4.3.4. ABOUT SEISMOTECTONIC ACTIVITY OF BULGARIA

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4.3.4.1. Introduction

The tectonic data for the country are represented in various interpretations. In several of them the accent is fallen on the static evolution of the country territory, in other ones - on its dynamic development. The dynamic interpretations are dominantly distributed during the last twenty years. Ch. Dabovski (1991) and P. Gočev (1991) are among the authors of publications with large argumentations for the dynamic evolution of the geological structures in Bulgaria and the surrounding Balkan regions. There are very rational ideas in the both publications. Now for the recent study I will use the interpretation of Gočev 1991.

The remote sensing data are included in the study as well. The network of photolineaments proposes supplementary information for the recent tectonic situation in the country. The remote sensing data are obtained from American and Russian satellite images. Several remote sensing interpretations are published and used for the recent study (Mozaev et al., 1976, Gočev, 1976, Gočev et al., 1984, Katskov et al., 1985, Gočev, Matova, 1989). The data that are included in the study were are taken from previous publications (Gočev, 1976, Gočev et al., 1984, Katskov et al., 1985, Gočev, Matova, 1989) and very new regional interpretations of the author based on the analyses of numerous meteorological satellite images (Matova, 2003).

The seismic data are based on the Balkan Catalogue for earthquakes (Shebalin et al., 1974), recent published catalogue for the Bulgarian earthquakes during 1981-1990 (Solakov, Simeonova, 1993), periodical information of NOTSSI published in he Bulgarian Geophysical Journals and regional investigations of the seismicity (Botev et al., 2000, Ranguelov et al., 2001, Matova et al., 2003).

4.3.4.2 Main stages in Alpine structural development

The Alpine structures of the country (Gočev, 1991) were developed gradually as a result of vertical and horizontal block displacements, faulting and folding in the upper part of the lithosphere. The structures from the Pre-Alpine stages were totally or partially remade.

The Alpine structure genesis depends from the local, regional and the planetary geological environment. Now the territory of the country represents mosaics of inherited relicts and newly formed structures. Using mainly the interpretation of P. Gočev (1991) it is possible to underline several stages in the Alpine development (Fig. 4.3.4.1.).

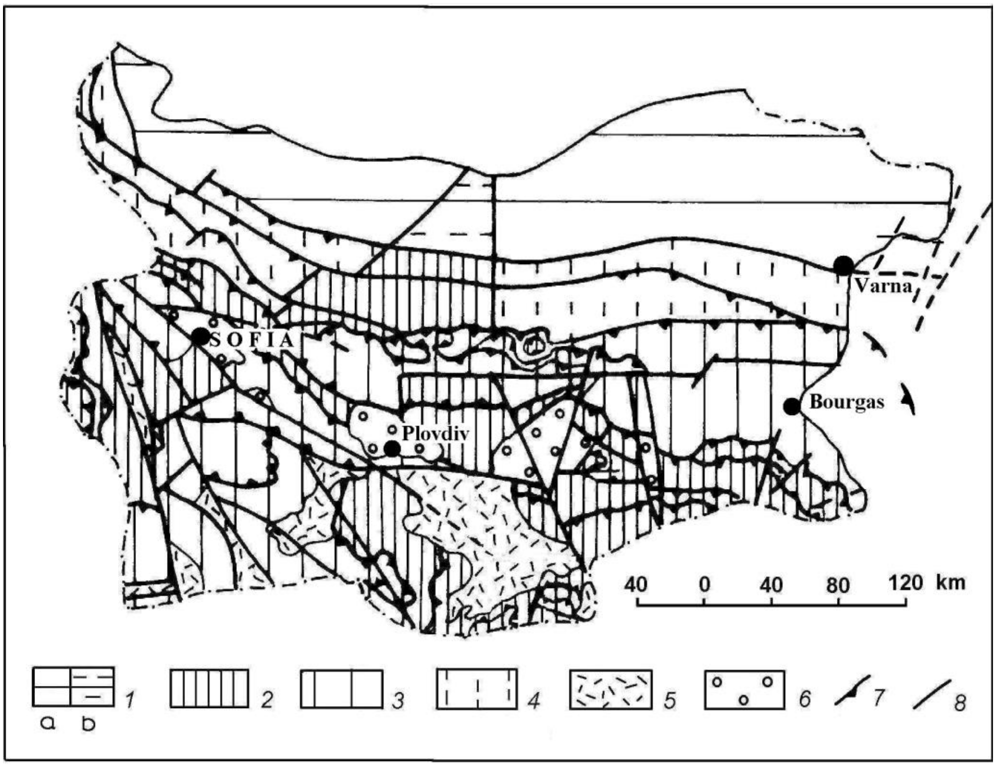

Fig. 4.3.4.1. Main Alpine structures (after Gočev, 1991, with several author's complements)

