ON THE MONITORING OF THE SEISMIC ACTIVITY IN THE TERRITORY OF BULGARIA AND SURROUNDINGS

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Abstract. Generalized analysis of the monitoring of the seismicity over the territory of Bulgaria and its very adjacent lands for the last 32 years is proposed. More than 32 000 seismic events with magnitude M > 0.5 are localized in this region since 1981 – the time of the modern National Seismological Network starting operated. Catalog of earthquakes with magnitude M>4.0 is applied. The time and space variation of the seismicity is traced out by the consequential analysis of the epicentral distributions around the seismic zones for each 5-years period during the time operation of the National Seismological Network. Some more or less clear expressed grouping of epicenters of strongest earthquakes around the main Quaternary active fault structures is established, as well as some kind of "migration" of the strong seismicity during the time – from north-east to south-west and vise versa.

Key words: Bulgaria, seismic monitoring, seismicity

The earthquake monitoring in Bulgaria is carried out by the National Seismic Network (NSN), part of the Seismological Department of the National Institute of Geophysics, Geodesy and Geography of Bulgarian Academy of Sciences (NIGGG of BAS). The network was run in 1980 and nowadays consists of 23 stations (16 permanent seismic stations and two local networks) – Fig.1. After 2005 NSN is developed as fully digital seismic network.

The main tasks of NSN are:

- to provide reliable recording and transfer of seismological data;
- to ensure rapid hypocenter and magnitude estimation and notification of the governmental authorities, media and broad public in case of felt or damaging earthquakes on the territory of Bulgaria;
- to provide a modern basis for seismological studies in Bulgaria

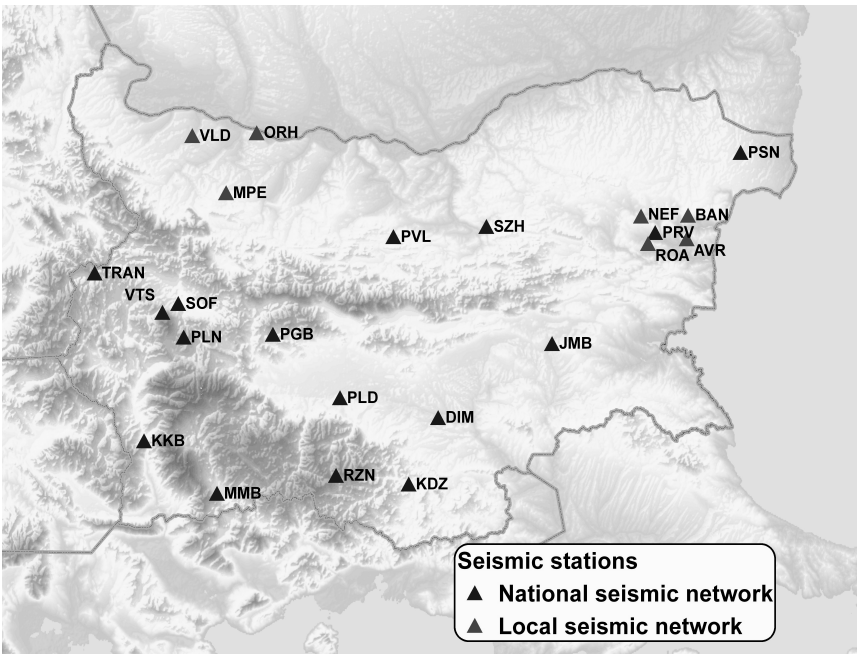

Fig.1. Modern seismological network of Bulgaria

At the National Digital Center (NDC) the data are automatically and manually processed and interpreted. Unified duration magnitude Md (up to 2006) and magnitudes based on P and S wave amplitudes (since 2006) are calculated. Both estimates of earthquake hypocenter parameters and magnitude, as well as station data are archived on a disc storage system. Additional information from foreign Balkan stations is used in hypocentral estimations. The monitoring process at the NDC also includes an assessment of the impact on the people and the buildings due to earthquakes and the relevant information is send to the responsible governmental bodies. In a case of a strong earthquake on the Balkans, the seismologist sends Bulgarian data to the neighboring and international seismological centers. Macroseismic information for about 30% of all events with magnitude M>3.0 is included in seismological catalogue. Epicentral intensity Io is published for events with compiled isoseismal maps.

