4.3.2. AN OUTLOOK ON LONG-TERM AND NOWADAYS SEISMICITY IN BULGARIA

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4.3.2.1. Introduction

The territory of Bulgaria which is spread within the Balkan Peninsula is a small part of the Alpo-Himalayan seismic belt. The seismicity in Bulgaria and the earthquake influence on its territory should be considered as moderate in general and, rarely, as quite dangerous. That is why some regional aspects of seismology have been in development in Bulgaria since the late 19th century, and in 1903 the Bulgarian seismological survey became a member of the International Seismological Association.

The non-instrumental seismology in Bulgaria started its development in 1891. At that time Spas Watzof, the director of Central Meteorological Station, Sofia, initiated the collection of macroseismic reports after organizing a network of correspondents for observation of felt earthquakes in Bulgaria. To unify the data collection, he spread an "Instruction and program on the earthquakes observation and documenting" over the country. In result, the scientific world has received annual reports on earthquake impacts in Bulgaria for about 75 years.

The instrumental seismology in Bulgaria started its development in 1905, when a Bosch-Omori seismograph was installed in Sofia. Two facts are noteworthy in this earliest stage: (1) the first bulletins, which systematized the registrations during 1905 and 1906, appeared soon after the instrument installation (Watzof, 1907); and (2) selected Bulgarian registrations were used by Mohorovicic (1910) and Reid (1910) in their world-recognized works. The Sofia station remained the only well equipped site up to 1961, as it was modernized at the end of 1934 by two horizontal Wiechert seismographs (To = 9-11 sec, magnification ca. 200). Much later, in 1980, certain attempts to gain the necessary covering of Bulgarian territory started.

In this paper some useful systematization of the seismic manifestations in Bulgaria is presented favored by both, the macroseismic (non-instrumental) and instrumental approaches.

4.3.2.2. Long-term seismicity through macroseismic sources

The acquaintance with the long-term seismicity and seismic influence is of prime importance to reliable hazard and seismic risk assessment. This requires availability of well compiled earthquake catalogues.

The first parametric catalogue in Bulgaria is compiled by Grigorova and Rizhikova (1966). Therein, an instrumental magnitude based on the Wiechert records appears as energy characteristics of the events for the first time. Later on, an enriched national catalogue together with isoseismal maps of the prevailable part of moderate and strong Bulgarian earthquakes prepared by Grigorova in the framework of a UNESCO project

has taken place in the first Balkan earthquake catalogue (Shebalin et al., 1974) and Balkan isoseismal atlas (Shebalin, 1974). These cover seismic events with a lower magnitude threshold 4 occurring since the antiquity till 1970. During another UNESCO project a catalogue of the strong Bulgarian earthquakes in the 70ies is compiled (Sokerova et al., 1982). Other smaller catalogues limited in time and area are compiled on occasion of impressive present-day earthquakes. Aiming to the seismic zonation updating, a revised catalogue was compiled in the end of the 70ies (Grigorova et al., 1978) proceeding from the systematization already produced and techniques used at the Balkan catalogue creation. The new catalogue presents more than 1400 entries within the territory closed by geographical coordinates 40 - 46^{o}N, 20 - 30^{o}E.

The above catalogues are based mainly on the annual reports on felt earthquakes in Bulgaria supplemented by data from the neighboring countries' catalogues. The Bulgarian macroseismic reports, issued until 1965, were changeable in type. They were of two parts, descriptions and macroseismic bulletins (Watzof, 1902, 1903, ..., 1923), or bulletins only (Kirov, 1931, 1945), or presenting isoseismal maps in addition to the bulletins. After 1965, many studies of moderate size earthquakes and atlases of isoseismal maps were published. Field observations were carried out for comprehensive investigation of the consequences of the 1977 Vrancea earthquake (Brankov, 1983), 1986 North Bulgarian earthquake series (Christoskov et al., 1988, Michailov et al., 1990), and of some weaker seismic events. The contribution of Bulgaria to long-term seismicity investigation of the Balkan region made in the framework of some recently completed European projects (Glavcheva,Radu, 1994, Albini, Stucchi, 1997, Ranguelov et al., 2000, Glavcheva, 2004) is worthy of mention.