1 – Bulgarian part of the Moesian Platform – foreland of Cimmerides-Austrides and hinterland of Illirides-Pyreneides: a – with an Austrian platform cover, b – with an Upper Cretaceous-Neogene cover; 2 – outer and inner zones of the Cimmerides-Austrides: Outer Balkanides (Fore-Balkan, Stara Planina) and Inner Balkanides (Kraishte, Sakar, Dervent etc.), also the Subhercinides, 3 – fragments of the Illirides-Pyreneides; 4 – back-arc zones in the island – an arc type of development; 5 – continental basins in the Kraishte-Thracia rift (with traces from the Savian phase); 6 – continental postcollisional basins with manifestations of the late Mediterranean "orogeny" (Shtirian phase and younger movements); 7 – thrust line, 8 – fault.

The first Bulgarian Alpine structures, the Old Cimmerian structures (Cimmerides), appeared during the Triassic. They were formed in the conditions of the accretion of the Moesian Plate from the N to the S. During the Jurassic the Tethys ocean that were situated from the S of our territories began a new spreading and manifestations of subduction-obduction tendencies of the Young Cimmerides. The appearance of the Austrian structures (Austrides) was related to processes of subduction and obduction of the oceanic lithosphere. The Cimmerides and the Austrides are included in the Paleoalpides. In our days the relicts of the outer and the inner zones of the Cimmerides and the Austrides could be observed in several regions of the N, the middle and the S Bulgaria. The Austrides include generally N vergent thrust belts and retrocharige thrusts. After the Austrides, the development of the territory occurred in continental conditions. Local or regional small oceans (Neotethys), marginal seas (Srednogorie) and gradually migrating to the S island-arcs (Strandzha) took place in the territory of the country and its surrounding from the Balkan Peninsula. The Subhercinides were formed after the Austrides. They included S vergent thrusts and nappes. It was the collisional stage of the tectonical evolution in our territories. Now the Cimmerides, the

Austrides and the Subhercinides took place generally in the earth surface of the middle and the Southern Bulgaria. The Cimmerides, the Austrides and the Subhercinides are unified in the proposed scheme (Fig. 4.3.4.1.).

The post-collisional stage began from the Priabonian. The post-collisional stage was of great importance for the seismotectonic analyses and interpretations. This stage represents a time when was formed the Mediterranean neoautochthon. More correctly, it was a time for considerable manifestations of regional and local block fragmentation, of various horizontal and vertical block displacements. It was a time of considerable deformation of the earth surface and the upper lithosphere. Numerous Paleogene-Quaternary and Neogene-Quaternary grabens or basins were developed generally in the middle and the Southern Bulgaria. The horsts that were situated on their boundaries had reached considerable heights mainly in SW Bulgaria.

4.3.4.3. Recent block fragmentation

The data for the recent block fragmentation of the country are based on the knowledge for the structural development and on the remote sensing structural analysis. The obtained results show the presence of considerable number of block structures (Fig. 4.3.4.2). The recent block fragmentation of the country was developed as a result of a large spectrum of slow and rapid geological processes during a very long-term interval. The not stopped block fragmentation represents one of the indications for the prolongation of the geological evolution.

The blocks are the most numerous and with specific development in the Southern and mainly in the South-Western Bulgaria. The block structures are of relatively limited quantity and without very contrast displacements in the North-Western Bulgaria.

The blocks are included in representative vertical movements. The vertical displacements provoke the impressive differences in the block levels in the regional scale (Fig. 4.3.4.2.). The uplifted on 2295 m continental Rila Mt. block and the subsided on more than 1500 m under the sea level of the Black Sea block marked the maximal regional difference in block levels.

