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DATA AND ANALYSIS OF THE EVENTS RECORDED BY NOTSSI IN 2016

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Abstract. A map of epicenters of 1399 earthquakes that occurred during 2016 in the Balkan Peninsula (sector outlined by latitude j =37^0- 47^{0}N and longitude l=19^0-30^{0}E) is presented. Expert generalized analysis of the seismicity over the territory of Bulgaria and its very adjacent lands (with more than 1038 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 2016. 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 2016 is realized by means of the new 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 new digital broadband seismometers of NOTSSI network, the magnitude determination for local and regional events is calculated by P wave amplitude ratio (Christoskov at all, 2011a, 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.

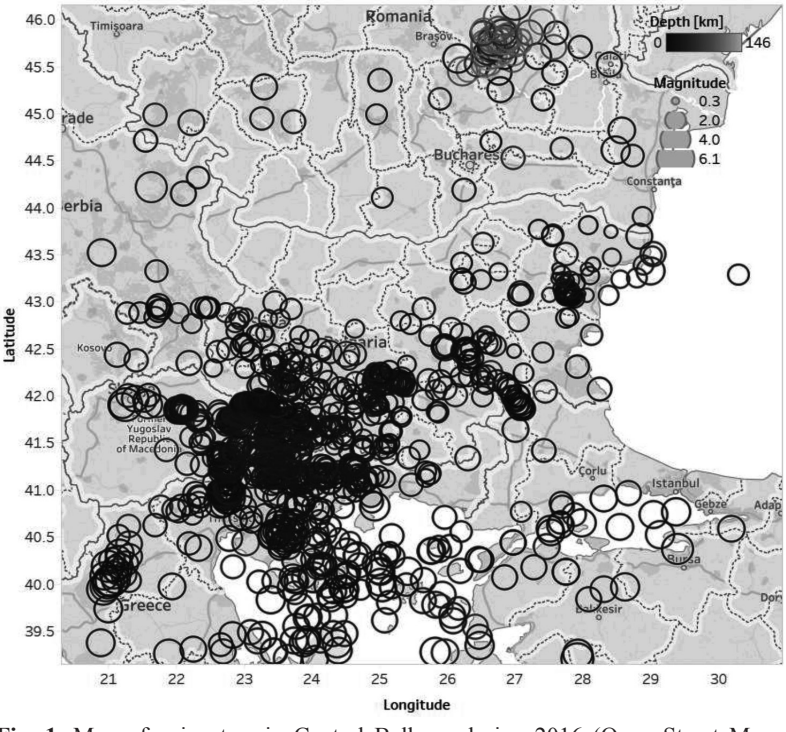

Fig. 1. Map of epicenters in Central Balkans during 2016 (Open Street Map - Tableau Desktop10.5.)

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 1399 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=0.5-1.9 is 594, in M=2-2.9 - 615, in M=3-3.9 - 157, in M=4-4.9 – 29, in M=5-5.9 – 2 earthquakes. During this not so active period there are 2 events with magnitude M>6.0. All earthquakes with magnitude more than 4.3 are out of Bulgarian borders.

As a whole, the seismic situation in the studied part of the Balkans during 2016 is characterized as not so high activity - 1399 events, compared with previous years: 1426 events in 2015, 1602 in 2014, 1622 in 2013, 1508 in 2012. The maximum realized earthquake is with magnitude Ms=6.1 in Vranchea, Romania, while this value for the previous years is M=6.6 in North Aegean sea (Greece, in 2014). It can be noted that the observed tendency of decrease of the activity compared with the former years is partly due to the lower level of earthquake activation out of Bulgaria, despite of relative increase of number of microearthquekes in the territory of our country.