To represent the seismicity pattern in Bulgaria from ancient times till 1980, this study deals with the catalogue by Grigorova et al., (1978) renovated by materials of later publications. These recent publications emphasize on how fully and how far critically the information sources were exploited, i.e. they are steps towards improvement of the supporting dataset (data from which the earthquake parameters are evaluated) quality. After checking the authenticity of the strong events in the catalogue, especially of these proceeding from a very poor dataset, some key catalogue events were clarified. Thus, the 1892, 14 October, Balkan earthquake having epicenters spread over more than 200 km due to fragmentary use of the initial data, has received its categorical solution (Glavcheva, Radu, 1994). Further, it was shown that the careless reading of initial records had provided false entries in the catalogue as the 1866 magnitude 7 event in the middle Strouma valley (Glavcheva, 1999) and the 1759 magnitude 6.3 event in the Pirin mountain massif (Glavcheva, 2000); similar events were omitted from the catalogue used. Some more revised cases are shown in (Glavcheva, 2004).

After precluding the catalogue renovation, the initial quantity of more than 1400 entries within the territory closed by geographical coordinates 40 - 46^{o}N, 20 - 30^{o}E is reduced to 1071 earthquakes felt in Bulgaria since ancient times till the establishment of high sensitive seismological network in Bulgaria in 1980. Some of them did not cause any damage (intensity lower than 6 degrees according to Medvedev-Sponheuer-Karnik /MSK/ scale), others were damaging (minimum intensity 6 MSK); all they are shown in Fig. 4.3.2.1. where the maximal intensity of impact on Bulgaria is marked in each earthquake's epicenter. About 25% of these earthquakes caused damages, from not serious to ruins. Fig. 4.3.2.2. illustrates their epicentral distribution stressing on 3 groups of consequences: full destruction (14 of the documented cases), high damages to buildings (in 22 cases), and easy retrievable losses (about 230 cases). The predominant

part of most severe shocks whenever happened has its origin along or near the rivers. Then, such a location of the epicentral areas is under most unfavorable conditions.

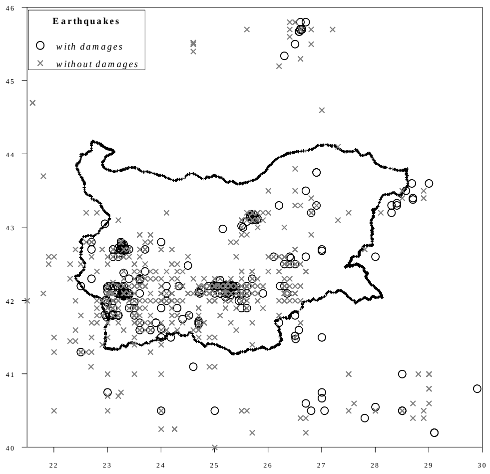


Fig. 4.3.2.1. Epicenters of earthquakes felt in Bulgaria since ancient times till 1980 (explanation in the text)

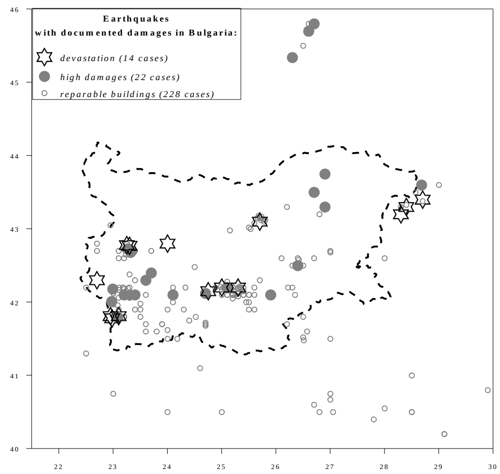
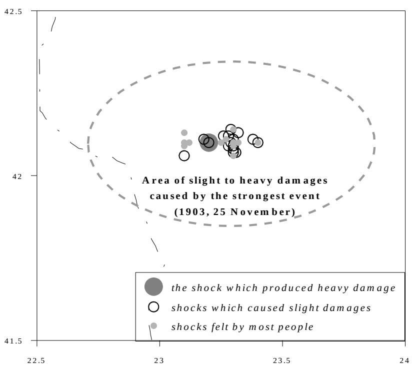


