of the study is to identify the seismotectonic features in the Moldova Nouă area required by seismic hazard studies.

GEOLOGIC AND TECTONIC SETTING

The Danube seismogenic zone, where the 2002 Moldova Nouă earthquake sequence occurred, lies on the south-western extremity of the Southern Carpathians (Fig. 1).

The geological history of the region is complex, the present structure and tectonics being the results of many Alpine tectogeneses. Three main geotectonic units are present in the region (Săndulescu, 1984): Median Dacides (Supra-Getic and Getic Nappes), Marginal Dacides (Danubian Unit) and Outer Dacides (Severin Nappe). They are basement nappes (crystalline schists and their Paleozoic-Mesozoic sedimentary cover) that overthrust from west to east along some tectonic planes and crustal almost west-dipping faults (Geological Map of Romania, 1968; Săndulescu, 1984). The subsequent Alpine magmatism crosses the basement of the region following several NNE oriented alignments (Fig. 1).

In the Neotectonic stage (started in the region in Middle Miocen, ca 14.5 m.y.) characterized by predominant vertical movements controlled by active fractures, different basement sectors suffered different displacements. Many intramountain depressions filled with Neogene sediments were formed onto pre-existing structures (Mutihac, Ionesi, 1974): Caransebeş–Mehadia Depression, Orşova–Bahna Depression, Sichevița Depression and Danube Passage, Bozovici Depression, Oravița Depression (Fig. 1).

Two major tectonic zones, with rather intensive activity, outcrop in the region: the Cerna Graben (CG), in the east and the Resița–Moldova Nouă Zone (RMNZ), in the west.

The 2002 earthquakes sequence occurred within the southern sector of RMNZ, at its western border. This zone represents the sedimentary cover of the Getic Nappe and is a regional NNE–SSW oriented syncline bordered by longitudinal faults. The structure is very complex due to secondary folds of which eastern flanks are laminated by longitudinal faults dipping to the west with different angles (the smallest in the upper layers of the crust). They form the so-called "scales folds" (Geological Map of Romania, 1968, Mutihac, Ionesi, 1974, Oros, 1984). In addition, transversal and oblique transcurent faults break up the whole zone into many tectonic blocks. The Oravița Fault (OF) is the western limit of the RMNZ. It can be observed at the surface from Resița to Moldova Nouă and farther to the south of the Danube. This crustal fault has controlled the major Alpine tectonic processes in the region. The Supra-Getic Nappes overthrust the Getic Nappe along it. There is also a clear relationship between OF system and the post-tectonic magmatism from Oravița down to Moldova Nouă (Fig. 1). The Neotectonic subsidence of several areas along the western boundary of the region appears to have been strongly influenced by the Oravița Fault System dynamics.

In the Moldova Nouă zone (Fig. 2), the OF is segmented by two local EW striking transcurent faults (North Moldova Nouă Fault and South Moldova Nouă Fault). The Moldova Nouă tectonic block resulted at the foot of the Locvei Mountains is shifted to the east and has its western margin covered by unconsolidated sediments (loess with sands and gravels of Quaternary age) (Geological Map of Romania, 1968).

Several NNV–SSE oriented faults can be observed in the Locvei Mountains area. Contemporary tectonic activity of the OF is mainly reflected in the seismicity recorded along it, between Moldova Nouă and Dognecea.

SEISMICITY

The seismicity of the Danube seismogenic zone is rather intensive, with crustal moderate size earthquakes (depth between 7.0 km and 20 km, Imax.obs = VIII MSK, Mmax = 5.6). A list of the historical earthquakes is presented in Table 1 (after Oncescu *et al.*, 1999; Romplus Catalogue, www.infp.ro). Detailed information on these earthquakes can be also found in the papers of Rethly, 1952; Florinescu, 1958; Atanasiu, 1961; Shebalin *et al.*, 1974; Radu, 1974; Constantinescu, Mârza, 1982; Zsiros *et al.*, 1988.

The distribution of the epicenters is shown in Fig. 2 and Fig. 7. The seismic activity is generated in two sub-zones: Orşova–Herculane Spa to the east and Moldova Nouă–Dognecea to the west (Fig. 7) which are well delimited on the maps of the regional tectonic flux (Oros, 1991, 1992).

Several significant epicentral areas are already well known (Ms ≥ 4.1, Io ≥ VI MSK): Orşova, Herculane Spa, Moldova Nouă, Oravița, Sasca, Anina, Bozovici and Dognecea. Three strong earthquakes are reported in the region: 10 October 1879, Io = VIII MSK, Ms = 5.6; 11 October 1879, Io = VIII MSK, Ms = 5.6; 18 July 1991, Io = VII-VIII MSK, Ms = 5.5. About 70 km to the south, on Serbian territory, in the Lapovo-Kragujevac seismic area, strong historical earthquakes (*e.g.* 08 April 1893, Io = IX MSK, M = 6.5) (Zsiros *et al.*, 1988) occurred as well.

