DATA AND ANALYSIS OF THE EVENTS RECORDED BY NOTSSI IN 2006

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Abstract. A map of epicenters of 1424 earthquakes that occurred in the Balkan Peninsula sector outlined b99y latitude $\varphi = 37^0$- 47^0N and longitude $\lambda = 19^0$-30^0E is presented. Expert generalized analysis of the seismicity over the territory of Bulgaria and its very adjacent lands (with more than 810 localized events) is proposed. Catalog of earthquakes with magnitude M>2.5 is applied.

Key words: Balkan Peninsula, Bulgaria, seismicity

The present scientific communication contains generalized information on the results of collection, processing and analysis of the data about the seismic events recorded by the National Operative Telemetric System for Seismological Information (NOTSSI) in 2006. The expanded information about the realized seismicity is suggested as a natural generalization and supplementation of the monthly publications of the preliminary seismological bulletin of NOTSSI. The analysis and evaluation of the space, time and energy distribution of the seismicity, periodically been made, open up possibilities for searching for time correlations with the parameters of different geophysical fields aiming to find out eventual precursor anomalies.

The recording and space localization of the seismic events in NOTSSI during 2006 is realized by means of the new digital network (Solakov et al., 2005). The routine processing and acquisition of the initial data is organized in a real time duty regime. The operations are fulfilled by the authors of this communication. In such a way the main goal of NOTSSI, namely the seismicity monitoring in order to help the authorities' and social reaction in case of earthquakes felt on the territory of the country, is realized. The computing procedure for determining the parameters of the seismic events is an adaptation of the widespread product HYPO'71 (Solakov , 1993). 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)

$$M = 1.92 + 2.72\log\tau - 0.026\Delta$$

The focal mechanism parameters are obtained by means of a program FOCMEC (Snoke,2009). The high sensitivity of the seismographs allows recording and processing of a great number of long distance earthquakes. As a result of the achieved experience in the authors interpretation work, different magnitude's lower threshold for successful determination of local, regional and long distance earthquakes is established: 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. The precision of the epicenter's determination is different; except on the distance it depends also on the specific position of the epicenter in relation to the recording network. The parameters of seismic events occurring at a distance more than 100-150 km outside the territory of Bulgaria should be accepted only informatively and cannot be used for responsible seismotectonic investigation.

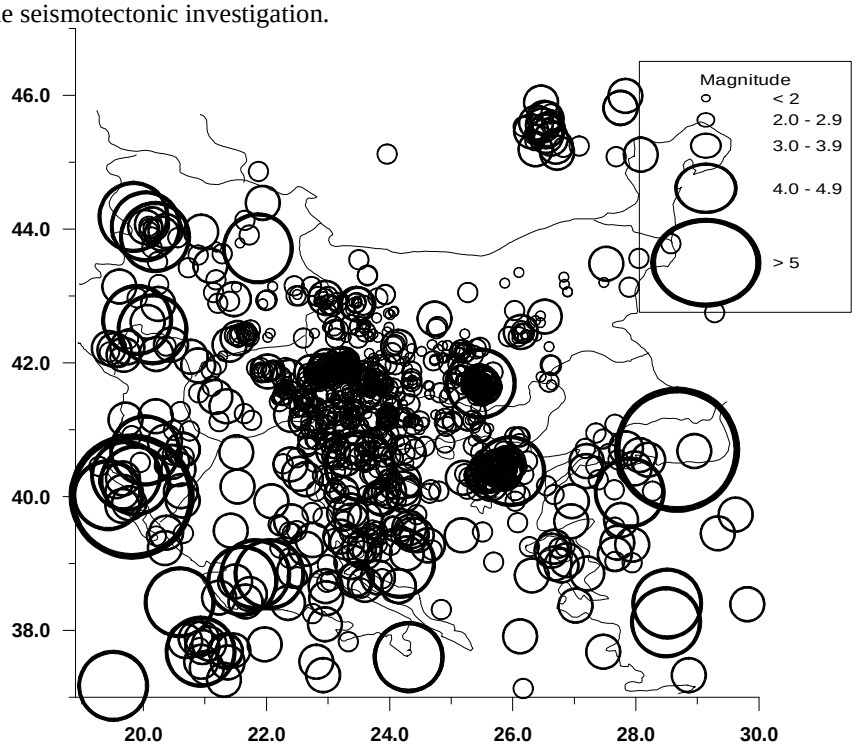

Fig.1. Map of epicenters in Central Balkans during 2006.