Fig. 4.3.2.2. Epicenters of earthquakes since ancient times till 1980 which caused damages in Bulgaria

There exists another important circumstance, which also causes the damage rate to rise. This is cumulating of effects in cases of damaging or nearly damaging shocks after devastating earthquakes. Appropriate examples could be found amongst the several well documented violent earthquakes as the 1892 earthquake in northeast Bulgaria (maximum intensity 8 MSK, magnitude around 7), the Black Sea earthquake in 1901 (intensity 9 MSK in northeast Bulgaria, magnitude 7 or more), the two transfrontier Bulgaria-Macedonia earthquakes in 1904 (maximum intensity in Bulgaria up to 10 MSK, magnitudes 7.1 and 7.8), the 1913 Gorna Oryahovitsa earthquake (maximum intensity 9 MSK, magnitude 7.0), and the 1928 couple of events in Central South Bulgaria (maximum intensity 9-10 MSK, magnitudes 6.8 and 7.0). Some of these events were followed by long-lasting series of strong aftershocks; this is the reason of overestimating of the actual released energy when instrumental registration is not available.

Hereafter, some cases of earthquake sequences whose interpretation is complicated by the next seismic activity in the same region are presented. In 1903-1905 the transfrontier Bulgaria-Macedonia region, known as Kroupnik-Kresna region, was very active. The occurrence of 1904 violent earthquakes was preceded by increased activity in the late 1903. The first shock of the series was the strongest one. It influenced the buildings in the area shown by elliptical curve in Fig. 4.3.2.3. to a different degree. At the shocks next in time, cumulative effects might have been documented.

On 4 April 1904 the first catastrophic shock (magnitude 7.1) occurred. It was followed by few smaller shocks. As a matter of fact, the Seismological Service documentation inherits the experienced horror. That means that some possibility exists of overestimation for the effects caused by the next shocks in devastated area (Fig. 4.3.2.4.). The worst came after the occurrence of the second devastating earthquake on 4 April 1904 (magnitude 7.8). Many aftershocks occurring in demolished area were damaging. The intensity assessment of consequences at these quakes is too complicated. How the epicenters are distributed during the next two months is shown in Fig. 4.3.2.5.



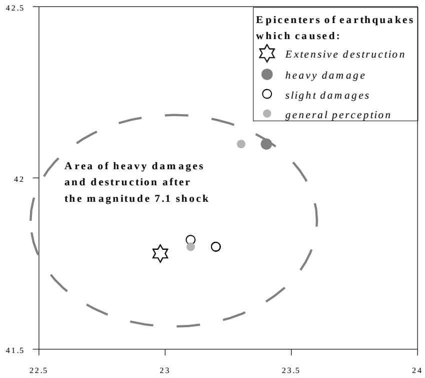
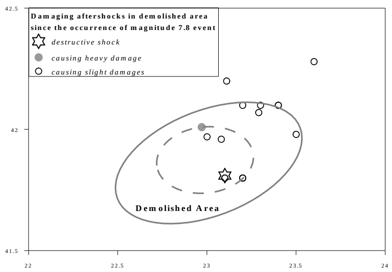


Fig. 4.3.2.3. 1903 pre-activity of the catastrophic 1904 earthquakes

Fig. 4.3.2.4. Earthquake epicenters of the foreshock activity in 1904



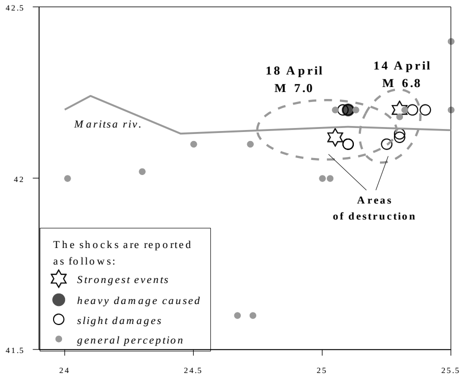


Fig. 4.3.2.5. Epicenters of damaging shocks in two months, imminently after the occurrence of the second large earthquake in 1904