The 1879–1880 Moldova Nouă earthquake sequence, one of the most important in the region, lasted for seven months. Within this time interval, 2 strong main-shocks (Ms = 5.6) occurred in two days and more aftershocks with Io = VII MSK occurred until April 1880. The main-shocks caused substantial damage in Moldova Nouă area (*e.g.* 93% of the houses of Moldova Nouă were severely affected). Surface faulting about 1.2 m width and 1,200 m length was also reported in the epicenter area. The two strongest earthquakes were felt at long distance, into an area of 76,000 km^2 (Rethly, 1952 – from Atanasiu, 1961). Since 1880, no seismic event with M ≥ 4.1 has occurred in the Moldova Nouă area. The macroseismic maps of the strongest shocks are displayed in Fig. 3 after (Shebalin *et al.*, 1974).

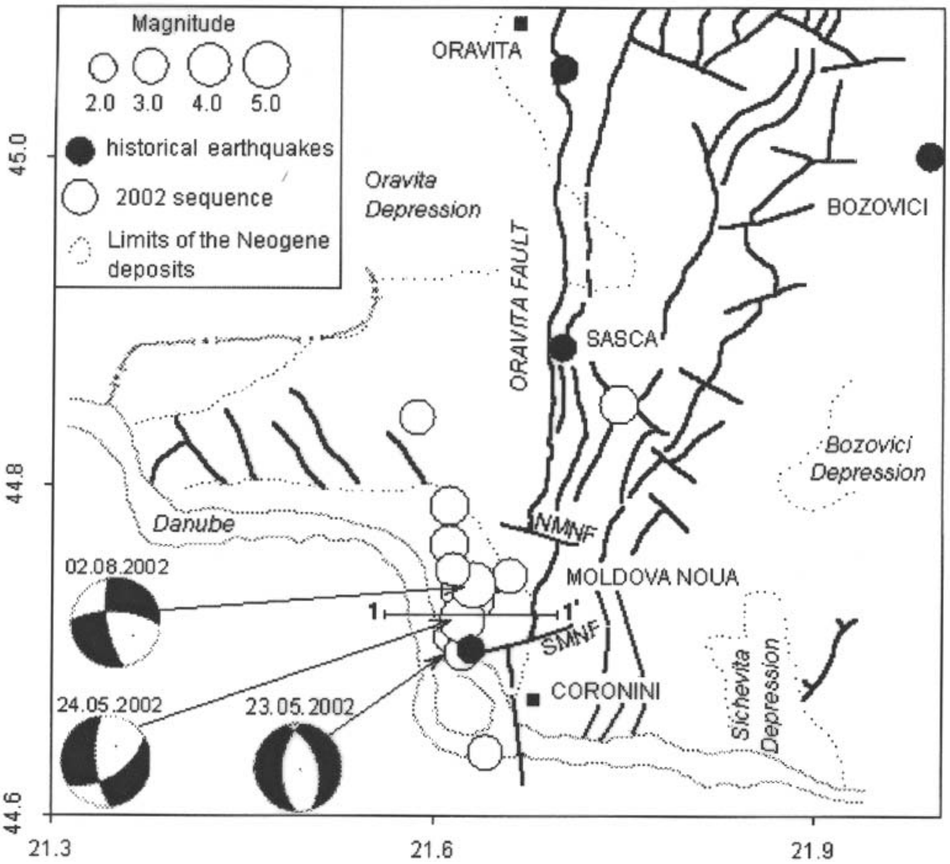


Fig. 2 – The 2002 Moldova Nouă earthquake sequence recorded by the Banat seismic network. The map shows epicenters and main faults (dashed if inferred) from the Geological Map of Romania (Reşiţa Sheet, 1968) and the focal mechanisms determined in this paper. The Ms≥4.1 (Io≥VI MSK) historical earthquakes are plotted with full circles. The profile 1–1' is also represented. NMNF is North Moldova Nouă Fault; SMNF is South Moldova Nouă Fault.

The recent seismic activity (1996–2002) is clustered in the two main subzones mentioned above, along the OF and CJFS (Oros, 2003; Oros, Niţoiu, 1998, 2000a, 2001).

DATA AND ANALYSIS

The 2002 Moldova Nouă earthquake sequence was recorded by the Banat seismic network which belongs to the National Institute for Earth Physics, Bucharest, Romania. Five seismic stations operate within this network, four of them being located NNW from Moldova Nouă area and one NNE (www.infp.ro). The most sensitive station (BZS), situated approximately 100 km NNW from Moldova Nouă area, has the detection magnitude threshold of $M_D = 2.0 \pm 0.3$ (Oros, 2000).