For the period of observations presented in this communication, the primary data about 2500 local, regional, distant earthquakes and industrial explosions on the territory of Bulgaria are recorded, classified and processed (as a work bulletin) in NOTSSI. After comprehensive analysis of the records and application of the above mentioned calculation procedures it is established that 1424 of all registered earthquakes are in the Balkan Peninsula region outlined by geographic latitude 37^0 - 47^0 N and longitude 19^0 - 30^0 E. The epicenters of the earthquakes differentiated by magnitude levels are plotted on Fig.1. The

number of the events in the magnitude interval M=1-1.9 is 639, in M=2-2.9 - 550, in M=3-3.9 - 208, in M=4-4.9 – 25 and for M>5.0 - 2 earthquakes.

As a whole, the seismic situation in the study part of the Balkans during 2006 is characterized by relatively high activity (1424 events against around 1100- 1300 for most of the previous years). It can be noted that the observed tendency of relative increase in the activity compared with the former years is partly due to the earthquake activation in Bulgaria, Western Greece, and Marmara Sea.

The strongest event outside Bulgaria during the study period occurred on the Adriatic coast of Greece/Albania boarder region on 8th August 2006. According to the Euro-Mediterranean Seismological Centre, the earthquake magnitude was determined between 5.2 and 6.1. One of the strongest event outside Bulgaria during the study period occurred on 24th October 2006 in Marmara Sea Region. Its magnitude was 5.1 by NOTSSI determination, and in the interval 4.5 - 5.5 according to the Euro-Mediterranean Seismological Centre. This earthquake was felt in Bulgaria very slightly (II EMS in Butgas). Some earthquakes of magnitude between 4 and 5 occuring in the neighbouring countries were also felt in Bulgaria. Effects of intensity III-IV EMS were reported from Montana in consequence of an earthquake in the Morava valley, Serbia (on 21 November). Two other earthquakes originated to the North of Thessaloniki (10 May 2006), and in the Mionice area at 75 km SW of Beograd (22 March 2006) provoked very slight excitation (disturbance of population living over high stores) in Gotse Delcev and Chiprovci, respectively.

As a whole, events with M<3.0 which occur outside Bulgaria are difficult to be localized by the national seismological system; consequently, not all of them have been marked on the scheme in Fig.1.

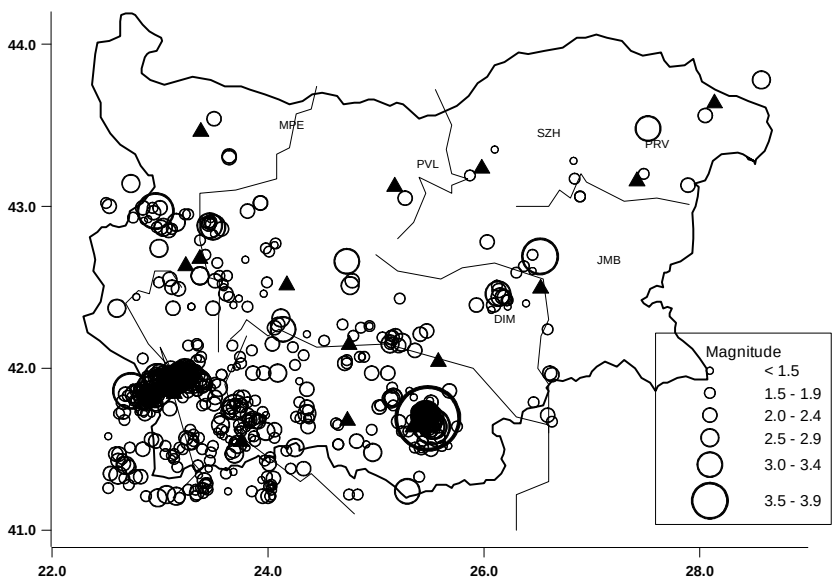

Fig.2. Map of epicentres in Bulgaria and adjacent lands during 2006

Fig.2 illustrates the seismicity just in the territory of Bulgaria and nearby lands ($\varphi = 41^0 - 44.5^0$N, $\lambda = 22^0 - 29^0$E). The earthquakes are differentiated by magnitude intervals. The seismic stations are also noted in the same figure by triangles. The parameters of relatively stronger earthquakes are presented in Table 1.

