MAIN FAULT ZONES CONTROLLING THE LATE ALPINE STRUCTURE IN THE AREA EAST OF SOFIA (SREDNOGORIE ZONE, WESTERN BULGARIA)

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ABSTRACT. The northwestern narrow tip of the Upper Cretaceous Panagyurishte sedimentary strip is cropping out along the eastern-north-eastern margin of the Neogene Sofia graben. In this area the sedimentary strip is split in two parts separated by an uplifted pre-Upper Cretaceous basement block. Both parts show syncline geometries with cores built of Upper Cretaceous rocks. The synclines are striking NW-SE and are extremely asymmetrical with vertical to overturned southwestern limbs. Within the overturned limbs meso-scale structural features such as imbrications, folds and small-displacement faults indicate strong flattening of the rock volume under generally top-to-the-N shear. These features were observed along the Kamenitsa-Rakovishki and Negushevo fault zones. Due to the relatively poor outcrop conditions the precise dips of these fault zones are still poorly known and there are no data about the fault cores. Thus, the general north-vergent character of the both fault zones is assumed on the basis of the semi-penetrative small-scale structures within their immediate footwalls and field relations. Our new data suggest that the northward translations along the Negushevo fault zone resulted in formation of approx. 30 long and 2 km wide basement uplift.

Keywords: Late Alpine tectonics, fault zones, Upper Cretaceous, Srednogorie

ГЛАВНИ РАЗЛОМНИ ЗОНИ КОНТРОЛИРАЩИ КЪСНОАЛПИЙСКАТА СТРУКТУРА В РАЙОНА НА ИЗТОК ОТ СОФИЯ (СРЕДНОГОРСКА ЗОНА, ЗАПАДНА БЪЛГАРИЯ)

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РЕЗЮМЕ. В източната и североизточна периферия на неогенския Софийски грабен се разкрива северозападният завършек на горнокредната Панагюрска ивица. На изток тя има монолитен характер, докато на запад (в изследвания район) е разделена на две части от издигнат блок на до-горнокредната подложка. И в двете части на ивицата пластовете на пост-херцинската подложка оформят синклинални гънки с ядра, изпълнени от горнокредни седименти. Синклиналите са с посока на осите NW-SE и са силно асиметрични с вертикални или преобърнати югозападни бедра. В тези гънкови бедра мезомащабни структури като имбрикации/дуплекси, гънки и малкоамплитудни разломи индикират силно изтискване на разреза и насочени към север срязвания. Регионално проявеното преобръщане или вертикализирането на разрезите, както и формирането на мезомащабните структури свързваме с транслациите по Каменишко-Раковишката и Негушевската разломни зона. Поради относително слабата разкритост, установяването на точния наклон на тези зони е невъзможно, а също така няма данни за строежа и особеностите на разломните ядра. Поради това северновергетният характер на тези две разломни зони се мотивира на базата на наличието на почти проникващите мезомащабни структури в обемите на техните непосредствени лежащи блокове, както и на някои теренни данни. Вероятно северно насочените транслации по Негушевската зона са довели до формирането на издигане на фундамента, приблизително 30 km дълго и 2 km широко, което е довело до разделянето на горнокредната ивица на две части.

Ключови думи: късноалпийска тектоника, разломни зони, Горна Креда, Средногорие

Introduction

Economically important Upper Cretaceous rocks, part of the large Apuseni-Banat-Timok-Sredna Gora volcano-sedimentary belt (Gallhofer et al., 2015), is traced from the area of the town of Panagyurishte to the NE margin of the Neogene Sofia graben in Western Bulgaria. Known as Panagyurishte strip (Bončev, 1940), this belt incorporates Upper Cretaceous sediments, volcanic and magmatic rocks as well as locally uplifted blocks of pre-Upper Cretaceous basement. All rocks are often strongly deformed and since the pioneering works of Poushkarov (1927) and Dimitrow (1936) the presence of upright regional-scale folds is well-documented. While in the area of Panagyurishte the Upper Cretaceous rocks form a coherent unit, to the NW, the Panagyurishte strip is split into two branches separated by the uplifted prominent basement block (Fig. 1). Two important tectonic zones are marking the southern margins of both branches. The aim of the current contribution is to re-evaluate their character and significance on the basis of new structural studies and tectonic analysis.

