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NEOTECTONIC AND SEISMOTECTONIC INVESTIGATION IN THE UPPER THRACIAN DEPRESSION AND THE TUNDJA LOWERING (SOUTHERN BULGARIA)

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INTRODUCTION

The Upper Thracian depression and the Tundja lowering are situated in the Srednogorian structural zone. The depression has an equatorial trending, with length of 200 km and width from 10 to 100 km, and the lowering has a meridional trending about 70 km long and wide from 5 to 20 km.

The two investigated structures are formed within territories of intensive late- and post alpine development comprising rocks suffered considerable transport mainly in horizontal direction. The mobilistic ideas about these territories are synthesized by Gocev (1991) and Dabovski (1991). According to Gocev the structures are developed over the Srednogorian Cretaceous paleorift and partly over the Northern margins of the Moravia-Rhodopes-Strandja island-arc system. At the end of the Cretaceous a number of North vergent thrusts of the island-arc system cover a great part of the paleorift (Boccaletti et al., 1978). From the Priabonian, after the first Pyrenean folding phase, a young continental Kraishtide-Thracian rift (Ivanov, 1968) is formed in these territories. An Oligocenian compression follows. South vergent thrusts are developed locally over the rift. Predominantly during the Neogene in parts of the Kraishtide-Thracian and the Moravia-Rhodopes-Strandja zone, the Tundja depression (described by Catalov, 1965) starts to appear. According to Dabovski (1991) at the Alpine stage the Srednogorie and the Rhodopes are part of the plateau situated between the main thrust belt (the inner Hellenides) to the South and the retrocharriage belt (the Balkanides) to the North, which in the Neogene are assembled together as a result of a collision between Apulia and Eurasia, or a sector of the deformed margin of the Moesian platform which is partly covered by the zone of the collage to the South. In some territories of the plateau or of the deformed platform margin and the collage zone the Paleogene-Neogene-Quaternary basins are developed and they mask the interactions between auto-, para- and alochtone structures. This analysis shows that the studied depression and lowering are situated in tectonic mobile volume between the Moesian and Aegean microplates.

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MAIN MORPHOSTRUCTURES AND THEIR EVOLUTION

As morphostructures The Upper Thracian depression and the Tundja lowering. belong to the Kraishtide-Srednogorian morphostructural region (Vaptzarov, Mishev, 1997) (Fig. 1a). There is a mosaic of blocks with different denivelation superposed over faults and blocks of the Srednogorian, Sakar-Strandja and the Rhodopian zones. The differentiated character of the tectonic movements during the Neogene and especially during the Quaternary and their specific intensity determine the formation of positive and negative morphostructural units. They are controlled and limited by faults mainly in 110-120° and 30-45° direction but during the different stages some other faults interfere such as those with submeridional and subequatorial trend. The main morphostructures are:

The Plovdiv lowering (Zafirov, Brankin, 1972) (Fig.1). It is bordered by the North Rhodopian fault zone (Tchunev, Dabovski, 1972), and the focilized Stryama fault (Zafirov, Brankin, 1972) and its satellites. It is filled up with sediments of the Dragoyna and Ahmatovo formations, (Kojumdzieva, Dragomanov, 1979) and thick Quaternary sediments.(Dragomanov et al., 1989. The Eopleistocene surface has a relative height of 50-70 m. The Pleistocene river terraces are reduced, lower and not so many (Table 1). The Pleistocene (overlaid by alluvial-proluvial sediments) and the Holocene (formed by flood terraces of Maritsa river and its tributaries) accumulative surface are widely developed (Angelova et al., 1993). During the Pleistocene the dynamic regime is negative, with different intensity.