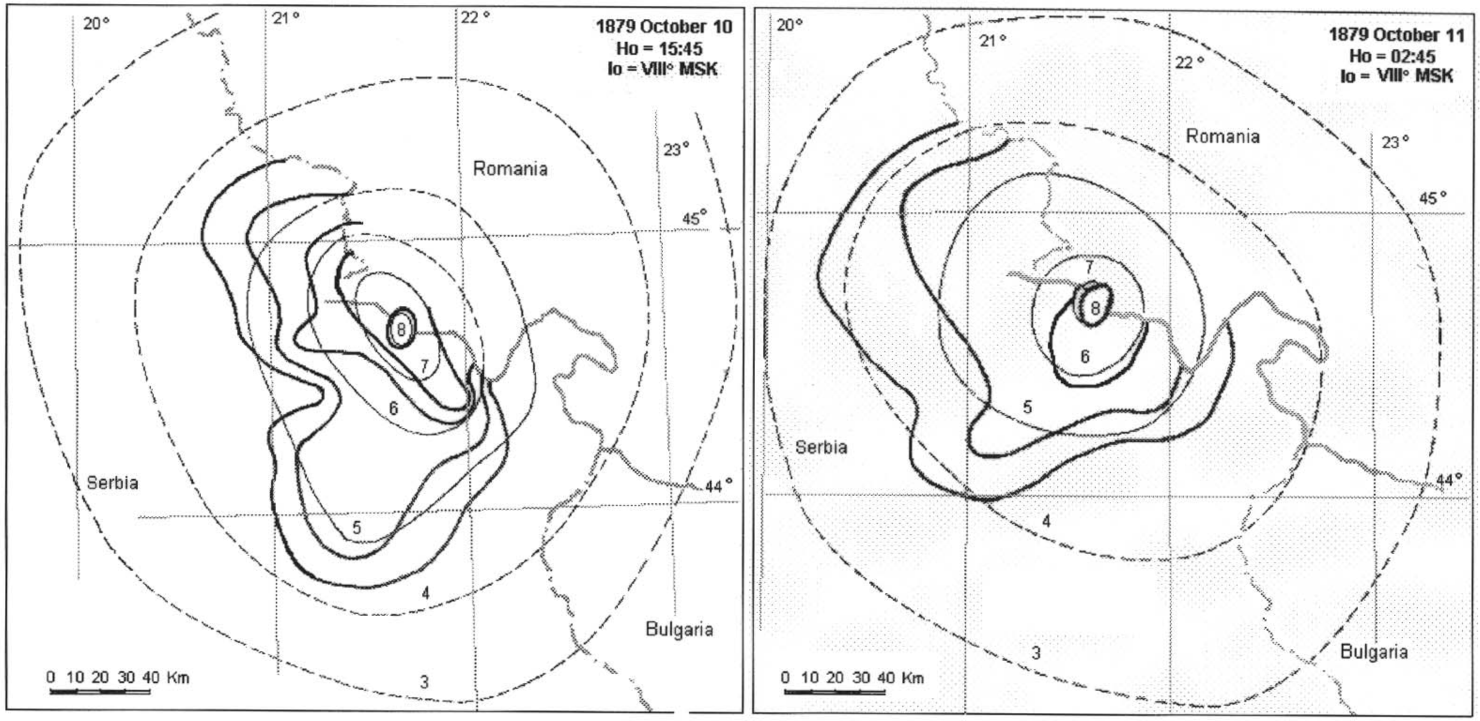


Fig. 3 – Macroseimic maps of the strongest earthquakes occurred within the Moldova Nouă area (after Shebalin *et al.*, 1974). Thick black lines are the original isoseismals reported by authors and the dashed thin lines are the generalized ones by Shebalin.

Seventy earthquakes ($1.8 \leq M_D \leq 4.8$) were recorded between 1 April 2002 and 31 August 2002. Good-quality focal parameters were obtained for thirteen of them, using additional data from other seismological agencies (especially from: Hungary, Serbia and Muntenegru). The P and S arrival times, coda and P-wave first-motion data were processed using SEISAN (Havskov, Ottemoller, 2002) and HYPOPLUS (Oncescu, Rizescu, 1996) seismological software packages.

The first focal mechanism solutions of earthquakes of the Moldova Nouă area are obtained in this study. The results are presented in Table 2 (focal parameters) and in Table 3 (focal mechanisms) and are displayed in the Figs. 2, 4 and 7.

Table 2

List of the earthquakes occurred between 01.04-31.08.2002 in the Moldova Nouă area

No.	Date d m y	Origin-time h	 m	 ss.s	Lat N ±SD	Long E ±SD	Depth (km) ±SD	MD	Ms / Io (MSK)
1	19.04.2002	22	41	48.1				1.8	
2	24.04.2002	0	12	33.3	44.731 9.1	21.633 10.1	6.4 6.7	3.6	2.8 / IV
3	24.04.2002	1	16	16.5				3.0	
4	25.04.2002	20	6	59.5				3.4	
5	27.04.2002	8	14	5.3				1.8	
6	28.04.2002	22	53	51.4				2.1	
7	01.05.2002	7	29	4.0				2.0	
8	03.05.2002	13	10	24.1	44.736 2.1	21.621 5.3	5.2 2.3	3.7	2.9 / IV
9	03.05.2002	14	21	43.3				2.9	
10	07.05.2002	3	38	2.4				2.6	
11	07.05.2002	17	13	59.7				2.5	
12	07.05.2002	22	3	45.2				3.2	
13	08.05.2002	0	1	27.7				2.8	
14	08.05.2002	2	3	43.0				2.1	
15	08.05.2002	6	6	41.6				2.5	
16	09.05.2002	10	33	28.8				2.9	
17	10.05.2002	23	54	26.8				2.0	
18	11.05.2002	0	5	28.6				2.3	
19	15.05.2002	14	4	35.9				2.1	
20	18.05.2002	5	33	16.6	44.638	21.641	10.0F	2.8	
21	20.05.2002	2	2	30.7				2.6	
22	23.05.2005	3	26	0.3	44.709 3.1	21.615 2.8	7.5 3.2	3.6	2.8 / IV

Table 2 (continued)

