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NEOTECTONIC FEATURES OF THE STRUMA FAULT ZONE

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Abstract: In this paper results of morphotectonic investigation of the Struma fault zone in southwestern Bulgaria are presented. This highly seismic active and deep fault zone probably originated in the Neogene and its variable geodynamic regime is distinctly expressed both in the geological structure and by the range of changes of the graben-type relief. Main stages of the geomorphological development of the Struma fault zone and their relation to evidences of recent tectonic activity are described.

Key words: morphotectonics; recent activity of faults

1. INTRODUCTION

The faults in southwestern Bulgaria are most impressive for the neotectonic stage of Bulgarian territory, owing to the density of fault systems, the amplitude of vertical tectonic movements as well as to the high seismicity. That is why our attention was directed to the deep seismogenic faults of southwestern Bulgaria.

The Bulgarian territories, like the whole of the Balkan Peninsula, are situated within the range of the Alpine geosynclinal belt (Bonchev, 1971). According to all structural plans, the alpine deformations have exerted a deep influence on the development of the structural units. Basing upon a young-Alpine Balkanide structural plan, the same author divides the Bulgarian region into two structural zones – the Moesian platform and the Thracian Median Massif, and into five morphostructural zones – the Forebalkan, Stara Planina zone, Sredna Gora, Kraishtides and Southern Carpathians (Fig. 1).

The Struma fault zone is located in the Kraishtide structural zone, which was first investigated by Bonchev (1936). The Kraishtides represent a well-restricted structural zone developed on the deep faulting ground. They are entirely laid upon the Thracian Massif, which they divide into two parts: the Rhodope Massif to the East and the Serbo-Macedonian Massif to the West. The direction of the Kraishtide structural zone in our territory is comparatively well sustained, mainly between 150–170°. The eastern limit of the Kraishtides has a faulted character, while their western limit represents the eastern boundary of the Serbo-Macedonian Massif, against which they lean closely.

The most typical structures in the Kraishtides are faults. Longitudinal faults of 150–170° stand out in the foreground. These are high-category faults, most of which have a deep character. Also belonging here are the Struma faults, which we shall later examine in detail. On the transverse system, best represented is the Yablanitsa fault (60–75°). The most important faults of this system divide the

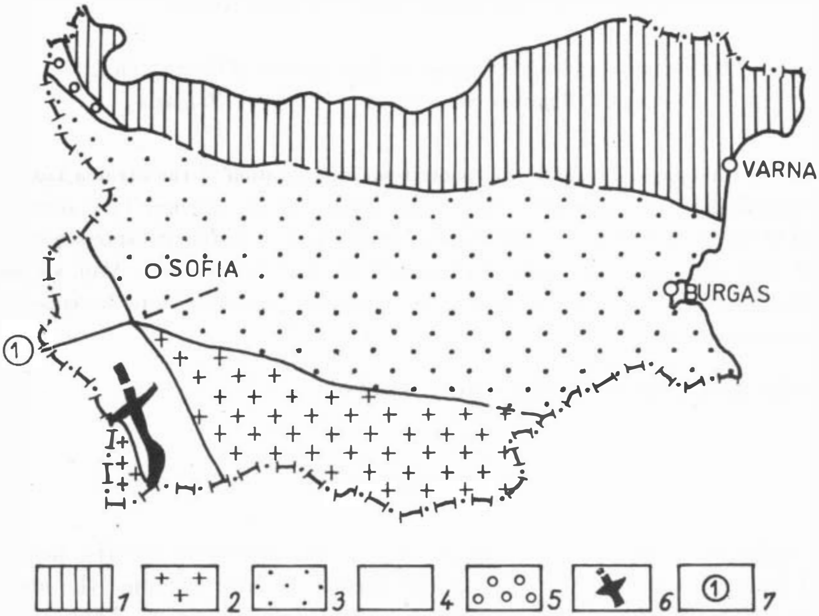

Fig. 1. Sketch of main structural regions in Bulgaria. Key: **1** – the Moesian Platform; **2** – the Thracian (Rhodope and Dardanian) Median Massif; **3–5** – Alpine mobile region: **3** – the Sredna Gora, Stara Planina structural zones and Forebalkan, **4** – Kraishtides (Kraishtide structural zone): **5** – the Southern Carpathians; **6** – investigated fault region; **7** – the Kyustendil fault.

Kraishtides into transverse blocks. Most typical in this respect are the Kyustendil and Krupnik faults. The Kraishtide structural zone is distinguished by a very complicated geological structure, high tectonic style and endurable permanent-impermanent tectonic development. The deep character of faults plays the main structural role here. The Kraishtide structural zone represents, from the tectonic aspect, a strongly and deeply faulted Earth's crust, which has all the signs of a tectonic lineament, distinguished by its own tectonic style.

As was already pointed out (Bonchev, 1971), the Struma fault zone has been formed over the eastern limit of the South Kraishtides, which has a marked fault character. In this zone, the longitudinal faults in the Kraishtide system (150–170°) emerge in the foreground. The Struma faults – the Pirin and the Struma faults belong here above all – are limiting it to the Northeast and Southwest, respectively. Most representative of the transverse faults in the Yablanitsa system (60–75°) are the Kyustendil and the Krupnik fault, which divide the Kraishtides into blocks. Both the longitudinal and transverse faults in the Struma fault zone are of a high category with deep character and a remarkable recent activity (Fig. 2).

Geologically, the Struma fault zone is the most interesting and at the same time the most dangerous fault zone in the territory of Bulgaria and the Balkan Peninsula. This is a zone of an early (Riphean) predestination and a lasting permanent-impermanent development. This was exactly the subject of a series of investigations by many foreign and local authors. However, the accent of these investigations was lately more frequently transferred to the latest development, which with full reason arouses the scientists' anxiety. For example, the most contrasting relief in our country is observed in the Struma fault zone, where the highest amplitudes of neotectonic vertical movements of the Earth's crust in Bulgaria have been established. The most powerful earthquake on the Balkan Peninsula has been recorded in this fault zone.

All this stimulated the continuation of specialized investigations of the Struma fault zone, which should attain a more complex character. The neotectonic and recent seismic activities of the zone should be accentuated in these investigations.

As already known (Vrablyanski, 1977), until the Neogene the Struma fault zone was considered a jointing zone between the Kraishtide morphostructural zone and the Rhodope Median Massif. However, after the Upper Miocene, a change in the tectonic tensions took place here – from compression to expansion, so this zone became a zone of differentiation between these two structural units. The same author comprehends this zone as an element of a big morphotectonic arch, which is characterized by a slow uplifting and swelling of the Earth's crust. After the Upper Miocene, the arch has been subsiding along its axial part and disintegrating into separate blocks with different signs of tectonic trends. The Struma fault zone was formed later, above the sunken block along the line of the deepest subsiding of the arch, which the same author named Struma arch.

These ideas were further developed during the last years (Vrablyanski, 1981) and connected with the newest ideas about the formation of the young continental rifts. Thus, even according to the late-Alpine structural plan, the Struma fault zone is now considered not only an element of a morphostructural arch, but also an element of a more complicated young continental riftoid structure.

The Struma arch is a first-order structure that includes the whole Rhodope Massif area, whereas its western parts envelop the territory of Macedonia and Northern Greece (Fig. 3).