Geological setting

Key elements of the Alpine structures cropping out along the eastern margin of Neogene Sofia graben are NW-SE to E-W trending fault zones that juxtapose pre-Alpine basement to the rocks of the Cretaceous cover. The northern zone is Negushevo fault zone (Bontscheff, 1910) while the southern one is known as Kamenitsa-Rakovishki fault zone (Fig. 1; Poushkarov, 1927; Bončev, 1940; Iliev, Katskov, 1990;

Katskov, Iliev, 1993). Despite the fact that they have been known for about a century (Poushkarov, 1927; Ivanov, 1940; Bončev, 1940) and detailed geological mapping was done in the area (Tzankov, 1961), almost nothing is known about their exact geometry and kinematics. Since the earliest studies it has been suggested that these main fault zones are rather steep to almost vertical. Without providing new structural data Angelov et al. (1992; 1995) interpreted them as reverse faults and drew highly mobilistic picture of extremely imbricated thrust stack. Another model was suggested by Ivanov (1998, 2017) who reinterpreted Kamenishko-Rakovishka zone as a major strike-slip fault.

In the study area the pre-Alpine basement consists of several Variscan units, whereas the high-grade gneiss-dominated unit has the largest areal extent (Pirdop gneiss complex – Angelov et al., 2010c, d; Central Srednogorie High-grade Metamorphic Complex – CSHGMC – this work).