The Zagora inversive lowering (Nenov et al., 1993) (Fig.1) is the same as the Zagora lowering (Panov, 1962). It is limited by the Tsenino fault to the North (Sokerova et al., 1966) and by the Maritsa fault bundle to the South (Bonchev, 1961). The Eastern and the Western borders are tectonic determined, but without a clear morphological manifestation (Petkov, 1961, Nenov et al., 1990). It is filled up with sediments of the Maritsa formation (Kamenov, Panov, 1976), the Gledachevo formation (Nedjalkov, Kojumdzieva, 1983) and the Ahmatovo formation (Nenov, 1987). Quaternary sediments of different origin and thickness can be found too. The Eopleistocene stage of the lowering is marked by a strongly disturbed and modified subinitial surface (Table 1) with relative height of 70-130 m, developed over deeply eroded sediments of the three pre-Quaternary formations. The surface is deeply sheared by the Pleistocene river net and serves as an initial surface of the recent river-valley net. During the Pleistocene only the North part of the lowering is suffers negative movements as a result of which the Stara Zagora local lowering appears (Nenov et al., 1990) In the other part there are positive movements, presented by complex river terraces (Angelova et al., 1993) (Table 1).

The Lozen lowering (Boyanov et al., 1963). It is bordered by Oreshetz fault, which is a border of the Ibredjek horst to the South, and to the North by the Lyubimetz fault, which separates it from the Harmanly step (Boyanov et al., 1963, Boyanov, 1971).

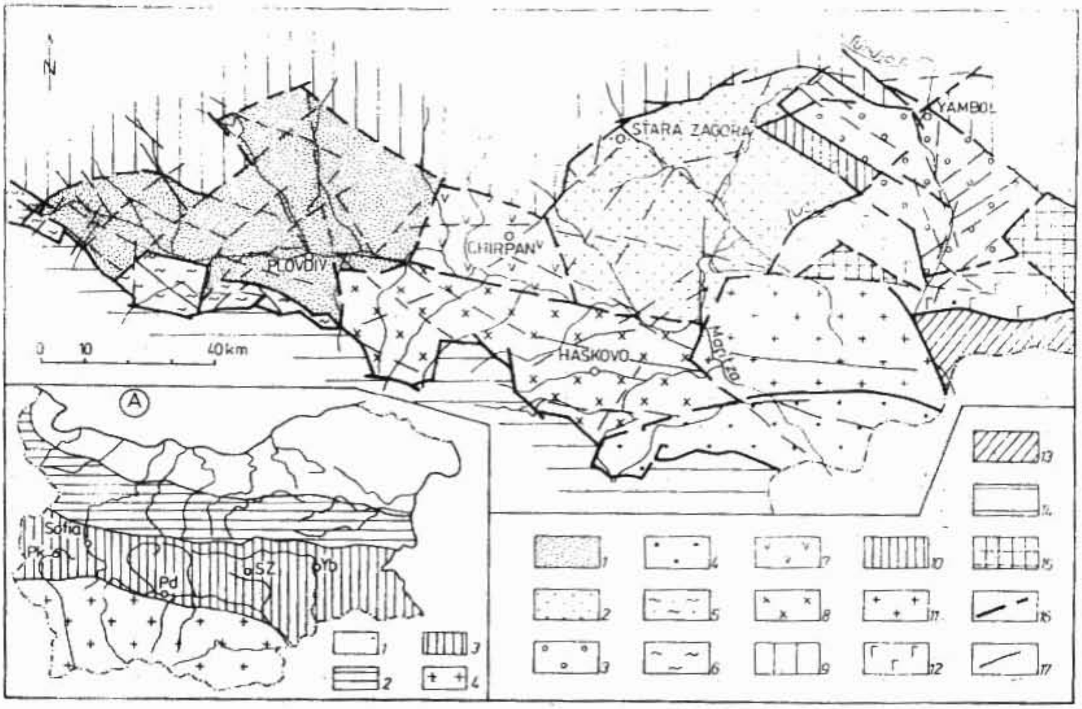

Fig. 1. Morphostructural scheme of Upper Thracian depression and Tundja lowering: 1-4 - lowerings/ 1-Plovdiv, 2-Zagora, 3-Tundja, 4-Lozen /, 5,7,10 - horsts / 5-Momina Klissura, 7-Chirpan, 10-Sveti Iliya /, 6,8,15 - steps / 6-Peshtera-Kuklen, 8-Parvomay-Haskovo, 15-Kara bair /, 9,11,12,13,14 morphostructures / 9-Srednogorian, 11-Sakar, 12-Manastir-Razdel, 13-Dervent, 14-Rhodopian/, 16 - morphogenic faults and lineaments, 17 - faults.

