FOCAL MECHANISMS OF SOME CRUSTAL EARTHQUAKES THAT OCCURRED IN THE PANNONIAN DEPRESSION (ARAD – SOUTH TIMIŞOARA AREA), THE MOESIAN PLATFORM AND NORTH-DOBROGEAN OROGEN

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The paper presents the results of processing made upon the observation data concerning the P-waves generated by the crustal earthquakes (and a few subcrustal ones) that occurred in the Pannonian Depression (Arad – South Timişoara area), the Moesian Platform (in the Wallachian and Dobrogean sector) and through the North-Dobrogean orogen. Short considerations about the seismicity of these active areas were made, as well as about the important seismotectonic elements.

Key words: seismic shock, focal mechanism, crustal earthquake, tectonic stress, active fault, Pannonian Depression, Moesian Platform, North-Dobrogean Orogen.

1. INTRODUCTION

Many papers (Romanian and foreign) analyzed the problem of earthquake mechanisms located in Romania, particularly those placed in the active region of Vrancea (Enescu, 1962; Constantinescu, Enescu, 1963; Müller *et al.*, 1978; Radu, 1965, 1979; Iosif, Iosif, 1979; Enescu, 1980; Constantinescu, Enescu, 1985; Oncescu, 1987; Crişan, Oncescu, 1987, 1988; Gerner, 1995; Radulian *et al.*, 1996; Ardeleanu *et al.*, 1996; Utale *et al.*, 1994, 1995, 1996; Popescu *et al.*, 1997, 1998).

Some of them were related to earthquakes occurred in other active areas such as: Râmnicu Sărat, Tulcea, Banat, Carpathian Foredeep, especially in the bending zone of the Eastern Carpathians, etc. A recent paper (Radulian *et al.*, 2002) is the compilation of results for 526 earthquake mechanism studies produced in Romania during 1929–1997. While preparing the paper, 26 sources of information were used, consisting in published papers (Romanian and foreign) and scientific reports from the archives of the National Institute of Research and Development for Earth Physics. Information is placed in the Vrancea region (subcrustal and crustal area), Banat, Danubian area (western the Southern Carpathians), the Făgăraş–Câmpulung region, Bârlad and Predobrogean Depression. The fault plane solutions were determined, based on P wave polarity (the first arrivals) and in some cases by waveform inversion of local earthquakes and teleshocks. All solutions were determined before 1980 and have been recalculated by Aki and Richards conventions (1980).

Given the diversity of the experts who compiled the survey, the authors of this paper proposed the resumption of this major problem with seismotectonic implications, based on a uniform treatment of primary observation data using the same processing method. Before the presentation of the mechanism parameters, brief consideration of the seismicity and seismotectonics of investigated areas were presented.

2. PANNONIAN DEPRESSION (ARAD – SOUTH TIMIŞOARA)

The area included in our analysis is limited to the following geographic coordinates: latitude – 45^0–46^0N and longitude – 20^0–22^0E. The first mentions on seismicity of the region were made by Mathei M. Drăghiceanu in his study published in 1896, *Monographie des tremblements de terre* *de Roumanie et des pays environnants*, referring to earthquakes produced during the 1892–1894 period in eastern and western part of the country (Banat, Drobeta-Turnu Severin).

Later, Prof. Ion Atanasiu (1949) appointed the seismic activity from this sector of the Pannonian Basin in the Banatic category, with epicenters at Banloc, Vinga, Sânnicolau Mare, Şag, Timişoara and Periam. Subsequent observations revealed large epicentral intensity (VII and VIII degrees on the Mercalli scale) in Banloc, Liebling–Voiteg, Şag–Parța, Timişoara, Jimbolia, Periam, Arad and Sânnicolau Mare (Oros, 1991). The author mentions the following strong earthquakes: 1915 (Banloc), 1959 (Şag–Parța), 1979 (Sânmihaiu Român), 1988 (Buziaş) and 1991 (Banloc and Voiteg). In 240 years (1766–2006), 269 earthquakes were located in this region, 6 of them with M ≥ 5.0 (1879, 1901, 1959 and three shocks in 1991), 51 earthquakes with M = 4.0 to 4.9 and 92 with M = 3.0–3.9.

The catalogue edited for the region indicated several periods of time with low seismic activity, namely: 1916–1920, 1928–1932, 1937–1940, 1942–1952, 1961–1967, 1969–1972, 1975–1977. In the last period seismicity analysis revealed a number of active periods in terms of the seismic activity, namely: July–December 1991, May–August 1995, October 1999, July–August 2000 and November 2002. The distribution of epicenters of the investigated area is shown in Figs. 1 and 2, showing the 2D and 3D image representation of the seismic foci.

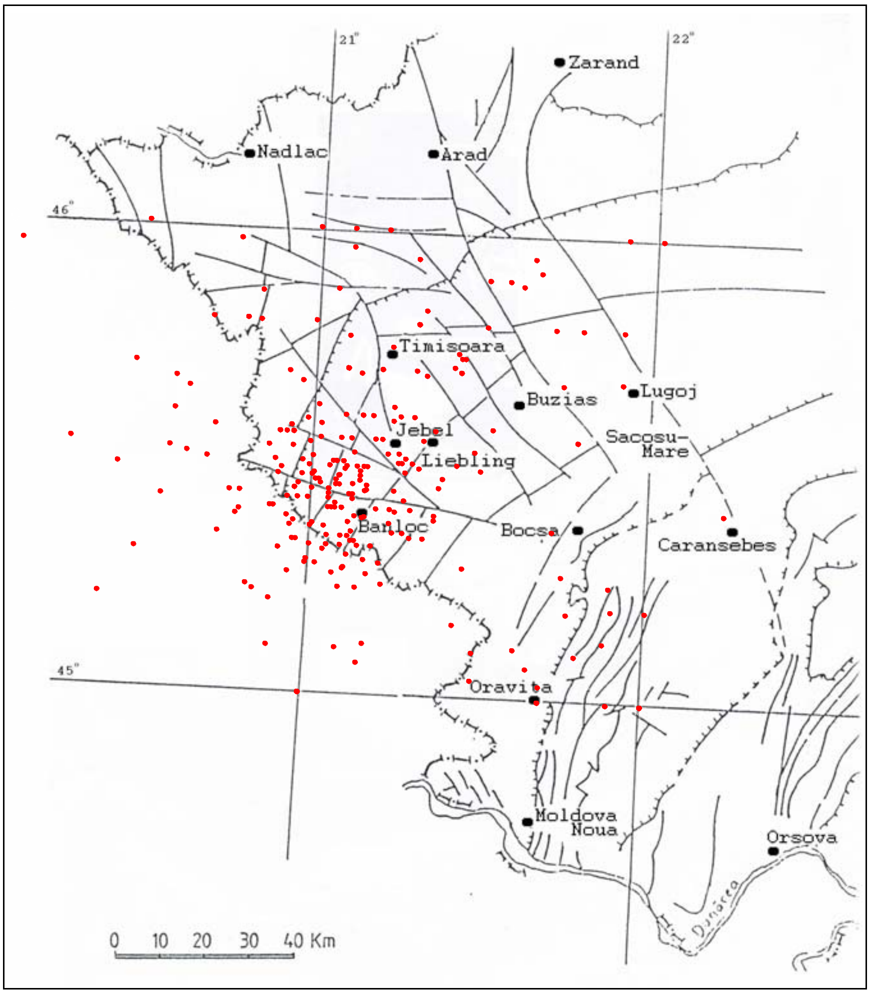


Fig. 1 – Earthquake epicenters distribution that occurred during the 984–2006 period (tectonic background by Radu, Oros, 1991).