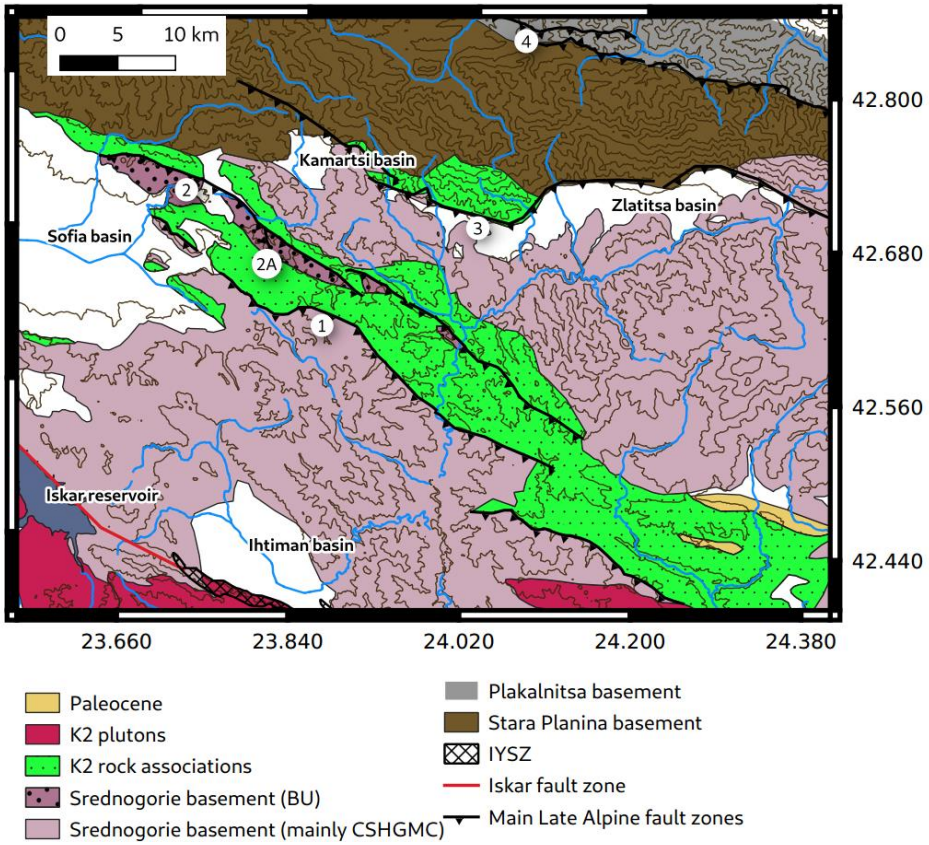

Fig.1. Tectonic sketch of a part of the Srednogorie Zone east of Sofia
Numbers: *1*, Kamenitsa-Rakovishki fault zone; *2*, Negushevo fault zone; *2A*, Upper imbricate of Negushevo zone, south of Makotsevo village; *3*, Mirkovo fault zone; *4*, Plakalnitsa fault zone. Abbreviations: *BU*, Basement Uplift; *CSHGMC*, Central Srednogorie High-Grade Metamorphic Complex; *IYSZ*, Iskar-Yavorishka Shear Zone

This unit is tectonically covered by a low-grade Frolosh unit which in the studied area consists mainly of "green rocks" – various in composition and fabric metabasic rocks. The uppermost position in the Variscan basement is built of weakly metamorphosed sediments – metapelites, metasiltstones and quartzites. Based on lithological similarities these rocks are considered as part of the Ordovician Grohoten Formation (Angelov et al., 2010c, d).

Triassic and Jurassic rocks are locally preserved. Details about Upper Cretaceous stratigraphy can be found in Angelov et al. (1992), Sinnyovsky (2005) and Angelov et al. (2010c, d).

Preliminary tectonic analysis and preparation for field work

Initial desktop GIS-based study was conducted as a first step of our research. We analysed all available map and cross-section data and they were incorporated into a GIS project. The geological data were cross checked against satellite and aerial imagery, thus allowing to delineate properly some geological boundaries. Since no precise descriptions about the dips of the main fault zones are available, geometric calculations were applied using three point problem method of the GeolMapDataExtractor software (Allmendinger, Judge, 2013).

The main results of this initial analysis are the following: 1) Remote sensing analysis clearly indicates that the existing geological maps (Angelov et al., 1992; Angelov et al., 2010a, b, c, d) do not show the real aerial extent of the Quaternary deposits. And this was confirmed via ground-truth collected data that also indicate that the aerial extent of the Miocene-Quaternary cover is much larger. The presented map (Fig. 2) is an attempt to show the real distribution of pre-Miocene basement. 2) Data analysis allow to propose synthesis of Late Alpine tectonics of the area (presented below) 3) Areas were delineated, where good outcrop can be expected to provide the necessary structural data.