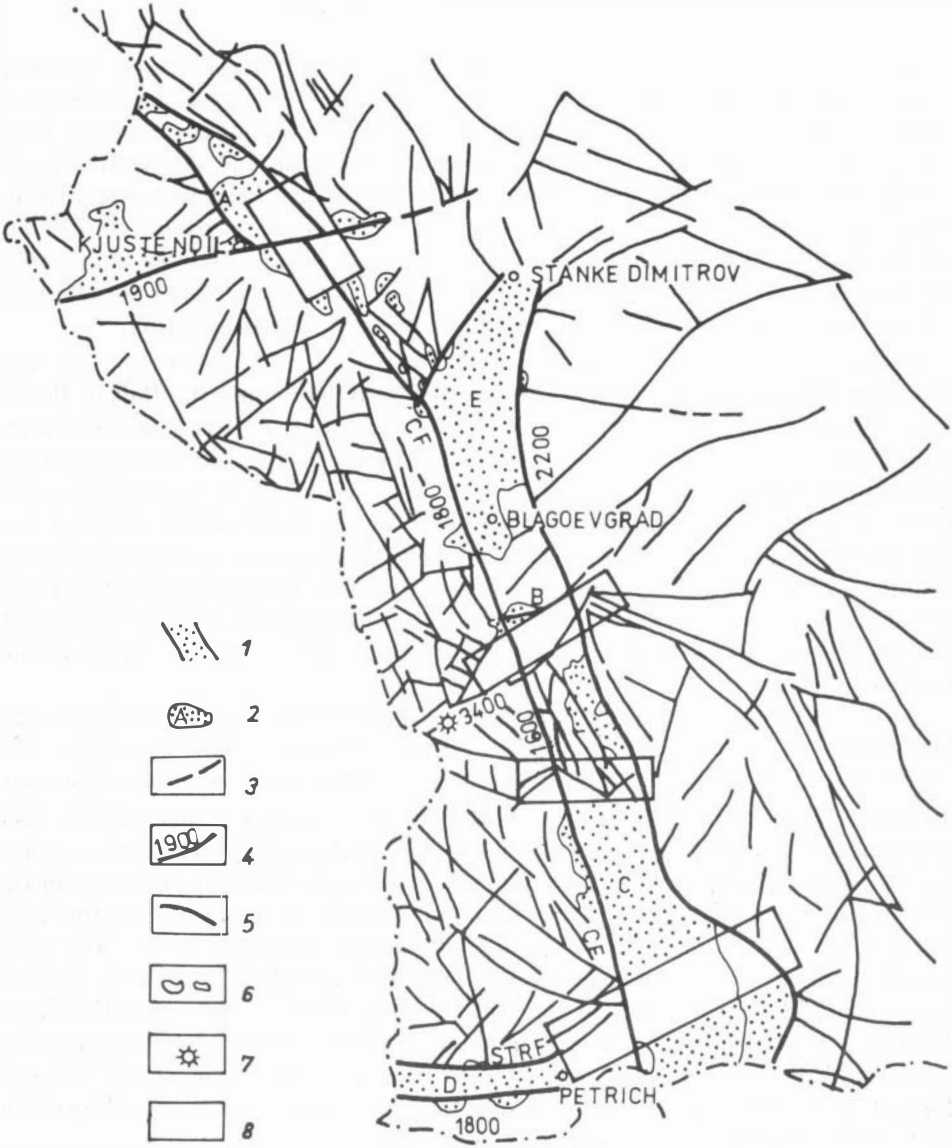

Fig. 2. Map of the Struma fault zone. Key: **1** – the Struma fault zone; **2** – grabens: **A** – Kyustendil, **B** – Simitli, **C** – Struma, **D** – Strumeshnitsa, **E** – Dzherman; **3** – faults in the Struma fault zone activated during the Pliocene-Quaternary period; **4** – amplitude of vertical movements (in metres) along the main faults in the Pliocene-Quaternary period; **5** – other faults; **6** – Pliocene-Quaternary volcanics; **7** – epicentres of 10^0 intensity earthquakes; **8** – local geodetic networks.

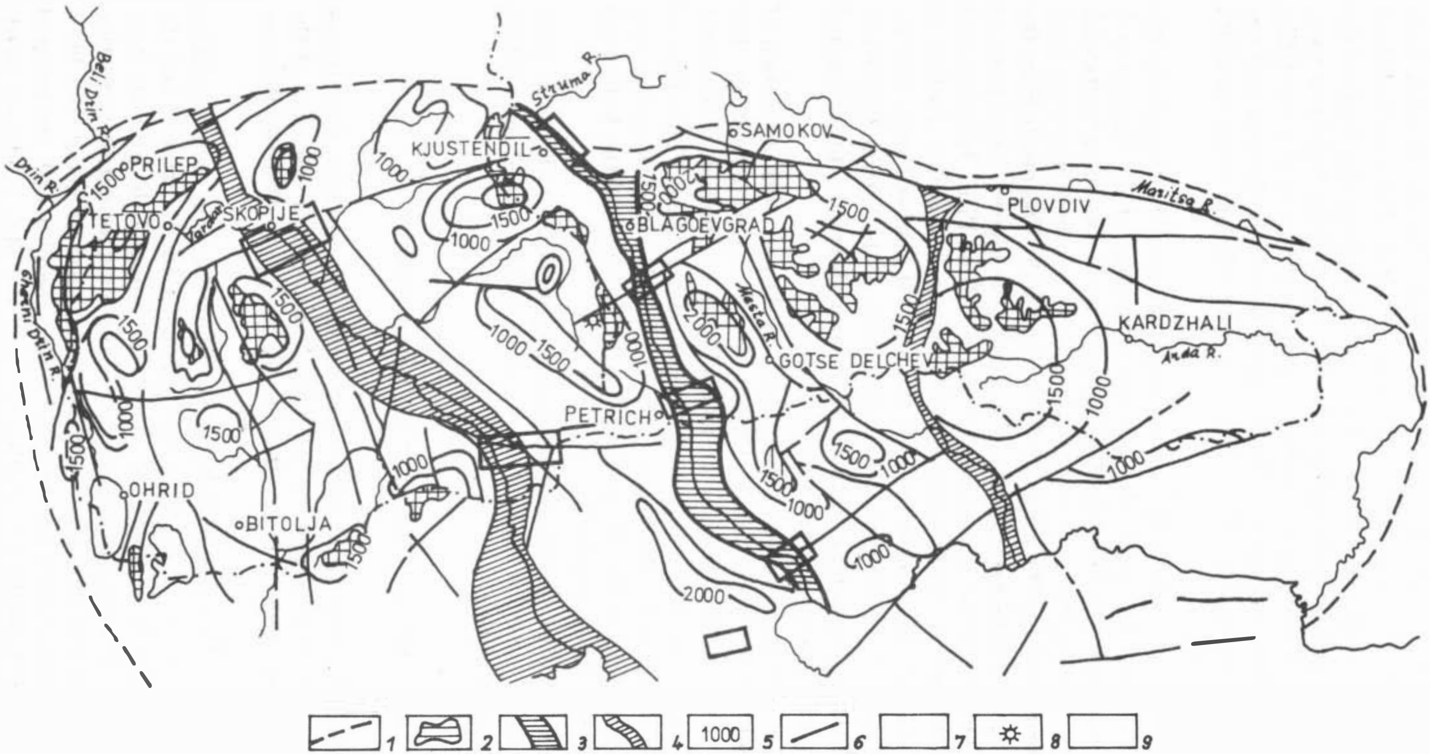

Fig. 3. Map of the Struma arch region. Key: 1 – contours of the Struma arch; 2 – relics of the initial pre-orogenic surface (orthoplain); 3 – the Struma fault zone; 4 – zone of interdomal structures; 5 – deformation isolines of the orthoplain in uplifted blocks during the stage; 6 – main faults activated during the neotecto with intensity $I_0 = 10^\circ$; 9 – local geodetic networks.

From the East and Northeast, the arch is differentiated by the Maritsa fault zone. Towards the North, the limit of the arch passes along the Poletina fault line, northwards of the Kyustendil fault. In the Yugoslavian territory, the limit of the arch follows a system of arched faults and reaches the valley of the Beli Drin river. The southern limit of the Struma arch is rather unclear. It passes, in all probability, along the North coast of the Aegean Sea. Within these limits, the Struma arch has an elongated form. Its length from West to East attains 520 km, while its width varies from 150 to 220 km.