Fig. 4.3.2.6. Earthquake epicenters in the interval 14 - 20 April 1928 in the Upper Thracia - damaging aftershocks are reported from areas of destruction formed by mainshocks

Another example of how difficult scientists have to make decisions after disastrous earthquakes is the case of two 20th century large events (M6.8, 7.0) in the Upper Thracia. These events occurred within an area of 50 x 20 km in 4 days' interval. The area heavy influenced by the two strongest events became the platform affected by next shocks. At that, in the first week after the earthquake series had began, damaging aftershocks were reported only from the already demolished area (Fig. 4.3.2.6.). This fact could be based on two reasons: (1) continuation of already started activity in the excited space and, again, (2) cumulating of damages to buildings.

The outlook on the long-term seismicity pattern in Bulgaria, from ancient times till 1980, shows that the sources of damaging impacts to Bulgarian territory are located in Bulgaria as well as in Romania, Turkey, Greece and Macedonia. The areas of maximum intensity in case the earthquake origin is in Bulgaria, spread mainly along the rivers and the Black Sea shelf. Then, the seismic risk in Bulgaria is much higher in the river valleys as well as on the loess ground in Moesian Platform, in case of unfavorable hydrogeological circumstances. The situation becomes quite difficult at occurrence of an earthquake series combined of catastrophic mainshock with strong aftershocks. Referring to the seismic impacts from neighboring countries, the northern part of Bulgaria is under the threat of severe Vrancea earthquakes, the South-East Bulgaria –

of the North-Anatolian fault system’s prolongation westwards, Rhodopean area – of Low Thracian sources, and South-West Bulgaria – of East Macedonian origins.

4.3.2.3. Instrumental seismic monitoring in Bulgaria

The modern national telemetric network for seismological observation in Bulgaria started to be constructed after the 1977 Vrancea large earthquake. The network started operating in 1980 with the intention to monitor the seismicity in real time and to inform expressly the public society in a case of an increasing seismic activity. The location accuracy of events depends on the instrumental sensitivity at each registration site and on the spatial position of the seismic source within the frame of the recording network.
About 12000 events are located on the territory of Bulgaria and its close vicinity for the last two decades of the XX century during the operation of the National Network (Botev et al., 1991-2001, Seismological Archives of Geophys. Inst., 1980-1990). Most of them are microearthquakes – more than 95% with a magnitude M<3.0. The strongest recorded by the NOTSSI event is the 1986 magnitude M5.7 Strazhitza earthquake in the central North Bulgaria.

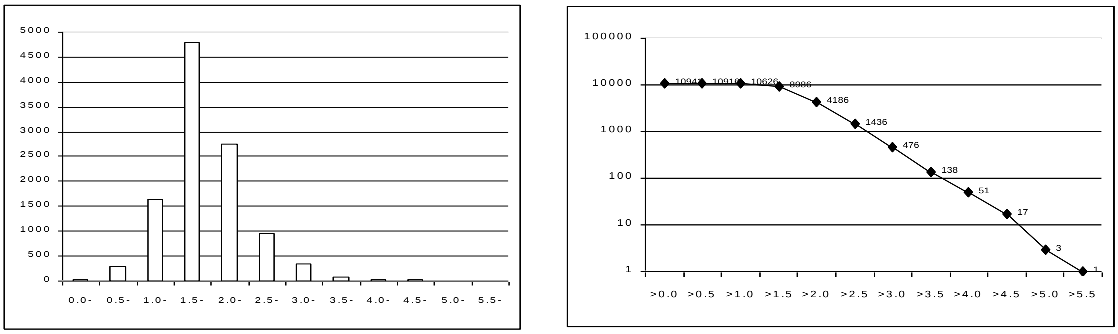


Fig. 4.3.2.7. N and cumulative Log N distributions of the events for different magnitude levels