Table 1. List of earthquakes with M ≥ 2.5 in Bulgaria and adjacent lands during 2006

Date	Time	Coordinates	H,km	M	Imax
20060110	06:50:05	41.94 23.05	13	2.5	
20060120	23:09:26	42.69 26.52	13	3.9	V
20060121	15:00:54	42.74 22.99	12	2.6	
20060128	03:31:38	41.65 23.56	4	2.8	
20060204	21:33:22	41.87 22.95	20	3.8	IV
20060204	22:50:06	43.48 27.52	20	3.0	
20060204	23:10:51	41.82 22.93	20	2.5	II-III
20060205	23:27:56	41.98 23.21	1	2.8	
20060208	19:35:20	41.96 23.28	2	2.8	
20060214	16:50:40	41.97 23.22	13	2.7	
20060215	21:50:32	41.88 22.93	13	3.4	III
20060215	23:50:40	41.83 22.87	9	2.7	
20060217	02:44:35	42.37 22.60	3	2.5	
20060220	17:20:09	41.69 25.48	13	4.5	VII
20060220	17:22:55	41.69 25.51	2	3.3	
20060220	17:43:25	41.68 25.46	13	3.1	
20060220	18:29:16	41.64 25.54	14	3.0	
20060221	15:20:59	41.64 25.52	15	3.5	IV
20060222	10:57:56	41.71 25.44	10	2.6	II-III
20060222	11:37:06	41.69 25.45	12	2.9	III
20060222	20:30:54	41.57 25.56	12	2.6	II-III
20060223	18:22:07	42.66 24.73	12	3.0	IV
20060223	22:01:26	41.71 25.47	12	3.0	III
20060224	10:36:39	41.72 25.47	20	3.1	IV
20060224	13:34:59	41.69 25.49	17	3.2	IV
20060224	21:26:34	41.97 23.00	16	2.8	III
20060224	23:40:00	41.85 22.95	19	2.6	
20060227	06:35:31	41.48 24.97	2	2.5	
20060228	17:00:39	41.95 23.22	10	2.5	
20060307	14:24:59	41.70 25.48	10	2.6	III
20060313	02:29:49	41.95 22.97	11	2.8	
20060313	18:46	41.7 25.48	10	2.8	III
20060314	08:06:47	41.70 25.45	12	3.4	V
20060314	08:26:05	41.69 25.45	14	2.8	III
20060314	08:39:03	41.72 25.45	10	3.3	IV
20060317	00:56:11	42.88 23.46	16	3.0	V
20060319	18:30:30	41.67 25.48	20	2.8	
20060323	11:12:24	42.90 23.15	10	2.5	
20060327	03:46:41	41.97 24.09	1	2.5	
20060406	00:24:35	42.16 25.24	20	2.5	