No.	Date d m y	Origin-time h	m	ss.s	Lat N ±SD	Long E ±SD	Depth (km) ±SD	MD	Ms / Io (MSK)
23	23.05.2002	10	9	19.6	44.698	21.612	10.0F	3.0	
24	23.05.2002	21	55	46.0				2.0	
25	24.05.2002	3	39	53.5				2.3	
26	24.05.2002	11	14	38.6				2.9	
27	24.05.2002	17	19	51.6				2.4	
28	24.05.2002	20	42	27.5	44.718 2.4	21.622 3.1	8.5 2.2	4.8	4.4 / VI-VII
29	24.05.2002	20	54	58.6				2.9	
30	24.05.2002	22	50	1.5	44.849	21.745	10.0F	3.3	
31	24.05.2002	23	7	0.5				2.4	
32	24.05.2002	23	38	59.8				2.0	
33	25.05.2002	7	46	22.6				1.9	
34	25.05.2002	9	46	0.2				2.0	
35	25.05.2002	12	57	42.1	44.745	21.660	10.0F	3.1	
36	25.05.2002	13	29	54.0				2.3	
37	25.05.2002	15	0	43.8				2.7	
38	25.05.2002	16	5	18.2				2.1	
39	25.05.2002	19	2	32.5				2.6	
40	26.05.2002	16	20	45.6				3.2	
41	28.05.2002	2	10	25.4				2.6	
42	28.05.2002	22	15	0.9				2.6	
43	08.06.2002	23	51	1.9				1.8	
44	16.06.2002	6	38	54.5				2.9	
45	18.06.2002	13	20	0.5				2.1	
46	21.06.2002	8	35	5.0				2.1	
47	23.06.2002	2	51	0.5	44.841	21.587	10.0F	3.1	
48	23.06.2002	15	13	26.2				2.3	
49	23.06.2002	21	29	9.3				2.4	
50	25.06.2002	13	1	15.5				3.1	

Table 2 (continued)

No.	Date d m y	Origin-time h	m	ss.s	Lat N ±SD	Long E ±SD	Depth (km) ±SD	MD	Ms / Io (MSK)
51	25.06.2002	20	3	41.3				2.5	
52	29.06.2002	21	49	35.6				2.1	
53	01.07.2002	21	27	33.8				2.4	
54	08.07.2002	17	19	44.2				2.2	
55	09.07.2002	18	18	4.9				2.5	
56	13.07.2002	5	32	11.9	44.764	21.613	15.0F	3.3	
57	24.07.2002	11	51	26.4				2.5	
58	31.07.2002	21	27	33.8				2.4	
59	01.08.2002	15	32	29.9				2.2	
60	01.08.2002	19	33	17.7				2.3	
61	02.08.2002	9	31	25.7	44.748	21.615	10.0F	3.1	
62	02.08.2002	9	37	19.1	44.739 2.2	21.638 4.6	6.2 3.6	4.6	4.3 / VI-VII
63	04.08.2002	6	4	9.5				1.8	
64	04.08.2002	18	27	27.5	44.787	21.612	10.0F	3.4	
65	05.08.2002	1	57	44.1				2.2	
66	09.08.2002	16	5	52.8				2.4	
67	13.08.2002	3	26	14.9				1.8	
68	13.08.2002	12	25	52.7				2.5	
69	31.08.2002	5	11	25.8				2.7	

The coda magnitude (M_D) obtained with Lee's formula (Lee *et al.*, 1972) is used for the analysis (maps, graphics, statistics). The maximum intensity (Io) is estimated using the relationship (Radu, 1974):

$$M = 0.6Io + 0.52 \quad (1)$$

where M is Ms derived from M_D – Ms conversion relationship (Radu, 1974):

$$Ms = -2.14 + 1.43M_D - 0.018\ M_D^2 \quad (2)$$

Source parameters (seismic moment, corner frequency, Mw, source radius, stress drop) for three earthquakes were derived from P-wave displacement spectra using SEISAN software package (Havskov, Ottemoller, 2002).

Table 3

Focal mechanisms parameters for three seismic events of the 2000 Moldova Nouă earthquakes sequence

No.	Date d m y	Origin-time (h:m:s)	Lat N	Long E	Depth (km)	Ms	Plane 1			Plane 2			P		T		No polarities gap
							strike	dip	rake	strike	dip	rake	strike	plunge	strike	plunge	
1	23.05.2002	03:26:01.0	44.709	21.618	7.5	2.8	183	49	-77	344	43	-104	157	80	264	3	25 78
2	24.05.2002	20:42:28.6	44.718	21.622	8.5	4.4	173	62	-132	55	49	-39	31	53	291	8	51 65
3	02.08.2002	09:37:21.0	44.739	21.638	6.2	4.3	171	65	-29	274	64	-152	132	37	223	1	37 73