As already stressed (Vrablyanski, 1977), as a result of stretching tensions in the tectonic force field during the Upper Miocene, the orthoplain of the Struma arch subsided in its highest parts and disintegrated into separate blocks along faults with deep predestination. During this process, second-order arches and separating fault zones have been formed within the range of the Struma arch. Fragments from the orthoplain (pre-orogenic initial surface) are preserved in the highest raised parts of the Struma arch. They are located in its central part – in Rila, Pirin, Belasitsa and Osogovo, where their absolute heights exceed 2200 m at some localities. Further to the East, their height decreases and in the East Rhodopes it reaches barely 1200 m. Along the western flank of the Struma arch, in the valley of the Cherni Drin river, a total uplifting of the orthoplain up to 2000 m has been observed – predestinated along young faults with intensive neotectonic activation.

The second-order arch forming was accompanied in its part with activation of longitudinal and radial faults (Vrablyanski, 1978) during the neotectonic stage. The evolution of these arches is obviously accompanied by the formation of a central graben attached to the core of the arch, and of peripheral grabens. The space of a central graben is occupied by the Mesta graben, which is attached to the core of the dome. The Simitli (near the Krupnik fault), the Struma and the Dzherman graben may be referred to as peripheral.

All stated facts lead to the conclusion that in South Bulgaria, both to the West and to the South, there existed a big neotectonic arch, which marked the preliminary stage of continental rifting.

3. GRABENS IN THE STRUMA FAULT ZONE

In the light of the new ideas about rifting as a neotectonic process, the Struma fault zone represents a totality of grabens belonging to a region of extension of the Earth's crust, which were formed approximately in the Upper Miocene-Pliocene period.

The Kyustendil graben. It was formed during the Upper Miocene over crystalline schists of the Prepalaeozoic age at the intersection point of the Kyustendil and the Poletin fault of the Struma fault zone (Fig. 2). In the filling of the graben, three formations of the Upper Miocene age are described: the main formation consisting of conglomerates, sandstones and clays with total thickness of about 100 m; a coal-bearing formation represented by clays and a coal complex with thickness of up to 20 m; a clay-marl formation consisting of clays and clay sandstone marls with thickness reaching up to 500 m. Above the Upper Miocene deposits in the Kyustendil graben, covering Pleistocene gravels with up to 80 m thickness are disposed. The total thickness of the filling of the Kyustendil graben is 700 m.

The Simitli graben. It was also formed during the Upper Miocene at the intersection point of the Krupnik and Struma faults over Precambrian metamorphites and Caledonian-Hercynian granitoids. The filling of the graben is represented by two horizons of the Upper Miocene, deposited along the bottom of the basin: the main one represented by conglomerates and sandstones, and a productive one constituted by clays, coal layers and sandstones, with total thickness of 160–200 m. Above the Upper Miocene sediments, boulders and large-pebble conglomerates follow, which Kamenov *et al.* (1965) relate to the Pliocene. The thickness of the Pliocene coarse molasse, which in reality fills in the graben, attains, in its central parts, 1000 m.

The Quaternary accumulation in the Simitli graben is closely connected with vertical movements along the Krupnik and Struma faults after the Levantinian. The most representative genetical type of the Quaternary accumulation attached mainly to the Krupnik fault, is the deluvial-proluvial one. It is presented by thick clusters of detrital fans. Another genetical Quaternary type present here are the alluvial deposits along the terrace levels of the Struma river, a large part of them belonging to the useless alluvium. The total thickness of the filling of the Simitli graben is 1200 m.

The Struma graben. It was formed after the Upper Miocene over the Struma bundle in the Kraishtide direction, in the river valley of the middle Struma between the Kresna and Rupel gorges. It is filled in by Pliocene sediments, grouped in four formations (Vrablyanski, 1971): the main conglomerate formation consisting of large-pebble conglomerates with thickness of about 460 m; a sandy formation, which constitutes the main part of the Pliocene profile, represented by an aulerite-sandy-gravel composition with beds of limestones and marbles, the thickness of the sandy formation being 800-1000 m; a hypoconglomerate formation, which passes from the sandy one and is constituted of psephite sediments, most frequently of granule- and boulder-gravel. With it terminates the Pliocene profile in the Struma graben (the thickness of the hypoconglomerate formation is 440–500 m): a volcano-sedimentary formation represented by subalkaline dellenites, tuff breccia, conglomerates, tuff sandstones and tuffs. It is a result of eruptive activity of the extinguished volcano Kozhukh during the Pliocene-Pleistocene period. The thickness of Pliocene filling in the Struma graben attains, at some localities, 1800 m.

The Quaternary lithostratigraphic complex in the Struma graben is broadly developed. It is divided stratigraphically into undivided Quaternary, Pleistocene, Upper Pleistocene-Holocene formations, and genetically into alluvial, eluvial-diluvial, diluvial-proluvial, eluvial, glacial and fluvioglacial sequences (Vrablyanski, 1971).

The Strumeshnitsa graben. It is formed over the Strumeshnitsa fault zone which is limited, to the South, by the Belasitsa fault. The main conglomerate formation of the Pliocene is missing here. The sedimentation in the graben begins with the higher parts of the sandy formation (section), which covers transgressively a diverse basement, consisting of conglomerates, sandy clays, tuffs of the Upper Pliocene age.

The thickness of the Pliocene sediments in the Strumeshnitsa graben is from 100 to 300 m.

The Dzherman graben. It also belongs to grabens in the Struma fault zone. It was filled in by Pliocene sediments and is represented by three formations: the main formation consists of conglomerates, clays, gravels, which cover its entire bottom. The thickness of the main formation is most frequently 200–300 m. The second sandy formation consists of sandstones and sandy clays. The thickness of this formation is also several hundred meters, but it attains 400–500 m between Kocherinovo and the town of Rila. The third formation consists of breccia-conglomerates, sandy aulerolites, impure clays, breccias. This formation terminates the Pliocene sedimentation in the graben. The thickness of Pliocene sediments in the Dzherman graben attains 1100 m.

The Quaternary in the Dzherman graben is represented by almost all genetic types, familiar in Bulgaria, but most representative are the diluvial-proluvial and alluvial sequences. The former are attached to the main faults activated after the Levantinian, whose development proceeded in conditions of an erosional relief (Vrablyanski, 1974). The latter are developed along the terrace spectrum levels of the Struma river, whose deposition is connected with the epoch of relative tectonic calm during the Quaternary.

4. NEOTECTONIC FAULTING

As already pointed out, the lowest parts of southwestern Bulgaria are occupied by Neogenic grabens filled in with upper molasse. They were formed along faults in the Struma fault zone. Main structures are represented by faults of deep character, which separate the megablocks. Faults in the Kraishtide (150–170°) and Yablanitsa (60–75°) systems are mainly of this character.

The Struma fault (150–170°). It has a character of a fault bundle, most frequently covered by Neogenic sediments in grabens of the Struma fault zone (Fig. 2). This cryptorupture passes along the western edge of the Struma graben. It has also the character of a cryptorupture in the Simitli graben. The fault here is a conductor of hot nitrogen hydrotherms. In the Dzherman graben it also represents an outstanding tectonic line, covered by Pliocene sediments and Quaternary deposits.

Northwest of Boboshevo up to the nearby Chitirtsi village, the Struma fault follows the Struma river valley, which forms the Skrina gorge over it in this place. The fault manifests here a stable neotectonic activation – the blocks on both sides had different gradients of uplifting during the Pliocene and the Quaternary (Vrablyanski, 1977). From here towards the Northwest, the fault structure is described as the Poletina fault zone (Boyadzhiev, 1971a), which intersects the Kyustendil fault at the homonymous graben, and it penetrates into Yugoslavia near the Gorno Vino village.

The Struma fault zone enters the conerosional stage of its Quaternary development during the late Holocene, if we pass in silence its brief activation in the Struma graben at the beginning of the Villlafranchian.