Date	Time	Coordinates	H,km	M	Imax
20060422	09:17:49	41.51 24.25	18	2.5	
20060427	12:38:14	42.57 23.37	2	2.9	V
20060429	00:26:32	41.68 25.46	16	2.5	
20060429	00:28:03	41.68 25.46	15	2.7	
20060502	02:55:59	41.65 25.46	20	2.5	
20060503	19:40:34	41.96 23.19	5	3.3	IV
20060505	19:44:35	41.96 23.18	8	3.2	
20060506	04:09:46	41.70 25.48	12	2.7	III
20060510	07:29:56	42.97 22.96	10	3.9	V-VI
20060510	09:31:05	42.46 26.13	7	3.3	V
20060510	20:01:05	42.44 26.15	17	2.9	III
20060514	05:08:00	41.64 25.52	9	3.0	III-IV
20060514	08:35:18	42.87 23.03	6	2.7	
20060514	17:10:06	41.70 25.51	11	2.7	III
20060518	20:06:17	41.96 23.19	17	2.9	II-III
20060519	03:29:06	41.69 25.48	10	2.5	
20060525	06:37:13	41.21 23.15	7	2.6	
20060602	07:20:25	41.98 23.23	8	3.0	III
20060612	09:58:35	41.96 23.20	10	2.5	
20060612	18:21:36	42.31 24.12	13	2.5	
20060617	12:38:56	41.22 23.06	15	2.9	
20060617	15:38:55	41.20 22.98	11	2.5	
20060618	07:31:07	41.53 23.72	15	2.8	III
20060621	08:30:15	41.47 23.69	3	2.9	IV
20060624	19:44:51	41.72 24.36	11	2.8	
20060627	04:40:09	43.14 22.73	6	2.7	
20060706	21:08:31	41.91 23.40	3	2.8	
20060708	01:15:46	41.94 23.36	20	2.9	
20060714	12:22:57	41.34 22.61	10	2.9	
20060714	12:23:48	41.40 22.68	5	2.7	
20060715	23:29:06	41.24 25.29	2	3.0	
20060717	16:51:47	42.15 25.13	16	2.8	IV
20060718	14:55:34	41.92 23.39	10	2.6	
20060722	20:02:10	42.24 24.14	20	3.1	III
20060731	01:30:34	41.95 23.05	19	2.8	
20060801	13:15:28	41.70 25.44	9	3.1	IV
20060805	05:38:13	41.96 23.20	14	3.1	III
20060807	02:44:33	41.95 22.97	20	3.1	
20060807	03:48:21	41.96 23.09	14	2.5	
20060813	02:09:55	41.76 23.69	13	3.0	
20060815	06:39:35	42.51 24.76	15	2.6	
20060824	21:00:02	43.78 28.57	8	2.8	
20060826	19:46:06	41.88 23.54	8	2.5	
20060903	21:54:32	41.93 23.25	2	2.5	
20060914	09:05:06	41.93 23.38	10	2.6	
20060920	04:25:43	41.55 23.27	15	2.7	III
20060926	12:03:37	41.61 23.98	13	2.6	III

Date	Time	Coordinates	H,km	M	Imax
20061120	01:02:25	41.86 22.73	7	3.7	
20061120	01:10:45	41.84 22.76	12	2.5	
20061212	19:35:15	41.82 25.16	14	2.9	
20061220	03:22:40	41.81 25.14	14	2.5	

On the territory of Bulgaria a relatively high degree of activity of weak earthquakes is observed during 2006 - 818 events against 600-700 for most of the previous years. The earthquakes of a magnitude higher than 3.0 are in a little bigger amount - 31 events compared with the averaged number of about 20-30 for most of the all previous years. The maximum realized magnitude M=4.5 is higher too than the maximum magnitude in the course of previous years; its usual value used to be about 4.0.

As usually, the largest concentration of epicenters is marked in the southwestern part of the territory presented in Fig.2. The Kroupnik seismic source, known with the strongest crustal earthquakes in Europe (M=7.8, 7.1) for the last 160 years (Christoskov and Grigorova, 1968). It is worth noting that in 2006 more than 100 events of M<3.0 and several of M≥3.0 occurred in this region. The strongest earthquake is with magnitude M=3.8 on the Macedonian border lands, it is felt in Bulgarian by intensity of IV EMS.

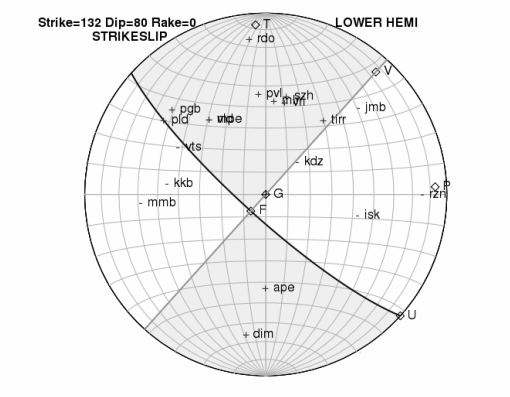

Fig.3. Focal plane solution of the Kardzhali earthquake

Strongest affects in 2006 were caused by the East-Rhodopean earthquake series that started on 20 February around the Kardzhali town [Glavcheva et al., 2006; Hadjiyski and Glavcheva, 2006]. The epicentral intensity at the main shock occurrence (M 4.5) was assessed to 7 degree EMS. The special fact to be underlined is that the prevailable part of damaged houses was of type A and B (classification by the EMS scale). Most often the bearing walls were erected of stones with clay connection and poorly fastened with the fillings; the basements predominantly were shallow settled into the ground. To no chance, many aftershocks followed the strongest one in the next 3 months. Almost 15-20 of the recorded aftershocks were felt, at that some of them with intensity V EMS, and increased the initial damages. Except of damages to buildings, the 20 February earthquake caused stonefalls, landslides and water changes. The distribution of the aftershocks shows northwest – southeast direction. This is in coincidence with one of the nodal fault plane (strike 132 degree, dip 80 degree and rake 0 degree)-Fig.3. For the determination of the

earthquake mechanism 17 polarities of the P waves from seismological stations in Bulgaria and surrounding area are used. The data are taken from NOTSSI and ORFEUS database (ftp://www.orfeus-eu.org/pub/data/continuous/2006/). The solution is displayed on lower hemisphere.

