DATA AND ANALISIS OF THE EVENTS RECORDED BY NOTSSI IN 2009

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Abstract. A map of epicentres of 2744 earthquakes that occurred in and around of the central part of Balkan Peninsula (sector outlined by latitude $\varphi = 37^0 - 47^0$N and longitude $\lambda = 19^0 - 30^0$E) during 2009 is presented. Expert generalized analysis of the seismicity over the territory of Bulgaria and its very adjacent lands (with 2017 localized events) is proposed. Catalog of earthquakes with magnitude M>3.0 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 2009. The expanded information about the realized seismicity is suggested as a natural generalization and supplementation of the monthly compilations 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 2009 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.

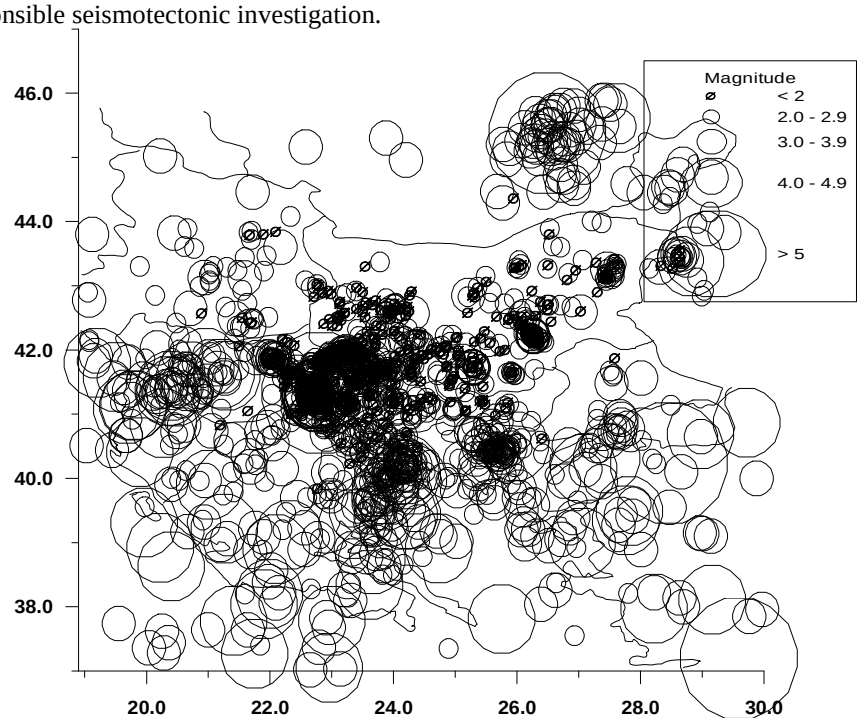

Fig.1. Map of epicenters in Central Balkans during 2009.

For the period of observations presented in this communication, the primary data about 3700 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 2744 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 1035, in M=2-2.9 - 1216, in M=3-3.9 - 423, in M=4-4.9 – 66 earthquakes. During this very much active period there are only 4 events with magnitude M>5.0. The maximum magnitude value is M=5.8.

As a whole, the seismic situation in the study part of the Balkans during 2009 is characterized by extremely high activity - 2744 events against 1775 in 2008, 1152 in 2007, 1424 in 2006 and around 1100- 1300 for most of the previous years. The maximum realized earthquake is with magnitude approximately six while this value for the previous years is lower then five, as a rule. It can be noted that the observed tendency of high increase of the activity compared with the former years is partly due to the high level of earthquake activation in FYR Macedonia, SW and NE Bulgaria, Romania, Aegean coast of Western Turkey and Marmara sea.

The strongest event outside Bulgaria during the study period occurred in the Vrancea mountain in Eastern Romania on 25th April 2009 with magnitude M=5.8. According to the Euro-Mediterranean Seismological Centre, the maximum value of the earthquake magnitude was determined up to 6.3, that is why it was felt on the almost whole territory of NE Bulgaria, with maximum V degree of MSC in the region of Silistra. Out of the earthquakes caused by sources situated in the neighboring south-western territory (region of Valandovo) only one was felt. Its origin was in Marmara Sea and the source energy was assessed by magnitudes a bit greater than 5. The influence was very slight, with intensity up to II- III degree EMS in region of Kardzhaly.

