DATA AND ANALYSIS OF THE EVENTS RECORDED BY NOTSSI IN 2015

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Abstract. A map of epicenters of 1426 earthquakes that occurred during 2015 in the Balkan Peninsula (sector outlined by latitude j =37^0- 47^0N and longitude l=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 1042 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 2015. 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 2015 is realized by means of the digital network (Solakov et al., 2006). 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 records duration by the formula (Christoskov and Samardjieva, 1983).

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

After bringing into use the digital broadband seismometers of NOTSSI network, the magnitude determination for local and regional events is calculated by P wave amplitude ratio (Christoskov at all., 2011 a, b).

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.

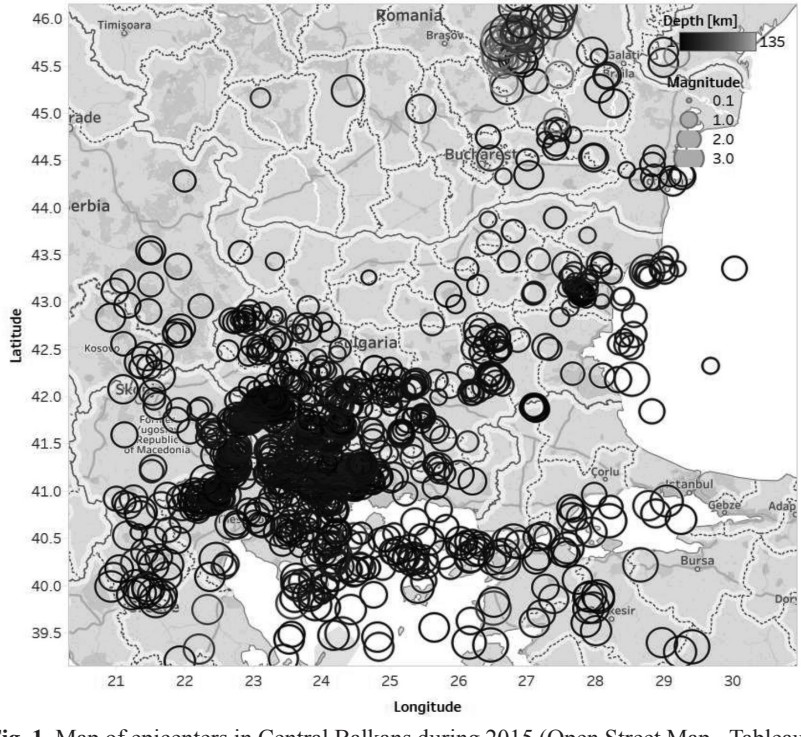

Fig. 1. Map of epicenters in Central Balkans during 2015 (Open Street Map - Tableau Desktop 10.4.)

For the period of observations presented in this communication, the primary data about 2000 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 1426 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≤1.9 is 670, in M=2.0-2.9 - 576, in M=3.0-3.9 - 155, in M=4-4.9 – 25 earthquakes. During this not so active period there is only 1 events with magnitude M>4.0 on Bulgarian territory and one in Black sea, which is close to the Bulgarian coast line. All other earthquakes with magnitude more than 4 are out of Bulgarian borders.

As a whole, the seismic situation in the studied part of the Balkans during 2015 is characterized as not very activity - 1426 events, which is less than previous years 1622 events in 2014, 1602 in 2013, 1508 in 2012, 1829 in 2011, 2401 in 2010, 2744 in 2009, 1775 in 2008, and around 1100-1400 for most of the previous years. The maximum realized earthquake is with magnitude Ml=4.9 in Vranchea seismic zone, Romania, while this value for the previous year is Ms=6.6 in North Aegean sea. The observed tendency of decrease of the activity compared with the former years is not only due to the low level of earthquake activation in North Aegean sea, Central Greece, Serbia and West Turkey, but also due to decrease of number of microearthquekes in the territory of Bulgaria.