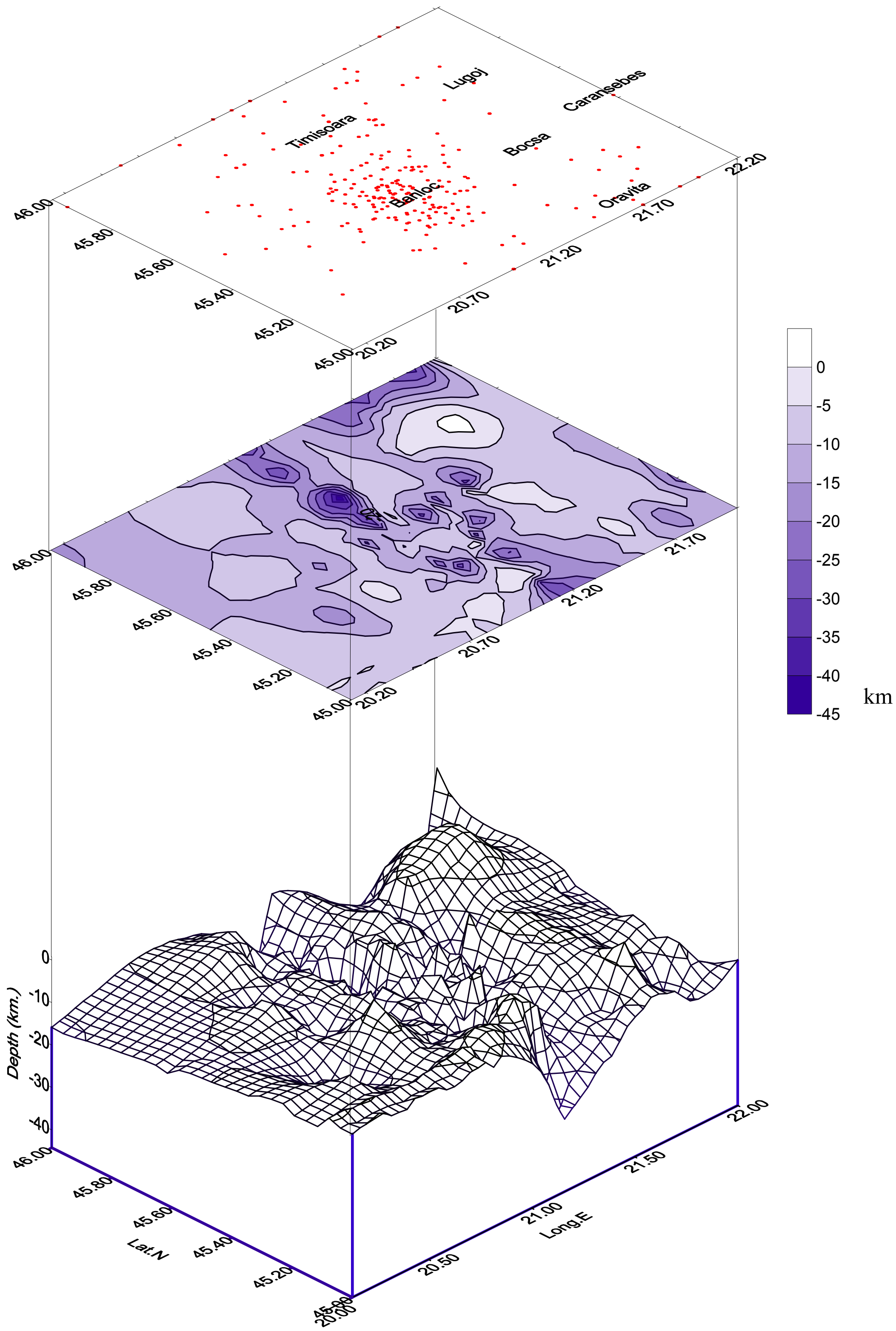


Fig. 2 – Earthquake epicenters distribution, isobath map and 3-D image of the seismic foci surface of Banat.

Referring to the most active sequence of 1991, within 6 months there have been produced 108 seismic shocks (3 with M > 5.0 and 7 with M ≥ 4.0). The three major earthquakes have epicenters in Banloc and Voiteg areas (South of Timişoara).

Geological and geophysical (gravity) studies evidenced several major fractures of the basement, E–W and NW–SE oriented, and the existence of vertical and horizontal movements along these (Visarion *et al.*, 1979). These faults are major tectonic blocks bounded with raising and sinking positions. In a seismotectonic study, Polonic and Malița (1997) noted that seismic activity is concentrated along Timişoara–Nădlac and Buziaş–Arad faults, that border the Caransebeş and Sânnicolau Mare grabens.

Among these, the elevation Battonya–Buziaş block is individualized; the Lucareț and N Timişoara faults are mentioned, the first separating (after some authors) the Pannonian Block (North) from the Geto-Danubian block (south of Lucareț fault).

The Timişoara area is characterized by large positive values (80–90 mWm^{-2}) of geothermal anomalies (Demetrescu *et al.*, 1991). The geothermal studies reveal that the heat flow source observed at the surface is placed in the upper mantle. After these authors, the temperature distribution in lithosphere of the region is a major factor determining the increase of thermoelastic stress, thus, the generation of normal earthquakes (crustal).

The stress indicators, the focal mechanisms of the earthquakes and *in situ* measurements (in wells) have shown that the accumulated stress in this active area is the compressive type, being caused by the convergence movement and rotation of the Adriatic microplate. According to Polonic and Malița (1997), the crustal earthquakes of this region are caused by the compressive forces acting between the Pannonian, Geto-Danubian and Banloc blocks, along the Lucareț reverse fault.

In Table 1, the focal mechanism solutions for 60 crustal earthquakes produced in the period 1991–2001 are shown. The processing observation data was made with the program Wickens and Hodgson (1967), improved by Oncescu (1980). In determining the location parameters of these earthquakes (epicenter coordinates, hypocenter depth) information from the archives of National Institute of Research and Development for Earth Physics and the data provided by the National Center in Denver, Colorado, USA (National Earthquake Information Center) and the International Seismological Centre Newbary, UK (International Seismological Centre, Edinburgh, Newbary) have been used. In connection with the observation data, in order to obtain good results, the distribution of azimuth around the epicenter, in at least seven seismological observatories, where focal mechanism solutions were primary calculated. Mechanisms of events with less than seven stations were estimated based on their polarities consistency mechanisms other events that could be determined with a high degree of confidence.

Seismic foci depths were 5–35 km in the middle crust (in lower domain of the granitic layer), here the Conrad discontinuity is considered to be at depths of 14–15 km.

Focal mechanism solutions indicate the faulting plane with two-average directions: the first, N41^{0}W (for 32 shocks) and the second, N47^{0}E (for 28 shocks); average inclination of the breaking plane was 56^0. The second (Plane 2) showed also mean directions: one, N50^{0}E (for 31 shocks) and the other, N48^{0}W (for 29 shocks) and average inclination – 60^0. Faulting type was 43 reverse faults and 17 faults strike-slip.

Concerning the tectonic stress, data processing indicated following compressive forces (P) and tension (T) orientations: for P axes, two prevailing directions around N37^{0}W (for 31 shocks) and N45^{0}E (for 29 shocks) and for T axes – N44^{0}W (for 35 shocks) and N52^{0}E (for 25 shocks). The predominant inclination of the compressive force P was around 17^0 and the tension forces (T), around 47^0 (Fig. 3).

Strong earthquakes on the Banloc and Voiteg of July 12, 1991 (Mw = 5.6) and December 2, 1991 (Mw = 5.5) were the fault plane azimuth WNW–SEE; compressive forces operated NW–SE, and the tension on NE–SW direction. Seismic foci depths were 11 km and 9 km and both faults were the strike-slip fault type.

Table 1

The focal mechanisms solutions of some earthquakes occured in the Pannonian Basin (Arad – South Timişoara area)

No.	Year	Month	Day	Origin Time hh:mm:ss	Lat.N	Long.E	Depth (km.)	Mw	mb	MG	MS	MD	ML	PLANE 1			Fault type	PLANE 2			Fault type	P		B		T	
														Strike	Dip	Rake		Strike	Dip	Rake		Dip	Az	Dip	Az	Dip	Az
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	1991	6	26	15:27:32	45,87	21,06	33							174	65	7	d.i.s.	82	84	155	i.d.	13	131	64	249	22	36
2	1991	7	12	10:42:21	45,36	21,05	11	5,6			5,7			87	59	178	d.i.d	178	88	31	i.s.	20	308	59	181	23	47
3	1991	7	12	13:55:15	45,59	20,99	10							365	79	46	i.s.	255	45	165	d.i.d.	22	118	43	6	39	227
4	1991	7	12	16:29:08	45,45	21,17	10		4,1		3,5			223	83	40	i.s.	127	50	171	d.i.d.	21	349	49	231	33	93
5	1991	7	13	05:10:34	45,50	21,08	10							329	40	16	d.i.s.	226	80	129	i.d.	25	287	38	38	42	173
6	1991	7	13	17:56:57	45,35	21,13	10						3,5	83	37	158	i.d.	191	77	55	i.s.	24	307	34	200	46	65
7	1991	7	14	17:03:26	45,40	21,07	10		3,3				3,5	61	56	159	i.d.	163	73	36	i.s.	11	289	51	185	37	27
8	1991	7	14	23:59:31	45,43	21,12	10						3,7	348	54	124	i.d.	119	48	53	i.s.	3	54	27	146	63	318
9	1991	7	19	01:19:52	45,34	21,12	10		4,4			4,8	4,7	339	63	129	i.d.	98	46	39	i.s.	10	42	34	139	54	298
10	1991	7	19	01:27:32	45,31	21,05	10		5,3					14	70	137	i.d.	121	50	26	i.s.	13	72	44	174	44	329
11	1991	7	19	05:24:20	45,32	21,10	10						2,9	191	86	32	i.s.	99	59	176	d.i.d.	19	321	59	197	24	60
12	1991	7	20	03:36:29	45,37	21,24	10				3,5		4,1	91	46	11	d.i.s.	353	82	136	i.d.	23	50	45	165	36	302
13	1991	7	20	03:58:47	45,34	21,10	10		4,1					289	50	119	i.d.	68	48	60	i.s.	1	359	22	89	68	266
14	1991	7	31	11:22:53	45,33	21,13	34,5						4,3	224	79	55	i.s.	118	36	160	d.i.d.	25	341	34	232	46	100
15	1991	8	1	12:57:24	45,44	21,06	19,3			3,7				91	46	18	d.i.s.	349	77	135	i.d.	19	47	44	156	40	300
16	1991	8	2	00:51:04	45,26	21,08	25,9					4,7		319	68	113	i.d.	90	32	46	i.s.	19	31	22	129	60	263
17	1991	8	6	15:04:46	45,40	21,06	11,2						3,6	286	42	80	i.	120	49	99	i.	4	204	7	294	82	86
18	1991	8	11	21:25:49	45,43	21,13	10						3,3	290	75	158	i.d.	26	69	16	i.s.	4	339	64	77	26	247
19	1991	8	12	04:59:39	45,46	21,15	10		4,2				4,5	172	85	68	i.s.	69	23	166	d.i.d.	36	281	22	174	46	59
20	1991	8	14	23:36:00	45,47	21,15	10						4,8	55	74	136	i.d.	160	48	22	i.s.	16	113	44	219	42	8
21	1991	8	15	01:34:33	45,48	21,28	10						4,4	2	24	175	d.i.d	97	88	66	i.s.	38	209	24	98	42	344
22	1991	8	18	23:01:44	45,45	20,97	10						3	337	33	178	d.i.d	69	89	57	i.s.	35	187	33	70	37	310
23	1991	8	29	07:58:03	45,31	20,92	10			3,4				271	55	102	i.	70	37	74	i.	9	351	10	83	77	210
24	1991	9	7	07:28:50	45,50	20,98	10			3,5				263	59	168	d.i.d	360	80	32	i.s.	14	128	57	16	29	226
25	1991	9	11	22:10:11	45,28	21,00	10			3,2				77	19	3	d.i.s.	344	89	109	i.	41	56	19	164	43	272
26	1991	9	13	12:12:46	45,35	21,28	10			3,2				139	63	119	i.d.	267	39	46	i.s.	13	207	26	304	60	93
27	1991	9	18	07:45:18	45,51	21,01	10			3,4				132	53	2	d.i.s.	40	88	143	i.d.	24	92	53	217	27	349
28	1991	9	19	07:34:05	45,42	20,94	10			3,4				159	87	77	i.	57	13	168	d.i.d.	41	261	13	159	46	56
29	1991	9	25	11:30:07	45,26	21,18	33			3,3				78	32	150	i.d.	195	75	62	i.s.	25	306	27	203	52	73