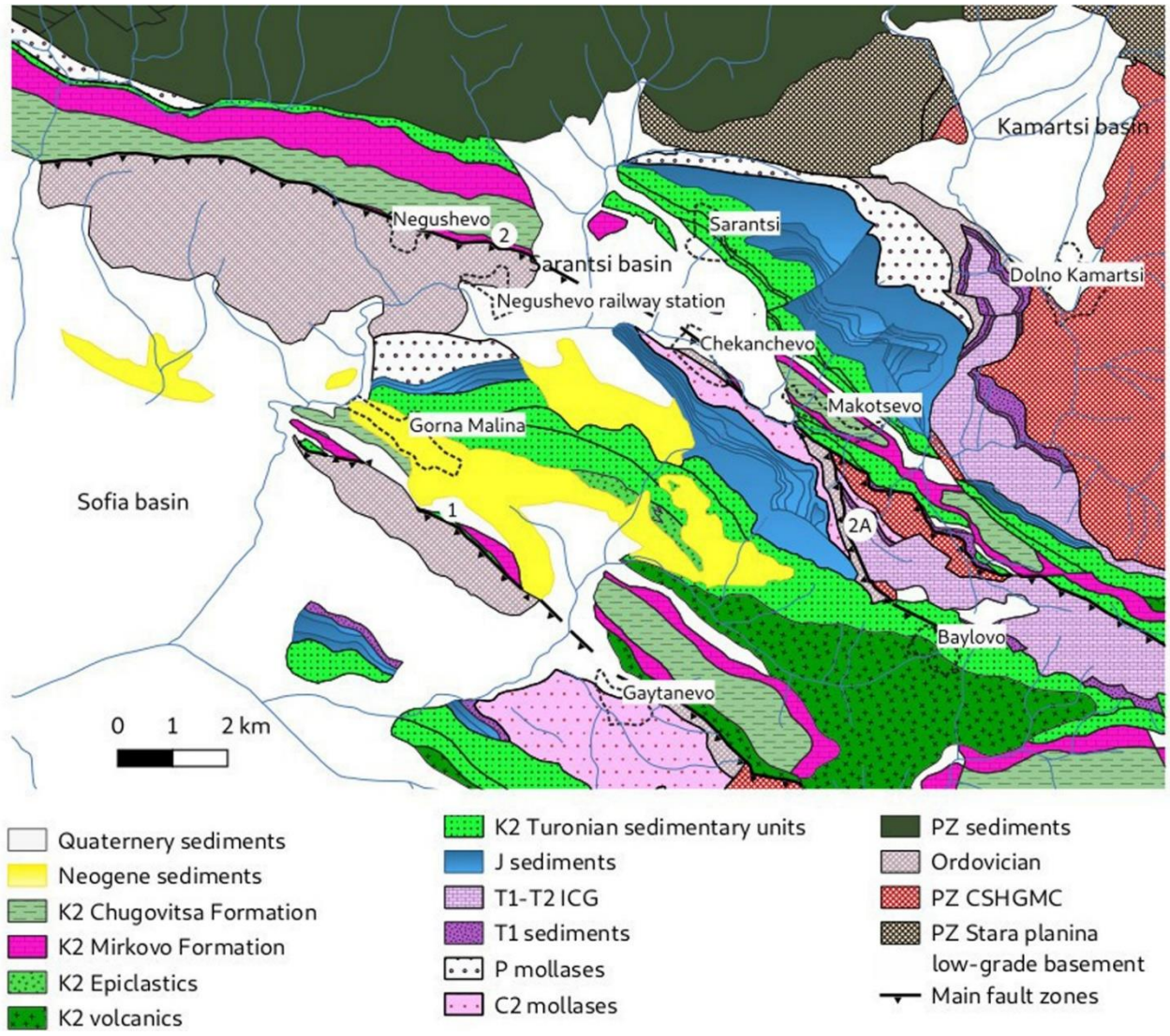

Fig. 2. Geological map with simplified stratigraphy and fault network
Numbers: *1*, Kamenitsa-Rakovishka fault zone; *2*, Negushevo fault zone; *2A*, Upper imbricate of Negushevo zone. Abbreviations: *CSHGMC*, Central Srednogorie High-Grade Metamorphic Complex

Field data

Situated at the margin of the Neogene Sofia graben, large part of the area is covered by Miocene and Quaternary sediments and their basement is cropping out sporadically, with the exception of the southern foot of Stara Planina Mountain. Field work was conducted along several profiles, oriented orthogonal to the strike of the main fault zones.

Kamenitsa-Rakovishki fault zone

In the studied area this zone is marked by the contact between the Ordovician basement and Upper Cretaceous rocks. Due to poor outcrop conditions it is impossible to observe the exact contact. The trace of the zone can be approximately mapped using sporadic outcrops and floating pebbles in the soil. Following its trace on the map and considering the steep dip of the Upper Cretaceous sediments it could be suggested that it is steeply dipping to the S. Only in one locality, SW of the village of Gorna Malina (E 23.68186, N 42.69218), the contact can be observed. Here, the Ordovician quartzites are juxtaposed to the Turronian sandstones along almost vertical contact. Unusually, strain localisation was not observed either on the very contact or within 2–3 metres of both sides of the contact.

Numerous structural data indicate that the Upper Cretaceous rocks from the footwall record strong shortening. On outcrop-scale this is marked by presence of cm-metre scale folds, often pronounced cleavage and presence of small-scale crosscutting bedding faults. Very informative outcrops were studied in the area SW of the village of Gorna Malina. Here Ordovician rocks are in contact with Turronian sandstones, siltstones and sandy limestones. Siltstones are penetratively cleaved and in some levels shallowly dipping to the S, SW, striated fault planes are rather common. They strongly resemble S1-C' fabric (Fig. 3).

