FAULT PLANE SOLUTIONS OF THE 2012 M_W 5.6 PERNIK (SW BULGARIA) EARTHQUAKE AND THE STRONGEST AFTERSHOCKS

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Abstract: An earthquake with magnitude M_L=5.8 (Mw=5.6) and epicentral intensity I_0= 8 MSK64 occurred in the vicinity of the city of Pernik (SW Bulgaria) on 22nd of May 2012. The earthquake was followed by intensive aftershock activity. In the study the fault plane solutions for 20 earthquakes (the main shock and 19 aftershocks) registered by the national seismological network of Bulgaria are presented. The orientations of the fault plane solutions and spatial distribution of the aftershocks coincide with the NW-SE trend of Pernik-Belchin fault. Additionally, basic geodynamic analysis is performed.

Key words: earthquake, fault plane solution, faulting, geodynamics

Introduction

An earthquake of moment magnitude 5.6 (I_0=8 MSK64) hit the Sofia seismic zone (SW Bulgaria) on May 22nd, 2012. The earthquake is located in the vicinity of the city of Pernik (epicenter coordinates 23.00º E and 42.58º N and 9 km depth) at about 25 km south-west of the city of Sofia. The earthquake was largely felt on the territory of Bulgaria and neighbor countries: northern Greece, FYROM, eastern Serbia and southern Romania. No casualties and severe injuries have been reported. Moderate to heavy damages were observed in the cities of Pernik, Radomir and Sofia and their surroundings. During the 20th century the strongest event occurred in the vicinity of Sofia was the 1917 earthquake of M_S=5.3 and I_0=7-8 MSK64 (Grigorova et al., 1979). The earthquake caused a lot of damages in the town and changed the capacity of the thermal mineral springs in Sofia and surroundings. The earthquake was felt in an area of 50000 km^2 and was followed by aftershocks, which lasted more than a year.

Fourteen days after the 2012 earthquake more than 650 aftershocks were registered, most of them are microearthquakes (M<1.0) (Botev et al., 2013a). The modern digital network allowed providing reliable detection, fast location and precise determination of the earthquake parameters. The spatial distribution of the aftershock epicenters is presented in Fig.1, and coincides with the NW-SE trend of Pernik-Belchin fault (identified by Karagjuleva et al., 1973).