Table 1 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
30	1991	10	17	14:37:51	45,23	21,10	10			3,5				357	25	50	i.s.	220	71	106	i.	24	298	15	35	61	154
31	1991	10	17	15:02:14	45,38	21,16	10			3,4				84	46	156	i.d.	192	73	46	i.s.	16	313	42	208	44	59
32	1991	10	24	16:38:42	45,35	21,25	33			3,3				132	78	137	i.d.	233	48	16	i.s.	19	189	46	300	38	83
33	1991	11	21	02:16:31	45,49	21,17	26,9					4,4		41	45	97	i.	211	45	83	i.	0	126	5	216	85	33
34	1991	11	23	23:36:36	45,36	21,01	10			3				49	37	89	i.	230	53	90	i.	8	320	0	50	82	140
35	1991	12	2	08:49:40	45,49	21,11	9	5,5			5,6			69	36	166	d.i.d	170	82	55	i.s.	28	287	35	176	42	47
36	1991	12	2	10:52:35	45,44	21,06	10	3,4					3,2	191	16	179	d.i.d	282	90	74	i.	43	27	16	282	43	177
37	1991	12	2	15:04:00	45,56	21,78	10							280	66	49	i.s.	165	47	146	i.d.	11	38	37	300	50	124
38	1991	12	13	12:02:04	45,55	21,09	10			3,3				122	52	1	d.i.s.	31	89	142	i.d.	25	83	52	210	27	340
39	1991	12	18	10:24:12	45,92	21,65	10		3,9					223	72	58	i.s.	106	37	148	i.d.	20	336	31	234	52	94
40	1991	12	19	03:12:22	45,90	21,56	10	3,8					4,5	1	52	128	i.d.	130	52	52	i.s.	0	246	29	156	61	336
41	1991	12	21	11:43:06	45,83	21,32	10		3,6					10	72	172	d.i.d	103	82	18	i.s.	7	236	70	126	18	328
42	1992	3	2	20:33:21	45,95	21,63	25,1		4,6					114	34	155	i.d.	225	76	58	i.s.	24	339	31	234	49	100
43	1992	5	24	15:46:44	45,90	21,50	21,9							183	52	69	i.s.	34	43	114	i.d.	4	287	16	196	73	32
44	1992	12	19	09:34:06	45,56	20,95	22,6		4,6				4,8	39	47	55	i.s.	265	53	121	i.d.	3	334	24	65	65	236
45	1992	12	23	21:05:14	45,55	21,03	35,2						4,8	239	60	80	i.	79	32	107	i.	14	337	9	244	73	123
46	1993	1	14	08:23:05	45,53	20,95	10						4,1	322	57	125	i.d.	90	46	49	i.s.	6	28	28	121	61	287
47	1993	5	8	08:57:57	45,55	21,21	10							183	46	132	i.d.	311	58	55	i.s.	7	65	29	331	60	167
48	1993	6	4	23:20:30	45,45	21,38	10							306	64	25	i.s.	205	68	152	i.d.	2	256	55	350	35	165
49	1994	10	13	13:49:28	45,55	21,19	23		4,4			4,1		127	33	108	i.	286	59	79	i.	13	24	9	292	74	168
50	1994	10	13	23:31:27	45,49	21,00	10							81	77	159	i.d.	176	70	14	i.s.	5	130	66	230	24	37
51	1994	10	15	01:42:51	45,47	21,01	10						3,8	146	53	40	i.s.	28	59	135	i.d.	4	88	37	181	52	353
52	1994	11	12	18:50:35	45,94	21,29	10					4,8		177	73	153	i.d.	276	64	19	i.s.	6	228	58	328	31	135
53	1994	11	12	19:34:39	45,54	21,00	10					4,1		228	71	91	i.	44	19	87	i.	26	316	1	47	64	139
54	1996	3	24	09:13:28	45,62	21,02	22,6		4,8					271	57	120	i.d.	44	43	52	i.s.	8	340	25	74	64	234
55	1999	10	3	04:43:40	45,86	20,84	5		3,2					289	73	76	i.	142	22	128	i.d.	27	29	13	292	60	178
56	2000	7	22	07:23:36	45,59	21,24	10	2,8						272	41	28	i.s.	160	72	127	i.d.	19	223	35	327	49	111
57	2000	8	16	22:14:01	45,58	21,03	33	3,3						97	14	12	d.i.s.	356	87	104	i.	40	73	14	175	46	280
58	2000	10	5	23:04:11	45,62	21,24	10	3,2					3	66	79	156	i.d.	160	66	12	i.s.	9	114	63	222	25	20
59	2001	6	20	15:44:48	45,69	21,33	10	3,1						317	89	170	d.i.d	48	80	1	i.s.	6	3	80	132	8	272
60	2001	8	2	21:50:45	45,33	20,96	10	3,3						81	65	1	d.i.s.	351	89	155	i.d.	17	39	65	169	18	303

Legend: n. – normal fault; **i.** – reverse fault; **i.d.** – reverse right-lateral oblique fault; **i.s.** – reverse left-lateral oblique fault; **n.d.** – normal right-lateral fault; **n.s.** – normal left-lateral oblique fault; **i.d.** – reverse right-lateral oblique fault; **i.s.** – reverse left-lateral oblique fault; **d.n.d.** – right-lateral strike-slip; **d.n.s.** – left-lateral strike-slip; **d.i.d.** – right-lateral strike-slip; **d.i.s.** – left-lateral strike-slip.

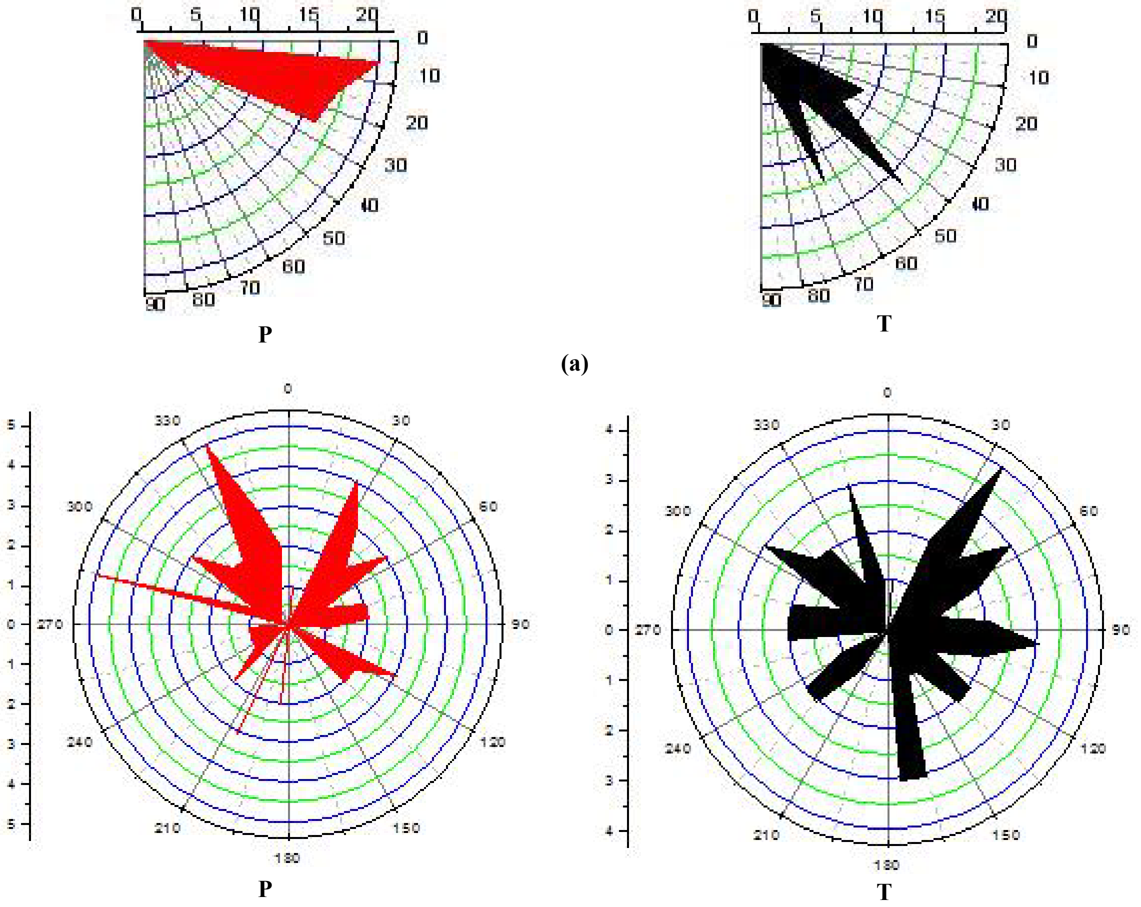


Fig. 3 – The dip (a) and azimuth (b) of P and T axes of earthquakes occurred in Banat.

In the Jebel–Banloc active area, moderate magnitude earthquakes in 1915 (Mw = 4.3 to 4.8), 1936 (Mw = 4.8), 1960 (Mw = 4.2) and 1980 (mb = 4.2) occurred. The active region is located in the sedimentary basin south of Sânnicolau Mare Graben.