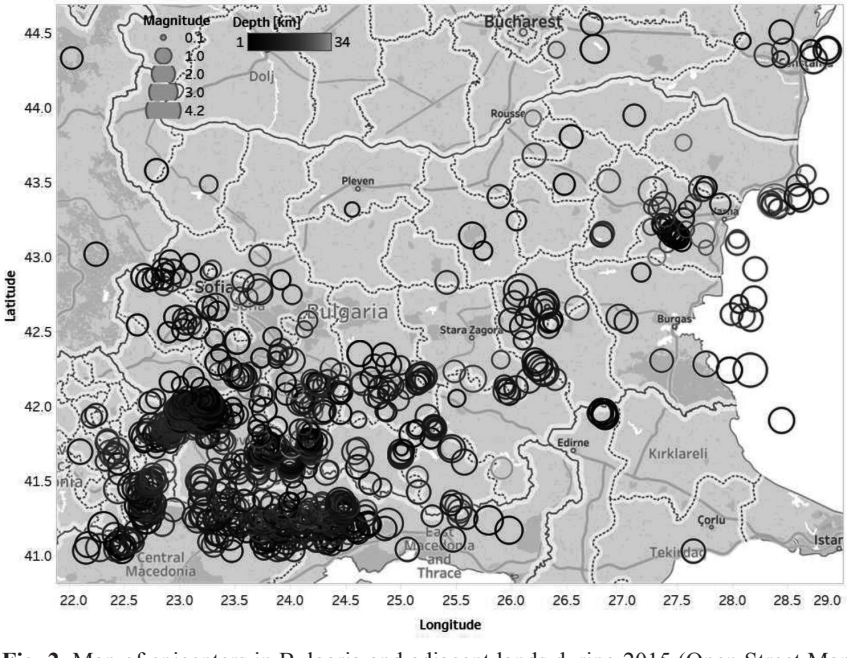

Fig. 2. Map of epicenters in Bulgaria and adjacent lands during 2015 (Open Street Map - Tableau Desktop 10.4.)

The strongest event outside Bulgaria during the study period occurred in the region situated around the Vranchea seismic zone (Romania) with magnitude M=4.9. Shakable effects because of Vranchea source zone in Romania during the study period occurred 2 times in north-eastern Bulgaria- with intensity II-III in towns of Ruse and Silistra.

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 illustrates the seismicity just in the territory of Bulgaria and nearby lands ($j = 41^0 - 44.5^0$N, $l = 22^0 - 29^0$E). The earthquakes are differentiated by magnitude intervals. The parameters of relatively stronger earthquakes are presented in Table 1.

Table 1. List of earthquakes with M³2.5 in Bulgaria and adjacent lands during 2015

Date	Time	Latitude [N]	Longitude [E]	Magnitude	Depth [km]
2 January 2015	5:50:53.7	41.21	23.98	3.3	9
	15:20:51.6	42.64	23.33	2.6	10
6 January 2015	7:48:57.2	41.00	22.17	2.6	7
10 January 2015	22:37: 3.6	41.69	23.89	2.6	15
14 January 2015	3:10:54.0	41.21	25.79	3.1	2
20 January 2015	17:21:47.1	42.65	26.31	2.6	9
4 February 2015	19:18: 9.3	42.57	26.97	2.5	15
5 February 2015	6:16:45.2	42.75	26.08	4.1	12
12 February 2015	6:21:50.6	41.74	23.83	2.9	14
13 February 2015	13:13:41.9	41.38	22.73	2.6	10
18 February 2015	18:58:40.9	41.67	24.59	2.5	17
3 March 2015	18:33:27.3	41.95	24.29	2.8	13
17 March 2015	20:59:38.4	41.20	22.70	2.5	8
18 March 2015	22:53:55.7	41.21	22.72	2.7	5
19 March 2015	16:56:28.4	42.17	23.58	2.7	7
24 March 2015	3: 7:37.6	42.09	24.83	2.7	15
	20:37:50.3	41.97	23.26	3.1	14
27 March 2015	22: 3: 2.6	41.84	22.85	2.8	15
28 March 2015	17:29: 1.6	41.30	22.69	3.8	10
	18:50:52.4	41.29	22.71	2.8	14
	19: 0:29.7	41.30	22.74	3.5	15
31 March 2015	2:12:35.6	41.46	23.57	2.5	12
2 April 2015	2:24:10.4	42.25	26.23	3.2	11
	2:27: 7.7	42.22	26.27	3.4	14
	2:28:45.0	42.21	26.29	3.2	14
	2:29:35.6	42.24	26.24	3.1	8
3 April 2015	22: 1: 8.6	41.05	22.46	2.5	2