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.

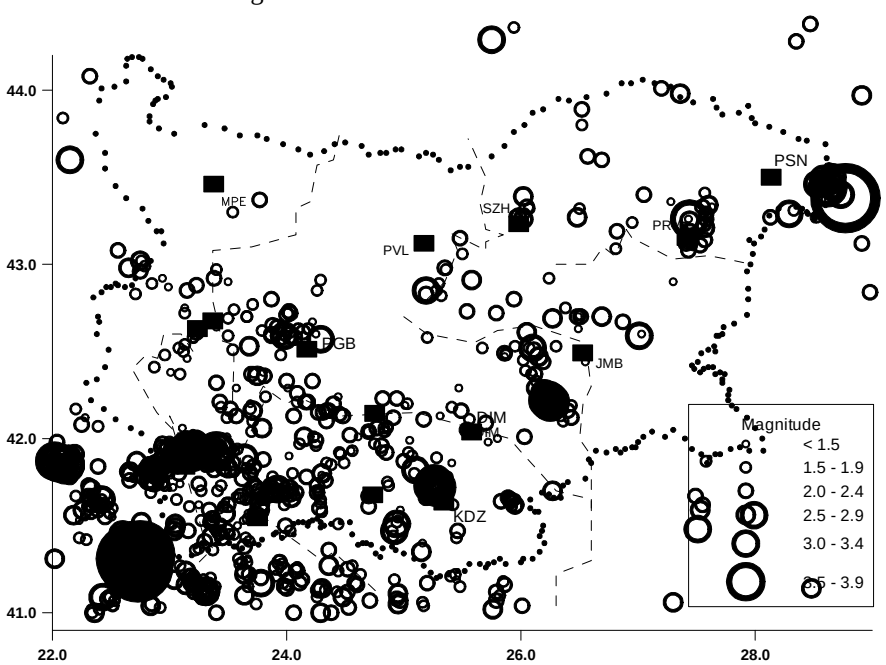

Fig.2. Map of epicentres in Bulgaria and adjacent lands during 2009

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 rectangular. The parameters of relatively stronger earthquakes are presented in Table 1.

Table 1. List of earthquakes with M ≥ 3.0 in Bulgaria and very adjacent lands during 2009

Date	Time	Coordinates	H,km	M
20090127	21:23:38	41.56 27.99	2	3.1
20090204	13:31:17	42.59 23.98	17	3.0
20090205	15:27:20	41.48 27.51	10	3.0
20090207	18:39:27	42.85 25.19	10	3.4
20090226	12:06:31	41.92 23.33	13	3.2
20090307	16:48:11	43.46 28.53	20	3.0
20090309	17:18:59	42.59 27.01	15	3.0
20090328	12:47:24	41.93 23.16	15	3.3
20090408	16:40:22	41.95 23.24	5	3.0
20090408	18:08:54	41.73 25.25	12	3.5
20090408	18:09:54	41.73 25.27	8	3.3
20090408	19:36:57	41.72 25.28	13	3.5
20090409	06:35:25	41.74 25.26	13	3.6
20090504	07:15:41	41.93 23.40	9	3.7
20090505	16:11:13	41.86 22.06	5	3.8
20090505	17:39:32	41.85 22.11	7	3.7
20090505	17:41:59	41.87 22.02	7	3.7
20090506	14:29:15	41.84 22.02	10	3.4
20090516	12:03:33	41.09 22.43	1	3.1
20090519	16:49:05	42.26 26.20	5	3.2
20090523	23:22:33	41.30 22.73	5	3.4
20090524	14:13:35	41.33 22.71	8	3.2
20090524	14:29:15	41.35 22.71	8	3.7
20090524	14:30:10	41.26 22.73	2	4.0
20090524	14:30:59	41.30 22.73	10	3.2
20090524	14:34:02	41.33 22.73	2	3.7
20090524	16:17:49	41.32 22.74	5	4.3
20090524	16:23:08	41.33 22.74	5	5.1
20090524	16:24:32	41.32 22.69	9	4.1
20090524	16:31:55	41.33 22.72	5	3.0
20090524	16:35:22	41.31 22.71	6	3.1
20090524	16:38:12	41.27 22.73	2	3.5
20090524	16:40:21	41.30 22.73	16	3.5
20090524	16:43:56	41.30 22.71	5	3.1
20090524	16:57:59	41.32 22.71	8	3.0
20090524	17:01:43	41.34 22.71	5	3.2
20090524	17:15:19	41.29 22.72	10	3.5
20090524	17:15:31	41.34 22.70	5	3.9
20090524	17:24:40	41.27 22.74	9	3.5
20090524	17:25:10	41.31 22.70	15	4.1