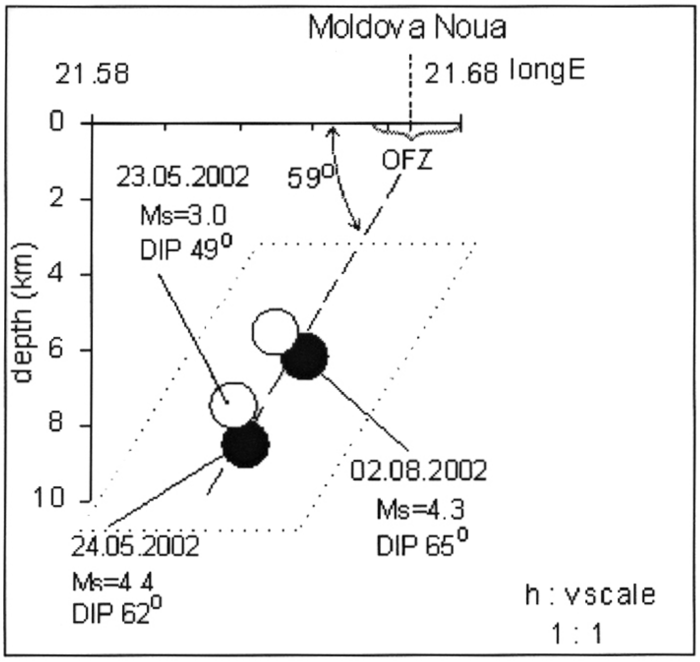


Fig. 4 – The 2002 Moldova Nouă earthquake sequence. Earthquake hypocenters projected onto the East–West vertical plane (profile 1–1' in Fig. 3). The best constrained hypocenters are displayed. The dashed line is the projection of the prolongation of the focal plane up to the surface (average angle 59º); it correlates with the Oravița Fault.

Macroseismic investigation was also carried out for the strongest shock of 24 May 2002 (Ms = 4.4). The map of the distribution of the macroseismic intensities is presented in the Fig. 6.

RESULTS

Our results, mainly the preferred nodal planes from focal mechanism solutions and spatial distribution of the epicenters can not be related immediately to surficial structures and faults, chiefly due to errors in locations, small number of earthquakes with reliable records and the poor knowledge of the 3D geometry of the tectonics. Only good-quality hypocenter determinations (errors in depth and horizontal coordinates less than 3.0 and 5.0 km, respectively) are used in the detailed analysis, for reliable interpretations.

Spatial Distribution. The relation between the focal zone of 2002 Moldova Nouă earthquake sequence and the nearby mapped faults is analyzed using the hypocenters of Table 2. The epicenters of the sequence are plotted on the map of Moldova Nouă–Oravița zone (Fig. 3). Their distribution forms a small NS elongated area (ca 2.5 km × 10 km) at about 5 km west from Oravița Fault Zone that has the same direction.

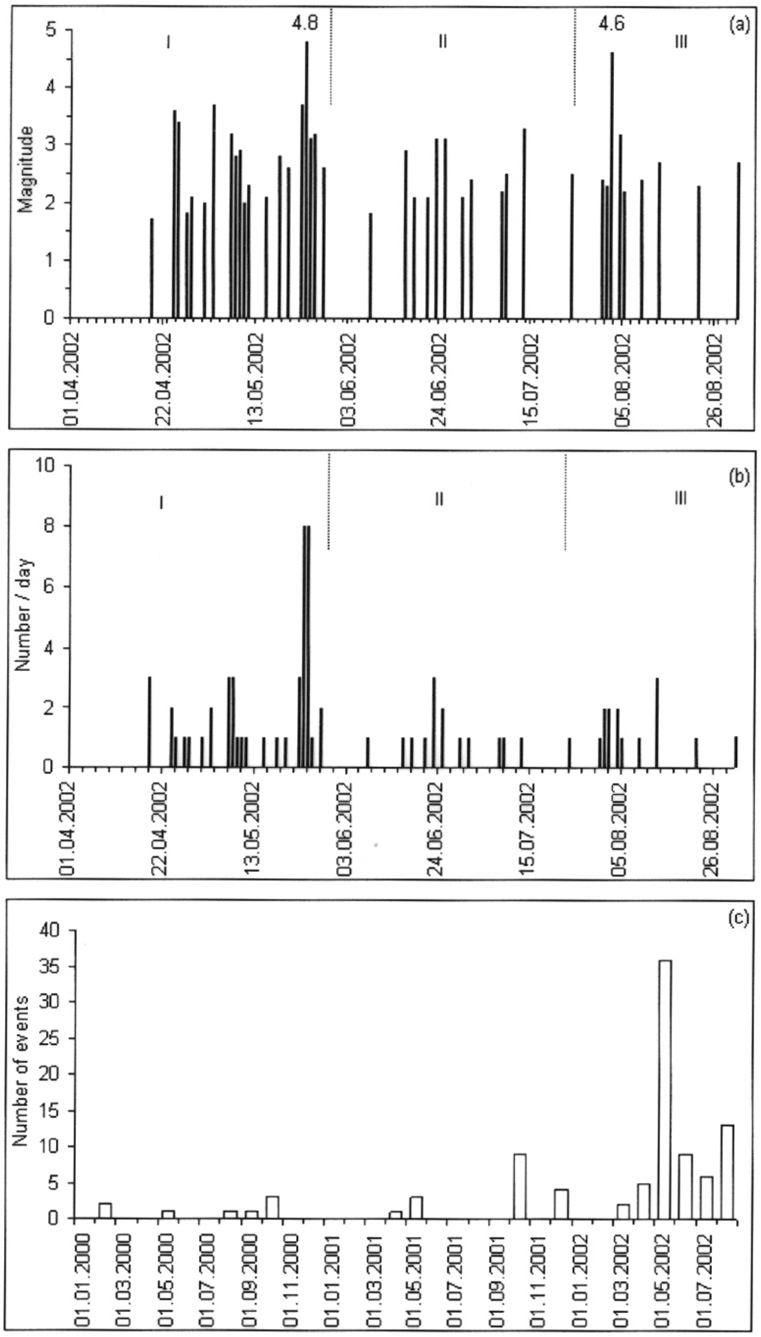


Fig. 5 – Time evolution of the 2002 Moldova Nouă earthquakes sequence. (a) Earthquake magnitude (M_D) *versus* time. (b) Absolute frequency (number/day) of the sequence events. The three stages of strain release (I, II, III) are marked by dotted lines. (c) Seismic activity recorded in the Moldova Nouă area between January 2000 and August 2002 (monthly absolute frequency).