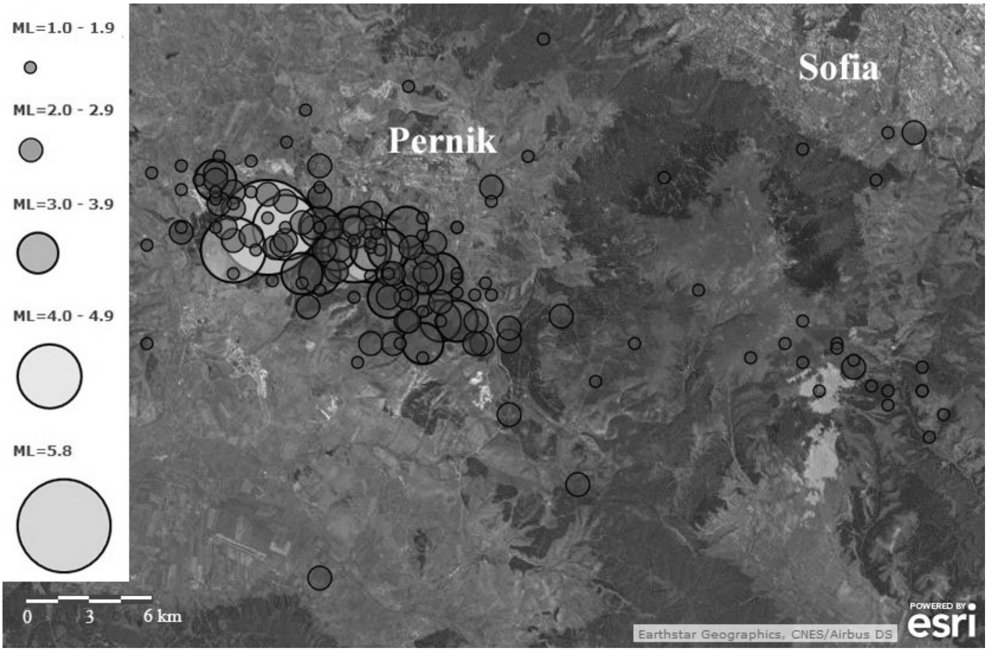

Fig. 1. Epicentral distribution of the events along Pernik-Belchin fault line (Natural Earth - Free vector and raster map data@naturalearthdata.com)

In the study new results of the present state of stress field in southwestern Bulgaria are obtained based on evaluation of 20 earthquake focal mechanisms. The results confirm the recent seimotectomic models for southern Bulgaria (Van Eck and Stoyanov, 1996).

Method and input data

The fault-plane orientations and slip directions of earthquakes can provide important information about fault structure at depth and the stress field in which the earthquakes occur. The source of a small earthquake is typically approximated by a double-couple point source, or focal mechanism, derived from observed P-wave first-motion polarities. A focal mechanism represents two orthogonal nodal planes that divide a reference sphere around the source into four quadrants: the first motion in two of them should be away from the source (cause compression), and in the other two quadrants the first motion should be toward the source (cause dilatation). First-motion-polarities are observed at seismic stations, and the position on the focal sphere for each observation is the azimuth and take-off angle at which the ray leaves the source, is computed for an assumed hypocenter location and seismic-velocity model (Botev et al., 1996). The computing program for determining the parameters of the seismic events is an adaptation of the widespread product HYPO'71 (Solakov, 1993). A focal mechanism can then be found that best fits the first-motion observations.

For the determination of the earthquake focal mechanisms the program FOCMEC is used (Snoke, 2009). Input data are the polarities of the P wave (the number of input data is in the range 9 – 49), azimuth and take-off angle at which the ray leaves the earthquake source. Output data are all possible orthogonal nodal planes that separate the compressional and dilatational first motions.

Results

Fault plane solutions for the main earthquake and 19 aftershocks with ML ≥ 3 are shown in Fig. 2 and their parameters are presented in Table 1. For the purposes of the present study, all the available focal mechanisms were collected, checked, tested and recalculated according to the definitions by Aki and Richards (1980) and to the procedure described by Christoskov (2007). All polarities were checked as waveforms (data from NOTSSI and ORFEUS database - ftp://www.orfeus-eu.org/pub/data/continuous/2012/), the strike, dip and rake are determined by FOCMEC software (Snoke, 2009) with accuracy up to 10 degrees and the solutions are displayed in lower hemisphere projections.

As it is seen in Fig. 2 and Table 1 for all focal mechanisms the average strike of one of the nodal planes is 311º NW-SE. That predominant nodal plane can be accepted as the main fault in this zone and it has the same NW-SE orientation as the Pernik-Belchin fault with average dipping 50º. If the chosen nodal plane of focal mechanisms is the main, then it is clear that the faulting is typical right-lateral (Kasahara, 1978). The foot-wall block is on the right side of line Pernik-Belchin – Golo Burdo and the hanging-wall block is on the left side - Pernik graben.

All earthquakes are characterized as a normal right-lateral faulting with small strike-slip component, except earthquake № 7, which is thrust faulting with small strike-slip component and earthquake № 16 is clear strike-slip motion. Position of event № 7 is at the end of the Pernik-Belchin fault line and it is the most NW earthquake with determined herein focal mechanism.