On the upper diagram the magnitude-frequency distribution for the all 12000 events is presented. The number of localized events (N) increases with decreasing of the magnitude M, respectively: one event with M=5.5-5.9, 2 events with M=5.0-5.4, 14 with M = 4.5-4.9, 34 with M=4.0-4.4, 87 with M = 3.5-3.9, 338 with M= 3.0-3.4, 960 with M = 2.5-2.9 and so on. The abrupt diminishing of the number of earthquakes in the last two intervals determines the registration possibilities of the network - it can be supposed that the M sample for levels with M>1.5 is closer to the reality for the almost all territory. The slope of the averaged straight line (the coefficient in the Gutenberg – Richter’s low) is bigger in comparison with other investigations (e.g. at stronger earthquakes). This suggests a certain “missing” of stronger events.

The depth-frequency distribution shows that the majority of events with M>2.5 (being with the highest accuracy of the hypocentral parameters) occurs down to 20 km depth. The slight decreasing of the number of events with the depth’s increasing is a natural phenomenon for the intraplate seismicity. The magnitude distribution of events versus the focal depth allows some differentiation of a “depth floor” between 10 and 20 km – this is the depth interval of the strongest earthquakes occurrence.

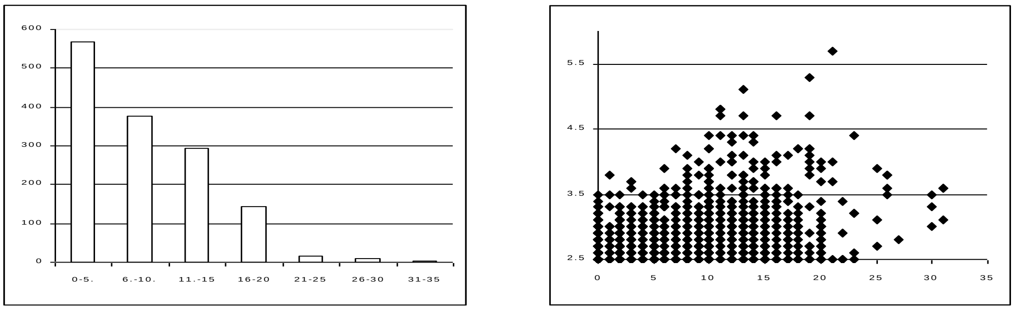


Fig. 4.3.2.8. Depth-frequency and depth-magnitude distributions of the events with M>2.5

From the time distribution of the events with M > 2.5 it proceeds that in the last years (after 1995) the frequency of events is steady higher in comparison with the previous years. The exceptions are 1986 and 1987 when the Strazhitza strong earthquakes' aftershock sequences occurred. The increase in the events number during 1997 and 1998 is due to the swarm sequences in Rila Mountain. The time distribution does not allow establishing of any quasi-periodic peculiarity of the seismicity.

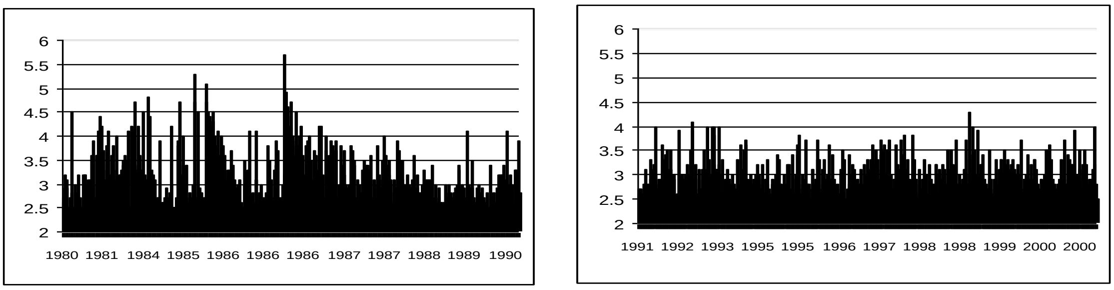


Fig. 4.3.2.9. Time distribution of the events with M > 2.5

The magnitude – time distribution of events shows typical decreasing of M in time for the aftershock series of the strongest earthquakes in February and December 1986. It is remarkable that the magnitude of the events after 1986 very rarely goes over the magnitude level M=4.0.