There are also important local accumulations of uplifted and subsided blocks. They are of great significance for the recent geological development of the country. Considerable vertical block displacements are marked localally in the areas of the towns of Blagoevgrad-Kresna (SW Bulgaria), Plovdiv-Chirpan (S Bulgaria), Sliven-Yambol (S Bulgaria), Varna-Shabla (NE Bulgaria), Gorna Oryahovitsa-Strazhitsa (NE Bulgaria), Vratsa-Mihailovgrad (NW Bulgaria) etc. (Fig. 4.3.4.2.).

The horizontal block movements have various characteristics. The movements are in right or left directions. In our days the southern blocks move mainly to the S and the SSW, the northern ones – to the N, the NE and the NNW. The block movements express the tendency for the regional extension in submeridional direction (Fig. 4.3.4.2.). Certain supplementary tendencies of displacements in WNW-ESE, ENE-WSW and NW-SE directions have only local or regional manifestations. These supplementary tendencies are established mainly in the eastern Bulgaria (Fig. 4.3.4.2.).

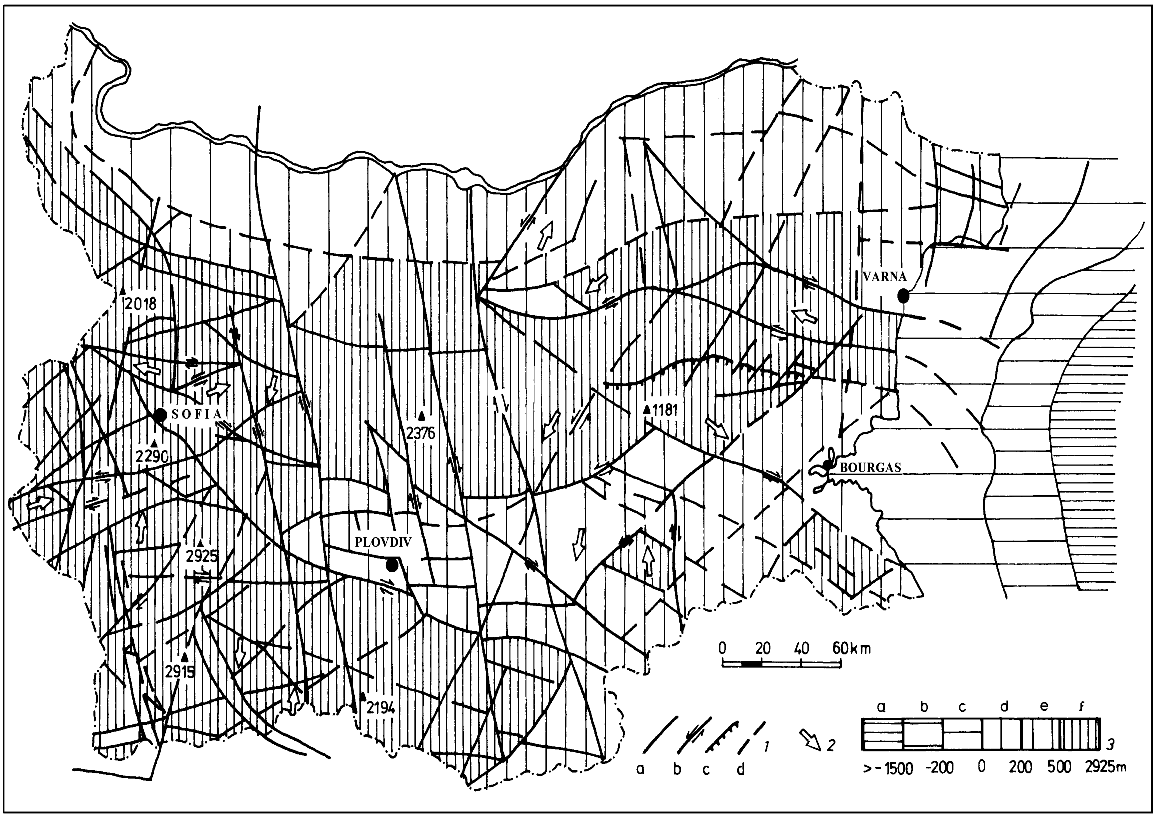

Fig. 4.3.4.2. Scheme of the main blocks, faults and photolineaments in Bulgaria with several data for their vertical and horizontal displacements