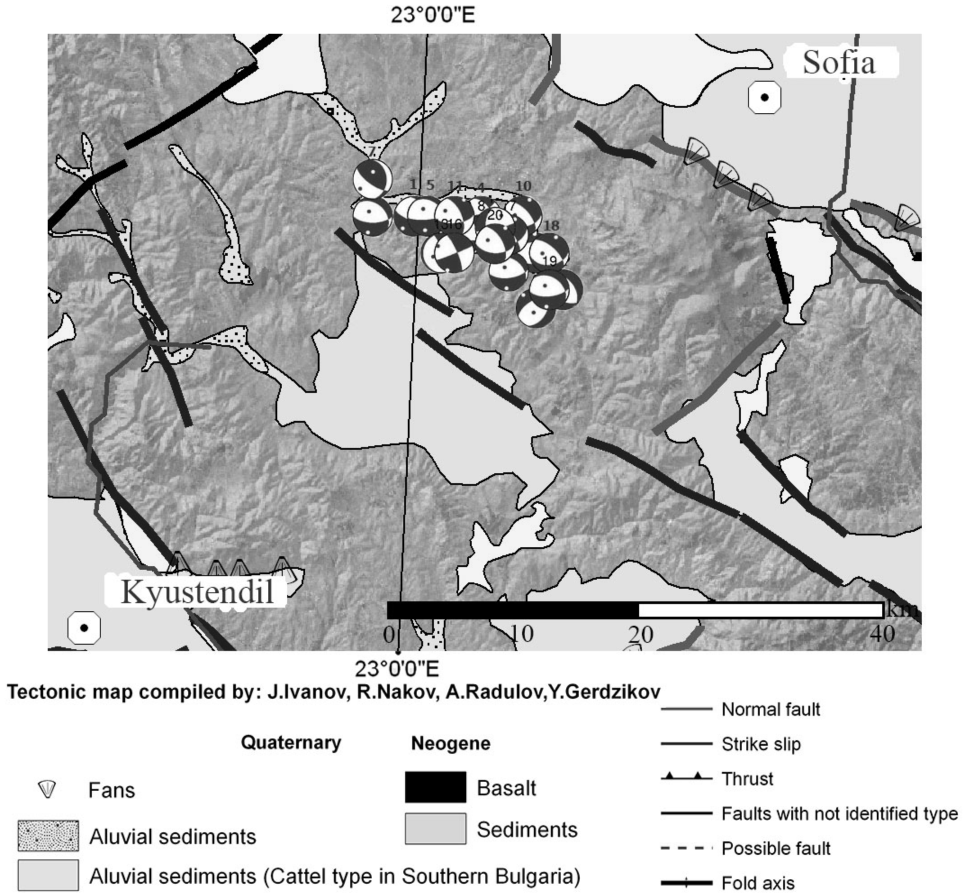

Fig.2 Fault plane solutions of the 2012 MW = 5.6 Pernik earthquake and aftershocks (modified from Ivanov et al., 2008)

Fault plane solutions for the main earthquake of 22 April 2012 with magnitude Mw=5.6 were obtained by forty-nine first motion polarities. The determined by the author focal mechanism is compared with other known solutions shown in Fig. 3 and their parameters are presented in Table 2. The small differences in the solutions determined by World networks are due to the use of different seismic-velocity models, number of first motion polarities, as well as the azimuthal location of the seismic stations around the earthquake epicenter. According to the focal mechanism parameters, the earthquake is characterized as jerk normal fault movement with small strike-slip component, the faulting takes place along a hidden fault plane, caused by extensional regional tectonic stresses (Botev et al., 2013b).