The present study contains generalized results concerning the seismic events recorded by the NSN after 1981. The expanded seismic information, the analysis and evaluation of the space-time and energy earthquake distribution give possibilities to study the space-time correlations with other geophysical parameters for earthquake prediction purposes.

The evaluation of the main seismic event parameters is performed by a computer program (Solakov , 1993) based on HYPO'71 (Lee, W. H. K. and J. C. Lahr, 1972). The energy parameters of the events are presented mainly by the magnitude M calculated according to the record's duration by the formula (Christoskov and Samardjieva, 1983).

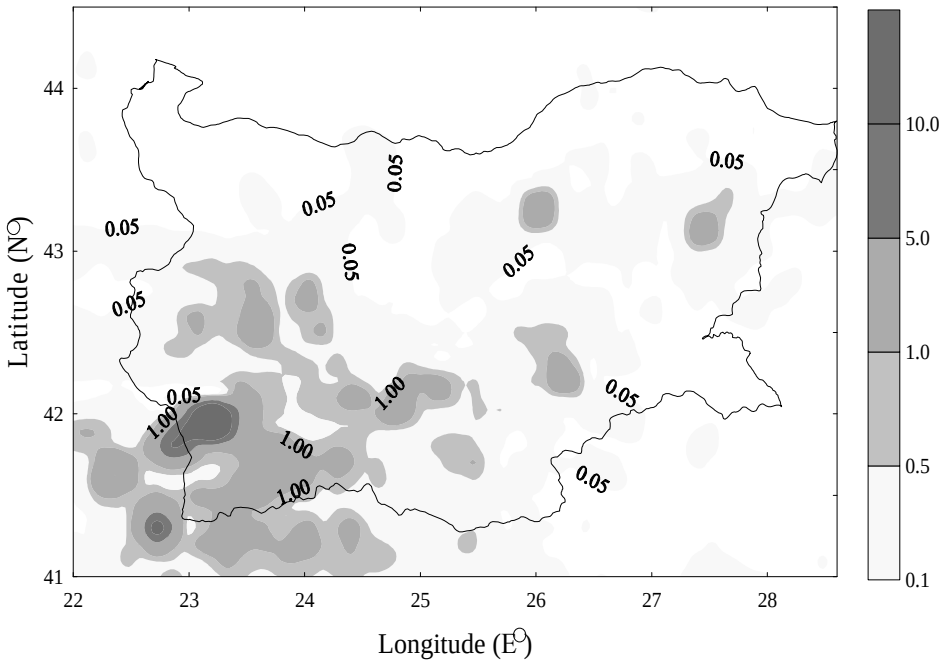

Fig.2. Epicentral density (events/100km^2/year) of the seismic events recorded after 1981 (M>0.5)

The focal mechanism parameters are obtained applying FOCMEC program (Snoke, 2009). The existing seismic network in Bulgaria provides a possibility to locate seismic events different magnitude threshold levels of local, regional and long distance earthquakes: M=1.5 for the territory of Bulgaria, M=3.0 for the central part of the Balkans, M=5.0 for long distance events.

More than 32000 events are localized on territory of Bulgaria and adjacent regions during the last 32 years – on Fig.2 the space distribution of the epicentral density is

