Seismicity of the Rhodope zone over the period 1980-2014

Milen Tsekov[1], Emil Botev[2], Rumen Borisov[1]

[1]Department of Meteorology and Geophysics, Faculty of Physics, St. Kliment Ohridski University of Sofia, tsekov@phys.uni-sofia.bg,
[2]National Institute of Geophysics, Geodesy, and Geography, Bulgarian Academy of Sciences.

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Милен Цеков, Емил Ботев, Румен Борисов, Сеизмичност на Родопската зона за периода 1980-2014. В настоящата работа изследваме сеизмичната активност в Родопската зона за периода 1980-2014, посредством анализ на данните от НОТССИ. Основните изводи от нашия анализ са следните. Сеизмичността в района се доминира от микросеизмична активност (97,29% от регистрираните сеизмични събития са микроземетресения). Само 4 земетресения с магнитуд над 4 са регистрирани в изследваната зона за периода 1980-2014. Сеизмичната активност не е дифузна, а е концентрирана по определени активни сеизмични разломи. Голяма част от сеизмичните събития с M>2.5 се концентрират в околностите на епицентрите на 4-те земетресения с магнитуд над 4, станали в района през изследвания период. Националната сеизмична мрежа е подходящо конфигурирана за регистриране на сеизмичните събития в района – магнитудът на пълнота на данните е 1,9. Както магнитудът на пълнота, така и b-стойността демонстрират стабилност във времето.

In this paper we analyze the seismic activity in the Rhodope zone (which we define as λ = 23.8° – 26.3° E and φ = 41.2° – 42.0° N) over the period 1980-2014. The Rhodopes are a mountain range in the southern part of the Balkan Peninsula, with over 83% of its area in southern Bulgaria and the remainder in Greece. We note that the studied region does not coincide strictly with the Rhodopes. Dimitrova and Botev, 2005 analyzed the seismic activity in the same region over the period 1980-2006. Here we extend and detail some of their findings. We also analyze in detail temporal variability of the magnitude of completeness and the b-value for the considered region and period.

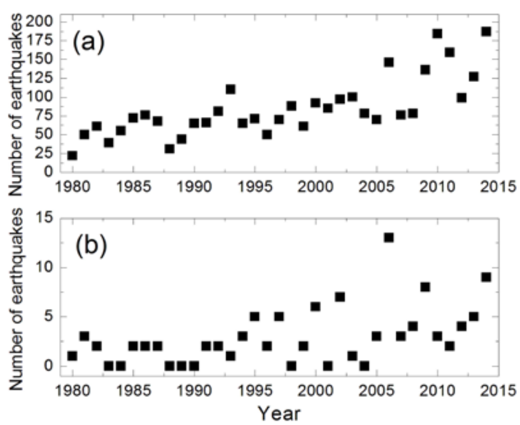

Figure 1. Annual number of earthquakes in the Rhodope zone: (a) all registered earthquakes; (b) events with M≥3.

Seismic activity in the Rhodopes is characterized by relatively high frequency of earthquake occurrence and by low energy release. Majority of the seismic events in the considered region are microearthquakes (2870 out of the 2950 recorded earthquakes for the period 1980-2014 or 97.29% have M≤3). Due to the predominance of microearthquakes, information about the historical seismic activity in the region is scarce. In the Bulgarian historical earthquake catalog (Grigorova et al., 1978) are listed only 134 events for the studied zone, including aftershocks. Detailed information about the seismic activity in the Rhodopes is available only after 1980 when National Operative Telemetric System for Seismic Information (NOTSSI) starts operating. In Figure 1a we present the annual number of earthquakes recorded in the considered region. Systematic increase in the number of recorded events is evident. In Figure 1b we present the annual number of earthquakes with M≥3 (way above the magnitude of completeness of the data, see below). It also has positive trend, indicating that the increase in the number of recorded events reflects higher seismic activity, and not increased detection capability of the seismic network.

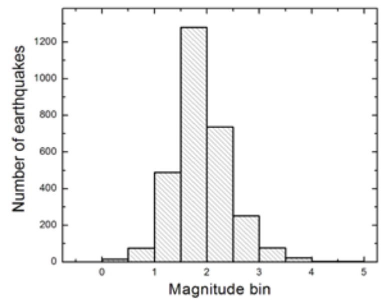

Figure 2. Frequency-magnitude distribution of the earthquakes registered in the Rhodope zone over the period 1980-2014.

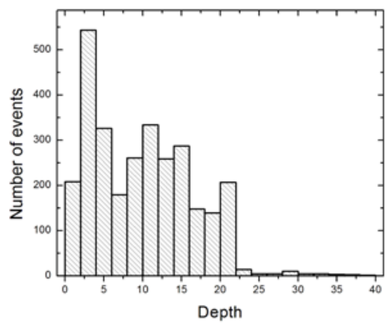

Figure 3. Depth distribution of the earthquakes registered in the Rhodope zone over the period 1980-2014.