Several cases of maximum intensity V EMS (M up to 3.9) were noted except at Kurdzhali aftershocks, in Yambol and Sofia seismic zones. Effects of intensity IV (maximum M=3.8) were registered at East-Rhodopean Kurdzhali activation, over the SW Bulgarian lands (a rarely populated region), in the Thracian Lowland and, provoked by a surprising seismic case in the Sopot vicinity. Slighter shocks (intensity lower than IV) were caused by sources spread over Central and South Bulgaria. No one earthquake originated in the NE seismic region was felt.

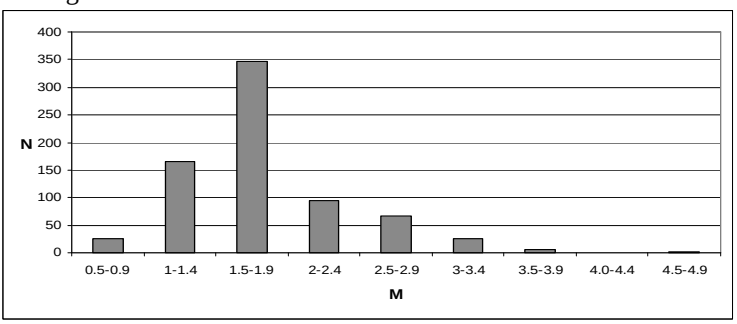

Fig.4. Magnitude - frequency distribution of the earthquakes

A detailed analysis of seismicity in the individual seismic zones is hard to be fulfilled because of the insufficient quantity of events and the narrow magnitude range of the earthquakes. The joint statistics of all the events in Fig.2 characterize predominantly the seismicity parameters of the southwestern part of the territory under investigation.

The magnitude-frequency distribution for the entire data set is presented in Fig.4. The number of localized events increases with the magnitude decreasing: for M=4.0-4.4 is 0 events, for M=3.5-3.9 is 5 events for M=3.0-3.4 is 25 events, for M=2.5-2.9 - 67, for M=2.0-2.4 - 95 and so on. The abrupt diminishing of the number of earthquakes in the first two intervals (M<1.5) in Fig.4 determines also the registration power of the seismic stations network.

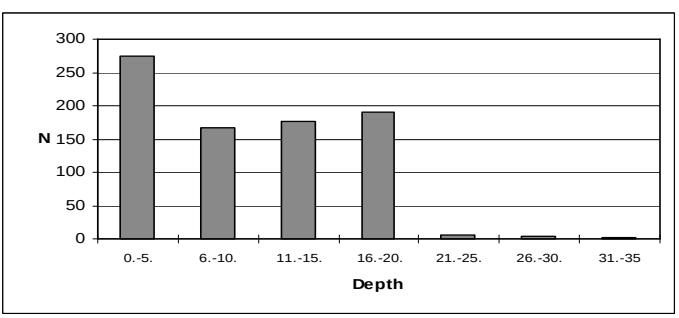

Fig.5. Depth - frequency distribution of the earthquakes

Taking the latter into account, it can be supposed that the magnitude sample for levels with M > 1.5 is comparatively closer to the reality for the bigger part of the Bulgarian territory.

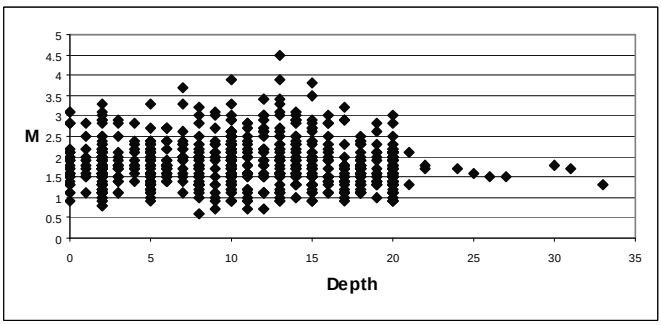

Fig.6. Magnitude - depth dependence

The picture of the depth distribution in Fig.5 shows that the majority of events occur down to 20 km depth. It is possible the established predominating depth (from 0 to 5 km) to be also due to the presence of unidentified industrial explosions. In the same time the number of events in the interval 15-20 km is comparative with this one. The magnitude distribution of the events in depth (Fig.6) permits to note some differentiation of depth "floors" with the increase of magnitude - some tendency of formation of some maximums can be traced out for the depth interval from 7 to 15 km.