Fig. 1 A. Main morphological units in Bulgaria: 1 - Danubian plain, 2 - Balkan, 3 - Kraishtides-Srednogorie, 4-Rila-Rhodopes.

The lowering is filled up with sediments of the Ahmatovo formation (Dragomanov et al., 1984). The Quaternary is presented by sediments of various origin and thickness, by two Eopleistocene surfaces and by full terrace spectrum (Table 1).

The Tundja lowering (Catalov, 1965). The submeridional and subequatorial faults border the lowering. In the regions of the fault crossing the pre-Neogene basement is disturbed intensively and units of higher rate are formed. Most typical are the Elhovo formation (Kojumdzieva et al., 1984), some relicts of the Maritsa and Gledachevo formations and the Quaternary sediments of various origin and thickness (Angelova et al., 1991). The Neogene-Quaternary stages have formed exogenic forms, typical for the morphostructure - wide development of Eopleistocene steps and complex of river terraces (Table 1). The movements along the Quaternary faults form marshes along the Kermen-Yambol line and some recent swampy areas in the flood terraces (the Kermen formation) (Angelova et al., 1992).

The positive block morphostructures are formed over different structural units. Some of them have a character of mountain foot steps and others - of step structures. During Quaternary the movements are very intensive, in different directions, connected with the dynamic regime of the surrounding mountain morphostructures and plain basements. The morphostructures are formed from Miocene-Pliocene to Quaternary (Nenov et al., 1990, Angelova et al., 1993) over the fault bundle of the North Rhodopes and they are integrated in the Rhodopes-Srednogorian step (Katskov, Spiridonov, 1981)

River terraces age meters / Morphological structures				Momina Klissura horst	UPPER THRACIAN DEPRESSION				Sakar block morphostructure	Tundja lowering	Lower Thracian depression	Stages in the Quaternary development
					Plovdiv lowering	Chirpan horst	Zagora inversive lowering	Parvomai - Haskovo mountain foot-step			Lozen lowering	
Eopleistocene				220 - 250				120 - 160	160 - 200		140 - 160	I stage
				130 - 170	50 - 70	60 - 90	70 - 130	70 - 100	120 - 140	70 - 130	110 - 120	
PLEISTOCENE	lower	overflood	T_7	90 - 110					90 - 110			II stage
			T_6	75 - 80					70 - 80		70 - 80	
			T_5	60 - 70			50 - 52	60 - 65	60 - 65	50 - 60	60 - 65	
	middle		T_4	40 - 48		40 - 47	40 - 45	45 - 55	45 - 57	42 - 45	40 - 45	III stage
			—	—		32 - 35	30 - 35	30 - 38	30 - 37	25 - 37	30 - 35	
	upper		T_2	20 - 25		14 - 25	18 - 22	18 - 25	20 - 27	18 - 22	18 - 22	IV stage
			T_1	10 - 14		6 - 10	8 - 12	8 - 12	12 - 14	6 - 10	8 - 12	
HOLOCENE	lower	flood	Tob	6 - 8	3 - 5	2 - 4	2,50 - 4	3 - 5	3 - 5	3 - 4	2 - 4	V stage
	upper		Toн	3 - 5	0,50 - 3	0,50 - 2	1 - 2	1,50 - 3	0,50 - 3	0,50 - 2	1,50 - 2	

Tabl. 1

The Momina Klissura, The Harmanli and the Chirpan horsts and Peshtera-Kuklen and Parvomay-Haskovo mountain foot steps (Fig. 1). The three horsts are transitional morphostructures with Quaternary origin. The two Eopleistocene surfaces, the full spectrum of terraces and the positive geodynamic regime are typical for them.

Within the Tundja lowering during the Quaternary, faults with submeridional and subequatorial trends have an important role in the process of disintegration. The faults have formed the Kokevetz horst which divides the lowering into two parts (Yambol and Elhovo) with relatively independent development (Savov, 1983).