Calcite fibres, as well as deflections of the cleavage toward the fault planes, indicate top-to-the N, NW sense of shear. In other cases (Fig. 4) striated fault planes are parallel to the penetrative cleavage. In rare cases, again in weaker siltstone lithologies, imbricated or duplex structures, indicating top-to-the N, NW shear are observed.

Fig. 3. Strongly cleaved (S1) sandstone with numerous shallow dipping to SW shear surfaces (white arrows) indicating top NW shear (E 23.68263675, N 42.69177306)

Fig. 4. Penetrative cleavage within siltstones and striated fault planes (arrows). Same locality

North of the village of Gajtanovo the immediate footwall of Kamenishko-Rakovishka zone is built by pinkish limestones belonging to the Mirkovo Formation. Bedding measurements indicate presence of decametre-scale tight upright folds with subhorizontal axes, trending parallel to the fault zone and axial planes being either vertical or steeply dipping to the S, SW. In an old excavation a mesoscale fold illustrates well this style of deformation (Fig. 5).

Fig. 5. Upright fold with axes 320/5. North of Gaytanevo village

Negushevo fault zone

In the area of Negushevo village the zone is traced along the contact between the Ordovician low-grade metasediments and the Upper Cretaceous sediments. North of Negushevo railway station the Ordovician succession is represented by greenish phyllites and grey, fine grained quartzites. Unfortunately, in the massive quartzites bedding and foliation have not been recognized. In the vicinity of the contact foliation the phyllites are dipping steeply (60–78°) to the S. Closer to the contact, the Upper Cretaceous sequence is represented by the red limestones of the Mirkovo Formation. The only place where close relations between the Ordovician and the Upper Cretaceous sediments can be observed is a section along the road to Negushevo village that continue along unpaved road (E 23.71998, N 42.72370). There the Ordovician phyllites are steeply dipping to the S. At the beginning of the unpaved road grey quarzites are cropping out. About 2 m northward (after an interval covered by soil and debris), below the Ordovician quartzite, strongly cleaved Upper Cretaceous red limestones are cropping out, whereas the contact between the two units was not observed. Cleavage is dipping steeply 70–80° to the south.

Eastwards, after being covered by the thin Quaternary cover of Sarantsi graben, the fault zone re-emerges in the SE outskirts of the village of Chekanchevo. Here, the Ordovician quartzites form spectacular outcrop just S of the centre of the village. On the easternmost margin of the village the Ordovician phyllites build the top of a small hill. Down-slope, to the north, after several metres covered interval there are outcrops of grey marly limestones, probably belonging to the Mirkovo Formation (E 23.77855, N 42.70023). The primary bedding is not recognizable as the main fabric is penetrative cleavage with steep (75°) dip to the S. These relations unambiguously indicate that the fault zone is steeply dipping to the S.

Further eastward the geometry of the fault zone is more complicated and it is represented by a splay of two or three stacked imbricates. Here, in the area south of Makotsevo village, field data, as well as calculation made by GeolMapDataExtractor software suggest that the Variscan basement (Ordovician rocks and CSHGMC) structurally overlie, along moderately dipping to the S (SW) contact, different units of the Upper Cretaceous succession. The upper thrust slab (labelled 2A in Fig. 1 and 2) is characterised by

normal stratigraphic succession: the lowermost part is built by thin (up to tens of metres) level of Ordovician phyllites and quartzites that are covered by coarse grained, red Upper Carboniferous molasse-type sediments. These rocks are covered by complete Jurassic succession. Internal deformation within this thrust slab was not observed. Strongly cleaved Turonian rocks or older Mezosoic units are building up the immediate footwall of the Upper imbricate.

The lower thrust imbricate emplaces Variscan gneisses (CSHGMC) and their Mezosoic cover onto various units of Upper Cretaceous sequence. According to Bončev (1940) and Angelov et al. (2010c, d) this is an independent fault zone called Frelin thrust that just by coincidence merges to the NW perfectly with Negushevo fault zone (cf. maps in the cited above publications). Our preferred interpretation is that the main fault zone is represented by the lower imbricate, thus we interpret Negushevo zone as NW-SE trending Late Alpine fault that probably merges further SE with Petrich fault (Bončev, 1940).

