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THE NEOTECTONIC PERIOD OF DEVELOPMEN OF THE RELIEF IN THE STARA PLANINA (THE BALKAN) OROGENIC SYSTEM

INTRODUCTION

The problem of periodic (stage) morphotectonic development of the relief in Bulgaria has always attracted attention of Bulgarian scientists. Recently, on the basis of new data and theoretical and methodological approaches related mainly to the application of the morphostructural analysis for various purposes, as well as, on comprehensive neotectonic interpretation of the geological and geophysical achievements, a more general concept has been formed about the morphostructural outlook of the country, and hence — about the stages of the relief development, including the Stara Planina orogenic system. This is shown in a series of publications (Galabov et al. 1964, 1965; Galabov 1968, 1970, 1982; Bonchev et al. 1961; Bonchev 1971, 1986, 1988; Gerasimov and Galabov 1984; Vaptsarov and Mishev 1982; Vaptsarov et al. 1969, 1978; Mishev 1959; Mishev et al. 1971; Mishev and Vaptsarov 1982, 1983; Lilienberg 1965, 1971; Popov and Kojumdgieva 1966, Kanev 1989, Totomanov and Vrablyanski 1980; etc.).

Galabov connects the periods of the relief development with the planation rhythms, which he concludes from the remains of morphostratigraphic (bench mark) levels, the flattened surfaces and river terraces being reasonably considered as such levels. He distinguishes an early orogenic stage in the Neogene period, when an initial flat surface (peneplain) is formed and a complete planation takes place, and an orogenic stage characterised by stronger, active, rhythmical, differentiated, vertical movements and by incomplete planation. The neotectonic period is obviously not clearly recognised, especially its lower boundary, but the Neogene period is subdivided into two intervals: an early orogenic and an orogenic period, whose further partition is actually based on the established flattened surfaces of regional importance. According to this author, the division for the Stara Planina

orogenic system is as follows: Sarmatian, Sarmatian–Pontic, Pontic, Old Levantine and Young Levantine (Galabov 1982).

D. Kanev uses the concept of "morphostructural period" for the periodicity of the relief development. He writes about the Fore-Balkan as follows ..."consequently, the morphostructural period had literally started from the Tertiary and more exactly — after the Eocene ..." (Kanev 1989). From all his publications concerning the problem of the periodicity of the relief development, from the concept of the "morphostructural period" it becomes clear that the lower boundary of the neotectonic period is prolonged in time (from the Eocene till now).

Totomanov and Vrablyanski (1980) consider a confined neotectonic period, assigning to it only the Pliocene and the Quaternary.

Many general geological works, and especially those treating the geotectonics of the Stara Planina orogenic system, do not distinguish a clearly partitioned neotectonic period in the geohistoric development. The concepts of "Neogene–Quaternary", "Neogene-Contemporary", "Pliocene-Quaternary" or "Neogene–Quaternary structural floor" are used instead (Bonchev 1971, Yovchev 1971).

Yaranov (1960) does not use the term "neotectonic period" in his book "Tectonics of Bulgaria". He considers the following periods of the Cenozoic: Eocene–Oligocene; Miocene and Pliocene-Quaternary.

All these concepts and terms have their proper places in the geochronological scale but they should not be mistaken one with each other. Their specific notion should be taken under consideration very strictly when used. In our opinion the neotectonic period refers to the tectonic development of the morphostructures of different order during the final period, i.e. from the Lower–Middle Miocene till now. This concept has been used in the above mentioned meaning in a number of our previous works and it should be understood in the same manner in this publication as well.

The morphostructural concept has recently found its further elaboration as a leading idea in explanation and description of the history of mountain formation owing to the development of a detailed relief classification based on genetic principles and age criteria. This classification was necessary for the creation of the new Geomorphological Map of Bulgaria, worked out by the authors of the present paper. The aim of the proposed publication is to put forth the basic concepts and ideas, related to the contents of the map and referring mainly to the neomorphostructural development of the relief of the Stara Planina orogenic system, as a part of the Carpathian–Balkan arch, as well as, in connection with the neighbouring geomorphological regions in Bulgaria.