MAIN STAGES IN THE NEOTECTONIC DEVELOPMENT

Taking into account the lithostratigraphical and geomorphological investigation, five main stages can be defined:

Upper Paleogene - Lower Miocene
Middle Miocene
Upper Miocene - Pliocene
Quaternary
Recent

The Upper Paleogene - Lower Miocene stage. In the Upper Thracian and Tundja lowering as a result of extensional stress tendencies some intermountain grabens are formed over the disintegrated basement (Krastev et al., 1992). They illustrate the different intensity and direction of the tectonic movements along the main faults. During the Upper Paleogene the subsidences dominate in the Upper Thracia. Their correlates are the continental molasses of the Ezerovo (240 m), Dragoynovo (500 m) and Maritsa coal bearing formations. There are the first signs of inner space disintegration. In the surrounding morphostructures the initial planation surface is highly deformed by the ongoing tectonic processes. The planation surface can be found in the Western and Central Sredna Gora at 1000-1200 m height, in the Eastern Sredna Gora - 700-800 m, in Sakar - 600-700 m, and in the Rhodopes - 1500-1600 m.

The Middle Miocene stage. At the beginning emersion conditions and denudation are established, resulting in the only Thracian morphostructure. Parts of it are found in drillings in Plovdiv, Stara Zagora and Elhovo regions at depth from 10 up to 300 m, and along planation steps and surfaces over plutons of the Elhovo-Malko Tarnovo strip and in the Western part of Zagora lowering. It is developed over different rocks in arid conditions (laterite weathered crust with ferruginous concretions with thickness varying from several centimeters up to 30 m). The change of this planataion surface between the Western part of Zagora lowering and the Central part of the Plovdiv lowering is 400 m. During the Middle Miocene sediments load only the Eastern part of the Zagora lowering and the Southern part of the Tundja lowering (there was a connection between the two structures). The sediments of Gledachevo formation are formed in the Eastern Maritsa basin (thickness 85 m) and in the Topolovgrad basin (thickness 30 m).

The Upper Miocene - Pliocene stage. It starts with a sudden activation of the tectonic movements, a new faulting with different intensity and direction, which causes the extension of the Upper Thracian morphostructure and additional forming of the Tundja morphostructure. The tectonic movements in different directions cause the considerable sinking of the Plovdiv (300 m), Tundja (300 m) and Lozen lowering (700 m), and cause a limited sinking of the Zagora lowering (60 m). During this stage the connection between the Eastern Maritsa and Topolovgrad region basins is cut off completely. Between the Upper Thracian and Tundja morphostructures remains only a local connection in the Northern parts between the Stara Zagora and Yambol local lowerings. But in the surrounding morphostructures there are strongly disturbed steps situated at various levels.

The Quaternary stage. It is the final stage of forming the structures in Southern Bulgaria. The specific by character and intensity tectonic movements are cyclic, marked by Eopleistocene surfaces and terraces, by terraces at Pleistocene and Holocene age (Angelova et al., 1993). The summary values of the Quaternary movements are various. Some positive values of the Quaternary structural movements are given in Table 1. The negative values are also locally determined and they correspond to different thickness of the sediments: in the Plovdiv lowering - 30 m (Nenov et al., 1990), in the Tundja lowering - 35-45 m (Angelova et al., 1991).

The Recent stage. The specific movements continue as a result of the recent geodynamic. The average annual value of the vertical movements is +1.2 mm/a in the Plovdiv lowering, +0.79 mm/a -- in Zagora lowering , and +1.0 mm/a -- in Tundja lowering (Totomanov, Vrablianov, 1980).

SEISMOTECTONIC INVESTIGATION

Epicenters of a series of seismic events noted in the historic documents or registered instrumentally, including the strong Southern Bulgarian earthquakes in 1928, are located within the studied territory (Grigorova, Grigorov, 1964, Grigorova, Rijikova, 1966, Shebalin et al., 1974) .The historical data are scanty, and concern only the area around Plovdiv, but include a shock with magnitude M 7.4. The information about the XX century is comparatively full, but the maximal shock is with M 7.

The spatial distribution of the epicenters of earthquakes with $M \geq 4$ is irregular (Fig.2). The epicenters of seisms are relatively numerous on the boundaries and within the Chirpan horst, on the peripheries of the Plovdiv lowering and the Parvomay-Haskovo step. A moderate quantity of epicenters is located along the Northern border of the Tundja lowering. A few epicenters are spread mainly within the Zagora lowering, the Manastir-Razdel morphostructure and the Sakar block. Thus the Chirpan horst is the most mobile morphostructure from seismic point of view.