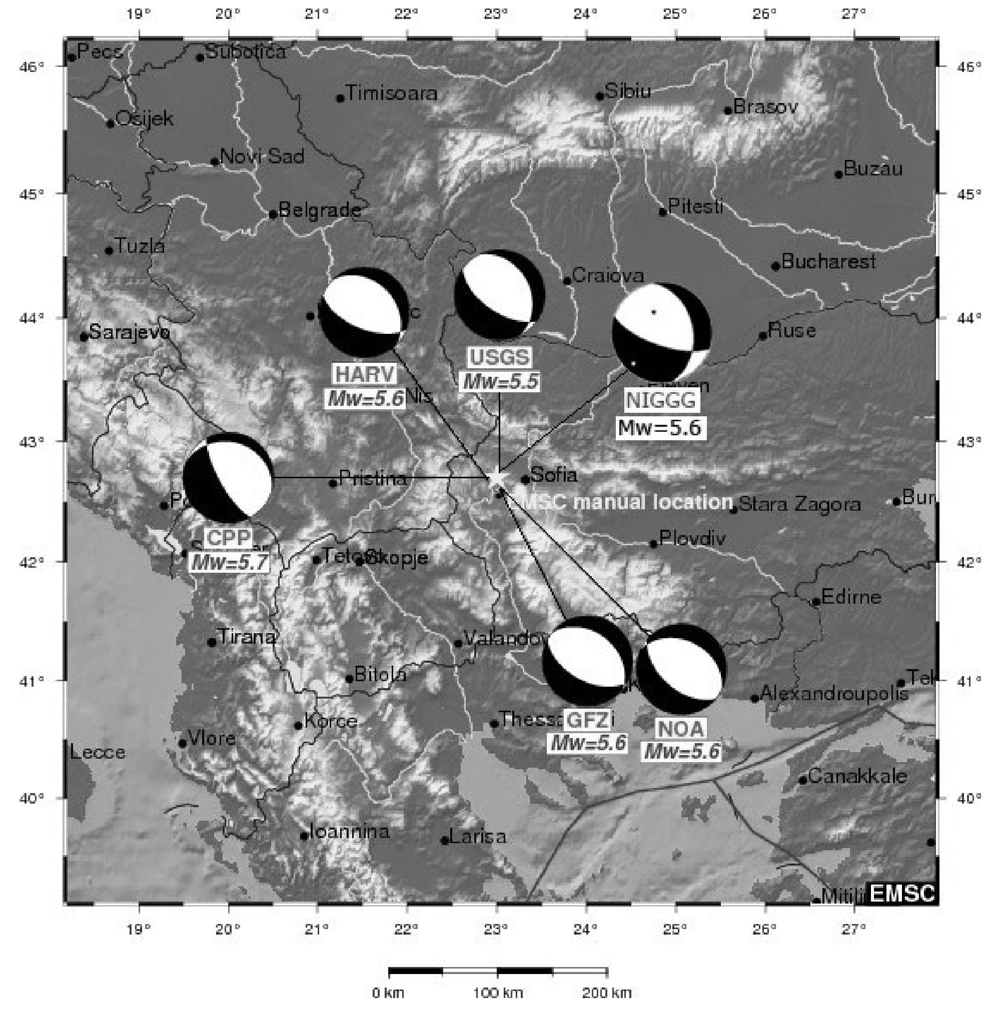

Fig.3 Fault plane solutions of the 2012 MW = 5.6 Pernik earthquake by NOTSSI and European-Mediterranean Seismological Centre (http://www.emsc-csem.org). World networks: NIGGG - National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Sofia, Bulgaria; CPP - Cal Poly Pomona University, California, United States of America; HARV - Harvard Seismology Group, Harvard University, Cambridge, United States of America; USGS - National Earthquake Information Center, United States of America; NOA - National Observatory of Athens, Greece; GFZ - Seismological Data Center, Potsdam, Germany.

Table 1. Parameters of the nodal planes for the main event and aftershocks. Date is given in year, month, day, origin time in hours:minutes, location is given as latitude (Lat Nº) and longitude (Long Eº) in degrees, event depth in kilometers (km), local magnitude (ML) is the Bulgarian magnitude. The two fault planes are specified with their azimuth (S1, 2), dip (D1, 2) and rake (R1, 2) in degrees. The focal mechanism principal axis of pressure (P), tension (T) and the null axis (B) are also specified by azimuth (az) and dip-plunge (pl) in degrees.