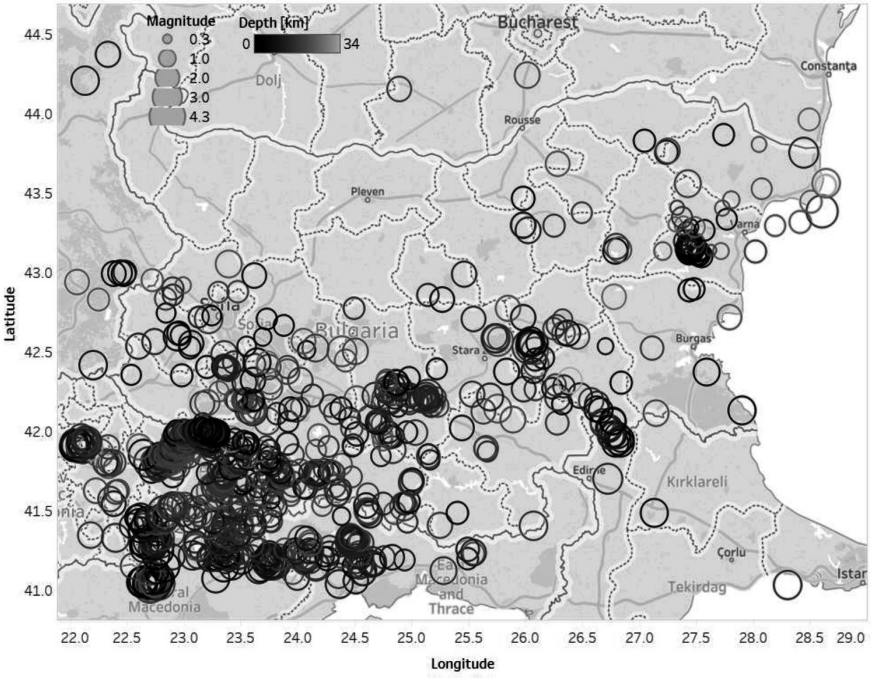

Fig. 2. Map of epicenters in Bulgaria and adjacent lands during 2016 (Open Street Map - Tableau Desktop 10.5.)

The strongest event outside Bulgaria during the study period occurred in the region situated in the Vranchea source zone in Romania with magnitude M=6.1. Shakable effects because of attacks from this side during September and December 2016 occurred 3 times in north-eastern Bulgaria (maximal intensity V-VI in towns of Ruse, Tutrakan 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 M ³ 2.5 in Bulgaria and adjacent lands during 2016

Date	Time	Latitude [N°]	Longitude [E°]	Local magnitude	Depth [km]
3 January	14:42: 4.8	41.01	24.37	2.7	7
24 January	21:19:52.4	41.12	23.43	2.5	7
27 January	21:31: 0.3	43.35	28.59	3.5	13
31 January	23:45:41.1	41.24	22.66	2.8	8
1 February	19: 7:26.6	42.19	25.69	2.5	9
	22:16:40.9	41.26	22.67	2.7	3
2 February	12:10:45.1	41.38	22.68	3.4	8
	18:49:43.3	41.43	22.63	2.7	5
5 February	14:44:25.1	41.86	24.83	2.5	14
6 February	3:49:17.5	41.42	23.06	2.5	14
12 February	16:58:18.1	41.26	24.48	2.5	13
15 February	6:59: 6.8	44.15	22.14	2.8	8
16 February	11:17:16.9	41.46	22.84	4.1	12
18 February	2:21:25.1	41.30	24.46	2.7	11
19 February	11:55:32.0	41.76	22.79	2.6	13
28 February	11:17:16.9	41.46	22.84	4.1	12
29 February	20:28:10.5	41.97	23.26	2.7	4
2 March	23:44:49.8	41.28	24.47	3.3	13
3 March	3: 5:55.3	41.29	24.47	2.5	9
	8:48:49.4	41.29	24.47	2.8	9
	14: 3:59.9	41.29	24.47	2.7	13
	18:55:17.9	41.28	24.47	2.6	10