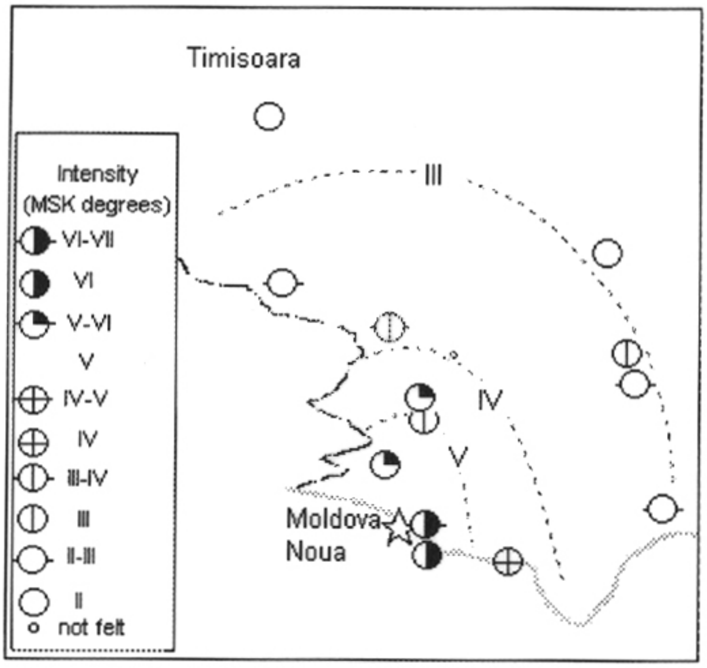


Fig. 6 – Distribution of the macroseismic intensities and isoseismals (dotted lines) for the strongest shock of the 2002 Moldova Nouă earthquake sequence (24 May 2002, H=20:42, Ms=4.4, Io=VI-VII MSK). The star is the epicenter located instrumentally.

The hypocenter distribution along an E–W vertical plane (profile 1-1' in Fig. 3) is presented in Fig. 4. The hypocenters are situated in the depth range 5.2 to 8.5 km on a west-dipping fault plane (average dip angle $59^0 \pm 6^0$). The intersection of this plane with the free surface correlates well with the observed Oravița Fault zone.

Focal Mechanisms. The focal mechanisms (Table 3 and Fig. 3) show: i) dominant normal faulting for the 23 May 2002 earthquake and ii) a strike-slip faulting with a large normal component for the two largest shocks (24 May and 2 August 2002, respectively). The preferred nodal planes, almost identical in all three cases, are oriented approximately NS and west-dipping in agreement with the orientation of the Oravița Fault. The T axis of all the events is almost horizontal and generally East–West oriented (Table 3), suggesting the extensional tectonic stress field, as pointed out in the Southern Carpathians by previous authors (Radulian *et al.*, 2000).

The spatial distribution of the hypocenters, the focal mechanisms and the tectonic features suggest that the 2002 Moldova Nouă earthquakes sequence occurred along a normal fault, striking almost NS and dipping around 60° westward.

Temporal Distribution and Statistics. For the Danube Seismogenic Zone, Radulian *et al.* (2000) reported an average b coefficient of 0.97. I obtained b = 0.83 ± 0.17 for the 2000–2002 time interval (153 events, $1.7 \leq M \leq 4.8$). The 2002

Moldova Nouă earthquake sequence exhibits a lower value: b = 0.68 ± 0.23 appearing as deficient in small shocks. This anomalous value of the b coefficient might be caused by several factors, the shallow depth of the sequence; heat flow; high state of stress in the focal region (Kisslinger, Jones, 1991).

The time evolution of the Moldova Nouă earthquake sequence is presented in Fig. 5. At least three stages of strain release can be evidenced (named I, II and III on the Figs. 5a and 5b).

The seismicity is characterized by a combination of sporadic events, swarms and aftershock series (magnitude threshold $M_0 = 2.0$, is determined by the detection capability of the BZS station). The sequence started on the 19th of April 2002 and several small mainshock-aftershock series occurred until 28 May 2002. The first mainshock (Ms = 4.4) occurred at the end of stage I and had a short aftershock series (14 events) lasting for four days; the strongest aftershock (M = 3.4) occurred after 2 hours. The stages II and III have few and isolated events. The second mainshock of the sequence occurred on the 2nd August 2002 (Ms = 4.3) without aftershocks with $M_D \geq 2.0$ for the first two days.