1 – faults and photolineaments: a - with vertical displacement, b - with vertical and horizontal displacements, c - with overthrust manifestations, d - with unsure tracing; 2 - general direction of the main block movement; 3 - blocks with different values of the block surface's levels: a - subsided in depth more that 1500 m under the sea level, b - subsided in depth of 201-1500 m under the sea level, c - subsided in depth of 200-0 m under the sea level, d - uplifted on height of 1-200 m, e - uplifted on height of 201-500 m, f - uplifted on height of 501-2925 m.

The blocks participate in vertical and horizontal movements with various intensities. The block movements represent the cause for beginning and the development of the next block separation in the limit of one or several blocks. In a lot of cases the new created blocks cause new manifestations of movements. The new movements represent preconditions for the next corrections in the block forms and characteristics. So, the block movements provoke the formation of new and new block configurations.

The recent configuration of the block structures in the territory of Bulgaria is interpreted as a summary result of the long-term tectonic evolution of the S periphery of the Eurasian plate, also of the Late-Alpine vertical and horizontal displacements in the regions and the localities.

4.3.4.4. Recent seismic activity related to the block fragmentation

- **Seismic activity in the block structures**

The seismic data are not homogeneous. In the literature there is rare information for historical earthquakes. There are also non-instrumental descriptions for seismic events

before the 20th century. The instrumental data are only for the events from the 20th and the 21st centuries.

The spatial distribution of the earthquake's epicenters and the seismic characteristics propose very significant information for the recent mobility of the country. They indicate certain active structures, especially active blocks and active fault's segments (Fig. 4.3.4.3.).

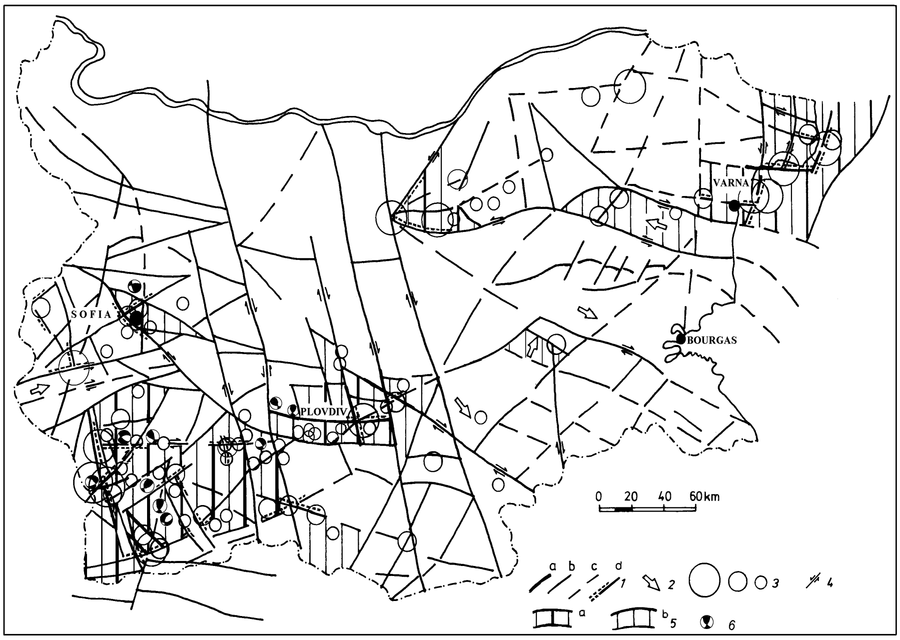

Fig. 4.3.4.3. Scheme for the distribution of the moderate and strong earthquake epicenters in the block fragmented territory

1 – faults and photolineaments: a - with vertical displacement, b - with vertical and horizontal displacements, c - with unsure tracing, d – segments with considerable seismic activity; 2 - general direction of the block movement; 3 - epicenters of earthquakes with magnitude M≥5: a - M = 7.0-7.8, b - M = 6.0-6.9, c - M = 5.0-5.9; 4 – direction of fault and photolineament displacement; 5 – blocks with significant seismic activity: a - high active one, b - relatively active one; 6 – data for fault plane solution of earthquake.