4 March	0:12:45.9	43.71	28.43	3.0	9
5 March	8: 2: 4.4	41.17	24.07	2.6	10
8 March	21: 4:48.9	42.39	22.21	2.8	5
9 March	7:55:12.4	41.78	22.70	3.0	10
13 March	13: 5:46.4	42.46	23.36	2.5	13
17 March	6:13:51.0	41.25	23.12	2.7	20
19 March	11:55:32.9	41.78	22.86	2.5	17
20 March	23:55: 3.6	41.82	22.80	2.5	4
21 March	3:36:53.6	41.82	22.84	2.9	12
	5: 7:20.2	41.80	22.78	2.8	9
	21:19:47.6	43.52	28.63	2.8	22
22 March	13:12:37.9	41.16	23.51	2.5	4
	15:42:10.3	41.78	22.33	2.5	16
27 March	7: 1:10.4	41.04	23.29	2.6	5
	17: 6: 7.0	42.11	23.61	3.0	12
30 March	13:24:48.5	41.26	22.74	2.5	4
	16:15:23.6	42.50	24.16	2.5	16
31 March	8: 2: 4.4	41.17	24.07	2.6	10
1 April	19:29:53.6	42.56	25.73	2.6	15
	19:46: 5.0	42.56	25.74	2.8	11
	19:51:11.6	42.55	25.75	3.3	17
13 April	0:48:42.8	41.12	24.16	2.5	14
	0:59: 6.1	41.12	24.16	2.9	15
	18: 4: 6.6	41.96	23.25	2.5	5
16 April	14:57:52.1	41.30	22.78	2.6	11
17 April	13:12:31.2	41.29	24.04	2.7	20
18 April	6:46:14.4	42.51	26.03	3.9	12
	6:48:18.7	42.48	26.08	2.5	17
	10:38:44.4	42.51	26.04	3.0	11
2 May	17:13:52.2	41.33	23.47	2.5	9
	20:16:25.8	42.53	26.03	2.5	6
4 May	11: 6:28.6	42.68	23.22	2.9	15
6 May	2:46:49.6	41.78	22.78	3.3	12
	12:17:21.8	41.12	22.84	3.0	2
	13:45:11.7	41.04	22.80	2.7	6

9 May	12:52: 3.2	41.69	23.79	2.9	17
	17:20: 4.1	42.21	25.14	3.0	11
19 May	18:52:32.3	42.57	22.95	2.7	3
22 May	8:58: 8.6	41.67	23.35	4.3	20
23 May	6:22: 1.8	41.62	23.29	2.7	16
	7: 3:50.1	41.63	23.28	2.7	15
30 May	21:52:11.8	41.15	24.65	3.1	10
11 June	6: 6:30.8	41.09	25.28	2.5	12
14 June	16:34:12.8	43.12	27.43	2.7	2
	16:46:26.3	43.11	27.44	2.6	2
15 June	5:21:14.0	41.46	27.12	2.7	2
17 June	17:55:58.7	42.54	26.04	2.7	6
18 June	17:24:18.5	41.95	26.74	2.5	11
19 June	5:54:18.3	41.39	23.22	3.1	20
23 June	13:59:34.5	41.28	24.50	2.8	13
	15:34:11.5	41.26	24.50	2.5	10
	16:40:21.0	41.28	24.50	2.8	10
24 June	18:48:40.4	41.94	23.03	3.0	19
6 July	18: 5:34.5	41.76	22.94	2.7	17
11 July	22:18:51.0	41.15	23.76	4.1	9
12 July	0: 1:47.0	41.14	23.76	3.8	9
	3:18:47.4	41.16	23.76	2.8	9
	13: 8: 8.2	41.15	23.73	2.5	8
15 July	9:14:36.4	42.35	27.58	2.5	2
16 July	19:16:56.8	41.58	23.32	2.6	20
21 July	14: 6:37.4	41.95	23.12	2.7	18
27 July	5:10: 7.1	42.04	23.74	2.5	16
29 July	13:24: 0.5	41.43	22.82	2.6	15
1 August	18:39:25.0	41.50	22.91	2.9	13
4 August	8:21:39.0	42.12	25.75	2.7	20
5 August	17: 2:29.6	41.10	23.66	2.6	8
7 August	1:44:45.6	41.88	22.05	2.7	1
8 August	0:39:42.3	41.87	22.12	2.9	10
12 August	21: 8:55.7	41.89	22.11	2.5	10
17 August	15:21:20.8	41.18	24.07	2.5	17