6 April 2015	9: 7:12.0	41.46	22.74	2.5	11
	18:28:20.2	41.26	22.67	2.8	5
8 April 2015	4:23:37.0	42.00	23.29	2.5	10
12 April 2015	12:41:51.4	41.10	23.46	2.8	6
16 April 2015	13:42: 5.2	41.11	24.11	3.0	9
19 April 2015	3:10:31.4	41.17	24.68	2.6	12
22 April 2015	9:30: 2.7	44.31	28.46	2.6	20
24 April 2015	14:18: 3.2	41.91	26.84	2.6	2
27 April 2015	21:26:14.6	41.02	22.29	2.8	15
5 May 2015	0:17:13.5	41.06	22.52	2.7	11
	1:24:21.9	41.07	22.53	2.8	15
	20:34: 8.1	42.01	24.10	2.9	13
7 May 2015	12:48:37.0	41.11	23.79	3.0	7
9 May 2015	18:52:50.5	42.27	23.36	2.6	2
10 May 2015	12:57:39.4	41.25	23.23	2.9	11
15 May 2015	20:36:46.2	41.99	23.16	2.5	7
20 May 2015	12:24:35.1	42.22	27.96	2.5	2
21 May 2015	5:13:39.4	41.07	23.97	2.7	7
28 May 2015	14:16:37.9	41.17	24.58	2.5	7
5 June 2015	1:29:33.5	41.26	22.73	2.5	8
7 June 2015	1:37:46.8	42.18	25.20	3.2	15
8 June 2015	4:28:24.9	41.84	22.76	2.7	9
10 June 2015	23:48:39.3	41.14	25.98	2.8	2
11 June 2015	11:11:50.8	41.97	23.22	2.5	7
12 June 2015	18:25: 2.2	42.16	25.65	2.6	20
13 June 2015	17:17:33.5	41.64	25.00	2.5	13
16 June 2015	14:15:53.7	41.92	26.83	2.5	5
17 June 2015	10:53:41.0	42.69	28.18	2.5	14
1 July 2015	20:24: 3.7	41.24	23.21	2.5	10
4 July 2015	23:23:17.6	41.29	24.48	2.7	12
5 July 2015	4:20:25.9	41.19	24.89	3.3	12
7 July 2015	12:15: 6.0	41.73	24.26	2.7	12
9 July 2015	0: 6:18.9	41.49	23.21	2.9	20
10 July 2015	0: 6:19.3	41.47	23.19	3.0	13
	2:39:37.8	41.48	23.21	2.6	16
15 July 2015	8:30:37.3	43.34	28.37	4.2	28
16 July 2015	3:33:42.5	41.96	23.27	3.3	10
	10:13: 4.4	42.66	26.29	3.3	10
24 July 2015	15:42:34.3	41.33	24.46	3.3	10
	21:30:25.2	41.29	24.48	2.8	12
28 July 2015	1: 3:46.8	41.27	24.47	3.5	13