For all registered earthquakes duration magnitude is determined according to the formula obtained by Christoskov and Samardjieva, 1983. The frequency-magnitude distribution of the Rhodope zone earthquake data (Figure 2) illustrates that the seismic activity in the region is dominated by microearthquakes (with M≤3). The depth distribution (Figure 3) reveals that the earthquakes in the region are predominantly shallow, with hypocenter depths rarely exceeding 22 km.

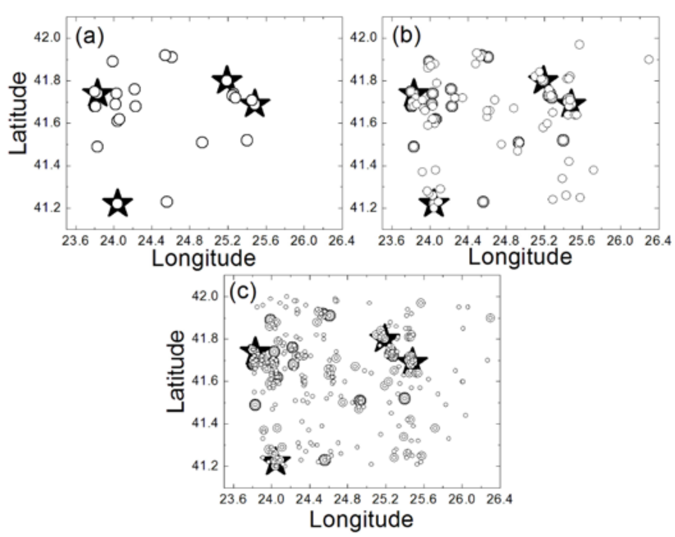

Figure 4. Geographic distribution of the earthquakes registered in the Rhodope zone over the period 1980-2014: (a) events with M≥3.5; (b) events with M≥3; (c) events with M≥2.5. Epicenters of earthquakes with M>4 are denoted with asterisk.

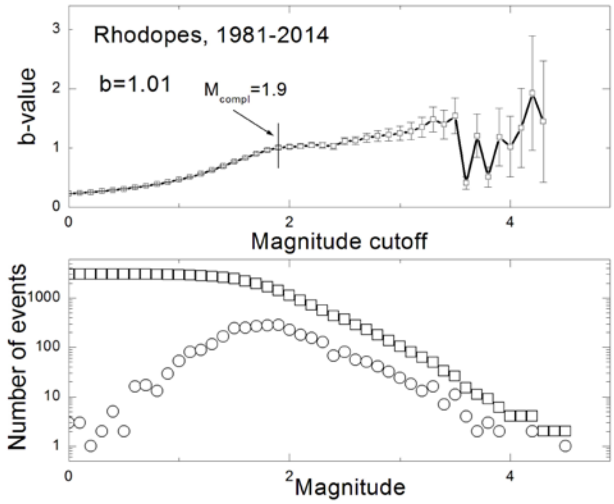

Figure 5. Completeness of the Rhodope zone earthquake data for the period 1981-2014. Top: b-value estimate as a function of magnitude cutoff. Bottom: Non-cumulative (circles) and cumulative (squares) frequency-magnitude distributions.

In Figure 4 we present the geographic distribution of the epicenters of seismic events for magnitude cutoff 3.5 (Figure 4a), 3 (Figure 4b), and 2.5 (Figure 4c). It is evident that the epicenters are not diffusely distributed but are concentrated along specific active fault zones. During the period 1980-2014 only 4 earthquakes with M> 4 occurred in the region. The strongest one (M=4.6) occurred on 09.11.1985 in the southern part of the zone (41.22N, 24.04E) near Drama, on the territory of Greece. Two M>4 earthquakes occurred in the region of Kardzhali (08.04.1982; 41.8N, 25.19E; M=4.2; and 20.02.2006; 41.69N, 25.48E; M=4.5). One M=4.2 earthquake occurred in the western part of the zone, 20 km NNE of Gotse Delchev (01.02.1996; 41.74N, 23.83E). All other events in the zone have magnitude M<4. Large portion of the seismic activity in the Rhodopes during the period 1980-2014 was concentrated in the vicinity of the epicenters of the four events with M>4 (Fig. 4).