18 August	9:10:36.7	41.95	23.18	3.3	11
	22:55:15.2	41.88	22.11	2.7	10
19 August	9:10:37.0	41.96	23.19	3.0	6
	9:13:14.1	41.96	23.19	2.5	7
20 August	5:26:39.1	41.97	23.23	2.5	5
27 August	15:18:54.9	41.50	24.93	2.6	17
30 August	9:26: 5.7	42.11	27.89	2.7	2
12 September	13:49:39.1	41.57	23.65	2.9	18
14 September	2:42:34.8	42.41	23.65	2.7	3
18 September	8:28:13.5	41.34	23.36	3.5	15
	9:19:47.6	41.96	23.22	2.5	20
	10:26:45.2	41.30	23.33	4.0	13
	15: 9: 8.3	41.39	23.38	2.6	15
	15:39:40.6	41.38	23.37	2.8	13
19 September	1:32:43.2	41.24	23.32	2.8	8
20 September	12:35: 8.9	43.52	27.42	2.5	16
	17:37:24.9	41.88	22.05	3.0	2
21 September	11: 6:32.7	41.89	22.11	2.5	11
22 September	10:13:44.5	41.09	24.57	2.8	10
24 September	22: 4:22.5	41.83	22.65	3.1	2
26 September	2:38:23.4	41.19	23.08	2.8	9
29 September	8:41:32.2	41.12	23.36	3.1	2
5 October	17:27: 7.2	41.38	26.07	2.8	13
9 October	21: 0:40.9	41.89	22.10	2.7	21
12 October	17:58:55.5	41.87	22.93	2.6	15
13 October	5:58:16.7	41.78	22.81	2.6	6
14 October	13: 5:55.2	41.97	23.19	2.5	8
17 October	0:49:16.7	41.68	26.72	3.0	10
	13: 2:33.3	41.29	22.70	3.8	8
	14:19:31.8	41.96	23.02	2.6	19
18 October	13:51: 7.3	41.90	22.16	2.8	10
21 October	7:24: 0.7	42.48	24.39	3.0	20
25 October	8:11:39.5	41.90	22.05	2.9	7
26 October	8:59:26.6	42.19	24.98	2.9	14
	12: 6:24.3	41.18	23.25	2.6	12

27 October	13:51:30.9	42.04	26.76	2.5	0
10 November	4:40:27.5	41.47	23.17	3.5	16
	12:44:45.9	41.02	22.69	3.0	1
16 November	7:38:50.5	41.01	22.79	3.6	14
19 November	1:44:20.2	41.01	22.76	3.4	3
	17: 5:48.3	41.03	22.65	2.7	2
	17: 5:49.3	41.01	22.75	2.6	3
21 November	8:42:33.4	41.02	22.64	3.1	6
22 November	3:47:31.3	41.02	22.65	3.2	2
24 November	1:25:38.1	41.03	22.75	3.7	22
	1:56:47.3	41.91	22.16	3.1	13
29 November	18:45:18.4	41.00	22.69	2.5	12
30 November	6:19: 7.0	41.01	22.69	2.7	2
	14:50: 7.4	41.02	22.75	2.6	20
	17:36:41.1	41.00	22.71	4.2	16
5 December	15: 1:30.9	41.90	26.78	2.5	1
6 December	9: 4:51.4	41.00	22.68	2.8	1
11 December	1:29: 5.6	41.02	22.73	2.8	2
12 December	13:15:35.5	41.90	26.83	2.5	3
15 December	4: 4:39.5	41.61	23.51	3.2	18
18 December	13:10:59.1	41.30	22.41	2.7	10
20 December	12: 6:16.1	41.00	28.29	2.9	10
23 December	10:33: 0.7	41.19	22.76	2.7	2
	11:48: 3.8	41.22	22.79	2.8	2
24 December	23:27: 5.1	43.02	23.40	2.5	20
29 December	3:32:26.9	41.94	22.96	2.5	13
31 December	14:33: 1.0	41.84	22.27	2.8	20

On the territory of Bulgaria relatively normal activity of earthquakes is observed during 2016 – 1038 events are observed, against 1042 in 2015, 947 in 2014, 1124 in 2013 and 932 in 2012. The earthquakes of a magnitude higher than 3.0 are in normal amount – 41 events compared with an averaged number of about 20-35 for most of the all previous years.

The maximum realized magnitude during 2016 is Ms=6.1 in close to Bulgarian border (on Romanian territory) occurs on 27th of December and caused macroseismic effects with intensity of V-VI degree of MSC.

As usual, the largest concentration of the epicenters in the other regions of Bulgarian territory during 2016 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. 27 of the events of M≥3.0 occurred in this region during 2016. The strongest felt earthquake for the south-western part of Bulgarian territory is with magnitude M=4.3, it is felt on 22nd of May in Sandanski region (western slopes of Pirin mountain) by intensity of VI degree of MSC scale.