The space distribution of the earthquake epicenters is irregular. The main accumulations of epicenters and the most representative recent seismic deformations take place generally in certain blocks. They are seismically high active blocks (Fig. 4.3.4.3.). These blocks are of different sizes. They are situated mainly in the SW, the S, the W and the NE Bulgaria (Fig. 4.3.4.3.).

The NE Bulgarian littoral blocs and their shelf surrounding represent seismically very active territory (Fig. 4.3.4.3.). Mainly the strong earthquakes provoke human loses and destructions. The strong earthquakes with magnitude M≥7 (I c. BC Bizone one, 543 Black Sea one, 1444 Varna one, 1901 Shabla one) and their aftershocks provoked significant damages. The strong, moderate and several weak earthquakes cause changes in the coastal line as well. In several cases they are related to the cutting of the continental blocks from the eastern periphery of the Moesian Platform and the enlargement of the blocks from the Black Sea depression. The seismically provoked

diminution of the Moesian Platform is well expressed in the regions of the towns of Balchik, Kavarna, of the cap Kaliakra, the village of Kamen bryag and the town of Shabla (NE Bulgaria). Certain seismically induced landslides, rockfalls and subsidence manifestations cause supplementary destruction and reduction of the coast. Significant changes in the relief were marked in the historical time as well. Maybe they will be not stopped in the future.

Other seismically active continental blocks of NE Bulgaria take place in the Gorna Oryahovitsa-Strazhitsa sector of the Fore-Balkan and of the Transitional zone (zone between the Moesian Platform and the Fore-Balkan) (Fig. 4.3.4.3.). The 1913 Gorna Oryahovitsa earthquake (M=7.0) and the 1986 Strazhitsa earthquake (M=5.7) deformed the local blocks and the faults in different degrees. They provoked considerable damages for the population and the society.

A complex of seismically active subsided blocks is situated near the Maritsa River and in the vicinity of the towns of Plovdiv-Parvomay-Chirpan. The 1928 Chirpan earthquake (M=6.8) and the Popovitsa earthquake (M=7.0) provoke significant human victims and significant deformation of the blocks and faults near the Maritsa River. These earthquakes are related to very heavy destructions in a wide territory of the Southern Bulgaria, to changes in the Maritsa River flow and in the discharge of Merichleri mineral water sources. Plovdiv City, the second important town in the country, was partially destroyed. These seismic events attracted the attention of the Bulgarian and foreign geologists and seismologists (Boncev, Bakalov, 1928, Mihailovic, 1933). The people received national and international help for the reconstruction of the road, railways, schools, hospitals, residential buildings in the damaged territory.

The seismically active blocks take place also in the Sofia region (W Bulgaria). The 1858 Sofia earthquake (M=6.5) caused human victims and destructions. The cited earthquake provoked positive and negative effects. The positive ones are related to the stop in the use the St. Sofia Church like mosque and to the appearance of the Ovcha Kupel mineral source. The Church was temporary transformed in mosque during the Turkish domination. After the earthquake the mosque lose its minaret and the Turkish people refused to visit it. The Ovcha Kupel took place in territory without any previous source. The negative effects are more representative. A considerable part of the city was destroyed. The society was fallen in a great panic. The people avoided the staying at the destroyed home during several months after the earthquake.

There are very limited data for the 1641 Kyustendil earthquake (W Bulgaria) with M~7.2. Its epicenter is near the contact of the Osogovo Mt. and the surrounding plain.

The most significantly uplifted Rila Mountain horsts and several subsided grabens along the Strouma, the Rilska and the Bistritsa Valleys (SW Bulgaria) are seismically active ones. Here is the highest peak in the Balkan Peninsula – the peak Mussala (2 225 m). The Rila Mountain blocks and the surrounding grabens are numerous. Very often they participate in seismic events (Fig. 4.3.4.3.). The earthquakes from the Rila Monastery registers are the most numerous in the country. Some of the earthquakes were with M≥7 during the historical past.