31 July 2015	8:33: 4.7	43.35	28.60	2.5	13
2 August 2015	8:24:36.5	41.31	24.46	2.8	13
4 August 2015	22:42: 4.5	41.43	22.58	2.9	6
5 August 2015	13:53:42.5	41.77	22.71	3.1	6
15 August 2015	10:32: 8.6	41.96	23.01	2.7	17
16 August 2015	9:39: 5.0	41.42	22.46	3.1	16
	21:36:57.8	41.62	23.71	2.7	11
20 August 2015	2:18: 5.7	41.28	23.24	2.7	14
	13:45:23.5	41.89	23.28	2.5	2
23 August 2015	1:28: 0.1	44.33	26.75	3.3	2
27 August 2015	22:41:56.1	41.79	22.79	2.5	5
6 September 2015	12:15:29.9	41.19	23.55	2.5	10
8 September 2015	3:13:13.3	41.93	23.14	2.5	16
11 September 2015	21:44:16.0	41.51	23.76	2.7	18
12 September 2015	7: 8:19.7	41.90	23.26	2.8	13
19 September 2015	13:23:52.7	43.11	25.64	2.6	3
21 September 2015	21:33:57.7	41.60	25.57	2.5	10
25 September 2015	2:55:33.4	41.31	22.63	2.5	2
5 October 2015	0:40:12.8	42.76	23.71	3.2	15
	9:52:36.2	42.28	24.02	2.5	13
8 October 2015	21:35:16.8	41.28	24.48	2.5	13
9 October 2015	7:56:55.7	41.30	25.52	2.8	18
10 October 2015	0:49:47.9	41.68	23.82	2.5	9
	17: 6:50.5	41.63	23.80	3.1	18
	19: 4:26.5	41.61	24.02	2.8	5
	20:13:17.5	41.55	24.02	2.5	17
12 October 2015	21:31:58.1	41.91	23.25	2.8	5
15 October 2015	16:49:15.1	41.64	23.81	2.5	15
16 October 2015	17:54:33.9	42.01	23.24	2.8	5
18 October 2015	19:33:17.5	41.60	24.00	2.5	17
20 October 2015	22:40:27.5	41.60	24.01	3.2	12
21 October 2015	4:20:33.8	41.61	23.99	2.5	10
22 October 2015	4:34:33.0	41.68	23.82	2.8	8
6 November 2015	0:54:46.5	42.33	24.63	2.5	2
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	23:54:46.5	42.33	24.63	2.5	2
	9: 1:33.3	41.27	24.47	2.5	5
11 November 2015 13 November 2015	13: 6: 0.8	41.91	26.83	2.5	8
	7:14:56.9	41.43	22.62	2.8	5
14 November 2015	20:44:10.9	43.40	27.27	3.2	21
20 November 2015	22: 1: 4.3	41.08	24.24	2.5	11

21 November 2015	0:42:34.9	41.16	22.32	3.5	2
21 November 2015 1 December 2015	6:13:52.4	41.69	25.46	2.8	12
	9:28:20.5	41.65	25.00	2.5	14
4 December 2015	7: 1:10.7	41.91	23.27	2.8	2
4 December 2015 5 December 2015	23: 4:15.5	41.29	24.48	3.1	10
	6:34:48.5	41.97	23.28	2.6	2
11 December 2015	21:52:41.7	42.41	23.52	2.5	10
13 December 2015	14: 4:34.8	41.70	24.17	2.6	13
21 December 2015	8:56:13.0	41.79	22.67	2.5	11
23 December 2015	12:35:49.2	41.93	26.80	2.5	7

On the territory of Bulgaria relatively normal activity of earthquakes is observed during 2015 – 1042 events are observed, against 947 in 2014, 1124 in 2013, 932 in 2012, 1205 in 2011 and 1607 in 2010. The earthquakes of a magnitude higher than 3.0 are in normal amount – 30 events compared with an averaged number of about 20-35 for most of the all previous years.

The maximum realized magnitude is Ms=4.9 in the region of Vranchea seismic zone which is the lowest maximal magnitude of earthquakes, in comparison with the maximum magnitude in the course of previous years. The strongest event during 2015, close to Bulgarian border (on Romanian territory) occurs on 23th of August and caused very weak macroseismic effects with intensity of II-III degree of MSC scale in the town of Tutrakan – not so far from the town of Ruse.

As usual, the largest concentration of the epicenters in the other regions of Bulgarian territory during 2015 is marked in the southwestern part of the investigated region (presented in Fig. 2). The Kroupnik seismic source is known with the strongest crustal earthquakes in Europe (M=7.8, 7.1) for the last 160 years. In 2015 only 3 events of M≥3.0 occurred in this region. The strongest felt earthquake for this part of Bulgarian territory is with magnitude M=3.3, it is felt on 16th of July in Blagoevgrad region by intensity of III of MSC scale – in the village of Dolno Osenovo (south-western slopes of Rila mountain).

The other Bulgarian seismic sources in 2015 are relatively not so active than during the previous years. They produced not more than 10 earthquakes affecting different localities in this country by intensity of up to IV-V degrees of MSC scale. Several earthquakes with magnitude more than 3.0 have occurred in the Monastery uplift and are felt by III degree of MSC scale on 2th of April. The maximum number of felt earthquakes is occurred around North-eastern Bulgaria. Three cases of magnitudes about 3.0 aroused shocks of intensity three or a bit more are felt in Provadia region – the strongest event is with magnitude M=3.2 on 14th of November . The maximum event for whole Bulgarian territory with M=4.2 in Black sea caused V degree of MSC scale on 03 December in Shabla region (Kaliakra cape in the north-eastern Black sea cost). A strong event M=4.1 in the neighbor region of Sliven town caused effects of IV-V degree of MSC on 5 th of February.