The Stara Planina orogenic system spreads, in general, from the Bulgarian–Yugoslavian border in the west to the Black Sea in the east. The system, being about 550 m long, has a prominent asymmetric pattern in plan. The

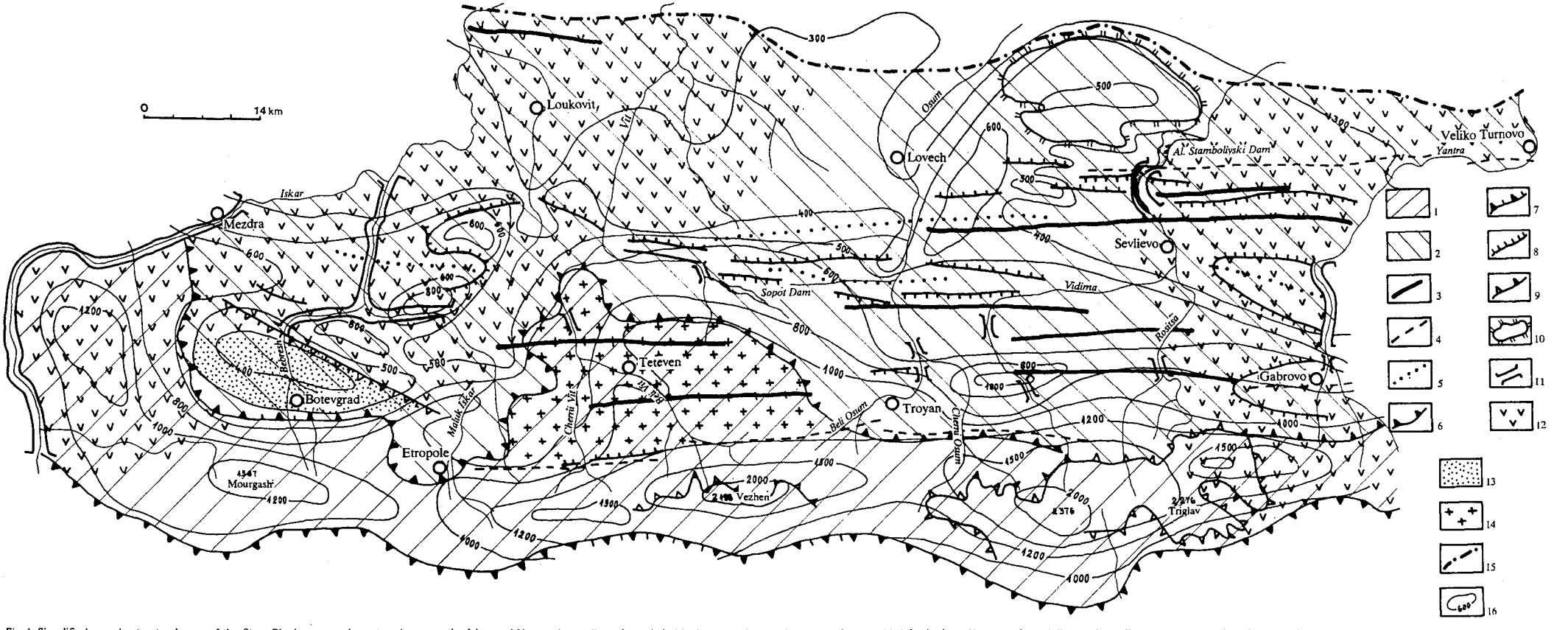

Fig. 1. Simplified morphostructural map of the Stara Planina orogenic system between the Iskar and Yantra river valleys. 1 — chain-block mountain morphostructural area with inherited pre-Neotectonic anticline and syncline geostructures, 2 — fold morphostructural hilly-ridge area with pre-neotectonic embedding and Jurassic-type of relief, 3 — axis of anticline conformable structure, 4 — axis of syncline conformable structure, 5 — axis of syncline disconformable structure (inverse to the tectonics relief), 6 — lineament morphostructures: throw and flexural, 7 — facetized throw slope, 8 — monoclinal ridge, 9 — thrust granitoid morphostructure expressed in the relief, 10 — karstified flat anticline-horst plateau, 11 — antecedent gorge, 12 — transversally lowered tectonic zones, 13 — Pliopleistocene internal mountainous kettle-graben morphostructure, 14 — fault-dome morphostructure, 15 — northern boundary of the Stara Planina orogenic system, 16 — isohypses in metres