Dynamic source parameters. Using SEISAN software (Havksov, Ottemoller, 2002) we obtained the dynamic source parameters for three earthquakes:

23 May 2002, 03:26, Mo = 1.59×10^{14} Nm, Mw = 3.4, σ = 26 bar, r = 0.4 km, fo = 3.2 Hz, MD = 3.7;

24 May 2002, 20:42, Mo = 6.3×10^{15} Nm, Mw = 4.4, σ = 81 bar, r = 0.5 km, fo = 2.7 Hz, MD = 4.8;

2 August 2002, 09:37, Mo = 2.0×10^{15} Nm, Mw = 4.1, σ = 77 bar, r = 0.5 km, fo = 2.3 Hz, MD = 4.6;

Here σ = stress drop, fo = corner frequency, r = source radius, Mo = seismic moment, Mw = moment magnitude. These estimated parameters are in a good agreement with the scaling laws for earthquakes (*e.g.* Wells, Coppershmith, 1994).

As described above, the seismic sequence occurred at shallow depth on a small normal fault, under extensional tectonic stress. The slipping seems to take place along the same plane and the rupture appears to migrate from South to North. The time evolution of the sequence indicates that the aftershock zones reached their final size short time after the mainshock occurrence. This peculiarity could be related to the local and regional seismotectonic conditions, *e.g.* i) the small source dimensions and the 3D geometry of the fault zone; ii) the changes in the stress-strain rate; iii) the mechanism of the transfer of the stress on dilatational faults, as Sibson (1989) suggests.

The second sized faults from Moldova Nouă area, especially the South Moldova Nouă Fault (Fig. 2) could also play an important role on the evolution of the faulting, at least on the final stage of the sequence.

We note a relative continuous rising of the recorded seismic activity in the Moldova Nouă area between January 2000 and April 2002 (Fig. 5c).

Macroseismic field. The map of the distribution of the macroseismic intensities, estimated from field information is presented in Fig. 6. The maximum values are recorded in Moldova Nouă (VI-VII MSK) and Coronini (VI MSK). The isoseismals are slightly elongated in North-South direction, parallel to the Oravița Fault. The intensities and isoseismals shape are in agreement with the attenuation laws in the region (Zsiros, 1996; Oros, Nițoiu, 2000b). The relatively high intensity (+ 1 MSK degree higher than expected), observed in the town of Oravița (at about 40 km north from epicenter) may be due to local effects (Quaternary unconsolidated sediments).

Seismotectonic features. The results evidence the seismogenic character of the Oravița Fault system and also provide, new data regarding: i) the geometry of the southern segment of this fault (striking almost NS and west-dipping with about 60º); ii) the type of the faulting (predominant normal); iii) the state of stress (extension with near horizontal T-axis); iv) the source properties (low corner frequency and stress drop, source radius less than 0.5 km); v) the depth of the stress concentration (upper level of the crust).

DISCUSSION AND CONCLUSIONS

All available information from the literature, concerning seismicity, geology, tectonics and focal mechanism in the Danube seismogenic zone (south west of Romania), was analyzed in relation with the results of the present study on the 2002 Moldova Nouă earthquake sequence. Finally, all these data are synthesized into a seismotectonic draft model for the whole region (Fig. 7).

The seismotectonic features of the Oravița Fault have been emphasized using space-time distribution of epicenters, focal mechanism solutions, and dynamic parameters of the sources. At least on its southern segment, the Oravița Fault appears to become again seismically active, as a normal fault, under the tectonic stress field acting now in the region.

This first interpretation could be extended to the whole region if the general trend of the regional tectonics is discussed. The last tectonic movements within the region were predominant vertical. Their intensities increase from east to west, which is supported by the sharp change in the topographic gradient (from altitudes of 2294 m in Godeanu Mts to less than 900 m in Locvei Mts). In this context, the NNE trending Oravița Fault and Cerna–Jiu Fault systems (Fig. 7) played an important role in the evolution of the sectors with Neogene-Quaternary subsidence (Fig. 1).

Moreover, the historical seismicity is obviously related to the NNE–SSW oriented and west-dipping faults of the Resița–Moldova Nouă Zone (Geological Map, 1968) and to the Cerna–Jiu Fault System (CJFS), with almost vertical faults (Furnică, Furnică, 1994).

The principal direction of the T axes are fairly well constraint. An attempt is made for a rough estimate of the regional tectonic stress field using the seven focal mechanisms available (Fig. 8).

A large variability of the azimuth (especially in the east) of the T-axis and almost constant lower values of its plunge (less than 25º) are displayed. The extension axes tend to be mainly EW oriented, almost perpendicularly to the active tectonic structures and to the major faults of the region in their plunge which is lesser for all the event, but their azimuths are very large.