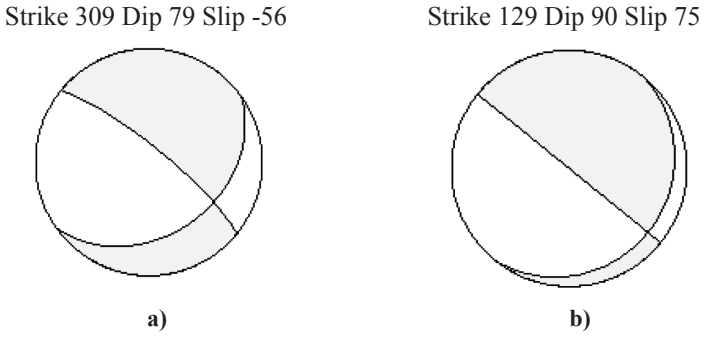

Fig. 3. Focal plane solutions of two earthquakes: **a)** 15 km north-western of Sliven (05.02.2015, 6:16 GMT, Ml=4.1, H=12 km) and **b)** in Black sea, 5 km south-eastern of Kaliakra cape (15.07.2015, 8:30 GMT, Ml=4.2, H=28 km)

For the determination of the earthquake mechanism the program FOCMEC is used. Input data are the polarities of the P wave. Forty-six first motion polarities data are used for defining the focal mechanism of the earthquake near Sliven city (Fig. 3.a) and only twelve for the earthquake near the Kaliakra cape (Fig 3.b). Data from seismological stations in Bulgaria and surrounding area, taken from NOTSSI and GFZ Seismological Data Archive database (Bianchi et al., 2015) are included in the double - couple focal mechanism - Fig. 3. The solutions are displayed on lower hemisphere. All polarities are check as waveform. The strike, dip and rake are determined in accuracy up to 5 degrees for first earthquake and up to 10 degrees for second. Both earthquakes are characterized as a dip-slip faulting, with very small strike-slip component.

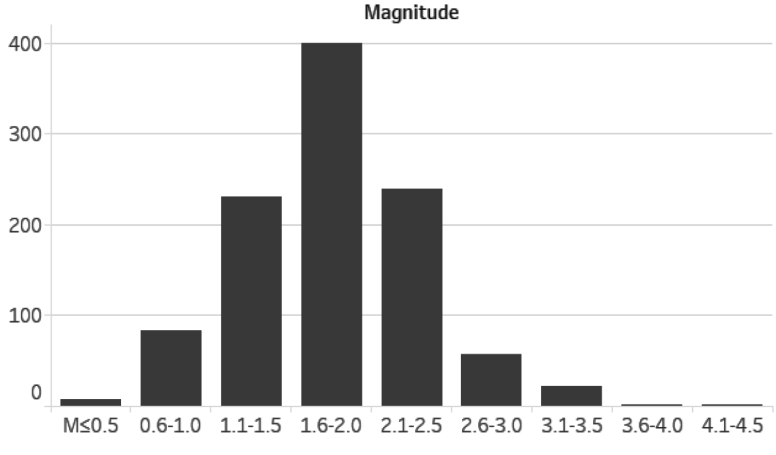

Fig. 4. Magnitude - frequency distribution of the earthquakes

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.