The other Bulgarian seismic sources in 2016 are relatively not so active than during the previous years. They produced not more than 15 earthquakes affecting different localities in this country by intensity of up to IV-V degrees of MSC scale. The maximum number of felt earthquakes is occurred in the region around the town of Petrich. About four cases of magnitudes more than 3.0 aroused shocks of intensity three or more are felt in this region of the south-west territory of Bulgaria. The maximum event with magnitude M=4.0 south of town of Petrich caused IV-V degree of MSC scale on 18 September in the town. A stronger event M=4.2 in the neighbor region of Doiran lake (Greek territory) caused effects of III-IV degree of MSC in the boundary regions located west of town of Petrich on the 30 November 2016. In the rest part of the Bulgarian territory the felt events caused excitation of lesser intensity during 2016.

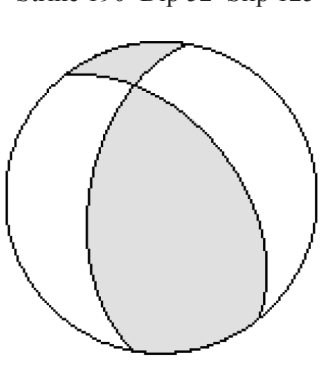

Fig. 3. Focal plane solution of earthquake near to Sandanski city (22.05.2016, 8:58 GMT, Ml=4.3, H=20 km)

For the determination of the earthquake mechanism the program FOCMEC is used. Input data are the polarities of the P wave. Forty-five first motion polarities data from seismological stations in Bulgaria and surrounding area are used (Fig.3), taken from NOTSSI and GFZ Seismological Data Archive database (Bianchi et al., 2015) are included in the double - couple focal mechanism The solution is displayed on lower hemisphere. The polarities are check as waveform. The strike, dip and rake are determined in accuracy up to 5 degrees. The earthquake is characterized as a reverse faulting, with very small dip-slip component.

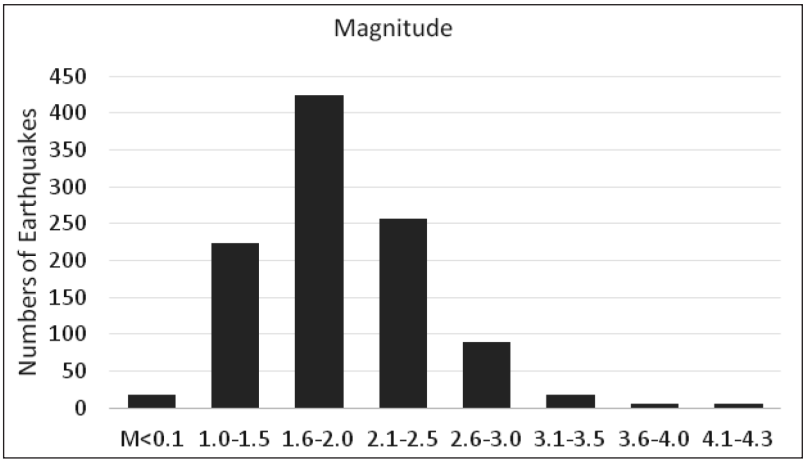

Fig. 4. Magnitude - frequency distribution of the earthquakes

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.

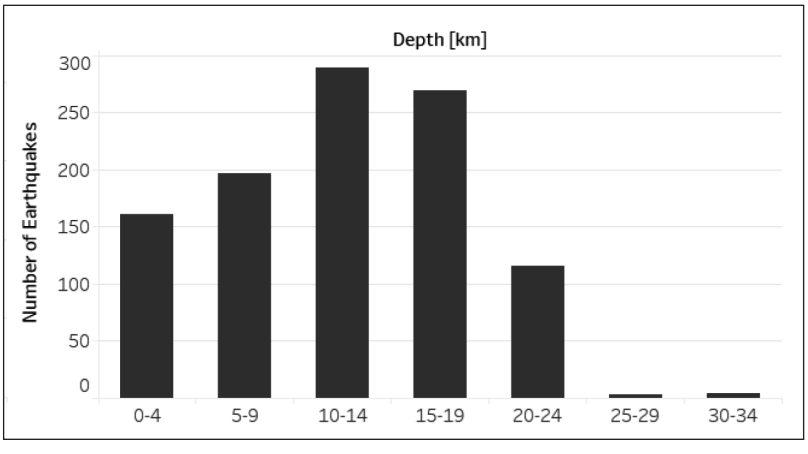

Fig. 5. Depth - frequency distribution of the earthquakes

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= 4.1-4.3 are 6 events, M=3.6-4.0 are 6 events, for M=3.1-3.5 are 17 events, for M=2.6-3.0 - 89, for M=2.1-2.5 - 256 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. 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.