Earthquakes with relatively higher magnitude $M \geq 5$ (Fig.2) are located mainly in the Plovdiv lowering, then comes the Chirpan horst and the Tundja lowering. Isolated earthquakes with this magnitude occur in the Sakar block, the Lozen lowering. The strongest seisms, $M \geq 7$ (Fig.2) occur in Eastern part of the Plovdiv lowering, i.e. near its contact with the Chirpan horst and the Parvomay-Haskovo step. So the morphostructure where the seisms reach the highest relative magnitude (the Plovdiv lowering) is situated next to the one with the greatest number of seisms (the Chirpan horst).

The distribution of hypocenters of seisms with $M \geq 4$ in the crust ant the upper mantle in the region of the Upper Thracian depression and the region of the Tundja lowering has been studied too. The geophysical data about the lithosphere in the two regions are based on Dachev (1988). In the region of the Upper Thracian depression in the crust, which is thicker (Fig.3a), and in the upper part of the upper mantle four seismogenic layers (Fig.3b) are developed within the following ranges:

First seismogenic layer	5-18 km;
Second seismogenic layer	20-30 km;
Third seismogenic layer	35-45 km;
Fourth seismogenic layer	50-60 km.

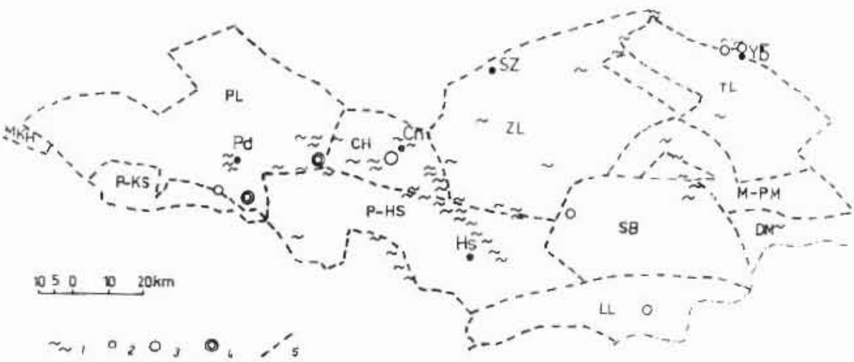

Fig. 2. Scheme of epicenters of earthquakes in the Upper Thracian depression and Tundja lowering: 1-4 - epicenters of earthquakes with different magnitude M / 1-M < 5, 2-M 5-5.9, 3-M 6-6.9, 4 -M 7-7.4/, 5 - morphostructural limit.