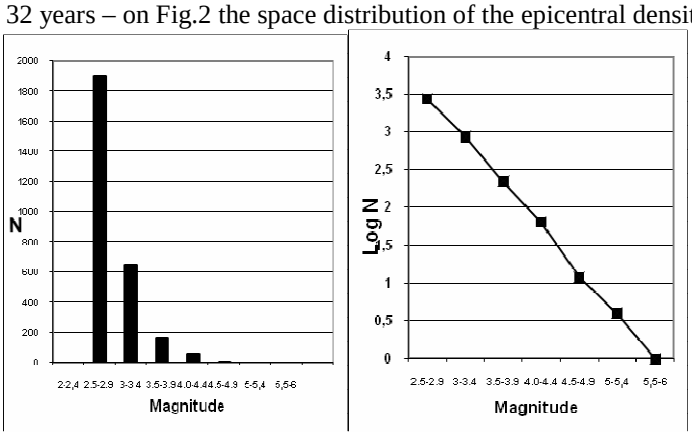

Fig.3. Magnitude-frequency and cumulative LogN-magnitude distributions of the earthquakes with magnitude M > 2.5

presented. The strongest earthquake is realized in Central Western Bulgaria with magnitude M_w=5.6. The maximum number of events is occurred in South-western part of the region of interest. Almost 97.3percentage of the events are micro earthquakes - with magnitude less than 3.0. For the analysis of the seismicity in Bulgaria during the period of National Seismic Network operation (since1981) catalogue of the earthquakes with M>2.5 have been used (Archives of NIGGG; Botev et al., 1991-2012; Solakov&Simeonova/eds/,1993).

The magnitude-frequency distribution (Fig. 3a) of the earthquakes with magnitude M > 2.5 shows that the number of the events increases with the decrease of magnitude: 1 event of M > 5.5, 3 event of M > 5.0, 7 of M=4.5-5, 54 of M=4-4.5, 162 of M=3.5-4, 646 of M=3-3.5 and 1904 of M=2.5-3. The cumulative magnitude-frequency dependence (log(N)=a ± bM) or so called Guttenberg – Richter relation (1965) is presented on the diagram on Fig. 3b. A linear distribution of the events with magnitude M> 1.5 is observed. The distribution line has coefficients a = 5.93 and b = 1.09. The value b is approximately in the range of the corresponding values from the standard dependence for longer periods and stronger events which means that some equilibrium between our period of investigation and the whole period with all strong events is available.

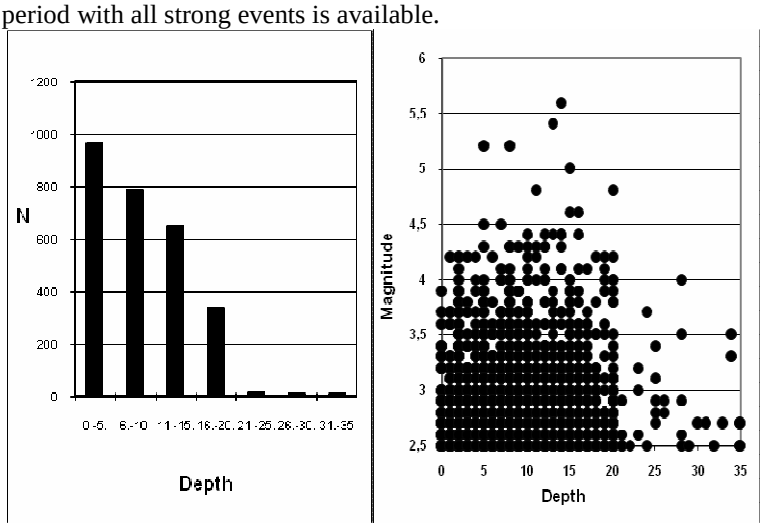

Fig.4. Depth and Depth-magnitude distributions of the events with magnitude M > 2.5

Depth distribution of the events with magnitude M > 2.5 shows that the hypocenters of the earthquakes are concentrated in the subsurface 20 km depth interval; they reach down to 30-35 km depth for a few events mainly in the SW part of Bulgarian territory. The smooth increasing in the events number with the depth's decreasing to 0-5 km is probably an evidence for availability of very small quantity of unidentified industrial explosions. The distribution of the events' strength (magnitude) in depth does not permit distinguishing any depth "floor"; the stronger events can be traced out within a large depth interval – from 5 to 20 km , the maximal events – 13-15 km.