Synthesis of Late Alpine tectonics

Field data as well as calculations made using the GeolMapDataExtractor software indicate that both Kamenitsa-Rakovishki and Negushevo fault zones are steeply dipping to the south. The precise angle is difficult to estimate, and of course, for some of the segments of these zones, later reactivations which have changed the original dip cannot be excluded. Such reactivation seems the most plausible explanation also for the observed lack of intensive deformation at the supposed position of Kamenitsa-Rakovishki zone SW of the village of Gorna Malina. In most of the cases the dips of the fault zones are steep (>60°) and only in the area S of Makotsevo village the dip of Negushevo fault zone is moderate.

Fault cores of both zones are not cropping out, but on the basis of the character of small-scale structures in their footwalls (the case of Kamenishka-Rakovishka zone) and field relationships between the Variscan basement and the Upper Cretaceous sediments around villages of Makotsevo and Chakanchevo (the case of Negushevo zone) they can be regarded as N-NE-vergent compressional fault zones. The small-scale structures include decimetre-metre scale imbricate structures, stacks of lineated fault surfaces, north-vergent shear-related folds, etc. Our data indicates that in a number of cases these structures are often found in the immediate footwalls of the main fault zones. These findings are complemented by similar observations in the area of Topolnitsa River.

In a regional scale the Upper Cretaceous sequences form footwall synclines with subhorizontal axes trending parallel to the main fault zones. The synclines are strongly asymmetrical and have both overturned or vertical southern limbs and normal northern limbs. Greater complexity is typical for the inverted limbs while northern limbs, in most cases, preserve intact stratigraphy that can be used as a key to decipher the nature of the stratigraphic sequences within the different parts of the Upper Cretaceous basin. Features as inverted sequences, presence of strongly sheared domains, etc., all indicate that southern limbs are affected by secondary top-to-the-north faulting. Recently Butler et al. (2018) made a detailed review of the structural complexities and the possibilities for multiple structural scenarios in the similar thrust footwalls setting. Although not so well outcropped, the lack of significant late overprint of the immediate footwalls of both compressional fault zones in our studied area provides important insights into such complicated setting described by Butler et al. (2018). For example, our new data can further help constraining structural geometry and evolution in the footwall of Mirkovo fault zone (Fig. 1) – a zone severely overprinted by Miocene–Quaternery normal faulting.

The synclines (Makotsevo-Smolsko, Negushevo and Belopopsko-Kamenishka) have been known since pioneering researches in the area (Ivanov, 1940; Tzankov, 1961), but it must be noticed that they do not form classic syncline-anticline pairs as suggested previously (Tzankov, 1961; Angelov et al., 2010a, b, c, d), because the anticlines are simply not existing. What was described as anticlines (Babutitza-Voynyashka and Srednogorska) are actually south-dipping monoclines underlined by top-to-the-N fault zones (Negushevo and Mirkovo zones, Fig. 1). The origin of regional uplift at the place of the so called Babutitsa-Voynyashka anticline can be related to the uplift in the immediate hanging wall of the Negushevo fault zone. Such uplift is responsible for the division of the Panagyurishte sedimentary strip into two branches and the strong squeezing of the Upper Cretaceous sequences in the northern branch (especially pronounced north of Negushevo).

The relative timing between folding and movements along the main fault zones has long been commented. Recently, it was explicitly stated that the folding of Upper Cretaceous sequence and the movements along the main fault zones are temporarily distinct events (Angelov et al., 2010a, b) – the first one regarded as a result of the Laramian (latest Cretaceous) deformation, while the second one – as a product of the Iliryan (Eocene) compression. Despite being not conclusive, our data fit better with a model of simultaneous formation of these two types of structures. This is in line with the original ideas of Bončev (1940) and interpretations of Ivanov (1998; 2017).

The proposed tectonic synthesis is a product of ongoing research that must be further supplemented by balanced cross-sections and shortening estimates (work in progress, not presented here). As often in such models it will probably require further changes in the interpretations as a result of acquired new data.

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