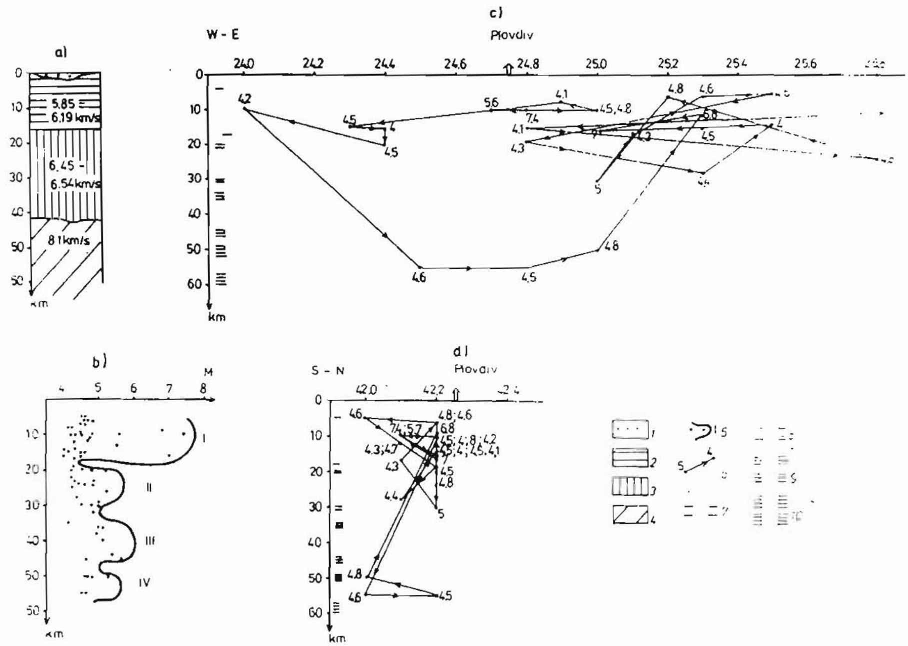

Fig. 3. Cross-sections intthe Upper Thracian depression with data about the main geophysical layers in the crust / according Dacev, 1988/ /a/, about the seismogenic layers /b/, about the spatial-temporal migration of the hypocenters of earthquakes with magnitude M ≥ 4 /c,d/: 1-3 - layers of the crust with different seismic characteristics, 4 - upper mantle, 5 - seismogenic layer, 6 - vector of successively activated hypocenters of the seisms , 7-10 - seismogenic layers / 7-first, 8-second, 9-third, 10-fourth /.

In the region of the Tundja lowering in the crust which is thinner (Fig.4a) and in the upper part of the upper mantle four seismogenic layers (Fig.4b) are developed too, but they are with reduced thickness. The layers are within the following ranges:

First seismogenic layer	5-12 km;
Second seismogenic layer	14-22 km;
Third seismogenic layer	24-32 km;
Fourth seismogenic layer	34-42 km.

In both investigated territories the foyers of the strongest earthquakes are placed in the first seismogenic layer (Fig.3b,4b).

In both regions the migration of the hypocenters of seisms with magnitude M ≥ 4 among and within the four seismogenic layers is a subject of a special research. Summarized cross-sections with orientation West-East and North-South (Fig.3c,3d,4c,4d) are prepared using Matova's method (1987). The directions of the seismic migration are presented by vectors connecting the hypocenters in the succession of their activation. The migration is studied in three aspects.

- interrelations between the vectors and the borders of the seismogenic layers, the quantity of intralayer vectors;

- interrelations between the vectors and the structures of the lithosphere, importance of the horizontal and vertical structures to seismic movements;

- presence or absence of peculiarities in the hypocenter migration before the strongest earthquake in the two regions.

As to the first aspect, in the studied region the hypocenter migration is realized within or between the seismogenic layers, but the intralayer vectors are presented better than the interlayer ones. In the Upper Thracian depression (Fir.3c,d) the intralayer vectors are about 75 %, and in the Tundja lowering (Fig.4c,d) -- about 60 %. This characteristic of seismic migration shows that the accumulated seismic energy in the two regions is distributed mainly in the volume of the indicated seismogenic layers. This tendency is very clear for the first layer.

As to the second aspect, in the two regions the subhorizontal vectors are very well developed especially in the first and the second seismogenic layers. The vectors are often inclined to the South. The position of the vectors shows the big significance of the subhorizontal structures in the lithosphere during seismic movements. The inclination of the vectors mainly to the South may be related with the presence of the Northern vergent thrust belts. Only in the area around Yambol the vertical migration of the hypocenters is quite significant. The activation of the Yambol fault bundle can be one of the reasons.

As to the third aspect, in the two regions the hypocenters in the deeper seismogenic layer are activated before the strongest seisms with foyers in the first seismogenic layer. So the Chirpan earthquake (April 14, 1928, M 6.8), the first of the three strongest earthquakes