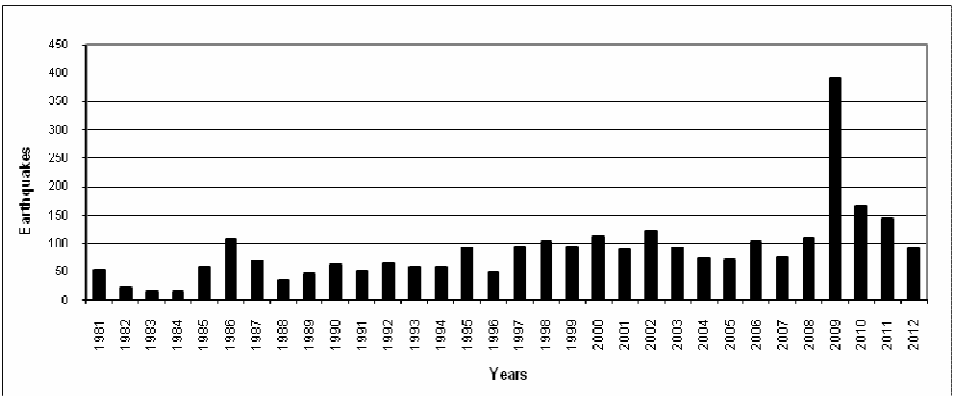

Fig.5. Time - distribution of the events with magnitude M > 2.5

From the time distribution of the events with M > 2.5 it is remarkable that in the last years (after 1997) the frequency of the events is stable higher in comparison with the previous years. The increased number of events during 1986 is due to the aftershock sequences of the Strazhitza earthquakes (magnitudes 5.1 and 5.4). The increased number during 1997 and 1998 is due to a swarm sequence in Rila mountain. The significantly increased number of events in 2009 due to the Valandovo aftershock sequence with main event magnitude M=5.2.

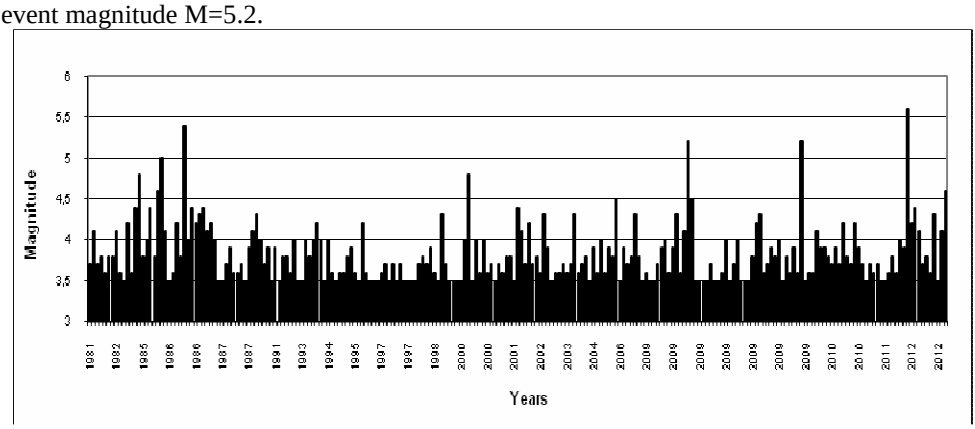

Fig.6. Magnitude – time distribution of the events with magnitude M > 3.5

The magnitude – time distribution of the strongest events (with magnitude M > 3.5) shows the typical decreasing of M in the time for the aftershock series of the strongest earthquakes (Fig.6.). This "energy" distribution of the earthquakes does not allow the establishment of a quasi-periodic peculiarity of the seismicity, but in the same time confirms an idea for some kind of a periodicity. As it will be seen in the next part, this periodicity will be associated with the "migration" of the strong seismicity during the last 32 years – from north-east to south-west and vise versa.

The time and space variation of the seismicity could be traced out by the consequential analysis of the epicentral distributions of the each about 5-years period during the NSN operating (Fig.7.).