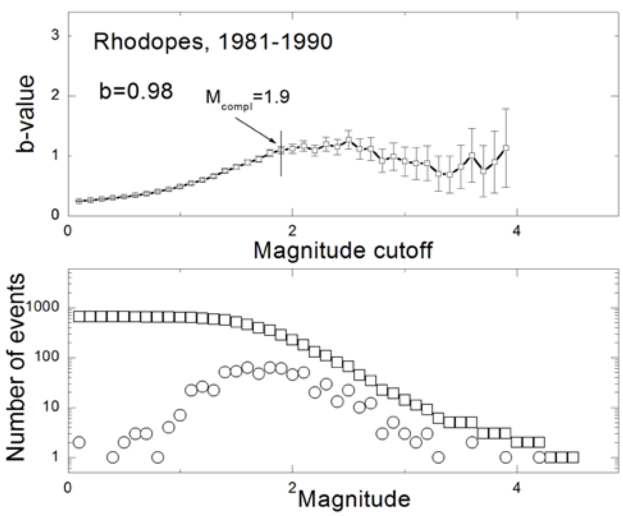

Figure 6. Completeness of the Rhodope zone earthquake data for the period 1981-1990. Top: b-value estimate as a function of magnitude cutoff. Bottom: Non-cumulative (circles) and cumulative (squares) frequency-magnitude distributions.

We assess the magnitude of completeness of our data using two different methods: (1) the Maximum Curvature (MAXC) technique (Wyss et al., 1999; Wiemer and Wyss, 2000) and (2) the magnitude of completeness by b-value stability (MBS) approach (Cao and Gao, 2002). The MAXC technique provides a fast and simple approach to estimate the magnitude of completeness of an earthquake catalog. It relies on determination of the point of maximum curvature of the cumulative frequency-magnitude distribution which coincides with the magnitude bin of the non-cumulative frequency-magnitude distribution with highest number of observed events. MAXC technique generally provides lower estimates of the magnitude of completeness of earthquake catalogs than alternative techniques, including MBS (Mignan and Woesner, 2012). It may underestimate the real magnitude of completeness, especially for gradually curved cumulative frequency-magnitude distributions (Mignan and Woesner, 2012). The MBS technique is based on determination of the b-value as a function of magnitude cutoff. The estimate of the b-value is low for magnitude cutoff lower than the magnitude of completeness. It increases for magnitude cutoff approaching the magnitude of completeness and remains stable for magnitude cutoff greater than the magnitude of completeness of the earthquake data. For very large magnitude cutoff the estimate of the b-value exhibit significant statistical fluctuations due to undersampling. The MBS technique is a conservative approach which generally provides higher estimates of the magnitude of completeness than other techniques (Mignan and Woesner, 2012).

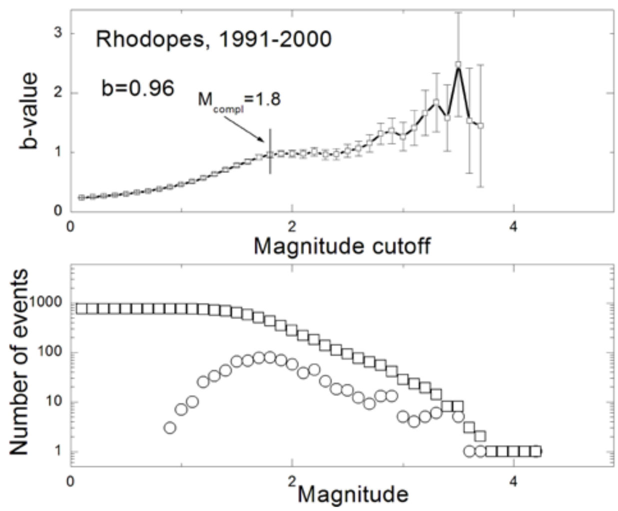

Figure 7. Completeness of the Rhodope zone earthquake data for the period 1991-2000. Top: b-value estimate as a function of magnitude cutoff. Bottom: Non-cumulative (circles) and cumulative (squares) frequency-magnitude distributions.

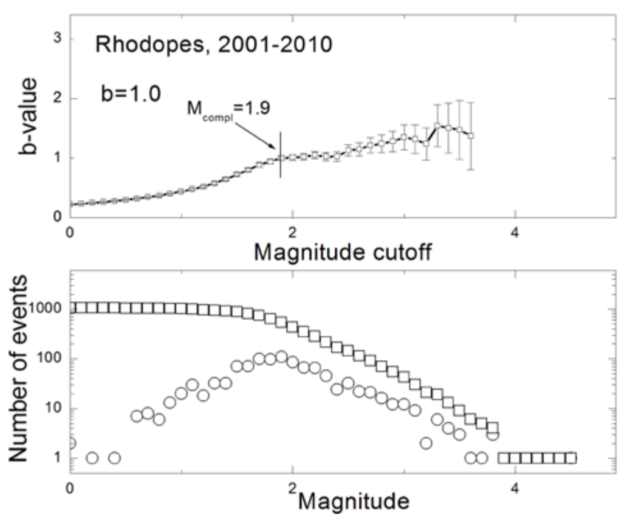

Figure 8. Completeness of the Rhodope zone earthquake data for the period 2001-2010. Top: b-value estimate as a function of magnitude cutoff. Bottom: Non-cumulative (circles) and cumulative (squares) frequency-magnitude distributions.