№	Date	Origin time	Lat N°	Long E°	h km	M_L	S1 [°]	D1 [°]	R1 [°]	S2 [°]	D2 [°]	R2 [°]	Paz [°]	Ppl [°]	Taz [°]	Tpl [°]	Baz [°]	Bpl [°]
1	120522	00:00	42.58	23.00	9	5.8	349	38	-36	109	69	-122	337	54	223	15	125	30
2	120522	00:04	42.58	22.97	8	3.9	312	36	-54	90	62	-113	311	63	193	9	103	20
3	120522	00:16	42.56	23.09	13	3.0	279	46	-73	75	46	-107	268	75	178	0	89	11
4	120522	00:43	42.58	23.05	10	3.4	334	45	0	224	90	135	298	30	187	60	63	45
5	120522	01:30	42.58	23.01	9	4.4	316	23	-41	85	75	-107	322	56	190	30	91	15
6	120522	01:34	42.53	23.09	10	3.0	244	55	-66	26	42	-120	204	68	320	1	47	20
7	120522	02:11	42.60	22.97	12	3.0	126	69	66	357	31	137	233	7	359	60	136	22
8	120522	02:13	42.57	23.05	5	4.1	289	43	-24	37	74	-131	263	45	156	31	52	38
9	120522	04:09	42.57	23.04	2	3.2	345	48	-31	97	67	-133	320	48	217	10	119	38
10	120522	04:29	42.58	23.08	15	3.1	318	61	-56	83	44	-135	276	58	25	7	120	30
11	120522	17:07	42.58	23.03	15	3.3	336	60	-35	85	60	-144	288	42	209	2	119	45
12	120523	10:57	42.54	23.11	11	3.0	319	43	-82	128	47	-98	330	84	223	0	133	5
13	120523	11:41	42.56	23.02	2	3.1	186	11	-63	339	80	-95	242	59	70	36	338	5
14	120523	21:59	42.56	23.10	10	3.7	312	63	-62	82	38	-132	267	62	29	10	118	23
15	120529	05:36	42.55	23.07	7	3.4	301	34	-58	83	62	-110	312	66	188	11	94	16
16	120529	07:23	42.56	23.03	6	3.8	337	78	-3	68	87	-168	299	10	198	8	80	77
17	120616	04:51	42.57	23.07	10	3.0	324	74	-45	69	47	-158	278	43	23	15	130	43
18	120714	12:52	42.57	23.06	8	4.3	78	83	-40	174	50	-170	29	32	130	20	250	49
19	120731	00:10	42.54	23.10	7	3.3	306	36	-54	84	62	-113	313	67	188	10	95	19
20	120816	02:11	42.57	23.06	10	3.0	331	58	-49	92	50	-136	297	50	34	2	126	33

Table 2. Parameters of the nodal planes for the main event 22nd of May 2012, origin time 00:00 GMT. The symbols are same as in Table 1, except moment magnitude (M_W) and World networks are the same as Fig. 3.

Network	Lat N°	Long E°	H km	M_w	S1 [°]	D1 [°]	R1 [°]	S2 [°]	D2 [°]	R2 [°]	Paz [°]	Ppl [°]	Taz [°]	Tpl [°]	Baz [°]	Bpl [°]
NIGGG	42.58	23.00	9	5.6	349	38	-36	109	69	-122	337	54	223	15	125	30
CPP	42.70	23.00	9	5.7	288	22	-132	152	74	-75	83	58	230	27	328	15
HARV	42.55	23.00	12	5.6	316	32	-70	113	61	-102	355	72	211	15	119	10
USGS	42.68	23.02	12	5.5	292	41	-104	130	50	-78	95	79	212	4	302	9
NOA	42.60	23.06	10	5.6	296	36	-102	131	54	-81						
GFZ	42.67	23.01	16	5.6	310	37	-80	119	54	-96	1	80	213	8	123	5

Regional stress field

Fig.4 displays the horizontal projections of the individual P (pressure) and T (tension) axes of all twenty earthquake focal mechanisms. The projections of compression (P-axis) are predominantly of NW-SE orientation and are significantly smaller than the axes of extension (T-axis) in NE-SW. The plunge of P-axes varies in the range 10º-84º, about 51° in average, and the plunge of T-axes is in predominant sub-horizontal orientation (0º -60º), about 15° in average. The above pattern indicates for extensional stress field in the studied area.