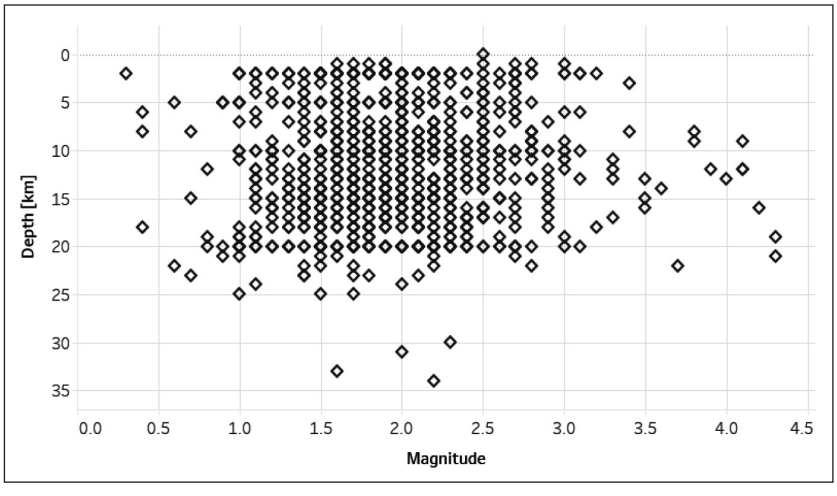

Fig. 6. Magnitude - depth dependence

The picture of the depth distribution in Fig. 5 shows that the majority of events occur 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 10 to 20 km) to be also due to the presence of small number of unidentified industrial explosions on the surface. In the same time the number of events in the interval 10-14 km is biggest.

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 8 to 22 km. It is remarkable that the strongest events are relatively deep situated and the maximal events are associated with 20 km depths.

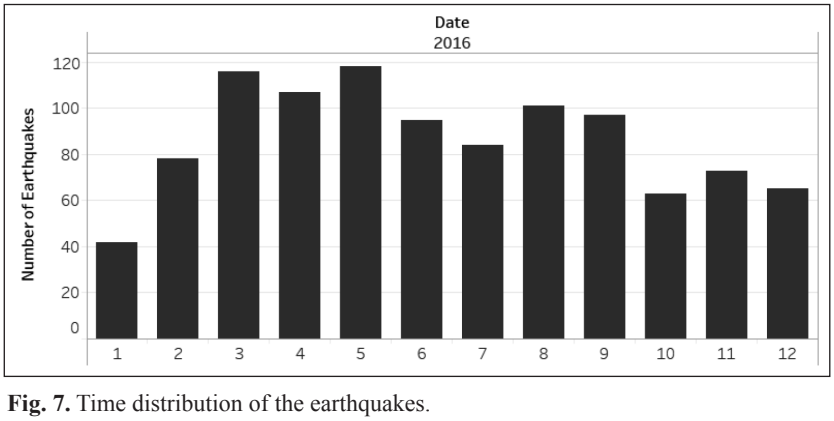

Fig. 7. Time distribution of the earthquakes.

Fig. 7 illustrates the distribution of seismicity in time according to the number of events per months. The biggest earthquake's amount is in the months from April to May, when about one third of all earthquakes occurred. The maximal months amount (about 120 events) during the May is associated with aftershock activity of 22May maximal earthquake. The lowest earthquake quantity is in January - around 40 events. The energy release suggests that the period April - September, when the relatively all biggest earthquakes occurred, is the time with maximum of energy release.

Additionally, about 900 distant earthquakes have been recorded in the period under study, as well as more than 800 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 2016

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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 2016 г. Представена е карта на епицентрите на общо 1399 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 1038 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.