The Pirin fault (150–170°). This is the other main fault line of the Struma fault zone, which controlled the sedimentation in the Struma and the Dzherman graben during the Pliocene. In these parts, the fault is characterized by a wide zone of cataclasis. The shearing plane of the structure is variable, but most frequently it is inclined towards the Pirin horst. The subsidence of the Dzherman block, over which molasse sediments are deposited, and the uplifting of the western Rila block to the East are realized along the Pirin fault.

The northeastern continuation of the Pirin fault between the villages of Bistritsa and Klissura displays an oblique orientation towards the Struma fault zone. The Pirin fault enters the conerosional stage of its Quaternary development in the beginning of the Villlafranchian, and terminates the stage within its limits. During the whole Pleistocene and the Holocene, it does not show any signs of tectonic activity. At that time, the region was under the effect of a general uplift. Facets in an initial phase were formed, along the uplifted block, while over the subsided block, in the peripheral parts of the Struma graben, covering gravels were accumulated.

It results from the above statement that the Struma fault zone is limited by the two main longitudinal fault structures – the Struma fault, which separates the Ograzhden-Maleshev block from the Struma graben to the East, and the Pirin fault, which separates the Struma and Dzherman grabens from the Pirin horst to the East. These fault structures are subparallel up to a certain extent and limit the same structural zone: some authors (Boyadzhiev, 1971, a,b, and others) accept them therefore as structures, which are controlled by one and the same deep fault.

The Kyustendil fault (70–75°). It belongs to faults within the Yablanitsa system, which are also typical of the tectonic activation of the Struma fault zone during the Pliocene-Quaternary period. It displays a tectonic activation even before the Pliocene. The Kyustendil graben is formed over the subsided northern block along the fault. Coarse molasse was deposited in it during the Upper Miocene and the Pliocene. In the northeastern direction, the Kyustendil fault connects itself to faults of the same direction, which separate the Radomir field from the Southeast. Its continuation further to the Northeast is probably a typical wrench fault along the Subbalkan fault, towards the North of the town of Klissura (Vrablyanski, 1975).

The Krupnik fault (60–75°). This fault is almost analogous to the Kyustendil fault regarding its direction and activity after the Upper Miocene and during the Quaternary. To the Southwest of this territory, the Krupnik fault originates from the valley of the Struma river. The fault was activated during the Upper Miocene, which is confirmed by the Upper Miocene sediments covering the Simitli graben. However, the activation along the fault proceeded in reality very intensively during the Pliocene and the whole Quaternary. Therefore, the northwestern block, subsided along the fault, is loaded with coarse molasse over 1200 m thick.

The northeastern continuation of the Krupnik fault is constituted by faults in the same direction, which separate the Razlog graben from the Rila block. Further to the Northeast, the Krupnik fault line includes the Yadenitsa-Mesta fault structure, while, in the valley of the Maritsa river, it separates the Upper Thracian graben from the West.

The Krupnik fault is distinctly characterized as a neotectonic structure beginning from the Upper Miocene, continuing during the whole Quaternary to the present time. At the beginning of the Levantinian, the fault enters the conerosional stage. Along its length, a remarkable geomorphologic hiatus becomes evident – the Villafranchian levels and the whole terrace spectrum along the Brezhanska river are missing (Vrablyanski, 1974a, b). On the other hand, new landforms are created along the fault – diluvial-proluvial trains, facets, cut-in valleys. All this gives sufficient evidence to relate the Krupnik fault to those fault structures, whose Quaternary development proceeded very actively during the conerosional stage. These conerosional features characterize it as a fault structure of completed development during the Quaternary.

In the Struma fault zone, in addition to faults in the Kraishtide and Yablanitsa systems, the Balkanide fault system is also present. These are the Belasitsa and the Strumeshnitsa faults (Fig. 2).

The Belasitsa fault (70–90°). It separates the Strumeshnitsa graben from the Belasitsa horst to the south. The shearing plane along the Belasitsa fault is inclined southwards to the massif of the same name. This is also obvious from the location of the Pliocene strata along the Strumeshnitsa river. The most remarkable movements along the fault correspond to the Villafranchian age as it enters the conerosional stage. Since the beginning of the Middle Pleistocene until actual time it manifests complete passivity (Vrablyanski, 1974).

The Strumeshnitsa fault (70–105°). The fault separates the Ograzhden-Maleshev block from the Strumeshnitsa graben to the South. At some localities, it has the character of a cryptorupture. Along the slope near the Purvomay village to the North of the fault, Pliocene sediments in coarse facies are preserved, which suggest movements along it after the Levantinian. The only representative of the Pliocene-Quaternary period of volcanism in the range of the Struma fault zone is connected with the intersection point between the Strumeshnitsa and the Struma faults – the extinguished volcano Kozhukh, of a dellenite composition (Fig. 2).

The volcanic activity of Kozhukh during the Pontian (Vrablyanski, 1971) is also confirmed by the presence of Pliocene pyroclastics in the Struma graben. On the other hand, the absence of high levels from the terrace spectrum of the Struma river along the height of Kozhukh gives the grounds for a manifestation of volcanic activity, even younger than the Pontian. The extinguished volcano Kozhukh was active even during the Quaternary. Evidently, the processes of youngest volcanism in these parts are in a correlative connection with the neotectonic movements along the faults of the Struma fault zone.

Thus, the deep faults played a main part in the structural building of the Struma fault zone during the neotectonic stage. The movements along them create a sharply underlined contrast relief and greatly belevelled megablocks of the Earth's crust. These are faults mainly in the Kraishtide (150–170°) and the Yablanitsa (60–75°) systems, along which differentiated movements were realized during the Pliocene-Quaternary time, distinguished according to duration, sign and intensity of their manifestations.

The longitudinal faults of the Struma fault zone – the Struma and the Pirin faults – belong to the Kraishtide system (Fig. 4). Vertical movements are realized along