3. MOESIAN PLATFORM

The investigated region includes the sector of the Moesian Platform and a part of the Carpathian Foredeep. Seismic data have been extended to 44.8^0N latitude, and in south to latitude 43.5^0 N and between meridians 22.5^0 and 29^0E. The catalogue includes the period during 1276–2007, 629 earthquakes, of which 565 produced in Romania, 63 in northern Bulgaria and Black Sea and a seismic shock in Serbia.

In Fig. 4 the distribution of the earthquake epicenters within the area referred is shown; a seismic foci 3D representation is shown in Fig. 5.

Earthquake epicenters distribution in this area reveals that the western sector (Wallachian) is much less seismically active than the eastern sector (Dobrogean) located eastern of the Intramoesian Fault. Temporal analysis of the seismic shocks produced in the XX^{th} century has shown a significant decreasing of seismic activity in some periods: 1917–1922, 1924–1929, 1931–1941, 1943–1955, 1957–1959, 1961–1966, 1968–1974 and 1978–1979. It's worth mentioning an increasing of the seismic activity in other years as: 1977 (18 earthquakes), 1982 (43 earthquakes), 1995 (22 earthquakes), 1996 (21 earthquakes), 1999 (29 earthquakes), 2005 (60 earthquakes) and 2006 (48 earthquakes).

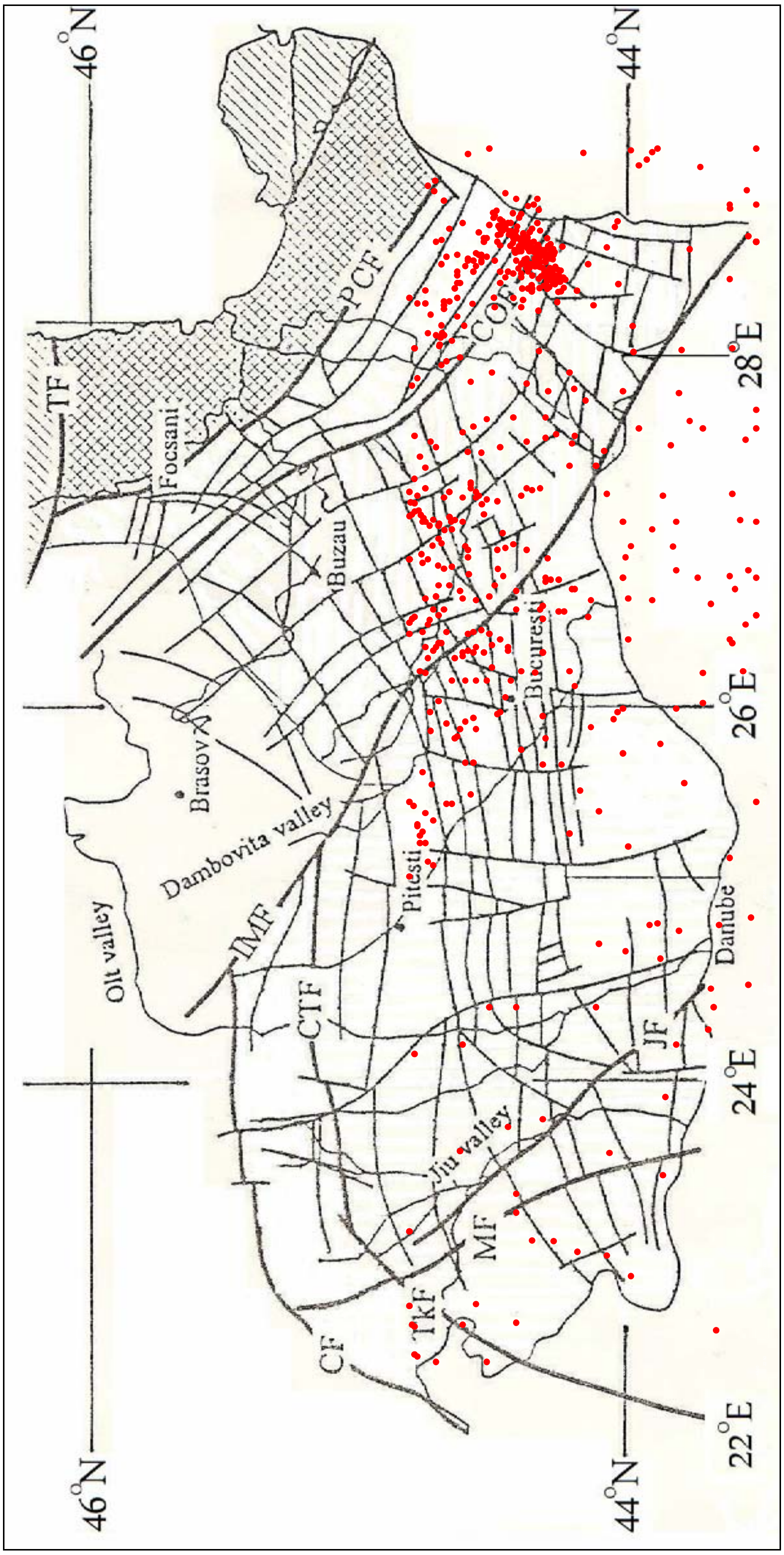


Fig. 4 – Earthquake epicenters distribution during the 1276–2007 period in the Moesian Platform (tectonic background after Visarion *et al.*, 1988).

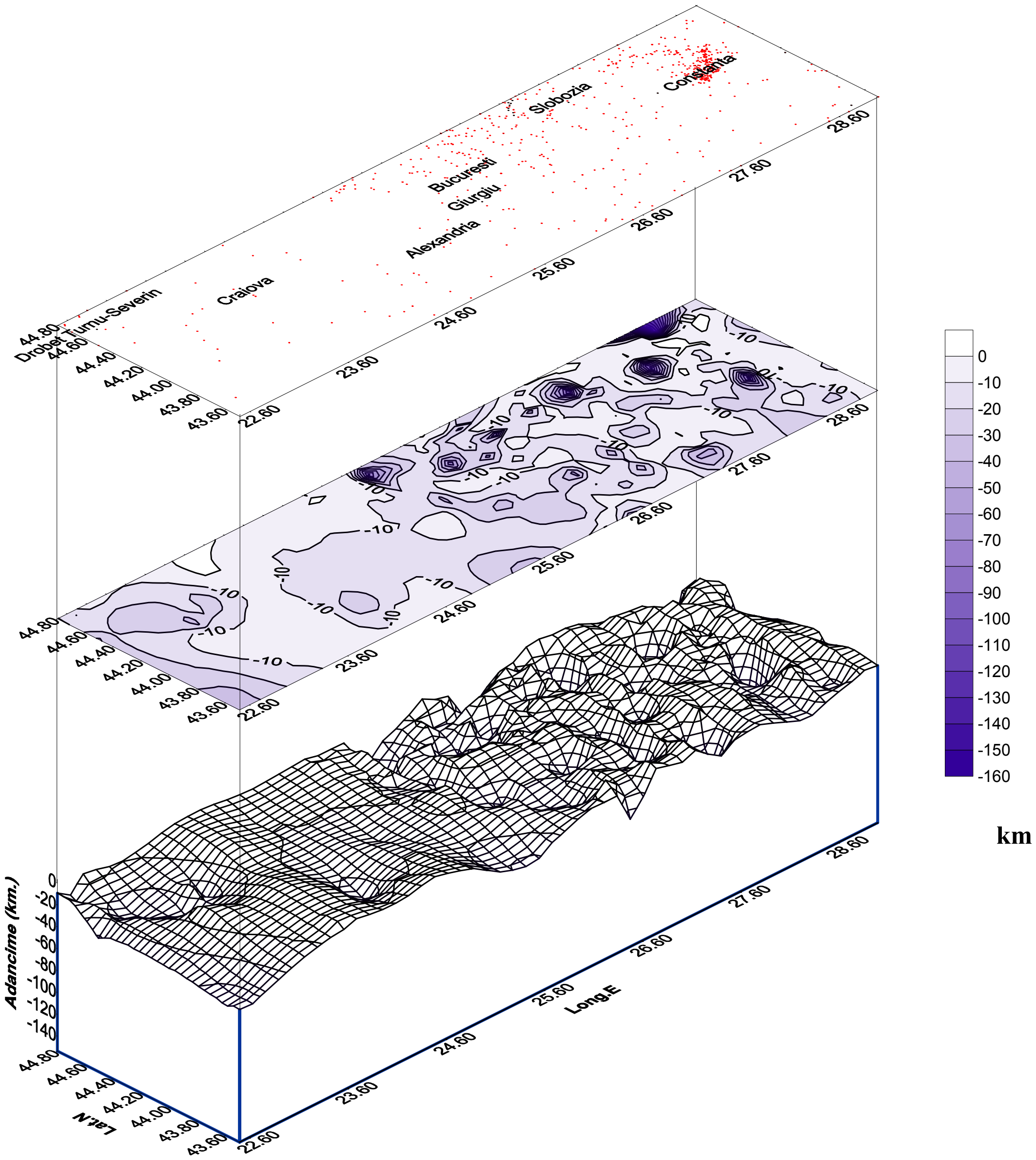


Fig. 5 – Earthquake epicenters distribution, isobath map and 3-D image of the seismic foci surface of the Moesian Platform.

On the Carpathian Foredeep area, it seems that, in time, it was a migration of the seismic activity from east to west, from an earthquake of magnitude 4.5 on July 9, 1912 (the epicenter west of Râmnicu-Vâlcea) to a seismic shock of 5.2 magnitude on June 20, 1943 (north of Târgu-Jiu) and July 18, 1991, earthquake with Ms = 5.6 (north-west of Drobeta-Turnu Severin), the last one located in the Southern Carpathians. Most of the XXth century earthquakes occurred in the range 0–10 km deep (about 65%), the rest (about 35%) at depths of 11–35 km. Thus, the earthquakes mostly occur in the sedimentary crust (or in the upper crystalline, consolidated crust), few of them have focus in the middle crust and others in the lower part of the consolidated crust.