The epicentral distribution of seismic events with M>2.5 (with considerable possibility of being felt) are shown in Fig. 4.3.2.10. The basement is the scheme of the fault setting of Bulgaria (according to Milev and Vrablyanski, 1988; Zagorchev, 1992; Vaptzarov et al., 1995; Alexiev, 1999) where the Legend's symbols are: a – borders between the main structural provinces; b – faults with preneotectonic activation; c - faults with neotectonic activation; d – strike-slip faults; e - recent uplifting zones; f - quaternary depressions; g – vertical displacement along some faults. The numbers mark main fault lines – the Maritza, Struma, Mesta, For-Balkan, Sub-Balkan ones. There is not much correspondence between the territorial distribution of the epicenters and the main structural provinces throughout the Bulgarian territory. It is not so clear that Moesian platform is characterized by the lowest seismic activity – the strongest events are realized in the central part of North Bulgaria. The biggest concentration of epicenters is observed in the western part of Rhodopean superunit (SW Bulgaria). Some grouping of events appears in the western and central part of the Srednogorie zone (Central Bulgaria).

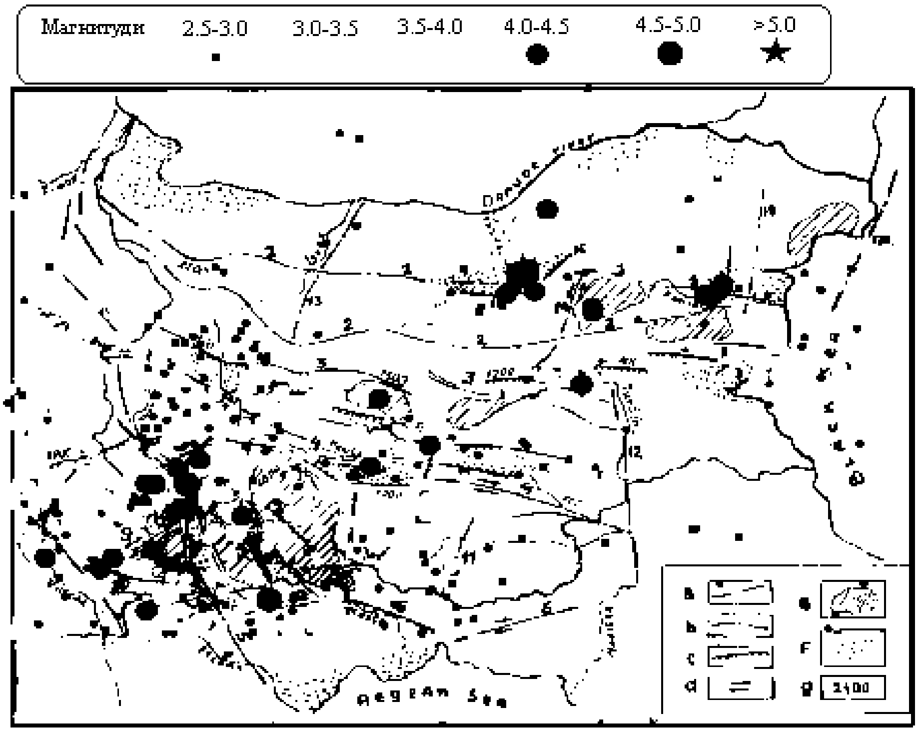


Fig. 4.3.2.10. Epicentral distribution of the events with M > 2.5

The biggest concentration of epicenters in SW Bulgaria is associated with the Simitly quaternary depression, with the tectonic activity of the Kroupnik fault. The seismic process spreads in ENE direction to the town of Razlog and in the West to the faults of the Delchevo graben in Macedonia. As a whole, the seismic activation there has a transversally orientation in relation to the first order Strouma fault zone. Transversal faulting process can be marked in the region of Kovatchevitza, crossing the Upper Mesta fault zone. Transversally to the Strouma fault lineament is the seismicity in the SW corner of the region, and it is associated with the Belasitza and Stroumeshnitza faults. Belasitza fault is a part of the Middle Mesta lineament, which determines the activity in the southern part (in Greek territory). The activity in Srednogorie zone (Central Bulgaria) is associated with the faults of the Upper Thracia depression and Sofia depression. The strongest activity in the central part of North Bulgaria is associated with the eastern border of Strazhitza depression (Strazhitza fault) and the southern one of the Ressenski trough. The seismicity in Provadia region (NE Bulgaria) is associated with the eastern border of the Provadia depression which is crosslying to the Fore-Balkan first-order fault. Other crosslying seismogenic zones are those along the Kaliakra and Dobrich fault lineaments at the NE edge of Bulgaria – these fault systems are not well expressed on the surface and the seismic activity there is relatively low.