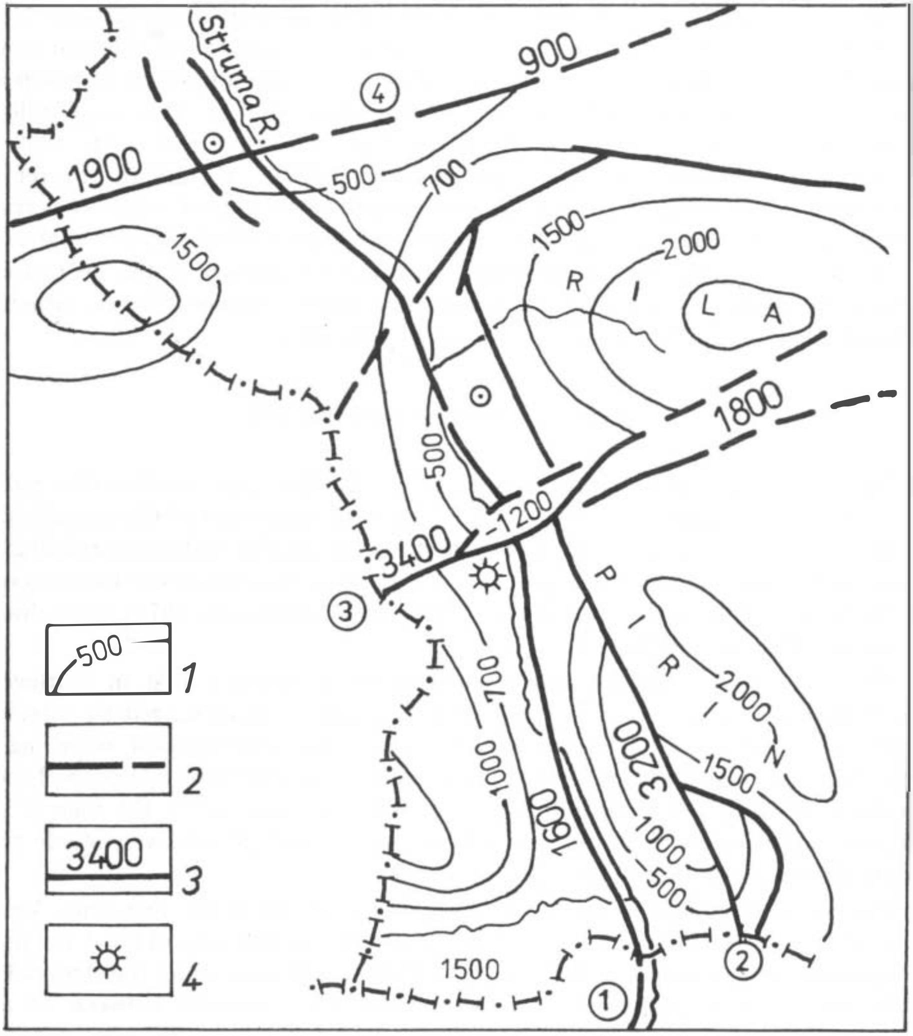

Fig. 4. Neotectonic map of the Struma fault zone. Key: **1** – isolines of total deformations of the initial pre-orogenic surface (orthoplain) during the neotectonic age; **2** – main faults activated during the neotectonic stage; **3** – amplitudes of vertical movements (in metres) along the main faults at the neotectonic stage; **4** – epicentre of earthquake with intensity $I_0 = 10^\circ$ and/or magnitude $M = 7$–8.

the Struma fault and their total amplitude for the neotectonic stage attains 1600 m. In recent ages and at present, the Struma fault displays remarkable seismic activity. Most intensive movements along the Pirin fault were also those taking place during the Pliocene, the total amplitude of which attains, in the Struma graben, 3200 m. Today, this fault does not display any intensified seismic activity.

There are faults in 60–75° directions included in the Yablanitsa system. Most representative of this system are the Krupnik and Kyustendil faults. Vertical movements were also realized along the Krupnik fault, the total amplitude of which attains, for the neotectonic stage in the Simitli graben, 3400 m. This amplitude in a northeastern direction – near the Razlog graben in Rila – is reduced to 1800 m, and further to the East – in the Upper Thrakian graben – to 1200 m. Therefore, the Krupnik fault in the Struma fault zone manifests the highest values of vertical movements in Bulgaria during the Pliocene-Quaternary period. Almost analogous to the Krupnik is the Kyustendil fault. The total amplitude of the neotectonic vertical movements along it in the Kyustendil graben reaches 1900 m, which is reduced to 900 m in the vicinity of the town of Radomir.

5. RECENT VERTICAL MOVEMENTS

The neotectonic stage of development of the Earth's crust involves also recent vertical and horizontal movements. The correct co-ordination of the quantitative geodetic data, on one hand, with the qualitative geological and geomorphological data, on the other, enabled a map of recent vertical movements of the Earth's crust in the Struma fault zone (southwestern Bulgaria, Vrablyanski, 1971) to be drawn by means of isobases (Fig. 5).

The analysis of recent vertical movements of the Earth's crust in southwestern Bulgaria indicates that this part of the country is characterized by a regime of intensified mobility and recent vertical movements differentiated according to sign, duration and intensity. Three zones can be separated here: (1) zone of most intensive uplifting (with absolute velocities above $+3\ mm.yr^{-1}$), (2) zone of less intensive uplifting (between +2 and $+3\ mm.yr^{-1}$), and (3) relatively stable zone (with absolute velocities below $+2\ mm.yr^{-1}$).

The region of Dospat in the western Rhodopes belongs to the first zone. Velocities of up to $+5.9\ mm.yr^{-1}$ are typical of it. This is the zone of most intensive recent vertical movements in Bulgaria. The Pirin, the Belasitsa and the Ograzhden-Maleshev mountains belong to the zone with absolute velocities between +2 and $+3\ mm.yr^{-1}$. As seen from the map, isobase +2 follows almost everywhere the recent outlines of these morphostructures. The Kresna threshold is also clearly outlined with the isobase of $+2\ mm.yr^{-1}$. The Neogenic grabens along the Struma river are mainly referred to the relatively stable zones with absolute velocities below $+2\ mm.yr^{-1}$. The isobase of $+1\ mm.yr^{-1}$ outlines the lowest parts of the recent relief of valleys, which correspond to the sections with useless alluvium and marshlands.

The map of recent vertical movements indicates that they are a direct reflection of the main neotectonic structures and of their tendencies towards uplifting, stabilization, or slow subsidence. The change of signs corresponds most frequently to the locations of big faults, activated during the Pliocene-Quaternary time. This is obvious in the Struma fault zone. On the other hand, localities with useless alluvium and marshlands along it in the middle Struma valley, which reflect the trends towards subsiding since the middle of the Holocene, coincide with the lowest values of recent vertical movements. In spite of the general correspondence between the map of velocities of recent vertical movements and the map of neotectonic lineaments, some local discrepancies between them still exist, which is entirely natural and completely logical. For example, the Rila block, located between the Struma fault zone, the Krupnik and Maritsa faults, manifests the most intensive total

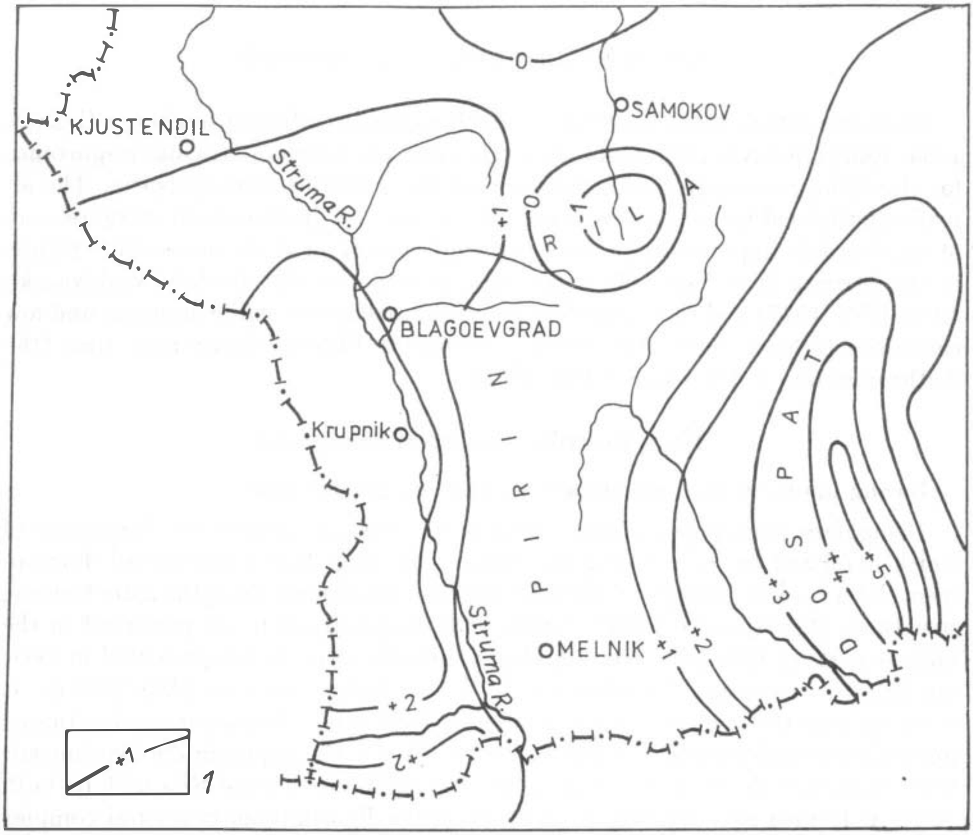

Fig. 5. Sketch of recent vertical movements of the Earth's crust in southwestern Bulgaria. Key: 1 – isolines of the velocities (in mm . yr^{-1}) of recent vertical movements of the Earth's crust.

uplift in Bulgaria during the neotectonic stage. The faults, which surround it, also display the largest total amplitudes of movements for the Pliocene-Quaternary period. However, the velocities of recent vertical movements in this block are of negative values, reaching almost -2 mm . yr^{-1}. This and other examples from the country indicate that the velocities of recent vertical movements of the Earth's crust are not maintained at the same values for longer periods of time.