High blocks take place also in the northern part of the Pirin Mountain, in the Vlahina Mountain and the Maleshevo Mountain (SW Bulgaria). The subsided Struma River and the Mesta River blocks delimited the mountains. In this part of the country there are also blocks with very significant contrast development. The seismic manifestations are

the strongest ones in Bulgaria. Some more, they are the strongest in the Balkan Peninsula during the last 150 years. The epicenter of the 1904 Krupnik earthquake (M=7.8) and of other strong and moderate ones (Fig. 4.3.4.3.) are situated in this area. During the 20th-21st century the most seismically active blocks are placed in SW Bulgaria. Up now the seismic activity of the territory Krupnik-Bansko is the most remarkable in the country. In the future the blocks of the area of Kresna-Petrich-Melnik could show important seismicity as well.

Several vertical block displacements of local importance are established in the regions of the towns of Sliven-Yambol (SE Bulgaria), of Galabovo-Radnevo (SE Bulgaria), of Botevgrad (NW Bulgaria), of Etropole (NW Bulgaria) and of Mihailovgrad (NW Bulgaria). Moderate seismic manifestations take place mainly in the first of them (Fig. 4.3.4.3.). The 1909 Yambol earthquake (M=5.5) was the most considerable seismic event in SE Bulgaria. There are information for an historical destructive earthquake in Etropole region during 1704, for several moderate seismic events in Botevgrad area and for 1928 Galabovo earthquake (M=5.69).

The horizontal block displacements are widely distributed in the investigated territories as well. They are well represented in the country, but the values of the displacements are limited. A part of the horizontal block displacements is related to the earthquakes.

- **Seismically active segments and crossings of faults and photolineaments**

The faults and the photolineaments take place mainly along the block boundaries (Fig. 4.3.4.3.). The faults and the photolineaments have specific mobility in the different segments. Now the spatial distribution of the epicenters of earthquakes with magnitude M≥5 permits to trace certain segments of the faults and photolineaments with considerable activity and to pay attention to their importance (Fig. 4.3.4.3.).

The seismically active segments of faults and photolineaments are developed mainly along the Strouma, the Mesta, the Kyustendil, the Krupnik and the Gotse Delchev faults and photolineaments in SW Bulgaria. In the middle part of the Southern Bulgaria there are active segments along the Velingrad, the Rakitovo, the Plovdiv, the Olt, the Yambol and the Tundzha faults and photolineaments. In the NE Bulgaria there are seismically active segments along the Gorno Ablanovo, the Zlataritsa, the Balchik, the Kaliakra, the Devnya and the Chirakman faults and photolineaments.

These seismically dangerous segments are placed in territories that are limited from the towns of Kyustendil, Petrich, Gotse Delchev and Bansko in SW Bulgaria. Similar segments are developed also in areas around the towns of Velingrad, Plovdiv, Chirpan, Haskovo and Yambol in the middle part of the Southern Bulgaria and in the regions of the towns of Gorna Oryahovitsa, Varna, Kavarna and Shabla in NE Bulgaria (Fig. 4.3.4.3.).

The seismic activity increases and the magnitude obtains high values in and near the crossings of the seismic active segments of faults and photolineaments (Fig. 4.3.4.3). The strong earthquakes from the 20th century have epicenters in close vicinity to cited crossings. These positions of the epicenters is characteristic for the 1901 Shabla earthquake (M=7.2), the 1904 Krupnik one (M=7.8), 1913 Gorna Oryahovitsa one (M=7.0) and 1928 Popovitsa (Plovdiv) one (M=7.0).

The epicenters of significant historical earthquakes (the 1st c. BC Bizone earthquake with M=7.0 near the town of Kavarna, the 1641 Kyustendil earthquake with M=7.2, the 1858 Sofia earthquake with M=6.5) could be related to crossings of seismically active faults and photolineaments in the NE and the SW Bulgaria.

Several moderate earthquakes from the second half of the 20th century have epicenters in vicinity of fault and photolineament crossings. The 1977 Velingrad earthquake (M=5.3) in the Southern Bulgaria and the 1986 Strazhitsa earthquake (M=5.7) in the Northern Bulgaria propose examples for the position of epicenters near fault and photolineament crossings.

- **Fault plane solutions**

The obtained from the seismological literature data for the fault mechanism give very important information for the recent tendencies of the geological evolution. These data permit to receive the general characteristics of the seismic processes on the bases of the movements in the earthquake hypocenters.