20090524	17:31:55	41.30	22.70	6	3.1
20090524	17:46:26	41.27	22.70	10	3.0
20090524	18:12:53	41.36	22.71	9	3.5
20090524	18:23:29	41.30	22.68	20	3.0
20090524	18:23:48	41.27	22.76	5	3.8
20090524	18:24:35	41.29	22.72	11	3.0
20090524	18:50:17	41.32	22.71	7	3.5
20090524	18:53:13	41.28	22.72	5	3.3
20090524	18:53:14	41.33	22.75	2	4.2
20090524	19:14:11	41.31	22.69	19	3.0
20090524	19:15:04	41.30	22.72	3	3.4
20090524	19:42:58	41.36	22.72	4	3.4
20090524	19:49:21	41.30	22.71	15	3.4
20090524	19:50:01	41.29	22.73	4	3.6
20090524	19:53:08	41.27	22.70	20	3.3
20090524	19:53:51	41.26	22.70	12	3.6
20090524	20:00:15	41.29	22.70	12	3.3
20090524	20:03:58	41.27	22.71	8	3.3
20090524	20:04:37	41.26	22.70	10	3.2
20090524	20:09:34	41.29	22.71	6	3.0
20090524	20:10:05	41.28	22.75	6	3.0
20090524	20:17:49	41.33	22.73	10	3.0
20090524	20:23:20	41.30	22.67	14	3.0
20090524	20:32:36	41.28	22.72	9	3.5
20090524	20:34:14	41.28	22.72	12	3.0
20090524	20:34:53	41.29	22.69	11	3.3
20090524	20:36:25	41.39	22.71	3	3.0
20090524	20:47:00	41.18	22.71	20	3.4
20090524	20:48:01	41.28	22.69	9	3.2
20090524	20:54:03	41.31	22.72	4	3.2
20090524	21:56:50	41.29	22.74	11	3.1
20090524	22:09:09	41.33	22.73	5	3.0
20090524	22:20:08	41.32	22.71	8	3.5
20090524	22:46:53	41.30	22.69	11	3.5
20090524	23:56:46	41.26	22.71	8	3.2
20090525	04:50:02	41.35	22.67	10	3.6
20090525	07:44:59	41.29	22.72	5	3.7
20090525	07:59:40	41.31	22.67	4	4.5
20090525	08:01:17	41.28	22.68	0	3.4
20090525	09:31:17	41.29	22.76	8	3.2
20090525	10:38:37	41.28	22.68	9	3.0
20090525	17:11:24	41.31	22.71	13	3.8
20090525	21:01:28	41.31	22.69	10	3.5
20090526	03:02:49	41.28	22.74	10	3.0
20090526	04:10:06	43.60	22.15	5	3.0
20090526	08:22:52	41.26	22.68	10	3.1
20090526	14:56:38	41.37	22.72	2	3.1
20090527	15:31:36	41.26	22.74	10	3.5