An interesting example in this respect is the Dospat Massif (western Rhodopes), where recent uplifting is most intensive – with velocities reaching $+5.9$ mm . yr^{-1}.

If these movements with such an intensity had existed during the whole Quaternary (even if reduced to one million years), then Dospat, which is now at 1200 m altitude above sea level, would have to be raised today to more than 5900 m. Consequently, recent vertical movements of the Earth's crust change in the course of time not only in their intensity, but in their sign as well. The uplifting of Dospat with velocities of up to $+5.9 \text{ mm} \cdot \text{yr}^{-1}$ spatially coincides with the maximum thickness of the Earth's crust in Bulgaria (42–46 km) along the Moho boundary (Bonchev, 1969).

6. GEOMORPHOLOGICAL INVESTIGATIONS

These investigations in the Struma fault zone and the adjacent territories (Ivanov, 1954, 1959; Glovnya, 1959; Gulubov *et al.*, 1960, etc.) are of particular importance for clarifying general geomorphological features of southwestern Bulgaria. The already specialized investigations of the neotectonic morphostructural categories are of considerable importance for the correct interpretation of the neotectonic regime in the Struma fault zone. Recently, they were genetically divided (Vrablyanski, 1970, 1971, 1977) and were considered as high (orthoplain and pediments) and low categories (terrace spectrum), formed during the Pliocene-Quaternary time (the Anthropogeian, in the sense of Kat, 1972).

High morphostructural categories

Basing upon our own investigations, they are divided into:

Orthoplain (initial peneplain). This is the primary surface, the formation of which is related to the pre-orogenic stage. This stage had a widespread development, later broken through by intensive tectonic movements along the main tectonic structures (Vrablyanski, 1974). Today, only fragments of it are preserved in the highest parts of Rila, Pirin, the Rhodopes, Belasitsa, etc. It is represented in western Rila by two stages (Vrablyanski, 1977). The higher one is at 2400–2600 m. It occupies only the highest belevelled parts of Malyovitsa. The lower one is situated immediately underneath – at 2200–2300 m. This is the approximate hypsometric level of most of the High Rila Lakes. The orthoplain in western Rila with its both stages is formed over crystalline schists from the Precambrian structural complex as well as over Caledonian-Hercynian granitoids.

Pediments (Pyotrovski, 1964) are steps in the relief, formed during the neotectonic stage of the process of orogenic development. Three pediment levels were determined in the western parts of Rila, in Pirin, Belasitsa and the Ograzhden-Maleshev Mountains.

Pediment I is determined at different altitudes above sea level. In northwestern Rila, it is raised at the altitude of 2100–2450 m, sheltered to the North by the seven Rila Lakes. In western and southwestern Rila, the pediment is situated at a lower hypsometric level – 1900–2200 m. In Pirin, it lies at an altitude of 2200–2300 m, in Belasitsa – at 1600–1800 m, and in the Ograzhden-Maleshev Mountains – at 1400–1600 m.

Pediment II is more broadly developed. This level follows generally the distribution of pediment I, occupying higher parts of the slopes of river valleys, cutting into them up to their springs. This level also shows considerable hypsometric differences. Its highest uplift is in northwestern Rila, where it is established at 1400–1800 m. In western Rila it nearly stands at its lowest limit, while in southwestern Rila it again rises and reaches 1600 m. In Pirin it lies at the altitude of 1250–1750 m, in Belasitsa – at 1100–1300 m, and in the Ograzhden-Maleshev Mountains – at 900–1100 m.

Pediment III has a more limited development in Rila and a broader one in the other considered mountains. This morphostructural level is almost everywhere located between Pediment II and the main fault structures activated during the Pliocene. It is established at different altitudes above the sea level, while a subsiding trend of the level from Northwest to Southeast is observed in Rila. In this way, in northwestern Rila it lies at 1050–1350 m, in western Rila it is at 1100–1300 m, and in southwestern Rila the level does not exceed 1200 m. In Pirin it lies at 800 to 1150 m, in Belasitsa at 760–900 m, and in the Ograzhden-Maleshev Mountains at 600–800 m.

This situation of the morphostructural level, at which its higher parts have a denudational origin, while the lower ones pass into the accumulative Upper Levantinian level, gives us enough grounds to consider it as polyfacial.

All the three high morphostructural categories, which were already mentioned, as well as the orthoplain, are cut into the rocks of the Precambrian structural complex – Archean and Proterozoic, into the rocks of Caledonian-Hercynian granitoids, into the Struma diorite formation, into the diabase phyllitoid formation, and into the Triassic sediments.

Villafranchian levels of glaci type. To the high morphostructural categories are also referred the Villafranchian levels of the glaci type. It is well known that pediments are formed over hard rocks at a determined tectonic regime. The scientists stand on almost the same grounds, when they launch the idea about the foothill surfaces, formed over soft and unstable rocks and called "foothill surfaces of glaci type". Thus, the idea of the glaciplanation of the slope was created, an important condition for which is the presence of soft unstable substratum.

The foothill surfaces of glaci type are well established in Bulgaria, too (Vaptsarov, 1975; Vrablyanski, 1977). They are described as Villafranchian levels (Vrablyanski, 1970), which shall now be named Villafranchian levels of glaci type. Hypsometrically, they are developed between the Levantinian pediment III and the highest terrace level of the Struma river basin.

First Villafranchian level of glaci type. In western Rila it is determined at 800 to 1000 m, in Pirin at 460–800 m, in Belasitsa at 450–620 m, and in the Ograzhden-Maleshev Mountains at 400–550 m. It has almost everywhere an erosional-denudational character. It is cut into most places of the Pliocene accumulation surface.

Second Villafranchian level of glaci type. It is determined between the above described first Villafranchian level and the highest terrace levels of the Struma river and its bigger tributaries. It cuts into the late Pliocene accumulation surface. In western Rila, this level is established at 500–600 m, in Pirin at 350–550 m, in Belasitsa this Villafranchian level is lacking, and in the Ograzhden-Maleshev Mountains it is found at 160–320 m (Vrablyanski, 1970).

Low morphostructural categories

The terrace levels of old valley bottoms of rivers (terrace spectrum), formed during the Quaternary are referred here. Their detailed investigation enabled the values of the neotectonic movements during the Quaternary to be traced. Different instrumentational methods were exercised in the field (Vrablyanski, 1977) to this purpose.

Fragments of six above-flood plains and one flood plain terrace are determined along the Struma river within the range of the Struma fault zone. Our investigations indicate that remarkable differences exist in the hypsometric location of all terrace levels on both sides of the Struma river and its bigger tributaries. These data show that in the space between the terrace spectra on both sides of the rivers, fault structures are present with clearly underlined tectonic activation during the Quaternary. These fault structures have developed during the Quaternary also clearly delimited blocks of different intensity and manifestation.

Morphostructural and hypsometrical data of the high neotectonic morphostructural categories indicate that the intensity of neotectonic movements in separate blocks of the Struma fault zone and in their distinct parts was different during the Pliocene. Its highest values are encountered in western Rila and Pirin and lower ones in Belasitsa and the Ograzhden-Maleshev Mountains, respectively. Another feature, which the high morphostructural categories display, is their different vertical distance from one another in each of the considered mountains. Their location indicate that the neotectonic movements with a positive sign at the beginning of the Pliocene have proceeded more intensively than at the end of the Pontian and during the Levantinian. This is in complete correspondence with the character of sediments in the grabens, which are correlated to the orthoplain and the pediments. After the Levantinian, however, when the Villafranchian levels are formed, the uplifting intensity is again increased. Then the Upper Levantinian sediments were uplifted along faults: in the Ograzhden-Maleshev Mountains to 650 m, and higher in Rila, Pirin and Belasitsa, respectively. This is the period of most intensive neotectonic movements in the Struma fault zone.