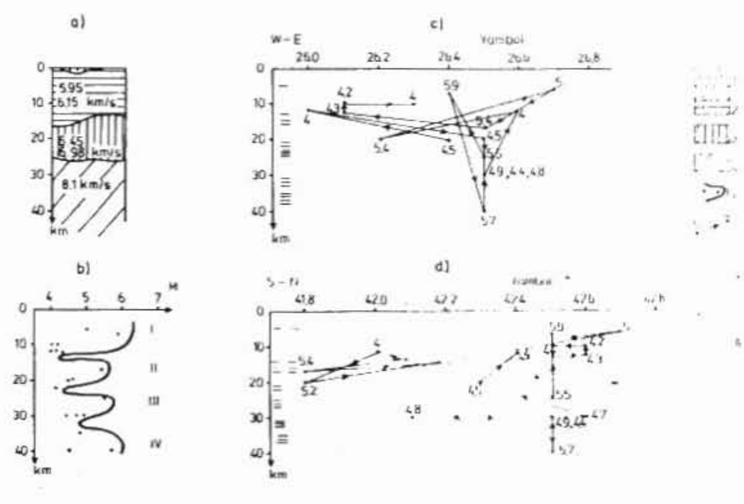

Fig. 4. Cross-sections in the Tundja lowering. The explications are the same like in fig. 3.

in Southern Bulgaria, follows the seismic movements in the fourth seismogenic layer. The Yambol earthquake (February 15, 1909, M 5.9), the strongest seism in the Tundja lowering, follows the seismic movements in the third seismogenic layer.

The special research of the migration of the epicenters of shocks with M ≥ 4 using Matova's method (1967, 1972) provide some more details to the problem of the seismic behavior of the morphostructures (Fig.5). In the region of the Upper Thracian depression the vectors with direction E-W are of the highest importance. Isolated vectors with trend N-S and NE-SW are presented as well. This characteristic indicates seismic activation mainly along the margins of the extremely elongated in E-W direction morphostructures. In the region of the Tundja lowering the vectors have various directions. The morphostructures here are with complicated contours and with different orientation.

The seismotectonic information about the two regions is presented in Fig.6. Relatively high seismic activity is observed in the Chirpan horst, in the Eastern part of the Plovdiv lowering, in the North-Eastern and South-Western parts of the Parvomay-Haskovo step and in the Northern part of the Tundja lowering. Fragments of faults and lineaments along the East and South-Eastern borders of the Plovdiv lowering, along the Western and Southern borders of the Chirpan horst, along the North-Eastern and South-Western borders of the Parvomay-Haskovo step, along the Northern borders of the Tundja lowering are characterized as seismic active structures. Some sectors of the borders of the morphostructures coincide with vectors of epicenter migration too. These borders of the morphostructures are of considerable significance for the seismic movements. Such sectors of morphostructural borders are situated in the Southern part of the Chirpan horst, along the South-Western parts of the Parvomay-Haskovo step, along the South-Eastern borders of the Plovdiv lowering, along the Southern part of the Zagora lowering, along the North-Eastern and South-Western margins of the Tundja lowering. In these cases the seismic movements rarely appear in the four seismogenic layers (South-Eastern part of the Plovdiv lowering, South-Western parts of the Parvomay-Haskovo step) and often -- in the first and second seismogenic layers.

Summarizing all these seismotectonic data, we find out that the seismic potential is higher in localities where there are not only seismic mobile blocks, but also seismic active faults and faults with vectors of epicenter migration. These localities are mainly three:

- between Plovdiv and Chirpan;
- around Yambol;
- South-Eastern of Chirpan.

The three localities are at the contacts of several morphostructures in which Neotectonic and especially Quaternary movements are performed in a special way. It is logical that significant tectonic, including seismic, stresses can be reached at the contacts of such structural units.