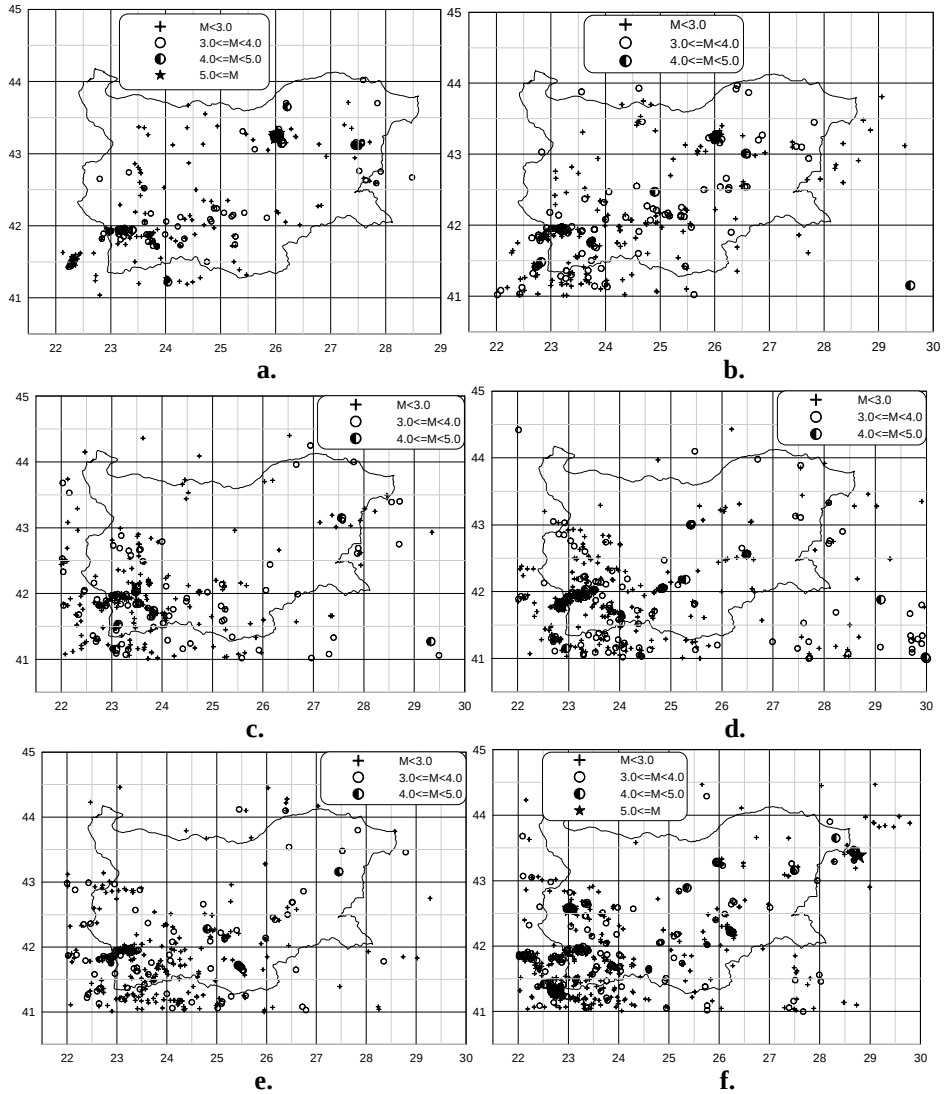

Fig.7. Epicentral distribution of the events with M>2.5 during a)1981-1986,b)1987-1992, c)1993-1997, d)1998-2002, e)2003-2007 and f)2008-2112

From the analysis of the epicentral distributions in the pictures of Figs7(7a, 7b,…., 7f) it is seen that relatively stronger seismicity is observed only during the first and the last time period (Figs 7a and 7f) where the epicenter locations are presented by more specific symbols. Only on these two figures earthquakes with magnitude M >4.5 are observed – with only one exception in Fig7e for Kardzhaly M=4.6 event. The most specific feature of the seismicity during the first time period (Fig.7a) is the NE-SW oriented 1986 Strazhica sequences (Mmax =5.4) in the eastern edge of the Gorna Orjahovitza zone in the central northern Bulgaria and the grouping of epicentres in Provadia zone without strongest

seismicity (Mmax=4.3), in the mainland of NE Bulgaria. With similar specific picture of seismic activation is characterized the seismicity during the last time period (Fig.7f), but now the stronger is the 2009 activation in NE part of Bulgarian territory – Shabla zone in northern Black sea coast (Mmax=5.2). But the strongest event for whole Bulgarian territory occurs after all this activity of Central and Eastern North Bulgaria – in May 2012 by the relatively short Pernik sequence (Mmax=5.6) the strongest seismic activity migrates to the central parts of West Bulgaria.