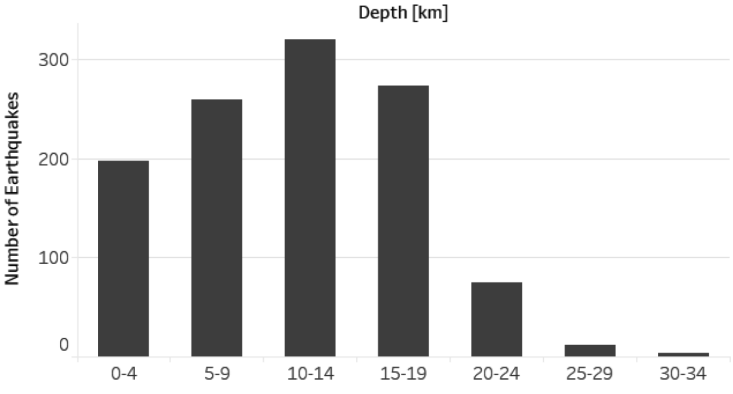

Fig. 5. Depth - frequency distribution of the earthquakes

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 is 3 events, M=3.6-4.0 is 1 event, for M=3.1-3.5 is 22 events, for M=2.6-3.0 - 57, for M=2.1-2.5 – 239, 1.6-2.0 - 400 and so on. The abrupt diminishing of the number of earthquakes in the first three intervals (M<1.5) in Fig. 4 determines also the registration power of the seismic stations network. 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.

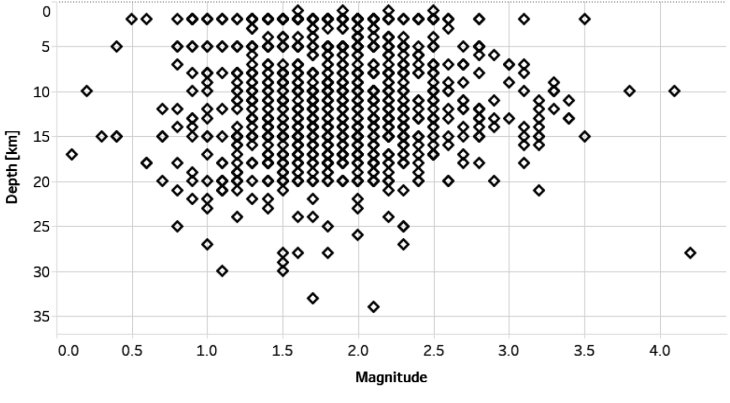

Fig. 6. Depth - magnitude distribution of the earthquakes

The picture of the depth distribution in Fig.5 shows that the majority of events occur in range 10-14 km depth. The number of events does not decrease smoothly with increase of the depth. It is possible the established predominating depth (from 5 to 20 km) to be also due to the presence of small number of unidentified industrial explosions. In the same time the number of events in the central interval is bigger.

The magnitude distribution of the events in depth (Fig. 6) permits to note some differentiation of depth "floors" with the increase of magnitude - the maximums can be traced out for the depth interval from 5 to 15 km. It is remarkable that the strongest events are not deep situated and the maximal event is associated with 10 km depth.

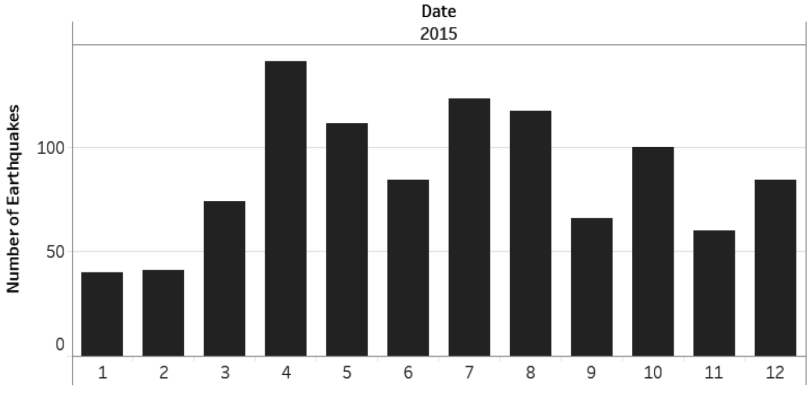

Fig. 7. Time - frequency distribution of the earthquakes

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 April, when more then 140 earthquakes occurred, and it is associated with swarm activity in the beginning of April. The lowest earthquake quantity is in January - February, around 40 events. The energy release suggests that the period July - August, when the relatively high activity in Kaliakra cape region occurred, is one of the time with maximum of energy release. Local maximum of events is observed in October, when about 100 earthquakes occurred.

Additionally, about 800 distant earthquakes have been recorded in the period under study, as well as more than 700 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 2015

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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 2015 г. Представена е карта на епицентрите на общо 1426 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 (повече от 1042 сеизмични събития в район с координати l= 22^0 - 29^0E и j =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.