The recent seismic hazard assessment for SW Bulgaria and especially for the 1904 great earthquakes' aftershock area, the Kroupnik area, suggests the highest seismogenic potential in Bulgaria (Boncev et al., 1982, Papazachos et al., 1994). On this reason, the area is an object of special observation and analyses. The recent weak seismicity in the Kroupnik area recorded by high sensitive seismographs clearly shows WSW-ENE general seismogenic direction, the same as of the activated seismogenic structures in the past. At present these structures are involved into seismogenic movements only partly. Nevertheless, the weak seismicity shows some important peculiarities.

The first one is that no close correlation exsists between the seismogenesis and the Strouma faults which form the main structural system in this part of Bulgaria (Figs. 4.3.2.2, 8, 10.). This is evident from the epicenter migration throughout the area in the course of a half a year (Fig. 4.3.2.11.). In our example a group of earthquakes appeared at 1 July 1995 in the West from the Strouma fault system and developed in 5 hours (series 1, Fig. 4.3.2.11.). During the next 18 days the seismic activity developed to the east of the Strouma River, along the west Pirin fault (series 2, the same figure). An occurrence of two events in Macedonia, NW from the town of Berovo followed (noted as 3). In August-September the territory to the East of the Strouma fault zone was active again (not marked). Further on, two series of earthquakes developed simultaneously to the E and to the W of Strouma faults (series 4). The seismogenic process to the West shows an arch-shaped epicenter distribution. Its eastern periphery is in the Kroupnik graben.

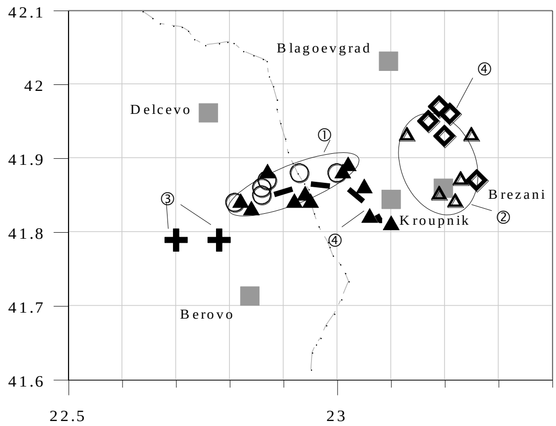


Fig. 4.3.2.11. Seismicity in 1995, July – December; magnitudes lower than 3

Another specificity is that the seismic activity in the area developes in clusters. Some sites of seismic clustering are shown in Fig. 4.3.2.12. The elliptical outlining curves show the most likely elongation of each cluster area. One of the clusters (that one of 12 events in 5 days, 1993, 13-18 January) is developed on the northern edge of the faults setting. From the two eastern clusters (1993, 4-9 February and 2000, 3-4 June), the second one (cluster 1 in the figure) seems to have been connected with the conjunction of the Kroupnik and Predela faults. Cluster 2 (1993, 3-4 April) is between the Elenovo fault, Gradevo fault, and the Vlahina horst.