Ryc. 1. Schematyczna mapa morfostrukturalna Starej Planiny pomiędzy dolinami Iskaru i Jantry. 1 — blok morfostrukturalny z oddziedziczonymi przedneogeńskimi strukturami antyklinalnymi i synklinalnymi, 2 — sfałdowany obszar pagórkowaty, przedneotektoniczny i rzeźba typu jurajskiego, 3 — oś antykliny, 4 — oś synkliny, 5 — oś synkliny niezgodna ze strukturą (inwersja rzeźby tektonicznej), 6 — lineament morfostrukturalny: zrzut i fleksura, 7 — stok tektoniczny, 8 — grzbiet monoklinalny, 9 — zrzucona morfostruktura granitoidowa widoczna w rzeźbie, 10 — skrasowiała płaska wysoczyzna antyklinalno-zrębowa, 11 — przełom antecedentny, 12 — strefy poprzecznych obniżeń tektonicznych, 13 — plioplejstoceńskie, śródgórskie morfostruktury obniżeń i zrębów, 14 — morfostruktura uskokowo-kopulasta, 15 — północna granica systemu górskiego Starej Planiny, 16 — poziomice

Stara Planina system descends towards the north to about 400 m at the adjacent Danubian Plain hills, while as a whole, it is strongly dissected by steep slopes in the south, where relative height differences reach to more than 2,000 m above the Balkan graben valleys. The ridge of the main chain declines from west to east (with certain fluctuations), from more than 2,000 m (the Midzhur peak — 2,168 m) to 400–500 m at the coastal ridge branching. The continuation of the Stara Planina orogenic system in the Black Sea area turns to the south-east declines, and ceases along transverse and oblique faults and flexures, without any clearly proved connection with the North Anatolian mountains.

The Stara Planina orogenic system is divided into the Main Stara Planina Chain (the Balkan) — 11,596 km^2 and the Fore-Balkan in the north — 14,389 km^2, the total area being 25,986 km^2 which amounts to almost 1/4 of the Bulgarian territory (Galabov 1982).

The width of the main chain varies from 15 to 40 km and that of the Fore-Balkan — from 10 to 30 km. The mountain chain is classified as low and medium-high, hilly ridges, strongly dissected orogenic systems. Few of the summit parts of the ridges exceed the height of 2,000 m (the Botev peak is the highest — 2,376 m).

The main body of the Stara Planina chain has a fold-block-chain composition, represented by three anticlines — the Svoge, the Berkovitsa and the Shipka and by one syncline — the Louda Kamchia. In the Fore-Balkan there are multiple anticline and syncline structures, re-modelled to a different degree, which cause the relief to have a Jurassic appearance (Fig. 1).

MORPHOSTRUCTURAL SUBSTANTIATION OF THE LOWER BOUNDARY OF THE NEOTECTONIC PERIOD

One of the most debatable problems in morphotectonics and paleogeography, where great discrepancies exist, is determination of the lower Neotectonic boundary, and hence — of the extent of neotectonics as a relatively independent time span. Various criteria have been used for its extending in a geochronological scale. In general, it could be concluded that different boundaries are accepted for the Neotectonic period not only in Bulgaria but in other countries as well. These boundaries are included in the boundaries of the Eocene until the Pliocene. The maximum duration of the Neotectonic period seems to be more than 35–40 years.

We are conceived that this boundary for the Stara Planina orogenic system could be allocated to the Lower–Middle Miocene. What are the morphostructural arguments behind it?

Most geomorphologists assume that the fold movements have faded after the late Alpine orogenic period, followed by a long phase of a relatively

calm tectonic period. The dominating relief-creating process is planation leading to formation of a low flattened relief of a peneplain type. The subtropical climate has also contributed to this development. This peneplain is of the Oligocene–Lower Miocene age and we consider it as an initial one, emphasising the fact that the origin of some basic neomorphostructures can be traced with it, while other neomorphostructures have been completely transformed.