The following can be distinguished as active seismic areas in western sector of the platform itself as: Alexandria–Chiriacu, Turnu Măgurele–

Caracal and Calafat–Strehaia North. In the transition zone to the Carpathian Foredeep area it has been shown some areas with seismic potential as Ludeşti–Cobia, Tărtăşeşti–Butimanu and Târgu-Jiu–Turnu Severin. North-western of Turnu Severin outlines a very active area, located in the Southern Carpathians. Here, on a relatively small area (about 2500 s/qkm), numerous seismic events occurred, of low magnitude, which culminated in the July 18, 1991 earthquake (Ms = 5.6, depth 11.6 km).

Correlation with regional tectonic elements indicates the connection of these earthquakes with Cerna fault. The great depth (33 km) of these earthquakes shows the extension of this major crustal fault in the lower crystalline crust; previous seismic studies indicating a thick crust of about 40 km.

Among the earthquakes produced in the central sector of the platform, the Alexandria area one (on February 7, 2001, M = 3.2) was optimal for the focal mechanism determination. The analysis showed the fault plane oriented N25^{0}W (dip 42^0); depth focus (33 km) places, respectively in the subcrustal domain (Table 2).

The seismic activity of the eastern sector (Dobrogea) of the Moesian Platform is well known, especially after strong earthquakes on 1960 and 1967, with magnitudes (Mw) of 5.4 and 5.0 respectively (Iosif, 1960; Iosif, Iosif, 1971). An increasing seismic activity was observed after the Vrancea earthquake of March 4, 1977, so at the end of 1977, there have been 23 earthquakes in this area, five of them having magnitudes of 3.6 to 3.9 degrees on the Richter scale (Cornea, Polonic, 1979). Macroseismic observations first made by I. Atanasiu (1949) have shown in this part of the platform many epicenters and lines of "seismic sensitivity", interpreted as representing the structural alignments of the crystalline basement.

Among the earthquakes produced in the 1960–2007 period, it was possible to determine the focal mechanism only for 75 (Table 2). From these, we mention the earthquakes of January 4, 1960, from Căzăneşti (Ms = 5.4) and February 27, 1967 at Răduleşti (Ms = 5.0), with foci at 40 km, and 42 km, respectively.

Determinations of 63 earthquakes produced in the Dobrogea (east of 26^{0}E meridiane) showed one or two predominant faulting directions, one – N39.6^{0}E (for 32 earthquakes) and another – N49.3^{0}W (for 31 earthquakes) and inclinations of 59.4^0 and 55.6^0, respectively. For other breaking plane the prevailing direction was N35.7^0 E (for 39 shocks) and N 44.9^0 W (for 24 events) and prevailing inclinations of 55.8^0 and 58.6^0, respectively.

The types of faulting derived from the focal mechanism solutions were the reverse faults and strike-slip faults.

Concerning the tectonic stress, the axis of compression forces (P) presented two prevailing directions, quasi NW–SE (N49, 5^{0}W) and NE–SW (N 41.6^0 E).

The dips of the compressive forces were almost horizontal, with average dips of 20^0 and 18^0, compared with the tension axis (T) which operated to dips of 41^0. Tension stress occurrs around the direction of N42.5^{0}E and N62.5^{0}W. In Fig. 6 were represented the azimuths and dips of the P and T axes for all 75 earthquakes in the investigated area of the platform.

In conclusion, the fault plane solutions from the Dobrogea sector have shown the existence of two faulting systems (already known from previous geophysical works), one mainly oriented NW–SE and the other side, NE–SW. The first category includes the major active faults (from west to east): Intramoesic fault and Nehoiu–Smeeni–Dragalina, Slobozia–Feteşti and Capidava Ovidiu faults. The group of secondary faults is composed of Bărăitaru–Făurei–Oprişeneşti, Urziceni–Jugureanu, Ileana–Colelia, Cartojani–Grădinari and Videle–Bălăria faults (from north to south).

The events analyzed in the 1960–2007 period have shown the existence of a compressive regime, oriented NW–SE, the same tectonic stress appeared too at the earthquake occurred at Răduleşti on February 27, 1967 (Ms = 5.0). Along the Intramoesian fault were located only a few earthquakes. Also, more seismic shocks were related to fracture Nehoiu–Smeeni–Dragalina, this fault seems to be related to the shock from January 4, 1960 (Ms = 5.4).

Table 2

The focal mechanisms solutions of some earthquakes occurred in the Moesian Platform and Carpathian Foredeep

No.	Year	Month	Day	Origin Time hh:mm:ss	Lat.N	Long.E	Depth (km.)	Ms	MD	ML	Mw	PLANE 1			Fault type	PLANE 2			Fault type	P		B		T	
												Strike	Dip	Rake		Strike	Dip	Rake		Dip	Az	Dip	Az	Dip	Az
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	1960	1	4	12:51:52	44,60	27,00	40				5,4	138	40	-51	n.s.	271	60	-118	n.d.	63	134	24	286	11	21
2	1967	2	27	21:00:42	44,90	26,70	42	5				187	71	-31	n.s.	289	61	-158	d.n.d.	35	145	54	339	7	239
3	1977	4	20	21:16:15	44,18	26,12	11	3,9			3	17	82	-63	n.d.	318	16	-31	n.s.	51	271	14	19	36	119
4	1980	12	8	19:51:18	44,07	27,38	34				3,2	331	89	45	i.s.	240	45	179	d.i.d.	29	96	45	332	31	205
5	1983	8	25	07:59:04	44,55	25,89	25			4	3,1	287	49	117	i.d.	69	48	63	i.s.	1	358	20	89	70	266
6	1988	7	7	19:01:05	44,75	25,34	2			4,2	3,5	287	49	-63	n.s.	69	48	-118	n.d.	70	266	20	89	1	358
7	1990	6	12	04:21:19	43,98	26,37	19				3,4	252	56	144	i.d.	4	61	40	i.s.	3	127	42	34	48	220
8	1991	8	21	04:54:42	44,23	25,70	33				2,6	339	90	35	i.s.	249	55	180	d.d.	24	108	55	339	24	210
9	1991	8	23	19:12:32	44,79	22,70	10					95	89	11	d.i.s.	5	79	179	d.i.d.	7	229	79	100	8	320
10	1991	10	1	03:06:33	43,80	26,73	15					110	83	124	i.d.	210	35	12	d.i.s.	30	173	34	285	42	52
11	1992	2	17	11:00:59	44,40	22,71	13	2,9				94	53	58	i.s.	320	47	125	i.d.	3	206	25	115	65	303
12	1993	5	31	12:43:20	44,74	27,18	10				2,9	309	48	23	i.s.	204	73	135	i.d.	16	261	43	7	43	157
13	1993	6	28	22:01:36	44,33	23,15	33					352	32	149	i.d.	109	74	62	i.s.	24	220	27	117	52	346
14	1993	9	29	00:03:44	44,47	27,11	10	3,4	4,1		3,1	196	50	135	i.d.	301	57	50	i.s.	4	76	33	343	57	172
15	1993	10	4	04:25:00	44,52	27,04	10	3				278	46	55	i.s.	144	54	121	i.d.	4	212	24	304	65	113
16	1994	5	30	13:07:48	44,34	27,17	10				2,6	129	71	56	i.s.	14	38	149	i.d.	19	244	32	141	52	359
17	1994	7	15	09:34:20	44,54	27,14	4	3			3,2	221	36	-164	d.n.d.	118	81	-55	n.s.	43	62	34	291	27	181
18	1994	7	15	12:57:14	44,78	27,46	0				3,1	121	75	-54	n.s.	230	39	-156	d.n.d.	47	69	35	290	22	184
19	1995	3	26	05:17:57	44,64	25,49						147	11	69	i.s.	348	80	94	i.	35	75	4	168	55	263
20	1995	3	28	18:26:42	44,69	26,91	10				2,7	236	82	149	i.d.	331	59	10	d.i.s.	15	287	58	43	27	189
21	1996	6	22	03:50:15	44,47	25,97	33					208	78	91	i.	25	12	87	i.	33	297	1	28	57	119
22	1997	11	1	10:12:31	44,43	26,31	10				3	45	76	59	i.s.	293	34	154	i.d.	25	159	30	53	49	281
23	1999	5	12	02:00:03	44,58	26,31	33					173	29	81	i.	3	62	95	i.	16	90	4	181	73	285
24	2000	8	5	12:19:08	44,60	26,59	10				2,5	54	42	123	i.d.	193	56	64	i.s.	7	301	21	208	67	49
25	2000	12	31	11:35:09	44,19	25,45	4				3,2	225	31	125	i.d.	7	65	71	i.	18	110	17	14	64	243
26	2001	2	7	01:41:48	43,99	25,76	33				3,2	50	77	130	i.d.	155	42	20	d.i.s.	22	111	39	219	43	359
27	2002	3	26	07:26:25	43,58	26,64	10					47	87	89	i.	240	3	103	i.	42	138	1	47	48	316
28	2002	10	7	11:27:03	44,66	27,86	38				2,6	144	15	33	i.s.	22	82	103	i.	36	101	13	200	52	306