As a whole the rest lower seismicity shows very similar features on the pictures of all Figs7. The epicentral distribution of the events with M>2.5 is relatively diffuse –the eppicenters of smaller arthquakes are not clearly grouped around the well known active geotectonic structures. Relatively outlined zones of grouping of the epicentres could be marked at the background of everywhere distributed epicenters of the weak seismicity during the last 32 years. The most active zone is the Struma area, in the southwestern part of the investigated region. Some other active zones are those of Plovdiv, Yambol, Kardzhali and Sofia. Very long swarm of seismic activity is observed after 2008 in the region around the Monastery uplift. Nevertheless the most significant feature of all pictures of Figs7 is the dominated biggest concentration of epicentres in southwestern parts of the investigated territory.

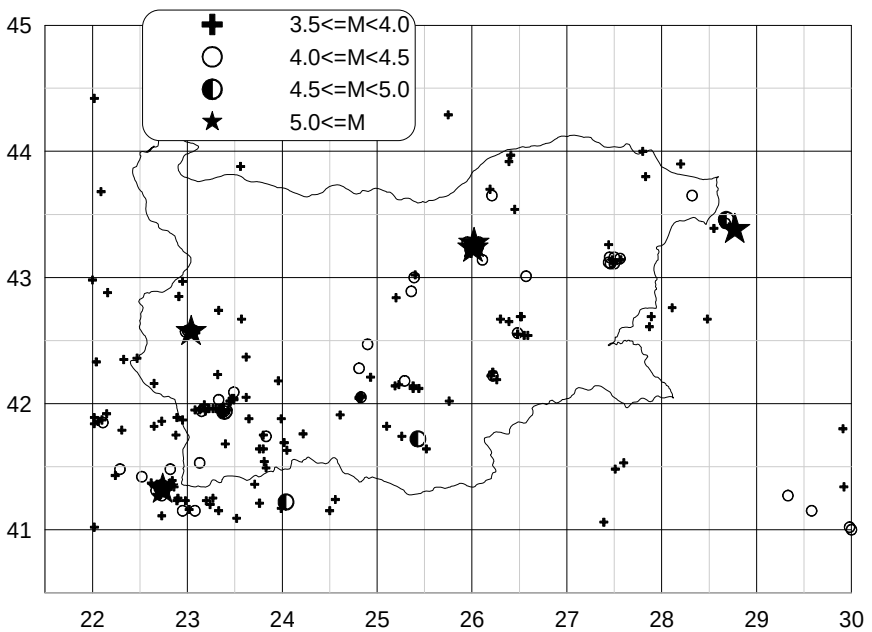

Fig.8. Strong seismicity during 1981 – 2012 (M > 3.5)

There is some correlation between the space distribution of the epicenters of the strong events (Fig.8, events with magnitude M>3.5) and the main Quaternary active fault sources in Bulgarian territory. It is no so clear that Moesian platform is characterized by the lowest seismic activity (like a platform) - on the contrary, several of the strongest Bulgarian events with M>5.0 and many aftershocks are realized in the central part of North Bulgaria

and to the north in the Black sea coast. The biggest concentration of epicenters is observed in western part of Rhodopian super unit (SW Bulgaria). Some grouping of events is seen in western and central part of the Srednogorie zone (Central Bulgaria). The epicenters show one very active south-western part of the investigated territory. The most active region of the state's territory here is the Kroupnik zone. It is to be stressed also on the seismicity tothe south of the Greek-Bulgarian border where many quakes are localized along the Middle-Mesta lineament. Some other polygons of activation can be fixed in the inner part of the Rhodope Mountain, in the region of Pernik (around Sofia zone), in the central parts of the Northern Bulgaria, in the northern Black sea coast and in the regions of Provadia, Jambol, Plovdiv and Kardzhali. The parameters of strongest events in these regions could be finding in the Table1.