The analysis of the low morphostructural categories (terrace spectrum) along the Struma river and its tributaries in the Struma fault zone enables us to make some conclusions about the motion of the youngest tectonic movements during the Quaternary. It indicates that, during the Pleistocene, the Struma fault zone was enveloped by a general rhythmic uplift, during which a terrace spectrum with a total vertical effect up to 100 m was formed. During the late Holocene, however, when the flood plain with the useless alluvium along it was formed, the old tendencies towards subsiding awoke again, in the Struma fault zone, with a total effect of up to 20 m.

The Quaternary development of the main faults in the Struma fault zone, which is closely connected with the recent tectonic activation, was dated even more precisely, when the conerosional method was applied (Vrablyanski, 1974 a,b). In this way, the tectonic activation of the Struma, Pirin, Belasitsa and Krupnik faults of the Struma fault zone during the Quaternary has been clarified.

It has been established, in connection with these investigations, that the Struma fault was activated at the beginning of the Villafranchian and during the beginning and the middle of the Holocene; the Pirin fault – only during the beginning of

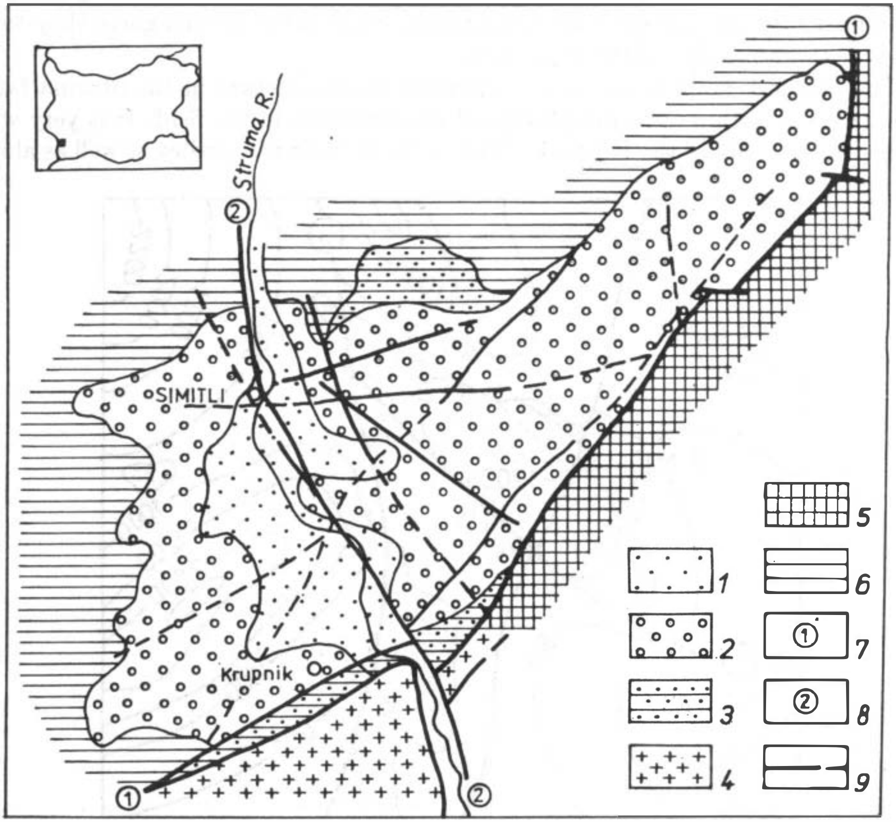

Fig. 6. Geological map of the Krupnik tectonic knot in southwestern Bulgaria. Key: 1–3 – sediments of 1 – the Quaternary, 2 – the Pliocene, 3 – the Oligocene ages; 4 – granitoids; 5 – Proterozoic metamorphites; 6 – Archean metamorphites; 7 – the Krupnik fault; 8 – the Struma fault, 9 – other faults.

the Villafranchian; the Belasitsa fault – during the Villafranchian and the Lower Pleistocene; the Krupnik fault – a complete Quaternary activation, which starts at the beginning of the Villafranchian, and continues without interruption through the whole Pleistocene and Holocene till the present time.

The Struma fault belongs to the most important fault lines in the Kraishtide direction. In the Simitli graben, it has the character of a cryptorupture. There, it crosses both the basement and the Neogenic sediments. Young vertical movements are present along it with total amplitude of up to 280 m, causing the Eastern block to subside. In the Kresna gorge, the fault is represented by subparallel fault structures of a 170° direction. This is well marked by a tectonized zone in the Proterozoic rocks and granites (Vergilov *et al.*, 1963; Zagorchev, 1968). These and other data indicate that the most important movements along the Struma fault in the Simitli graben during its last development stage occurred at the beginning of the Upper Miocene and after the Levantinian, while in the Kresna gorge they took place at the beginning of the Pleistocene.

The Krupnik fault is the most remarkable fault structure in the Struma fault zone (Fig. 6) with a clear morphological manifestation in the field. It is very well traced to the south of the Krupnik village in the Struma river valley as well as along

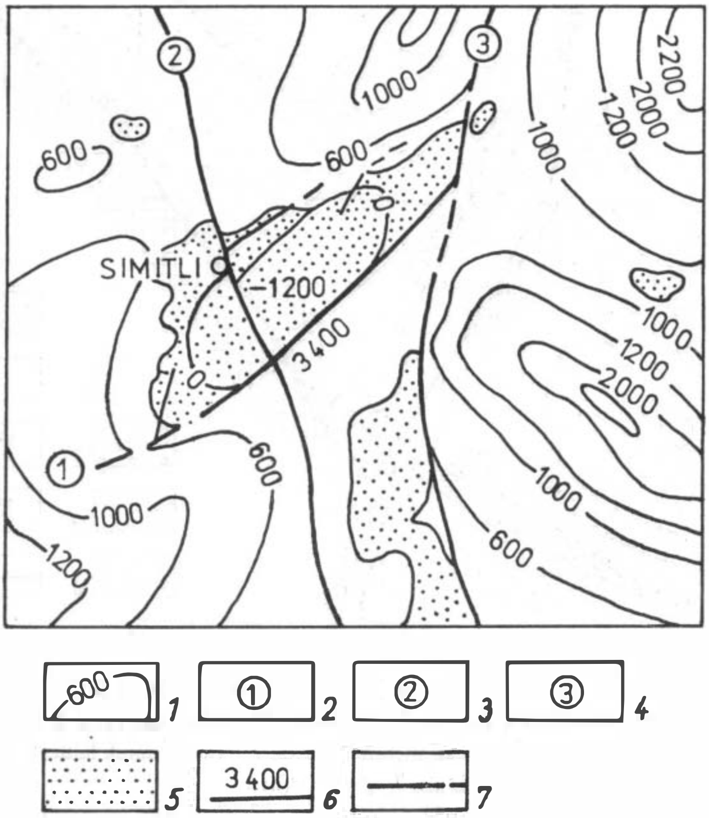

Fig. 7. Neotectonic map of the Krupnik tectonic knot (southwestern Bulgaria). Key: **1** – isolines of total deformations of the pre-orogenic surface (orthoplain) during the neotectonic stage; **2–4** – more important faults activated during the Pliocene-Quaternary period (**2** – the Krupnik fault; **3** – the Struma fault, **4** – the Pirin fault); **5** – localities of the Pliocene molasse sedimentation; **6** – amplitude of vertical movements along the Krupnik fault during the neotectonic stage; **7** – other faults.

the foot of the Kocho elevation (the amphibolite threshold). Along the fault plane, the granite is strongly crushed there and is altered to tectonic clay. According to bore hole data, in the Simitli basin nearby the Krupnik fault, another fault structure subparallel to the Krupnik fault is discovered which also crosses the foundation of the basin. Thus, the Krupnik fault has to be comprehended here as a complex rupture, into which at least two more subparallel faults are included and which is cut by transverse faults. As a neotectonic structure, the Krupnik fault was rejuvenated at the beginning of the Upper Miocene (Kamenov *et al.*, 1965) and continues to act through the Pliocene and the Quaternary. However, as a rupture of outstanding manifestation it was not formed before the end of the Levantinian and most of all during the Lower Pleistocene.