20090528	12:22:53	41.23	22.74	2	3.1
20090528	14:37:50	41.29	22.73	10	3.0
20090528	19:49:41	41.27	22.70	9	3.5
20090528	19:51:25	41.27	22.67	18	3.2
20090528	21:21:13	41.30	22.76	4	3.0
20090529	21:26:26	41.29	22.74	9	3.5
20090529	21:37:16	41.26	22.76	5	3.3
20090601	08:03:38	41.27	22.73	5	4.0
20090601	23:55:19	41.39	22.85	13	3.3
20090602	01:08:38	41.28	22.66	20	3.3
20090606	21:40:27	41.32	22.72	5	3.4
20090606	21:40:57	41.28	22.70	8	4.5
20090606	22:45:28	41.29	22.69	8	3.0
20090612	19:34:08	41.26	22.74	8	3.0
20090613	10:58:11	41.36	22.68	6	3.8
20090615	09:56:44	41.31	22.76	5	3.9
20090619	04:15:57	41.34	22.86	10	3.3
20090620	14:10:39	44.29	25.75	2	3.2
20090623	00:16:05	41.28	22.71	10	3.1
20090625	20:17:17	42.57	24.29	15	3.1
20090626	02:26:27	41.47	24.92	10	3.1
20090628	20:55:40	41.51	24.94	10	3.3
20090630	08:49:20	41.65	22.42	2	3.1
20090701	03:04:41	41.33	22.81	2	3.0
20090704	06:00:32	41.32	22.71	2	3.1
20090704	06:05:48	41.36	22.70	2	3.0
20090713	22:21:34	41.32	22.70	8	3.1
20090713	23:30:00	41.21	22.77	6	3.2
20090719	13:26:51	41.90	23.26	12	3.0
20090719	16:04:23	41.30	22.72	2	3.1
20090721	03:54:00	41.82	25.10	4	3.3
20090805	07:49:00	43.38	28.77	8	4.9
20090805	10:39:18	43.49	28.58	15	3.1
20090805	15:56:19	43.50	28.66	15	3.1
20090807	16:06:49	41.32	22.71	10	3.0
20090808	00:55:59	41.30	22.75	2	3.0
20090813	13:10:57	42.52	26.10	2	3.0
20090824	09:38:06	41.32	22.73	2	3.4
20090827	03:47:33	41.31	22.76	2	3.3
20090829	00:10:03	41.12	23.31	5	3.0
20090829	00:10:03	41.12	23.31	5	3.0
20090907	14:06:26	42.23	26.24	2	3.0
20090915	15:33:50	41.29	22.76	2	3.0
20090930	19:08:05	41.89	23.64	5	3.1
20091002	04:47:14	41.45	22.60	4	3.3
20091005	10:37:08	41.17	23.78	7	3.1
20091006	04:03:15	43.26	27.44	13	3.6
20091011	02:04:40	41.89	23.20	13	3.0

20091018	16:20:54	41.34 22.75	0	3.1
20091028	10:21:58	42.22 26.23	5	3.5
20091028	10:40:42	42.21 26.25	7	3.5
20091028	11:00:59	42.21 26.24	5	3.0
20091029	03:21:20	41.71 23.92	5	3.0
20091105	19:33:43	41.91 23.40	9	3.1
20091123	00:13:44	43.29 28.29	15	3.3
20091130	05:48:08	43.44 28.62	10	3.8
20091206	17:11:43	43.40 28.73	9	3.1
20091209	18:14:38	41.97 23.22	2	3.2
20091223	09:31:37	41.95 23.16	14	3.0

On the territory of Bulgaria a very high degree of activity of weak earthquakes is observed during 2009 - 2017 events against 1079 in 2008, 672 in 2007, 818 in 2006 and 600-700 for most of the previous years. The earthquakes of a magnitude higher than 3.0 are in a highest amount - 147 events compared with an averaged number of about 20-30 for most of the all previous years. That is because of the very long aftershock series of the strongest earthquake in Valandovo region. The maximum realized magnitude M=5.2 of this event is the highest too, in comparison with the maximum magnitude in the course of previous years.

As usually, the largest concentration of epicenters is marked in the southwestern part of the investigated 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). In 2009 about 110 events of $M<3.0$ and only three of $M\geq3.0$ occurred in this region. The 4 May event with M=3.8 is felt on Blagoevgrad region by maximum intensity of IV-V EMS. The strongest felt earthquake for the all Bulgarian territory is the mentioned earthquake in Valandovo region with magnitude M=5.2, which is felt in Petrich region on 24 May by maximum intensity of V EMS.