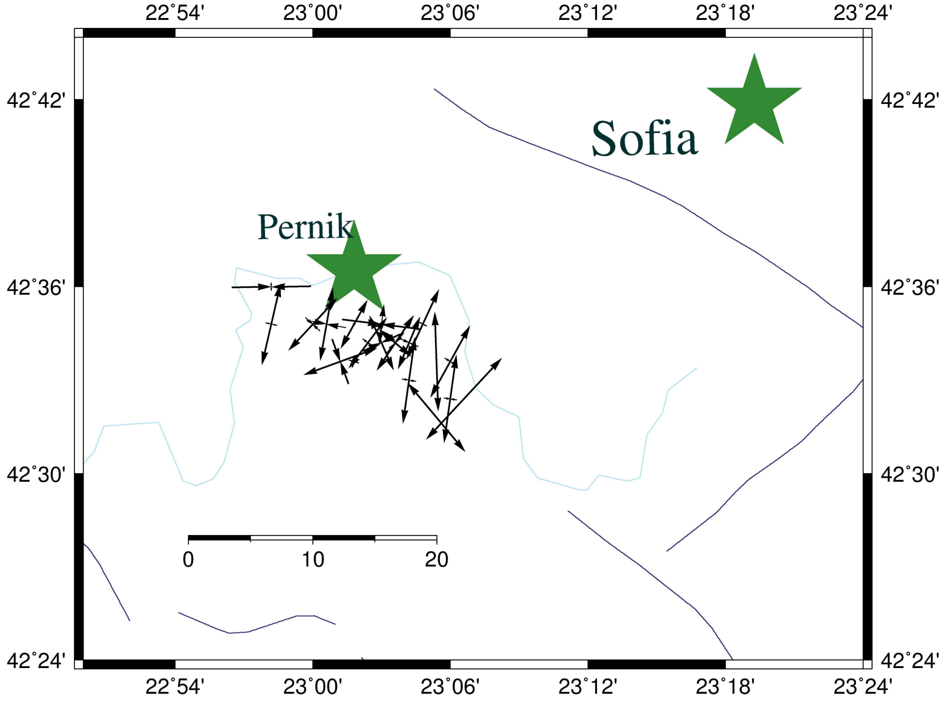

Fig.4 Horizontal projections of the individual P and T axes of the 2012 MW = 5.6 Pernik earthquake and aftershocks focal mechanisms (The Generic Mapping Tools - http://gmt.soest.hawaii.edu/home, the tectonic map is compiled after Barrier et al., 2004 and Georgiev et al., 2007). The stars mark the location of the cities of Sofia and Pernik.

Conclusion

The main result from the focal mechanism determination and the stress orientation analysis shows the prevailing of a normal or extensional stress regime in the studied region. Generally, the tension axes are sub-horizontal and of NE-SW orientation.

The observed sub-horizontal uppercut extensional stress with predominant NE-SW trend of the T-axes is consistent with the general trend of the regional extensional field on the territory of Bulgaria (e.g., Protopopova et al., 2013). This stress field corresponds to that found in southern Bulgaria (presented by Van Eck and Stoyanov, 1996) and confirms the hypothesis that the neotectonic movements in Balkan Peninsula region are the consequence of the long lasting extensional movements in the inner parts of the Aegean and Central Balkan regions.

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Определяне на механизмите на земетресението край град Перник M_W 5.6 през 2012 година (северозападна България) и по-силните афтършоци

В.Протопопова

Резюме: Земетресение с магнитуд M_L=5.8 (Mw=5.6) и епицентрална интензивност I_0= 8 MSK64 се случи в близост до град Перник (северозападна България) на 22-ри май 2012 г. Земетресението е последвано от интензивна афтършокова активност. В научната публикация са представени 20 определени фокални механизма (главният и 19 афтършока) регистрирани от Националната сеизмологична мрежа. Ориентацията на фокалние равнини на определените механизми и пространственото разпределение на афтършоците съвпада със северозападно-югоизточното направление на разлома Перник-Белчин. Също така е представен основен геодинамичен анализ.