The morphostructures in the investigated region formed during the neotectonic stage manifest therefore a certain individuality. The analysis of the high and low morphostructural categories as well as of the fault strucutres allows us to point out their above-stated features (Fig. 7).

The Simitli graben represents a neotectonic structure formed during the Upper Miocene over a block subsiding along the Krupnik fault, which is now its southeastern boundary. Thus, for the period since the Upper Miocene till today, the Simitli graben displays a maximum subsidence of over 1400 m, while for the Pliocene – 1200 m.

7. CONCLUSIONS

The Struma fault zone is considered until the Neogene, a zone of conjunction of the Kraishtides with the Rhodope Median Massif. At the end of the Upper Miocene the initial pre-orogenic surface (orthoplain) in these parts swells, and forming of the big morphotectonic Struma arch is achieved. Later, the Struma arch subsided along its apical part and broke apart into separate blocks with different (in sign) tectonic trends. The Struma fault zone is formed over the sunken block along the line of the deepest subsiding of the arch. In it, along deep faults of old predestination and lasting development in the Kraishtide (150–170°) and the Yablanitsa (60 to 75°) systems, Neogenic grabens filled with coarse upper mollasse are formed. The youngest volcanism in Bulgaria of the Pliocene-Quaternary age was of dellenite composition and was connected to the Struma fault together with a seismic focus of high intensity.

At the intersection point of the Struma deep fault in the Kraishtide direction (160°) and the Krupnik deep fault in the Yablanitsa direction (60–75°), within the Struma fault zone, during the Upper Miocene a first-order tectonic knot – the Krupnik knot – was formed. In its southern parts, the strongest (till now) earthquake on the Balkan Peninsula – the Kresna earthquake of the 10th degree according to the MK-1964 scale (magnitude 7.8) – was recorded in 1904. The Krupnik tectonic knot is marked on the surface by the deep Simitli tectonic graben, filled in with Neogene-Quaternary mollasses of remarkable thickness. Along the Struma fault, a multitude of springs with hot nitrogen thermo-mineral waters, coming from a great depth, are piped. Along the Krupnik fault in the range of the Struma fault zone, the most remarkable Pliocene-Quaternary vertical movements in Bulgaria took place. During the Quaternary in the conditions of the conerosional relief, the fault manifests permanent-impermanent tectonic activation.

REFERENCES

Boyadzhiev, St. (1971a). Struma fault zone, in *Tectonic development of Bulgaria,* Tekhnika, Sofia (in Bulgarian).

Boyadzhiev, St. (1971b). West Rhodopian block, in *Tectonic development of Bulgaria,* Tekhnika, Sofia (in Bulgarian).

Bonchev, E. (1969). What is the thickness of the Earth's crust in Bulgaria, in *Universe,* Sofia, Nauka i Iskustvo (in Bulgarian).

Bonchev, E. (1971). *Problems of the Bulgarian geotectonics,* Tekhnika, Sofia, 204 pp. (in Bulgarian).

Glovnia, M. (1959). Geomorphological investigations in the southwestern part of Rila mountain, *Ann. Sofia Univ., Biol.-Geol.-Geogr. Faculty,* 51, 2, Geography (in Bulgarian).

Gulubov, Z., K. Mishev, and V. Popov (1960), The terraces along the valley of Struma river between the gorges of Kresna and Rupel, *Bull. Geogr. Inst., Bulg. Acad. Sci.,* VI (in Bulgarian).

Ivanov, I. (1954). Geomorphological investigations in the western part of NW Rila, *Bull. Geogr. Inst.* 2 (in Bulgarian).

Ivanov, I. (1959). Geomorphological investigations in the middle part of Djerman river-Gorno pole, in *Sympos. in Honor of Acad. A. Beshkov,* Bulg. Acad. Sci., Sofia (in Bulgarian).

Kamenov, Bl., V. Konstantinova, and B. Yordanov (1965). Geology and coal-bearing of the Oranovo-Simitli Tertiary Basin, *Rev. Bulg. Geol. Soc.* XXVI, 1 (in Bulgarian).

Kat, N. (1972). The problem of distinguishing the stages of formation of the Earth's crust, *Bull. Acad. of Sci. USSR, Ser. geol.,* 9 (in Russian).

Pyotrovsky, M. (1964). On the problem of pediment formation, in *Problems of levelling surface,* Nauka, Moscow (in Russian).

Vaptsarov, I. (1975). Floorlike foothill surfaces of "glaci" type, *Problems of Geography,* 1, 2 (in Bulgarian).

Vergilov, V. *et al* (1963). Notes on the Prepaleozoic metamorphic complexes in the Rhodope Massif, *Bull. Geol. Inst.,* 12 (in Bulgarian).

Vrablyanski, B. (1970). Neotectonic level in the middle Struma basin, *Bull. Geol. Inst., Ser. Geotect.,* 19 (in Bulgarian).

Vrablyanski, B. (1971). Neotectonics of the middle Struma valley, *PhD. Thesis,* Geol. Inst., Bulg. Acad. Sci. (in Bulgarian).

Vrablyanski, B. and G. Milev (1973). Investigation on recent vertical movements of small crustal blocks in the Kresna gorge, *Bull. Geol. Inst., Ser. Geotect.,* 21–22 (in Bulgarian).

Vrablyanski, B. (1974a). Conversional stage in the Quaternary development of some faults of southwestern Bulgaria, *Bull. Geol. Inst., Ser. Geotect.,* 23 (in Bulgarian).

Vrablyanski, B. (1974b). Neotectonic investigations in the Simitli graben and its frame, *Bull. Geol. Inst., Ser. Geotect.,* 23 (in Bulgarian).

Vrablyanski, B. (1975). On the neotectonic activation of fault structures in Bulgaria, *Geotect., Tectonophys. and Geodyn.* **2** (in Bulgarian).
Vrablyanski, B. (1977). Neotectonic regime in the Struma fault zone to the North of the town of Blagoevgrad, *Geotect., Tectonophys. and Geodyn.* 7 (in Bulgarian).
Vrablyanski, B. (1981). Tectonic predestination of recent vertical crustal movements in Bulgaria, in *4th Intern. Symp. Geodesy and Physics of the Earth, GDR, Karl-Marx-Stadt, May 12–17, 1980, Proceedings* III, Potsdam (in Russian).
Zagorchev, I. (1968). Tectonics of Vlakhina and part of Ograzhden block, *PhD. Thesis,* Geol. Inst., Bulg. Acad. Sci. (in Bulgarian).

NEOTEKTONICKÉ RYSY STRUMSKÉ ZLOMOVÉ ZÓNY

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V práci jsou předloženy výsledky morfotektonického výzkumu Strumské zlomové zóny v jihozápadním Bulharsku. Tato vysoce seismicky aktivní a hluboká zlomová zóna vznikla pravděpodobně v neogénu a její variabilní geodynamický režim je zřetelně vyjádřen jak v geologické stavbě, tak rozsahem změn reliéfu grabenového typu. Podrobně jsou popsány hlavní etapy geomorfologického vývoje Strumské zlomové zóny a jejich vztah k projevům recentní tektonické aktivity.