We first asses the completeness of Rhodope zone earthquake data over the entire period 1981-2014 (we exclude the data from 1980 which are supposedly of lower quality). In Figure 5 we present the results of the application of MBS (top) and MAXC (bottom) techniques to these data. Both methods indicate that the Rhodope zone earthquake data are complete down to magnitude 1.9 over the entire period 1981-2014. The MAXC technique indicates that the data may be complete down to even lower magnitude threshold. It is interesting that the earthquake data for the whole territory of Bulgaria are complete only above M=2.2 for year 2013 (see the accompanying paper Tsekov, Botev, Mokreva, and Protopopova, On the completeness of Bulgarian earthquake data, in this volume). Therefore, the Bulgarian Seismic Network is appropriately configured to detect the seismic activity specifically in the Rhodopes. The b-value estimate for the period 1980-2014 is 1.01. Next, we divide the data into four segments (1981-1990; 1991-2000; 2001-2010; and 2011-2014) and we assess magnitude of completeness and b-value for each segment separately (Figs. 6-9). We observe temporal stability of both magnitude of completeness and b-value. The magnitude of completeness varies between 1.8 and 1.9 for the different time periods, while the b-value varies between 0.96 and 1.0.

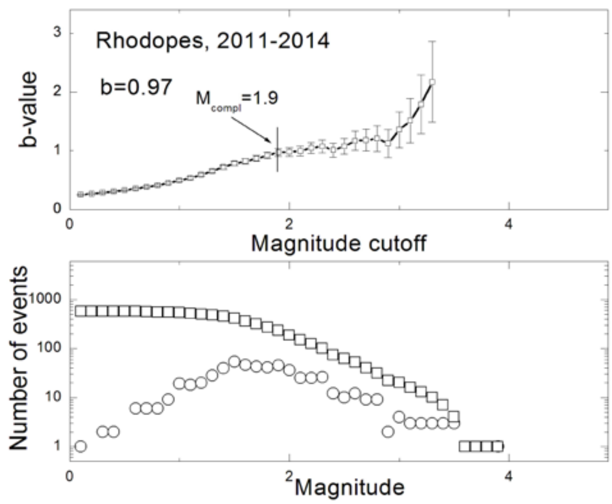

Figure 9. Completeness of the Rhodope zone earthquake data for the period 1911-2014. Top: b-value estimate as a function of magnitude cutoff. Bottom: Non-cumulative (circles) and cumulative (squares) frequency-magnitude distributions.

We can summarize our findings as follows. Seismicity in the Rhodope zone is dominated by microearthquakes. Bulgarian National Seismological Network is well configured to record the seismic activity in the Rhodopes. The magnitude of completeness is 1.9. Seismic activity in the region increases in the course of the last 35 years. Epicenters of earthquakes are not diffusely distributed, but are concentrated along specific active fault zones. The b-value and magnitude of completeness are temporally stable.

References:

Cao, A. M., and Gao, S. S., 2002, Temporal variations of seismic b-values beneath Northeastern Japan island arc, Geophys. Res. Lett., 29, doi:10.1029/2001GL013775.

Christoskov, L. and Samardjieva, E., 1983. Investigation on the duration of the seismic signals like an energetic characteristic of the earthquakes. Bulg. Geophys. J., 9 (1) (In Bulgarian).

Dimitrova, S., and Botev, E., 2005, Weak seismicity of Rhodopes from National Seismological Network observations (1980 - 2006), Bulg. Geophys. J., 31, 1-4, 97-104.

Grigorova, E., Christoskov, L., Sokerova, D., Rizhikova, S., and Roglinov, A., 1978, Catalogue of earthquakes in Bulgaria and the nearby territories during the period 1st cent. BC – 1977, Archives of the Institute of Geophysics., Bulg. Acad.Sci., Sofia.

Mignan, A., and Woessner, J., 2012, Estimating the magnitude of completeness for earthquake catalogs, Community Online Resource for Statistical Seismicity Analysis, doi:10.5078/corssa-00180805. Available at http://www.corssa.org.

Wiemer, S., and Wyss, M., 2000, Minimum magnitude of complete reporting in earthquake catalogs: examples from Alaska, the Western United States, and Japan, Bull. Seismol. Soc. Am., 90, 859-869.

Wyss, M., Hasegawa, A., Wiemer, S. and Umino, N., 1999, Quantitative mapping of precursory seismic quiescence before the 1989, m7.1 off-Sanriku earthquake, Japan, Annali Di Geofisica, 42, 851-869.