Finally, it is worth tracing how the seismogenic process developes in different parts of the Kroupnik area. In Fig. 4.3.2.13. two examples are shown. The seismic series in the western position (25 June – 3 August 1991) starts from east, and after several oscillations from the E to the W and conversely, the events disappear at the eastern edge of the activated space. The epicenters sketch out longitudinal direction, the maximum energy (M=3.1) is released in the western sector at the early and the final stage of activity. Another typical case of seismogenic development is that one in the eastern part of the study area. Starting from the mid-point (on 4 September 1999), the activation firstly covers the western part, after that the eastern part, and ends (9 September 1999) with the maximum energy release in the firstly activated space again.

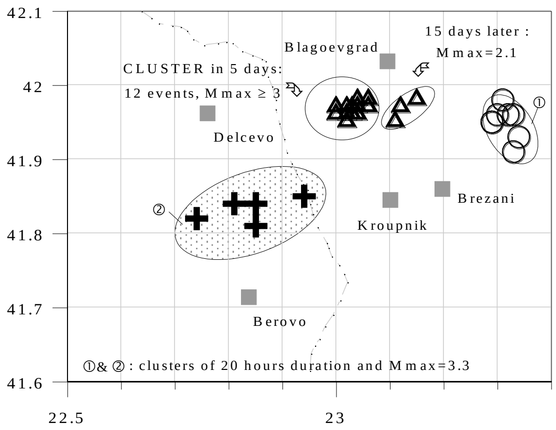


Fig. 4.3.2.12. Seismic activation in clusters

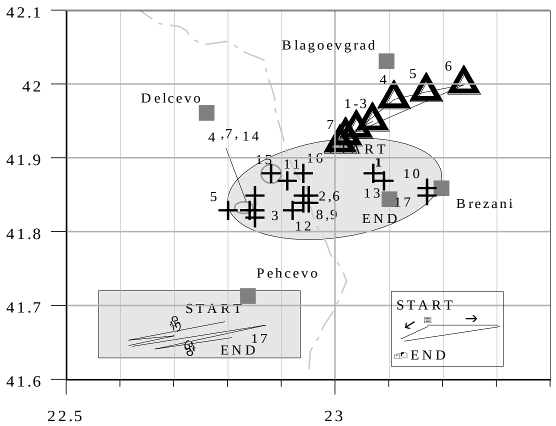


Fig. 4.3.2.13. Cases of seismogenic process development

Generalizing, many of the weak earthquake series in the Kroupnik area preclude by their strongest events, like the ones in June-July 1991, September and October 1998, January and September 1999, July 2000, etc. Rarely, the series are of a classical type – mainshock following by weaker aftershocks (in July-August and December 1998, etc.). It is common the strongest earthquakes in the investigated time-space (M>3) to occur isolated. Some of the series contain pairs of equal magnitudes, some others – swarms.

4.3.2.4. Conclusion

In this study the seismic manifestations are differentiated as originated within the territory of Bulgaria, on the one hand, and those ones only generating seismic effects on it, on the other. The authors' outlook on the seismic manifestations in Bulgaria since ancient times till the present based on two datasets, macroseismic (non-instrumental) and instrumental, leads to the following: (1) In case the earthquake origin is in Bulgaria, the areas along the rivers and the Black Sea shore are most risky in social aspect; (2) Sources of damaging impacts to Bulgaria take place also in the neighboring Romania, Turkey, Greece and Macedonia; (3) Circumstances become quite bad at occurrence of earthquake series combined of catastrophic mainshock with strong aftershocks. For many years the seismogenic sources in Bulgaria have been at low

activity but this country is not defended from unfavorable consequences, e.g. at a future Vrancea severe earthquake.

From the analysis of historical (long-term) and nowadays seismicity proceeds that many strong earthquakes and most dangerous seismic zones are localized in and around the border regions. Obviously, the earthquakes are quite complex trans-border phenomena and require multi national observation and research. There is no doubt that the close regional collaboration between the geoscientists from the Balkan countries should substantially contribute to the improving of the earthquake monitoring quality and to the successful seismic hazard and risk assessment in the Central Balkans.

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