The vertical movements have attained the importance after the fading of the fold tectonic movements, and they are manifested as chain-block, dome-block and lineament dislocations — rising and lowering. In consequence, the initially flattened surface became strongly craggy and turned into a peak-like one. Certain relicts of it are observed in the top zones of almost all Bulgarian mountains. Generally, it can be concluded that the planation period of a large regional extent was completed, followed subsequently by a strong tectonic activation. The end of this Pre-neotectonic period represents a Tortonian–Lower Sarmatian transgression in north-western and north-eastern Bulgaria, including also parts of the Fore-Balkan. This transgression and its consequences for the relief are very well studied and show that after its cessation, a change in the tectonic regime has been observed (Koyumdjieva 1961; Koyumdjieva and Popov 1989). The Baden (Tortonian) and Lower Sarmatian layers lie on a variegated strongly denuded substrate which is slightly monoclinally inclined to the north-east. These layers do not participate anywhere in fold-forming processes.

The development of some basic river-valley systems in the Stara Planina and in the Danubian platform also refers to the first order boundary of tectonic units. The establishment of available paleo-river valleys (Paleoogosta) as well as of many epigenic and antecedent gorges, the most typical ones being the Iskar and the Louda Kamchia gorges, provide evidence for this conclusion.

It can consequently be assumed that the beginning of the neotectonic period, as the etymology of the term implies, starts with the completion of a peneplain period that created mature, low flattened relief, and with the onset of another period characterised by predominating intensive structure-transforming activity. However, the great complexity of the problem to choose between one or another initial boundary is obvious. From the point of view of the morphostructural development we assume, the change in the regime of the tectogenesis with the activation of the rhythmical vertical relief-forming processes to be a basic criterion.

There are sufficient morphostructural grounds to divide the neotectonic period in three subperiods, namely: the Miopliocene, Villafranchian (Plio-Pleistocene) and Quaternary.

We shall briefly consider the specific features of the relief development in each of the subperiods.

MIOPLIOCENE SUBPERIOD

As already mentioned, the Miopliocene period begins with the activation of the tectonic movements when the vertical, differentiating movements become more important. These movements manifest in thrust-upthrust, syncline-graben, and others. Mountain morphostructures of different orders arise. The relief is rejuvenated due to its stronger morphosculptural transformation and exogenic dissection.

Another characteristic feature of the Miopliocene subperiod is the occurrence of a series of lake basins, which inherited older depressions or newly formed ones. This alters the lower base level of some river systems, especially to the south of the Main Stara Planina chain and the West Fore-Balkan, thus differentiating the planation processes and, locally, causing separation of the basins. The lake basins during the Pliocene, these in the middle part of the Balkan Peninsula in particular, play a significant role in relief formation. This provides the ground for some geomorphologists to distinguish a "lake phase" in the development of the discussed area.

The third characteristic feature of the considered subperiod is the domination of rhythmical pediplanation processes (incomplete pediplanation) when slope surfaces (steps) are formed, which we understand as montiplains, according to the terminology of Timofeev, and oroplains, according to Lilienberg, while others are riverside (valley) levels. The development of the latter is connected with the delineation of the old river valleys and the flattenings jut out in an inlet-like manner in the upstream direction. It can be concluded from the investigations carried out so far, that three slopes and a ridge represent denudation surfaces and were formed in Young Miocene, Pontic and Levantine. The unlevelled form of these surfaces is used to characterise the direction and rate of the neotectonic movements. The initial peneplain has been transformed into a summit surface with an amplitude gradient of about and above 2,000 metres.

Considerable morphosculptural activity took place during the Miopliocene period in the Fore-Balkan, leading to transformation of the geostructural units, and thus producing a characteristic, Jurassic-type relief, which developed further during the subsequent subperiods. It is characterised by monocline ridges, hogbacks, inverse relief, deeply incised river valleys, monocline and syncline valleys, transverse gorges, grid-like river-valley network, etc.

The fifth feature is lineamenting of the boundaries of some longitudinal morphostructures and formation of morpholineaments. The two transversal lowerings across the Stara Planina orogenic system — the Iskar–Vit and the Etar (Yantra) — are also reflected in the relief. Moreover, this is true for the Diagonal embankment, distinguished by Bonchev, which nowadays serves as a watershed boundary at a certain distance along the Main Stara Planina chain.