The Bulgarian seismic sources in 2009 were much more active than during the previous year. They produced more than 40 earthquakes affecting different localities in this country. Twelve cases of magnitudes between 3.2 and 4.9 aroused shocks of intensity four or more. In the rest part of the 2009 felt events caused excitation of lesser intensity. The prevailing number of them was caused by small dislocations in South-east Bulgaria, in the region of Monastery uplift, where a big earthquake sequence (swarm) had started. Several small events showed a certain seismic activity in the Central and Eastern part of the Balkan Mountain. In comparison with the year 2008 a small sequence reminded of activity in the Kardzhaly zone in April 2009. The maximal magnitude 4.9 earthquake (on 5 August) caused the maximal intensity value of VI degree EMS felt in the region of Kavarna on the NE Black sea coast.

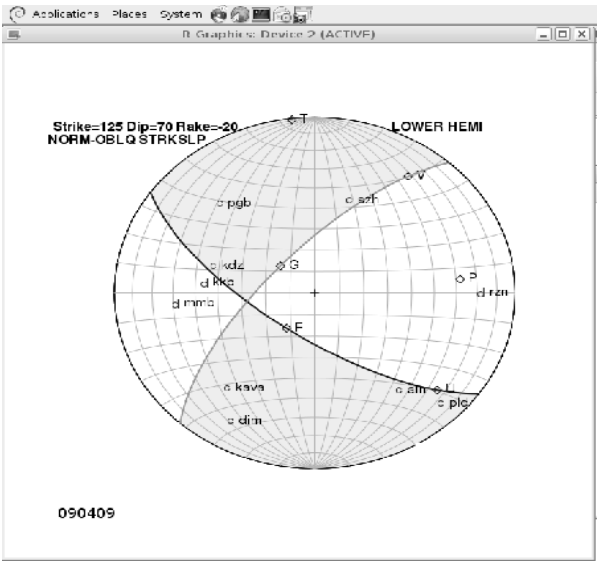

Fig.3. Focal plane solution of the strongest Kardzhaly earthquake (09.04.2009)

For the determination of the earthquake mechanism is used program FOCMEC. The polarities of P wave are used as a main input file. In the double - couple focal mechanism are included 12 first motion polarities data from seismological stations in Bulgaria and surrounding area taken from NOTSSI and ISC database (ftp://www.orfeus-eu.org/pub/data/continuous /2006/) - Fig.3. The solution is displayed on lower hemisphere. The polarities from ISC are not check as waveform. The polarities from seismological stations PLD and PGB are very poor and the solution is not with very good quality. The fault plane solutions of the rest events are with poor quality because of a low number of polarities.

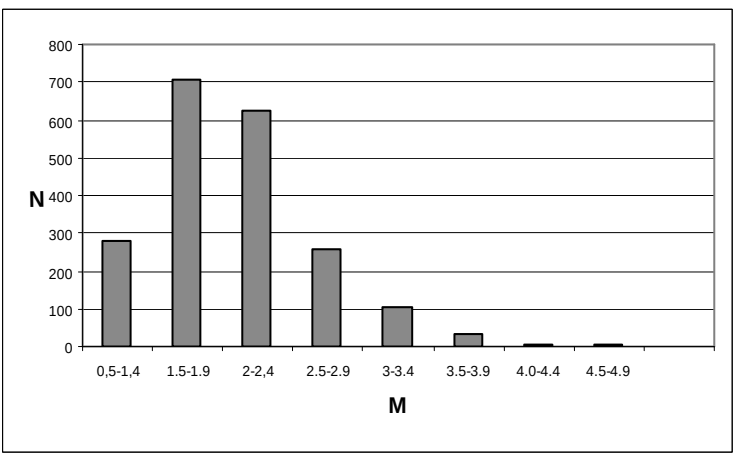

Fig.4. Magnitude - frequency distribution of the earthquakes

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=5-5.4 the number is 1, for 4.5-4.9 it is 3, for 4-4.4 is 6for M=3.5-3.9 is 35 events for M=3.0-3.4 is 102 events, for M=2.5-2.9 - 260, for M=2.0-2.4 - 624 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.