Table 1. List of earthquakes with M ≥ 4.0 in Bulgaria and very adjacent lands

Year	Month	Day	Hour	Minute	Latitude (°N)	Longitude (°E)	Depth (km)	Magnitude
1981	7	23	6	15	43.12	27.44	8	4.1
1982	8	27	9	58	43.65	26.21	19	4.1
1983	11	10	17	28	43.11	27.46	10	4.2
1984	12	3	9	29	41.94	23.39	12	4.4
1984	12	3	10	26	41.94	23.39	11	4.8
1985	6	12	14	5	43.11	27.50	12	4.0
1985	9	28	14	50	41.48	22.29	10	4.4
1985	11	9	23	30	41.22	24.04	16	4.6
1986	2	21	5	39	43.27	26.02	15	5.0
1986	2	21	6	18	43.26	25.97	16	4.1
1986	5	15	16	45	41.94	23.15	19	4.2
1986	12	7	14	17	43.23	26.01	13	5.4
1986	12	7	14	53	43.14	26.11	20	4.0
1986	12	7	17	26	43.22	25.98	14	4.4
1986	12	8	14	44	43.26	26.03	20	4.2
1986	12	12	19	29	43.27	26.05	12	4.3
1986	12	17	22	1	43.28	26.07	14	4.4
1986	12	18	7	16	43.23	26.06	14	4.1
1986	12	18	17	16	43.25	26.07	18	4.2
1987	12	1	9	54	43.26	26.03	15	4.0
1989	10	25	15	27	43.01	26.57	17	4.1
1990	1	31	10	16	41.48	22.82	12	4.3
1990	6	10	11	36	41.15	29.58	19	4.0
1992	8	24	21	43	42.47	24.90	20	4.0
1993	3	27	23	47	41.15	23.08	12	4.0
1993	4	21	16	53	43.15	27.56	8	4.0
1993	12	12	17	21	41.27	29.33	3	4.2
1993	12	16	9	22	41.53	23.13	11	4.0
1994	3	21	21	42	42.09	23.49	10	4.0
1996	2	1	17	43	41.74	23.83	1	4.2
1998	12	11	15	9	42.18	25.29	14	4.3
2000	4	2	18	57	41.02	29.98	10	4.0
2000	6	6	2	42	41.88	29.11	20	4.8
2000	8	22	11	40	41.00	30.00	2	4.0

Year	Month	Day	Hour	Minute	Latitude (°N)	Longitude (°E)	Depth (km)	Magnitude
2000	8	28	5	16	43.00	25.39	8	4.0
2001	8	13	14	26	42.56	26.48	16	4.4
2002	2	18	10	19	42.03	23.33	10	4.1
2002	4	5	13	13	42.05	24.83	11	4.2
2002	7	31	4	5	41.15	22.95	11	4.3
2003	12	17	23	15	43.16	27.45	9	4.3
2004	9	10	17	46	42.28	24.81	15	4.0
2006	2	20	17	20	41.72	25.43	7	4.5
2008	4	15	3	43	42.89	25.36	10	4.3
2009	5	5	17	39	41.85	22.11	7	4.0
2009	5	24	14	29	41.35	22.71	8	4.3
2009	5	24	14	34	41.33	22.73	2	4.1
2009	5	24	16	17	41.32	22.74	5	5.2
2009	5	24	16	23	41.33	22.74	5	4.5
2009	5	24	18	50	41.32	22.71	7	4.0
2009	5	25	7	59	41.31	22.67	4	4.0
2009	5	31	22	7	43.28	25.95	2	4.2
2009	6	1	8	3	41.27	22.73	5	4.3
2009	6	15	9	56	41.31	22.76	5	4.0
2009	8	5	7	49	43.38	28.77	8	5.2
2009	11	30	5	48	43.43	28.67	14	4.1
2010	8	20	2	34	42.22	26.22	6	4.2
2010	10	7	19	51	43.16	27.50	2	4.2
2011	10	11	19	49	43.65	28.32	28	4.0
2012	5	22	0	0	42.57	23.04	14	5.6
2012	5	22	0	4	42.57	22.98	4	4.2
2012	5	22	1	30	42.58	23.00	13	4.4
2012	5	22	2	13	42.58	23.07	12	4.1
2012	7	14	12	52	42.57	23.06	8	4.3
2012	8	27	16	26	41.42	22.52	7	4.1
2012	12	3	18	58	43.46	28.68	15	4.6