VILLAFRANCHIAN PLIO-PLEISTOCENE SUBPERIOD

The Villafranchian subperiod is characterised by a new activity of the tectonic, mountain-forming processes and by an onset of considerable climatic changes manifesting in a pluvial phase. We shall not discuss the problem of the limits of this subperiod. The continuous discussions in the Quaternary geological and geomorphological literature concerning the place of the Villafranchian in the geochronological scale and the "Pliocene–Pleistocene" boundary are still in progress. Here, it is important that this subperiod, although not very long and at the same time difficult to correlate with particular geologic periods, has a strong impact on the type of the relief formed and on specific landforms. In fact, these forms are concentrated mainly at the foot of mountain slopes and ridges.

The occurrence of a strong pluvial phase in the Stara Planina orogenic system is characteristic, as we have already mentioned, for the Villafranchian period. Because of a low relief of the Stara Planina, this phase does not lead, however, to the formation of glaciers but only to local small snow-drifts. The periglacial, destructive slope processes, however, are significantly intensified, being favoured most probably by a lack of a protective "plant screen". Flattened surfaces — steps of different genesis and inclination — are formed in the foothills due to pedimentation and accumulation.

The most typical of them are the glacis and the old proluvial trains. To the flattenings called glacis we assign all the varieties of foot steps and surfaces, connected also with faults, and having flat relief inclined to the neighbouring depressions that often cuts heterogeneous rock substrate and is covered by a typical in appearance and colour accumulative not very thick cover. The latter consists most often of gravels, boulders, as well as of larger rock blocks with a sandy-clayey filler of bright yellow-reddish colour. The gravels are strongly weathered, very often entirely disintegrated. Conclusions about them are drawn according to the preserved places of their incorporation. Gravel depositions of this type are widely spread in the foothills of the Main Stara Planina chain and in the lowerings between the ridges of the Fore-Balkan; they are transferred to the north in two levels, developed under the loess of the Danubian plain, and known as covering gravels (Vaptsarov et al. 1993). We correlate them with the related levels of the same age, established by the Romanian geomorphologists, and known as piedmonts.

Very well formed and preserved glacis have been found during our investigations and mapped in many regions of the Fore-Balkan and the foothills of the Main Stara Planina chain. As an example we can mention: the Barzia-Botun lowering; the south–west periphery of the Botevgrad basin, the Etropole lowering, the Kalnik river basin in front of Vasilyova mountain, the April and Elena undulated basin to the north of the Elena and Preslav anticline ridges and others. To the south of the Main Stara Planina chain they are characteristic of

the Strazhata transverse escarpment, of the Belene basin occurring to the east of the town of Sliven and in front of the Grebenets ridge, and elsewhere (Mishev 1959; Mishev and Vaptsarov 1983; Mishev and Daneva 1972).

QUATERNARY (PLEISTOCENE AND HOLOCENE) SUBPERIOD

The Quaternary subperiod could be also called a terrace-forming subperiod. It is distinguished based on rhythmical glaci-eustatical and other epeurogenic movements manifesting in a wide range of outcomes. We shall not discuss the hypotheses about the reasons of these movements, but we shall only mention that in Bulgaria the terraces are found everywhere and are differentiated. The terrace spectra are well studied in the river valleys of the Fore-Balkan, especially these of the rivers Vit, Ossam, Vidima, Rositsa, Yantra, where remnants of 6–7 overflood and flood terraces are found. The presence of a full terrace spectrum is an evidence of a rhythmical rising of the Stara Planina orogenic system during the Quaternary while a total amplitude of the Fore-Balkan is of 110–120 m (Galabov et al. 1965). This rising continued during the Holocene, which is proved by the fact that, in addition to the gorges and many widened valleys, the flood terraces have also a thin accumulative cover and a high erosion rock base.