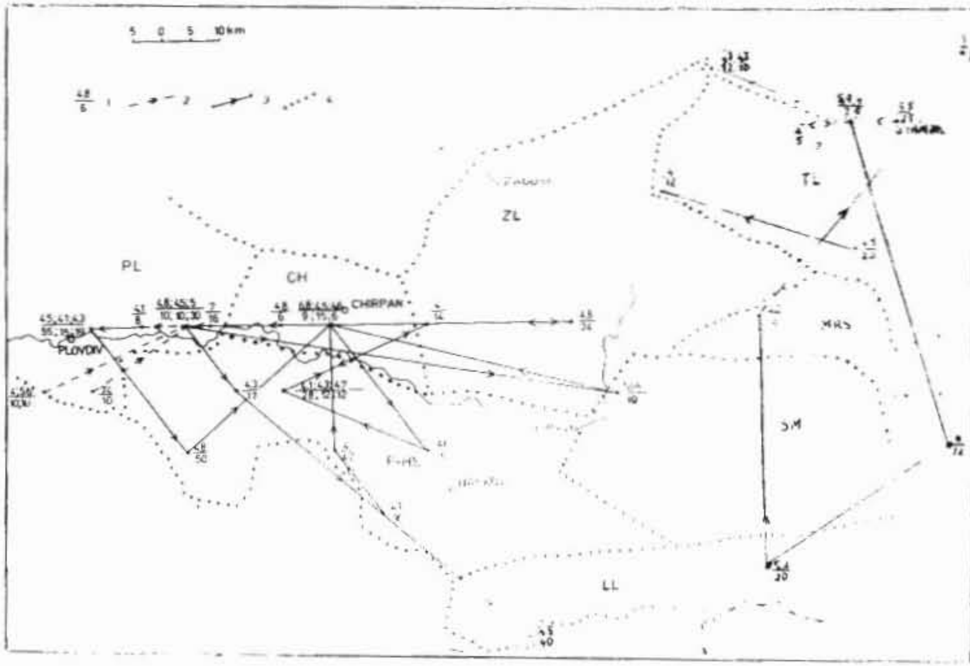

Fig. 5. Scheme of the epicentral migration of the earthquakes with M ≥ 4 in the Upper Thracian depression and in the Tundja lowering: 1 - epicenter of seism with determinated M / under line - the depth of the foyer /, 2,3 - vectors of epicentral migration / 2-before the XX century, 3-in the XX century /, 4 - morphostructural limit.

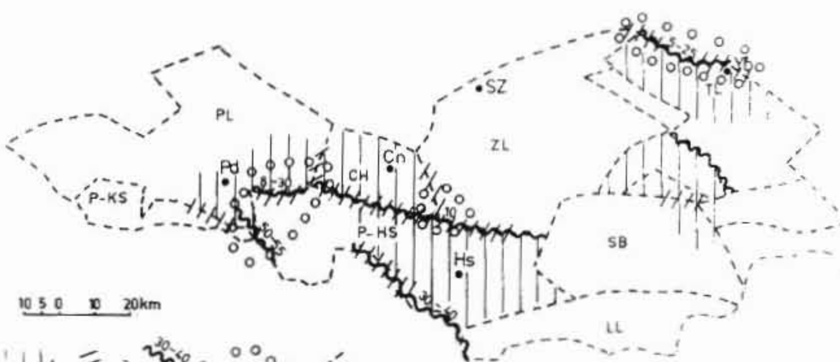

Fig. 6. Scheme of the seismic activity of the morphostructures in the Upper Thracian depression and the Tundja lowering: 1 - seismic mobile morphostructure or part of morphostructure, 2 - seismic active fragment of fault, 3 - sector fault covered by vector of epicentral migration, 4 - locality of high seismic potential, 5 - morphostructural limit.

CONCLUSION

The using of morphostructural and seismotectonic information in regional investigation contributes the deeper study of the connections between recent structural forms and recent seismic movements.

The seismic potential is highest in the following localities:

- at the contacts of morphostructures with high neotectonic seismic activity;
- in the presence of fragments of seismic mobile faults and lineaments;
- in the presence of sectors of faults and lineaments, along which the earthquake epicenters migrate.

Such localities are on the contact of:

- the Plovdiv lowering with the Chirpan horst and the Parvomay-Haskovo step;
- the Chirpan horst with the Zagora lowering and the Parvomay-Haskovo step;
- the Tundja lowering with the Stara Zagora lowering and Srednogorian morphostructures.

The first two localities have been subject of many seismotectonic investigations, but the third one has not.

The study of the temporal-spatial migration of the hypocenters of earthquakes with $M \geq 4$ shows that in the first two localities the strongest shocks are generated in the first seismogenic layer and come after earthquake activation in the deeper layers, e.g. the fourth seismogenic layer -- 3 months and 5 days before the Chirpan earthquake (April 14, 1928, M 6.8); and the third seismogenic layer -- 1 day before the Yambol earthquake (February 15, 1909, M 5.9).

This characteristic, of course, can be used for seismic prognosis only in combination with other indications of seismic activation.

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