From the analysis of the strong seismicity it is seen that the most seismic area in Bulgaria is situated in the Struma structural province in South-west Bulgaria. As usually, the largest concentration of epicenters is marked in the Kroupnik seismic source zone. This zone is characterized by faults transversal to the Struma lineament. One of the strongest crustal event for all Europe (M>7.8 in 1904) and about 30% of the present day weak seismicity are localized here. The biggest frequency of the earthquakes in Kroupnik zone is associated with the tectonic activity of Simitly quaternary depression, first of all with the activity of the Kroupnik fault. As it had been said, the seismic activation here has a transversally orientation in relation to the first order Strouma fault zone. Transversal faulting process can be marked in the region of Kovatchevitza, crossing the Upper Mesta fault zone. Transversally to the Strouma fault lineament is the seismicity in the SW corner of the region, and it is associated with the Belasitza and Stroumeshnitza faults. The activity in Central Bulgaria is associated with: Sub-Balkan fault lineament in the northern board of Sofia depression; the faults in the southern board of the Upper Thracia depression (the north flank of Rhodopes) and Tundzha fault linement in Yambol zone. The activity in the

central part of North Bulgaria is associated with the eastern border of Strazhitza depression and the southern one of the Ressenski trough. The seismicity in Provadia region is associated with the eastern border of the Provadia depression which is cross lying to the Fore-Balkan fault lineament. The relatively rare but strong seismicity in the Shabla zone on the Black sea coast during the last three years is associated with the activity of Kaliakra fault lineament in the sea aquatory.

Conclusions

The analysis of the instrumentally observed seismicity after the starting of NSN operation makes evident:

- The energetic level of the observed seismicity for the period 1981-2012 is relatively low – 97.3% from the all about 32000 seismic events are microearthquakes (M<3.0); the maximum magnitude event (M=5.6) is located in Pernik region – Central West Bulgaria.

- The magnitude-frequency distribution of earthquakes shows that the earthquake catalogue is complete for events of M > 2.5.

- The slope of the averaging straight line of the recurrence relationship of events shows some convenience between the weak and relatively stronger events from the whole seismic history of Bulgaria.

- The epicenter distribution of the events with M > 2.5 is relatively diffuse –the epicenters of all microearthquakes are not clearly grouped around the well known active geotectonic structures.

- Probably due to the high accuracy of determinations of epicenters for the stronger earthquakes (M>3.5), some more or less clear expressed grouping of epicenters around the main Quaternary active fault structures is established.

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Върху мониторинга на сеизмичната активност на територията на България и прилежащите земи

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Резюме. Предлаганата публикация съдържа обобщена информация за мониторинга на сеизмичната активност на територията на България и непосредственно прилежащите земи. Повече от 32 000 земетресения с магнитуд M > 0.5 са локализирани в този район след 1981 г. – времето на влизане в действие на съвременната Национална Сеизмологична Мрежа. Предлага се и каталог на най-силните земетресения с магнитуд M>4.0. Сеизмогенните прояви се обсъждат по отделни сеизмични зони в пространството и по петгодишни периоди във времето. Установено е повече или по-малко изявено групиране на епицентрите на най-силните земетресения около основните кватернерно активни разломи и обособени миграционни процеси на сеизмичната активност.