Another established feature is that the differentiation of the rising rate is related most often to the cutting through well developed plicative anticline morphostructures. Differences in topography are of the order of 10–15 m, reaching up to 30 m in the case of the high terraces. The terrace asymmetry has been stated in some valleys — the terrace spectra are much more developed along the western valley slopes. Another feature is the diminution of the heights of the terrace spectra in the Middle Fore-Balkan from west to east (from the Vit to the Yantra river), which is connected with the dynamics of the transverse lowerings. The decline in the terrace heights is almost twice as large as the local terrain drops related to the crossing of the linear morphostructures (Galabov 1965).

In tectonic aspect, the considered subperiod is characterised by the greater rise of the Main Stara Planina chain between the North and South Stara Planina and by the abrupt cutting of the summit denudation surface from the north to the south and its inclination to the east, somewhere along transverse flexures and thrusts, from more than 2,000 m to about 500 m. The periods in this chain-block rising event are determined also by the presence of remnants of old sediment cones at the outlets of a number of rivers, draining the Stara Planina mountain, to the adjacent lowerings to the south. Such cones with a relative height of 70 m and situated on 3–4 steps, some of them being cut by the line of the fault, have been stated by the authors in the Zlatitsa, Karlovo and Kazanluk basins. The small waterfalls at the outlets of many tributary river

valleys into the basins, as well as the rather significant, up to 100–200 m thick, Quaternary deposits in the neighbouring plains, covering at some places sediment cones and river terraces, provide evidence of the Quaternary linear geodynamics along the southern lineament slope of the Stara Planina mountain. The widely distributed, well faceted single sections of the southern macro slope also confirm the active young geodynamics.

NEOTECTONIC PERIOD FROM THE STANDPOINT OF SOME MODELS, DEVELOPED ACCORDING TO THE "NEW GLOBAL TECTONICS OF PLATES AND SUTURE ZONES"

Till the 60-ies of this century, the dominating ideas in the geomorphological and tectonic literature in Bulgaria were these of the geosynclinal concept and its modifications. In general outline, according to these ideas, the Stara Planina mountain was accepted as a part of the northern branch of the Alpine orogenic system, between which the intermediate Rhodope massif was developed. The formation of this double sided Alpine orogen was related to the classical ideas of the geosynclinal evolution of the Balkan part of the Alpine orogenic belt. According to this concept, the dominating tectonic processes in this part of the orogen was the vertical orogenic transfer, which determined the relatively constant delineation of the single morphotectonic zones, including the Stara Planina one. The neotectonic period is considered as the final one. In this period the morphostructures which show a similar pattern to the outline of the pre-Alpine development have been formed. The demarcation of deep-seated faults indicate the border zones between the morphotectonic units. This conventional concept was generally accepted and has been developing until recently.

Since the 60-ties of our century the ideas of the New Global Tectonics (the platetectonics) have been extensively developed in the works of a great number of Bulgarian scientists-tectonicians. These new ideas differ substantially from the morphotectonic model of the Balkanide part of the Alpine orogen. A number of Bulgarian and foreign scientists have proposed new tectonic models based on a mobilistic principle and on the idea of the dominating horizontal tectonic transfer. According to these models the Balkanide part of the Alpine orogen falls into the intermediate space between the East European and African–Asian lithosphere plates, where specific phenomena of collision, subduction and obduction occur along with the formation of orogenic zones of collision type. The stage models that have been proposed until now for the meso-neosoic evolution of the Alpine orogen do not always coincide between themselves and are not generally accepted.

During the last years the platetectonic ideas have also found their confirmation in the analysis of the neotectonic period. A considerable interest in this

respect represent the publications of the Hungarian scientist Balla (1987) as well as the works of some Bulgarian tectonicians as Gochev (1980), Tzankov et al. (1995), Tzankov and Nicolov (1995). The place of the Stara Planina neomorphostructure is referred in these works to the passive southern outskirts of the Eurasian continental plate, thus to a complex linear orogenic construction evolving through the Steerian, Atian, Pontic and Wallachian phases. The formation of the "Fokshani" depression in the Fore-Carpathian part and the "Lom" depression in the Moesian part of the plate is connected with the occurrence of collisions and cyclic subduction processes. The stresses are consequently connected with incorporation of some parts of the Fore-Balkan in the Main Stara Planina chain (the Vratsa mountain, the Teteven rising) and subjecting of other local zones to substantial neotectonic processing. These conclusions provide grounds to interpret in a new way the hypsometric relationships between the denudation flattened surfaces in the northern and southern periphery of the West Stara Planina mountain, the partial changes in the plan of the river-valley network and other geomorphological phenomena.