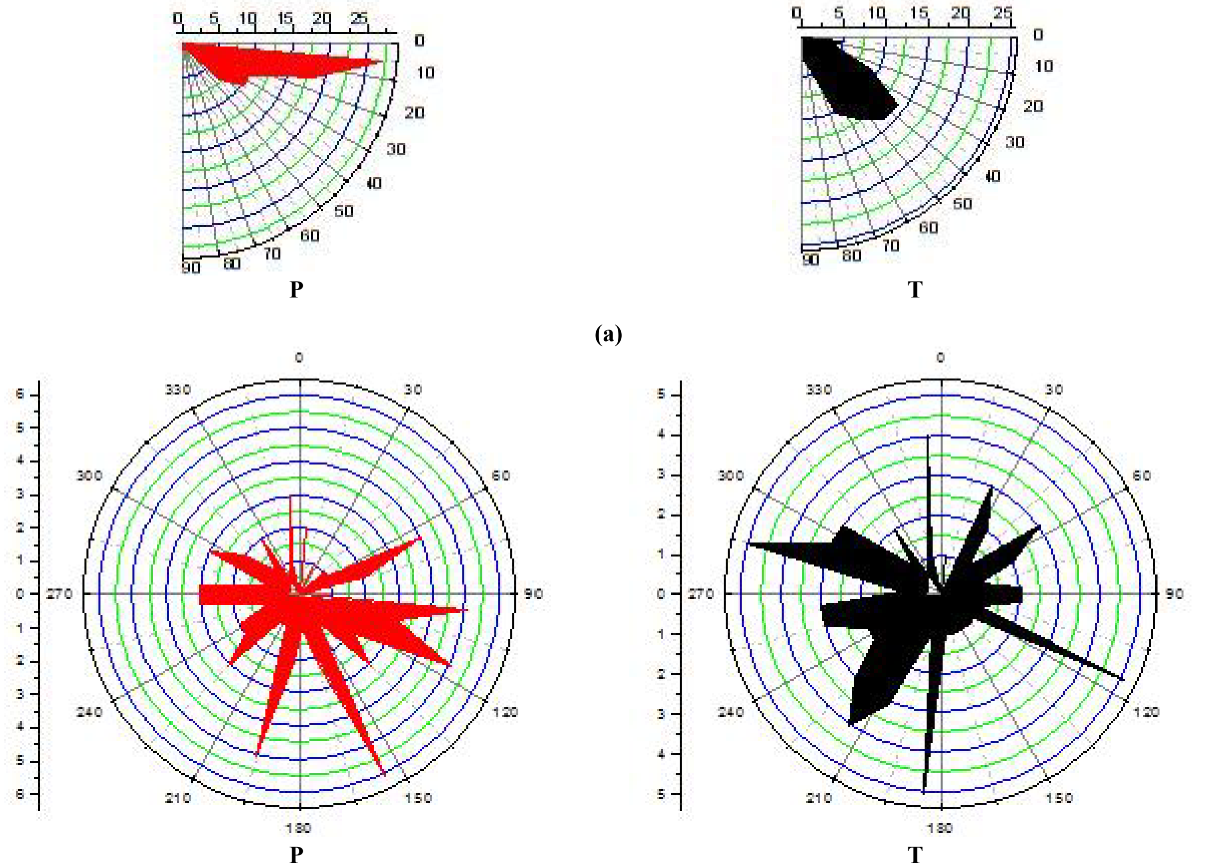
Table 2 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
29	2002	10	20	09:14:25	44,56	26,30	20				2,6	354	89	130	i.d.	85	40	2	d.i.s.	32	52	40	173	34	297
30	2003	1	16	20:34:20	43,60	26,71	0				2,8	96	58	139	i.d.	210	57	40	i.s.	1	154	40	245	50	62
31	2003	2	3	08:22:44	44,24	26,52	16				2,6	8	73	172	d.i.d.	100	82	17	d.i.s.	6	233	71	124	18	325
32	2003	3	5	06:39:12	44,31	27,18	2				2,9	340	37	1	d.i.s.	249	90	127	i.d.	34	308	37	69	35	190
33	2003	3	7	11:34:50	44,13	26,49	10				2,8	321	53	153	i.d.	69	69	41	i.s.	10	191	45	91	43	290
34	2003	3	10	00:13:52	44,22	26,52	10				2,9	198	43	92	i.	16	47	88	i.	2	107	1	17	88	252
35	2003	3	27	03;03:27	44,74	26,59	33				2,7	266	88	80	i.	163	11	167	d.i.d.	42	6	10	266	46	166
36	2003	4	7	23:43:16	44,30	26,55	7				2,6	235	86	45	i.s.	141	45	175	d.i.d.	27	359	45	239	33	108
37	2003	8	27	12:05:36	44,02	25,98	56				2,7	26	53	76	i.	227	39	107	i.	7	126	11	35	77	248
38	2003	11	2	01:33:10	44,63	25,84	33				2,8	212	53	43	i.s.	93	57	134	i.d.	2	153	36	245	54	60
39	2003	12	4	12:41:09	44,71	27,01	10		2,9			103	87	152	i.d.	195	62	4	d.i.s.	17	152	62	277	22	55
40	2004	7	10	12:12:17	44,47	26,85	2				2,6	1	71	11	d.i.s.	268	80	160	i.d.	6	315	68	60	21	223
41	2004	8	21	20:22:54	44,74	25,44	11				2,8	248	48	157	i.d.	353	73	44	i.s.	16	116	43	10	43	220
42	2004	9	4	11:08:25	44,36	27,74	0				2,3	272	54	5	d.i.s.	179	86	144	i.d.	21	231	54	354	28	129
43	2004	9	18	03:14:24	44,16	25,56	6				2,8	42	55	175	d.i.d.	135	85	35	i.s.	21	263	55	141	27	4
44	2004	10	5	10:43:12	43,90	24,84	5					180	52	61	i.s.	42	46	121	i.d.	3	290	22	199	64	27
45	2004	10	12	20:38:17	44,25	27,47	0				2,5	87	53	128	i.d.	215	51	51	i.s.	1	151	29	242	61	59
46	2005	2	12	00:01:25	44,41	26,88	0				2,8	323	36	72	i.	165	56	103	i.	10	246	10	338	75	113
47	2005	3	15	11:20:24	44,25	28,27	9		1,9			227	85	4	d.i.s.	136	86	175	d.i.d.	1	182	84	278	6	92
48	2005	4	6	05:04:43	44,64	27,00	10		2,2			1	44	11	d.i.s.	263	83	133	i.d.	25	321	43	76	37	211
49	2005	4	17	08:42:03	44,26	28,41	10		2,2			213	80	10	d.i.s.	121	80	170	d.i.d.	0	167	76	258	14	77
50	2005	5	8	03:53:47	43,81	26,87	11		2,9			299	11	15	d.i.s.	194	87	100	i.	41	274	11	14	47	115
51	2005	8	22	01:22:19	44,69	26,77	9		2,7			281	84	169	d.i.d.	12	79	7	d.i.s.	3	327	77	73	12	236
52	2005	8	24	17:07:24	44,76	27,03	10		2			55	51	131	i.d.	181	54	51	i.s.	2	297	31	206	59	30
53	2005	8	24	17:20:25	44,69	26,98	7				2,9	296	36	169	d.i.d.	35	84	55	i.s.	30	153	35	40	41	272
54	2005	8	24	21:18:04	44,80	27,03	10		2,8			332	57	160	i.d.	73	73	35	i.s.	11	199	52	96	36	297
55	2005	8	25	17:53:55	44,78	27,01	10				3,1	276	86	103	i.	24	14	19	d.i.s.	40	354	13	95	47	200
56	2005	8	26	12:23:23	44,31	27,91	5		2,7			165	58	25	i.s.	61	69	145	i.d.	7	115	50	214	39	20
57	2005	8	27	04:13:55	44,74	27,02	0		2,8			348	60	64	i.s.	213	39	128	i.d.	11	96	22	2	65	212
58	2005	8	27	12:18:09	44,75	27,00	3				2,7	227	64	162	d.i.d.	325	74	27	i.s.	7	94	59	354	30	188
59	2005	8	27	20:00:00	44,67	26,96	4		2,8			309	74	142	i.d.	51	54	20	d.i.s.	13	4	49	110	38	264
60	2005	8	27	22:55:42	44,79	27,03	9		2,9			187	52	97	i.	356	39	82	i.	7	272	6	3	81	132

Table 2 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
61	2005	8	27	23:50:52	44,76	27,06	5		3,1			258	47	43	i.s.	136	60	128	i.d.	7	199	32	294	57	98
62	2005	8	28	06:17:06	44,78	27,06	0		3			220	9	113	i.d.	17	82	87	i.	37	110	4	17	53	283
63	2005	8	28	15:59:07	44,69	26,99	10		3,1			296	52	18	d.i.s.	195	76	140	i.d.	15	250	49	358	37	148
64	2005	9	3	09:46:18	44,78	27,23	10		2,8			97	39	5	d.i.s.	2	87	129	i.d.	31	62	39	181	36	306
65	2005	9	15	16:33:26	44,75	26,82	8		2,7			324	58	158	i.d.	66	72	33	i.s.	9	192	52	91	37	289
66	2005	9	27	14:50:40	44,62	25,85	9				2,9	194	50	40	i.s.	76	60	133	i.d.	6	137	36	231	53	39
67	2005	10	16	11:14:19	44,29	26,70	6		3,1			53	49	55	i.s.	280	52	124	i.d.	2	347	26	78	64	254
68	2005	10	31	15:30:05	44,56	28,17	1		2,7			25	87	5	d.i.s.	294	85	177	d.i.d.	1	160	84	56	6	250
69	2005	10	31	16:54:50	44,12	26,58	6		3,1			138	84	138	i.d.	234	48	9	d.i.s.	23	193	48	311	33	87
70	2005	11	10	16:09:46	44,68	28,00	0		2,7			313	55	87	i.	138	35	94	i.	10	45	2	315	80	211
71	2005	11	14	03:43:13	44,02	28,27	15		2,4			226	62	172	d.i.d.	319	83	28	i.s.	14	90	61	333	25	186
72	2005	12	5	12:14:03	44,64	27,16	0		2,6			324	64	74	i.	176	30	119	i.d.	18	66	14	331	67	204
73	2006	2	6	10:47:06	44,73	28,08	30		3,6			293	32	62	i.s.	145	62	106	i.	16	223	14	317	69	88
74	2006	3	17	00:45:11	43,98	26,59	58				2,6	81	47	32	i.s.	328	67	133	i.d.	12	29	38	129	49	285
75	2007	4	24	03:58:24	44,73	26,27	15			2,9		338	8	158	i.d.	90	87	82	i.	42	187	7	90	47	352

Legend: **n.** – normal fault; **i.** – reverse fault; **i.d.** – reverse right-lateral oblique fault; **i.s.** – reverse left-lateral oblique fault; **n.d.** – normal right-lateral fault; **n.s.** – normal left-lateral oblique fault; **i.d.** – reverse right-lateral oblique fault; **i.s.** – reverse left-lateral oblique fault; **d.n.d.** – right-lateral strike-slip; **d.n.s.** – left-lateral strike-slip; **d.i.d.** – right-lateral strike-slip; **d.i.s.** – left-lateral strike-slip.