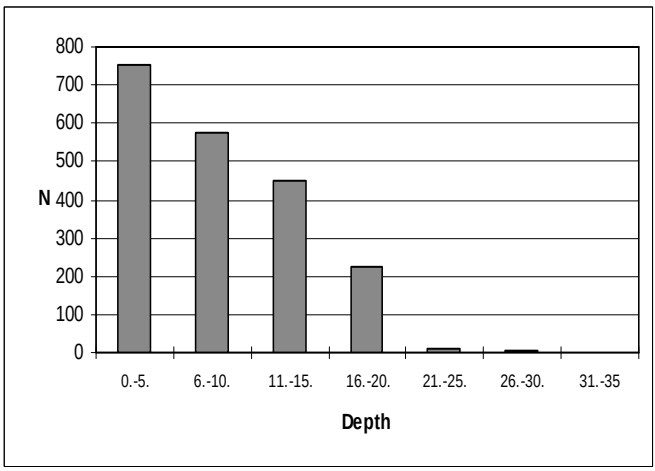

Fig.5. Depth - frequency distribution of the earthquakes

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.

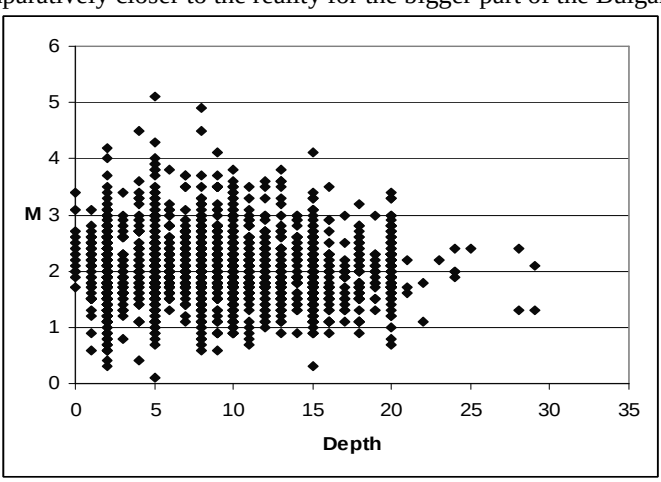

Fig.6. Magnitude - depth dependence

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. The magnitude distribution of the events in depth (Fig.6) don't permits to note some very clear differentiation of depth "floors" with the increase of magnitude, but some maximum can be traced out for the depth interval from 4 to 8 km.

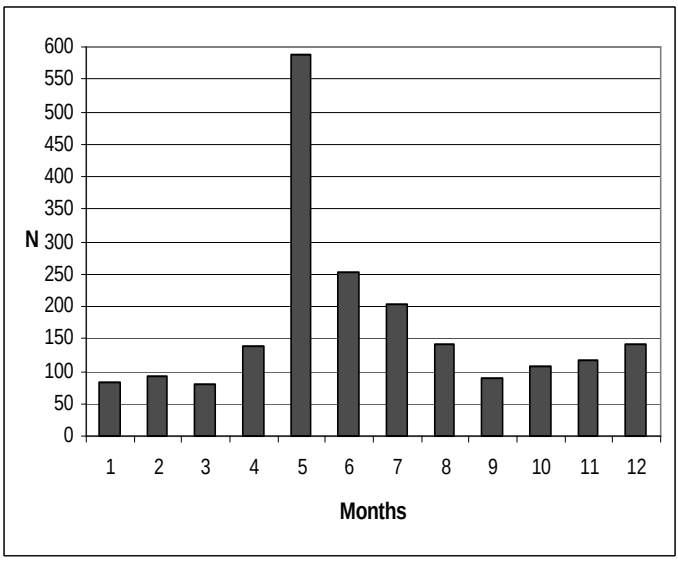

Fig.7. Time distribution of the earthquakes.

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 587 earthquakes occurred. That is because of the Valandovo earthquake series. The lowest earthquake quantity is in March, when only 81 events occured. The energy release suggests that May is the month with maximum of energy release. Some other strongest events occurred in August and December.

Additionally, about 1000 distant earthquakes have been recorded in the period under study, as well as more than 500 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 2009

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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 2009 г. Представена е карта на епицентрите на общо 2744 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 (2017 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>3.0. Сеизмогенните прояви се обсъждат по зони, сравнени със съседни периоди време.