The new ideas in the platetectonic domain are undoubtedly very interesting. However, they have not found their place in the neomorphostructural analysis yet.

The modern investigations of the relief-formation processes in the mountain chains in Bulgaria during the neotectonic period, and in the Stara Planina mountain in particular, are very convincing that the process is extremely complex. The endogenic, and especially the neomorphotectonic, shaping of the mountain system depends on the combination of processes resulting in both vertical and horizontal transfer of structures. This way, the vertical and horizontal displacements are mutually interrelated in one complex process which changes its character and direction, dynamics and morphologic outcomes, for the Stara Planina and the other mountainous systems in the framework of the Alpine orogen. Therefore, the mountain formation should be understood as a complex endo- and exodynamic process, whose essence requires a multilateral analysis from both geostructural and morphotectonic point of view without imposing any orthodox patterns or norms. In this respect, the principles laid by the authors of the work *Mountains in Suture Zones of the USSR and Plate Tectonics* (1990) edited by Korzhuev, clearly show the correct approach to similar scientific investigations in the future.

CONCLUSIONS

The neotectonic period, being the youngest one in the evolution of the morphostructures, is of the greatest importance in the characteristics of the contemporary outlook of the relief. It is continuing at present as well. The above discussed problems, although briefly synthesised, prove that during this

period both vertical and horizontal tectonic dynamics contributed to the relief formation. A well developed and mature relief of the type of the hilly landscape, low and medium-high mountains has been formed, which identifies the Stara Planina fold-chain system as the most important southern part of the Carpathian-Balkan arch with parallel spreading. It has much in common, as well as it differs considerably, with the rest of the mountain systems of the Alpine orogenic belt. The comparative morphostructural analysis of their neotectonic periods and subperiods would yield good results. This would bring us closer to the idea of developing a generally accepted morphotectonic periodicity. Such a periodicity should be based on genetic-age principles and comprehensive morphostructural analysis as well as on usage of paleogeomorphological criteria. It is likely that the periods and subperiods in the periodicity scheme would not coincide with geochronological divisions. However, this will not be a fatal shortcoming. This could even strengthen the position of one of the basic ideas in geomorphology, namely the idea about the relief development of the Earth surface in one geomorphological period yet in three morphocycles and of a duration of 200 million years, which had been put forth by Gerasimov and Meshteryakov in 1964, thus raising the prestige of geomorphology as an independent science in the system of the Earth sciences.

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STRESZCZENIE

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NEOTEKTONICZNY OKRES ROZWOJU RZEŹBY SYSTEMU GÓRSKIEGO STAREJ PLANINY (BAŁKANU)

W artukule przedstawiono problemy związane z genezą i rozwojem rzeźby systemu górskiego Starej Planiny w okresie neotektonicznym. Artykuł składa się z 7 części. Po wprowadzeniu autorzy omawiają poglądy na temat pojęcia „okres neotektoniczny". Ogólnie przyjmuje się w Bułgarii, że obejmuje on okres od eocenu lub pliocenu. Autorzy uważają, że podstawowym kryterium określenia granicy jest zmiana reżimu tektonicznego i uaktywnienie pionowych ruchów tektonicznych po późnoalpejskim cyklu tektonicznym. Jest to czas zakończenia dolno/środkowo mioceńskiej peneplenizacji. Wyróżniono trzy główne podokresy; mioplioceński, villafranchian i czwartorzędowy — podczas których były formowane najważniejsze cechy rzeźby Starej Planiny. Szczególną uwagę zwrócono na okres villafranchian. Omówiono również model rozwoju systemu górskiego Starej Planiny w świetle teorii tektoniki płyt. We wnioskach stwierdzono, że zarówno ruchy pionowe jak i poziome grały istotną rolę w formowaniu rzeźby neogeńskiej, ale zróżnicowanie ruchów pionowych odegrało rolę dominującą.