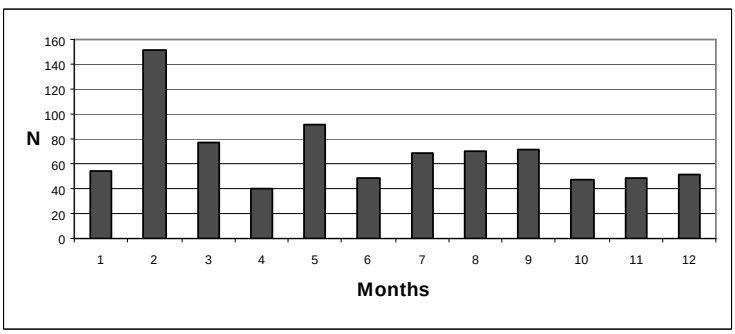

Fig.7. Time distribution of the earthquakes.

Fig.7 illustrates the distribution of seismicity in time according to the number of events per months. The biggest earthquake's amount is displayed in May, when about 150 earthquakes occurred – mainly because of Kardzhali's earthquake aftershocks series. The lowest earthquake quantity is in April, 40 events.

Figure 8 shows the energy release in time through the earthquake magnitude-time distribution. It suggests that February, the month when the most number of events occurred, is also with maximum of energy release. Some other strongest events occurred in January, May and November. The released energy amount in the second half of October and the beginning of November is lowest for the whole period of investigation.

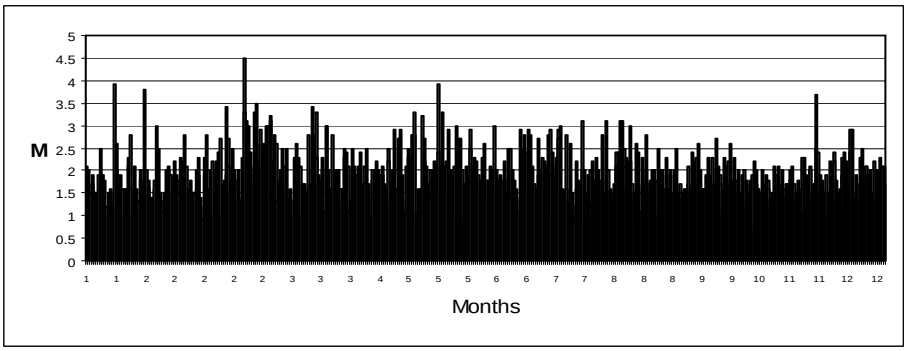

Fig.8. Magnitude-time distribution of the earthquakes

Additionally, about 700 distant earthquakes have been recorded in the period under study, as well as more than 400 industrial explosions, processed and classified in the preliminary monthly bulletins. In order to identify the artificial seismic sources the methodical approach described by Deneva et al. (1988) and some information about the quarry sites in Bulgaria have been used.

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Данни и анализ на сеизмичните събития регистрирани от НОТССИ през 2006

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Резюме. Предлаганото научно съобщение съдържа обобщена информация за резултатите от събирането, обработката и анализа на първичните данни за сеизмичните събития, регистрирани от Националната Оперативна Телеметрична Система за Сеизмологична Информация (НОТССИ) през 2006 г. Представена е карта на епицентрите на общо 1424 земетресения в частта от Балканския полуостров, ограничена от географска ширина 37^0 - 47^0 N и дължина 19^0 - 30^0 E. По-подробно се анализира сеизмичността за територията на България и прилежащите й земи (818 сеизмични събития в район с координати $\lambda = 22^0$ - 29^0E и $\varphi = 41^0$ - 44.5^0N). Предлага се и каталог на земетресенията с магнитуд M>2,5. Сеизмогенните прояви се обсъждат по зони, сравнени със съседни периоди време.