(b)

Fig. 6 – The dip (a) and azimuth (b) of P and T axes of earthquakes occurred in the Moesian Platform.

4. NORTH-DOBROGEAN OROGEN

The seismicity of this region has been observed since 1949 by Ion Atanasiu, who evidenced the lines of "seismic sensitivity": Tulcea–Isaccea–Galați, Cerna–Măcin–Brăila and Babadag–Nicolae Bălcescu. In a previous paper (1938), Ioan G. Popescu mentions the epicenters from Tulcea, Isaccea, Babadag and Topolog. There were located, between 1871–1929, 11 earthquakes in the Galați–Sulina area and 3 shocks connected by the Peceneaga–Camena fault.

The information presented by us refers to the area included within the following geographic coordinates: latitude 44.5^0–45.5^0N and longitude 28.0^0– 29.0^0E. In the south, the data included a part of Central Dobrogea too, belonging to the Moesian Platform.

Thus, between 1831–2006, were located 218 earthquakes with M = 1.9 to 5.6 and depths of 0–33 km, in the region; 51 shocks had magnitudes greater than 3.5 (Figs. 7, 8).

Historical earthquakes produced in the XIXth century and early XXth century had magnitudes and depths estimated at higher values; so, seismic events produced at depths of 40–50 km and a magnitudes of 5.3 to 5.6 existed. Epicenter distribution indicates their concentration in SE Măcin, Tulcea area north of Babadag.

In Table 3 are presented the focal mechanisms of 18 earthquakes produced during 1980–2006. The faulting plane indicates two average directions: one, N35^0E (NE–SW) and another, N43^0W (NW–SE), with a predominant dip of 56^0. The faulting type was the reverse fault (16) and two strike-slip faults. The average tectonic stress directions had been as follows: for compressive forces (P), N63^{0}E (ENE–WSW) and N44^{0}W (NW–SE), the latter being predominant, the tension forces (T), a main direction, N41^{0}W (NW–SE) and other, secondary, N60^{0}E (ENE–WSW). The compressive forces operated in a horizontal plane (with an average slope of 18^0) and the tension forces had an average dip of 60^0 (Fig. 9).

The strong earthquake occurred on November 13, 1981 (Mw = 5.1), located east of Tulcea, was generated on a fault oriented NE–SW, situated at depth of 4–9 km (Oncescu *et al.*, 1989). Main shock (MD = 5.4) was followed by six aftershocks with MD = 2.9 to 3.5. The authors noted the migration of seismic activity from NE to SW along a distance of about 23 km.

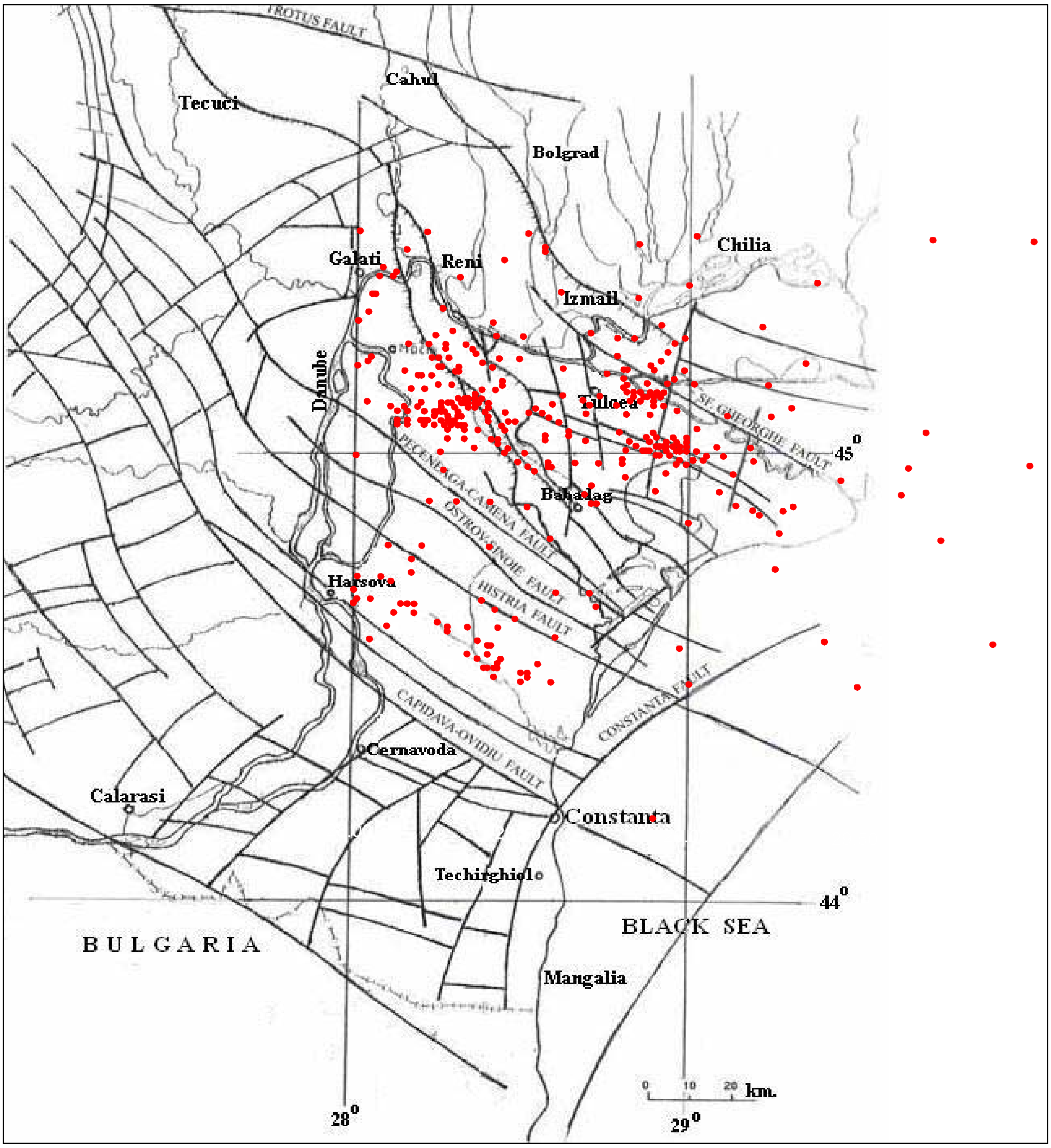


Fig. 7 – Earthquake epicenters distribution that occurred in Dobrogea during the 1831–2006 period (tectonic background after Visarion *et al.*, 1990).

The recalculating of the faulting plane indicates a plane oriented NE–SW (N120^{0}W). A similar solution provided Gabriela Polonic in 1986. The P axis was oriented ENE–WSW (N73^{0}E) and the tension axis (T) NNW–SSE (N11^{0}W).

The Niculițel–Cataloi–Cerna area revealed as a active seismic area with foci situated in the crystalline crust seismic of the Tulcea tectonic zone and of the Niculițel nappe. Many earthquakes are related to tectonic line Luncavița–Consul; foci were located at depths of 5–10 km, the area belonging to the crystalline crust.

The earthquakes located in the south of Tulcea are extended to the west, near the tectonic contact with the Măcin unit (line Luncavița–Consul). Some earthquakes are related to this tectonic contact or associated satellite faults. The region is particularly active there were located about 15 seismic shocks, concentrated in a relatively small area.