The first study of the mechanisms of the strong and moderate Bulgarian earthquakes was made for the UNESCO Balkan Project. The subject of study was mainly the seismicity during 1900-1970. The study indicates that the general regional tendency of the block movements in our country is of the extension. The extension has a submeridional direction (Ritsema, 1974).

Later this kind of study was enlarged. It was shown that in a lot of cases the seismic displacements in the earthquake foyers of SW Bulgaria are of the types of normal fault or strike slip-normal fault (Georgiev, 1987). The movements along the reverse faults are rare. The mechanisms of the analyzed strong and moderate earthquakes indicate that the seismic movements have specific characteristics in different block structures. There are various directions of seismically induced displacements, but the main tendency of is again of the vertical movements and of extension. The main direction is submeridional one as well.

The fault mechanism information testifies that the recent mobile blocks are included generally in vertical movements and regional extension. The manifestations of the compression are of a local distribution. The horizontal movements are of relatively limited significance in the recent period of earth's evolution.

4.3.4.5. Conclusion

The data from the field research are added with the remote sensing structural analysis. In the study the structural data are compared with the published seismic information. The seismotectonic investigation directs the attention to the recent development of certain structures in Bulgaria, to their block fragmentation and displacements in vertical and horizontal directions, to the traced faults and photolineaments and the distribution of the earthquakes manifestations in them.

The most significant vertical block displacements are fixed in SW Bulgaria. The horizontal block displacements are relatively limited and without very clear spatial localization. The faults and the photolineaments are widely distributed along the block boundaries and inside of blocks. The block fragmentation is of importance for the development of the geological processes, including the seismicity.

The seismic activity is concentrated in certain localities. The structural predestination and the obtained characteristics of the region or of the locality are of importance for the localization of the earthquake foyers, for the quantity of the liberated energy and for the for- and aftershock characteristics.

The earthquake activity was, is will be the most intensive in a part of the studied blocks and fault segments. The blocks in the vicinities of the towns of Kyustendil-Blagoevgrad-Krupnik-Bansko-Gotse Delchev-Petrich from the SW Bulgaria, of the towns of Gorna Oryahovitsa-Strazhitsa-Varna-Kavarna-Shabla from the NE Bulgaria, of the towns of Velingrad-Plovdiv-Chirpan-Haskovo-Yambol from the Southern Bulgaria are among the seismically vulnerable territories from the tectonic point of view.

On the boundaries of the studied blocks from the vulnerable territories and inside of them there are seismically active fragments of faults and photolineaments. Significant number of earthquake epicenters is situated along the fault and photolineament fragments and very often near the crossings points of them. In the recent days the most seismically vulnerable territory is the area of the towns of Blagoevgrad-Krupnik-Bansko.

The numerous seismically active blocks, also seismically active fault and photolineament segments are situated in SW Bulgaria. The SW Bulgaria is a territory of the contrast contacts between differently uplifted and subsided blocks. It is an area of the most significant seismic mobility during the 20th and the beginning of the 21st centuries. A considerable block fragmentation and several seismically active fault segments take place in NE Bulgaria as well. Three strong historical earthquakes occurred there. The recent dangerous destructive processes in the NE Bulgarian littoral are partially caused from the seismic manifestations (earthquakes, landslides, rockfalls, land subsidence etc.). The blocks of SW and NE Bulgaria have potential possibilities for next significant seismic movements.

The seismic information is applied also for the investigations of the main displacements in the earthquake foyers. The displacements in the earthquake foyers permit to obtain data for the movements in the most upper part of the lithosphere or generally in the Earth crust. The movements in the seismic foyers are related mainly with a regional extension in submeridional direction.

The seismotectonic investigations are of significance for the works related to the saving of the existing constructions, including the cultural heritage. They are of importance for the rational planning of the next activities of society and the state in the country, for the new perspectives in the development in the Balkan Peninsula and in the European Union.

The proposed remote sensing structural analysis presents a prolongation of the works that was made with my Bulgarian colleague Prof. Dr. Sci. Petar Gocev, who had a great interest for this kind of problems. Now he is not among us, but his main tectonic conceptions are applied up today. Now I am expressing my respect to him and will announce that I am very thankful for the period of the scientific collaboration with him.

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