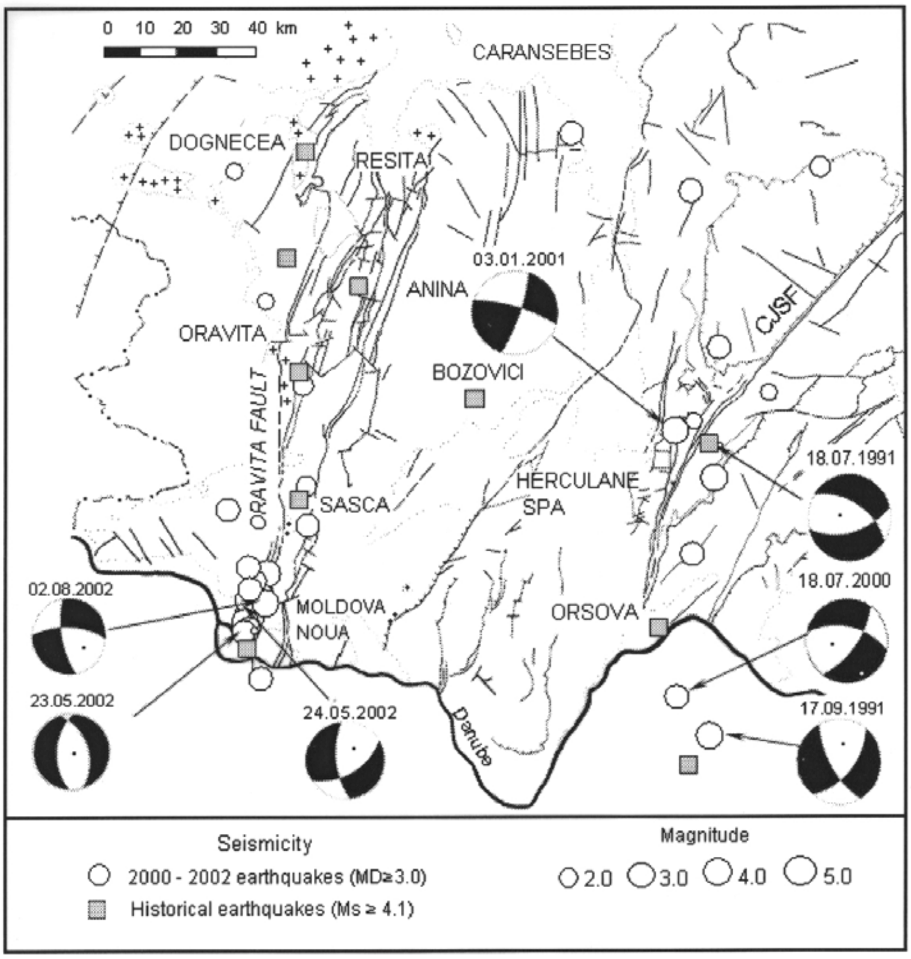
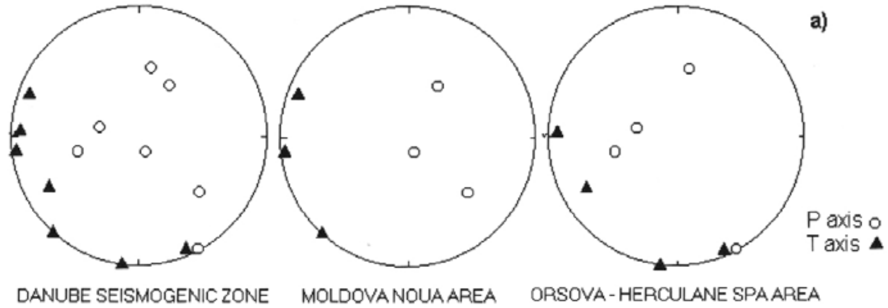


Fig. 7 – Seismotectonic features of the Danube Seismogenic Zone. Tectonics and geology after the Geological Map of Romania, (Reşiţa Sheet, 1968) – see caption of Fig. 1; epicenters of the historical earthquakes (Ms≥4.1) after Oncescu *et al.* (1999) and after Oros (2001; 2003) for the recent seismicity (2000–2002). Source mechanisms are from ISC (1991) for the 18.07.1991 earthquake, Gerner *et al.* (1999) for the 17.09.1991 event and Oros (2001; 2003) for 18.07.2000 and 03.01.2001 earthquakes and the three events investigated in the present paper.

However, we have to take into account that the available data derived mainly from small earthquakes that could thus occur under local stress concentration. In addition, the geology of the region is very complex and for firm and reliable conclusions we need more data about seismicity, state of stress and geology.

We speculate, under all the constraints discussed in the paper that the tectonics arrangement and the 3D geometry of the faults within the region and their relationship with the type, the orientation and the intensity of the tectonic forces seem to be very important in the regional dynamics and seismogenesis.

Thus, in the Danube seismogenic zone, where an extensional stress field appears as being principal and the faults are perpendicularly oriented to the extension axis, most of the faults can be seismically activated in the future as normal and/or strike-slip faults.



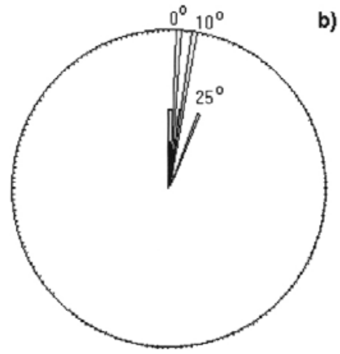


Fig. 8 – Lower hemisphere projections of the P and T axes derived from seven fault mechanism solutions (three from this study, four from other papers, as in Fig. 7) in the Danube Seismogenic Zone (a) and the diagram of the Plunge of T axis (b).

The earthquake potential of the Oraviţa Fault and of any other seismic faults in the whole Banat Seismic region is poorly understood, even if there are data about the historical seismicity and tectonics. More data are required about the geology and the seismic activity of all these faults to be able to describe and understand the space development and time evolution of the all active segments of the fault zones; and also to know more about the source parameters and the state of stress, both at local and regional scales. These data can be obtained only by a more dense stations network.

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