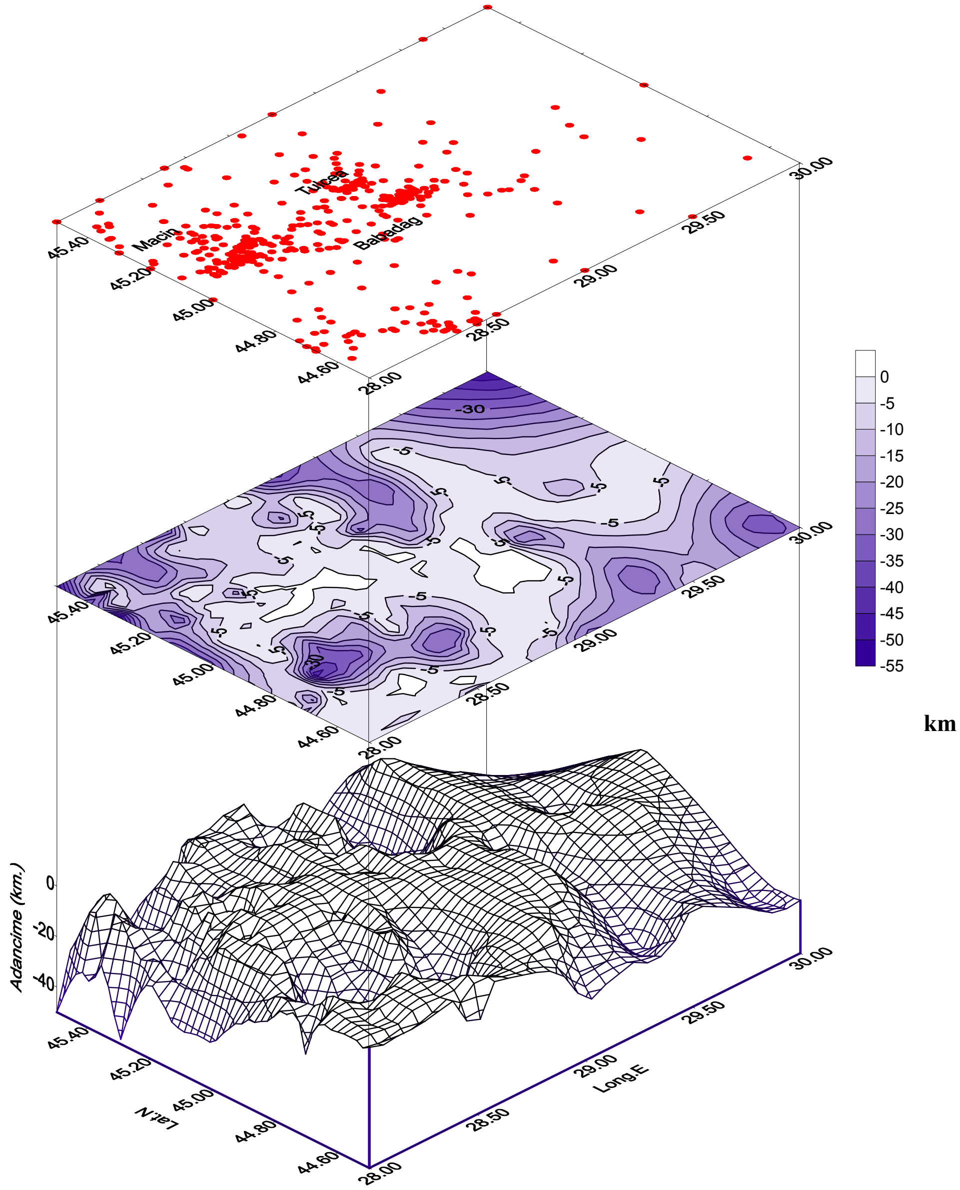


Fig. 8 – Earthquake epicenters distribution, isobaths map and 3-D image of the seismic foci of Dobrogea.

Table 3

The focal mechanisms solutions of some earthquakes occurred in the North Dobrogea

No.	Year	Month	Day	Origin time hh:mm:ss	Lat.N	Long.E	Depth (km.)	mb	Mw	MD	ML	PLANE1			Fault type	PLANE 2			Fault type	P		N		T	
												Strike	Dip	Rake		Strike	Dip	Rake		Dip	Az	Dip	Az	Dip	Az
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	1980	9	11	23:24:25	45,32	28,03	20,4		4,2			338	9	17	d.i.s.	52	87	99	i.	42	313	9	51	47	150
2	1981	11	13	09:07:13	45,17	29	15		5,1			34	56	66	i.s.	22	41	121	i.d.	8	141	20	48	69	252
3	1991	5	9	15:21:36	45,04	28,81	10					191	83	136	i.d.	288	47	10	d.i.s.	24	247	46	4	35	139
4	1992	6	3	20:21:43	45,2	28,9	10		3,1		3,9	237	63	100	i.	35	29	71	i.	17	320	9	52	70	168
5	1994	11	24	10:24:39	45,15	28,41	10			3,3		274	37	175	d.i.d.	9	87	53	i.s.	32	128	37	10	37	246
6	1997	6	13	09:23:59	45,02	28,89	5					294	48	131	i.d.	62	56	54	i.s.	4	176	29	84	60	274
7	1997	8	21	08:49:42	45,12	28,36	10			3,1		55	84	102	i.	171	13	27	i.s.	38	134	12	234	50	338
8	1998	8	6	11:03:45	45,12	28,39	5			3,4		300	36	15	d.i.s.	198	81	125	i.d.	28	260	35	12	43	141
9	1999	5	8	11:06:18	45,12	28,39	5			3,4		342	66	105	i.	128	28	59	i.s.	20	61	14	156	666	278
10	2001	1	19	15:12:47	45,12	28,03	33					306	82	38	i.s.	210	53	170	d.i.d.	19	72	51	316	32	175
11	2004	10	3	09:02:07	45,2	28,97	31	4,8				202	42	83	i.	31	48	96	i.	3	117	5	207	84	353
12	2004	11	8	08:55:55	45,22	28,24	0				3,1	73	65	62	i.s.	305	37	135	i.d.	15	183	25	86	60	302
13	2004	11	24	18:36:55	45,16	28,79	3				3,8	273	18	160	i.d.	22	84	73	i.	37	127	17	24	48	274
14	2005	1	18	17:15:30	45,14	28,88	0				3,8	252	55	149	i.d.	1	65	39	i.s.	6	124	45	28	45	221
15	2005	1	24	11:34:54	45,03	28,94	0				2,7	221	79	17	d.i.s.	128	74	168	d.i.d.	4	354	70	253	20	85
16	2005	4	18	12:29:21	45,18	28,94	5				3,5	223	89	172	d.i.d.	313	82	1	d.i.s.	5	268	82	36	6	178
17	2005	4	23	05:18:34	45,22	28,24	0				3,3	22	52	91	i.	201	38	89	i.	7	111	1	201	83	298
18	2006	2	6	10:47:06	44,73	28,08	30			3,6		293	32	62	i.s.	145	62	106	i.	16	223	14	317	69	88

Legend: n. – normal fault; **i.** – reverse fault; **i.d.** – reverse right-lateral oblique fault; **i.s.** – reverse left-lateral oblique fault; **n.d.** – normal right-lateral fault; **n.s.** – normal left-lateral oblique fault; **i.d.** – reverse right-lateral oblique fault; **i.s.** – reverse left-lateral oblique fault; **d.n.d.** – right-lateral strike-slip; **d.n.s.** – left-lateral strike-slip; **d.i.d.** – right-lateral strike-slip; **d.i.s.** – left-lateral strike-slip.

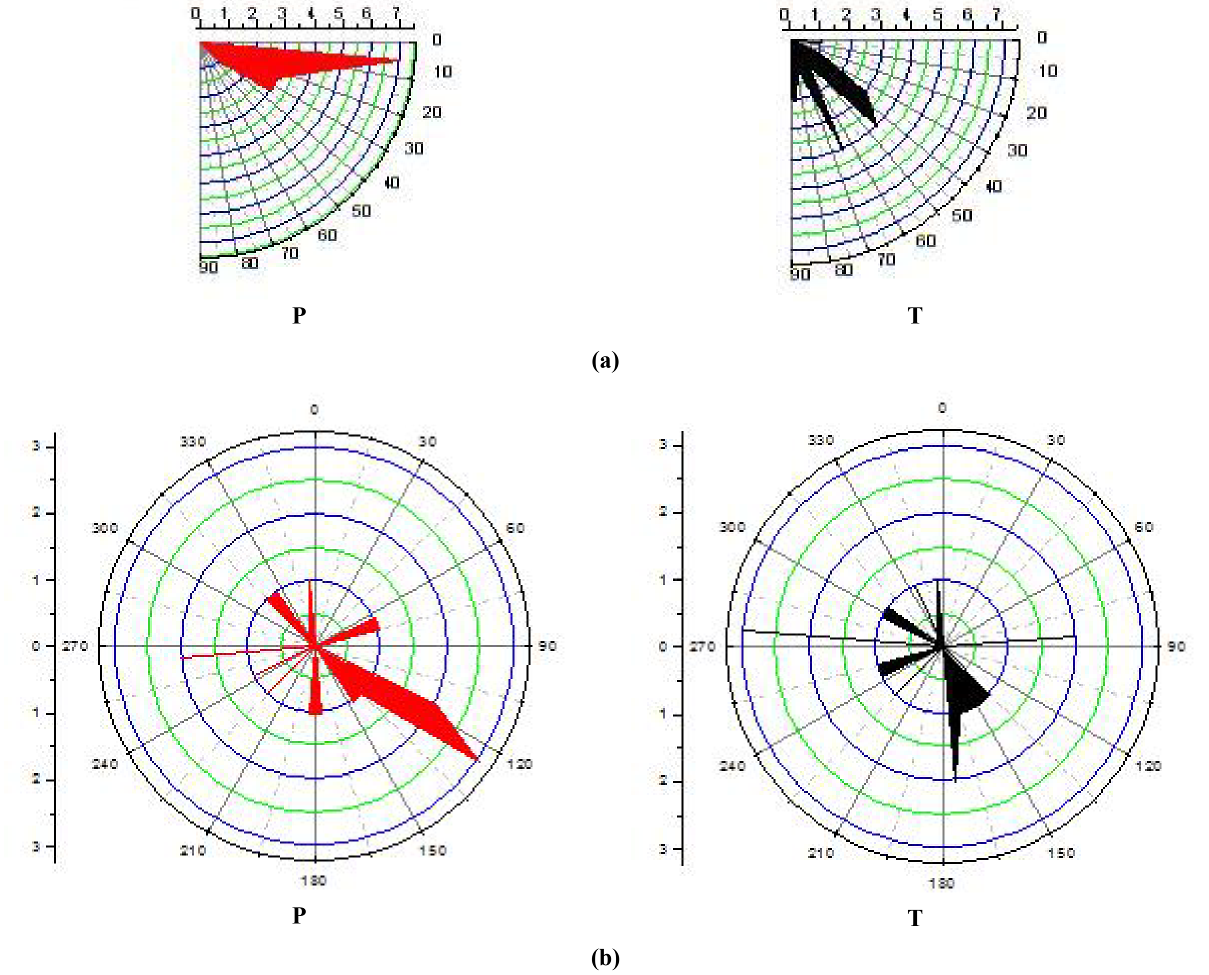


Fig. 9 – The dip (a) and azimuth (b) of P and T axes of earthquakes occurred in North Dobrogea.

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