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The Balkan Fold-Thrust Belt: an overview of the main features

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Abstract. The Balkan Fold-Thrust Belt is a part of the northern branch of the Alpine-Himalayan orogen in the Balkan Peninsula and represents a Tertiary structure developed along the southern margin of the Moesian Platform. The thrust belt displays of two clearly distinct parts: an eastern one dominated exclusively by thin-skinned thrusting and a western part showing ubiquitous basement involvement. A wide transitional zone is locked between both parts where the structural style is dominantly thin-skinned, but with significant pre-Mesozoic basement involvement in the more internal parts. For the western thick-skinned part the poorly developed syn-orogenic flysch is a characteristic feature that along with the very restricted development of foreland basin suggests a rather limited orogenic shortening compared to the eastern part of the belt. The Tertiary Balkan Fold-Thrust Belt originated mainly through a basement-driven shortening and this is explained by the occurrence of compatibly oriented reactivated basement weak zones of pre-Carboniferous, Jurassic and Early Cretaceous ages. The proposed re-definition of the Balkan thrusts system and internal structure of the allochthons also call for significant re-assessment of the existing schemes of tectonic subdivision.

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INTRODUCTION

The Balkanides (St. Bonchev, 1910) are spatially associated with the Balkan (Stara Planina) Mountain range which extends over 550 km in the central part of the Balkan Peninsula (Fig. 1). It is well known as a north-vergent fold-thrust belt, a part of the northern branch of the Alpine–Himalayan orogen: *sensu lato* – a product of two orogenic phases (Early and Late Alpine), and *sensu stricto* – a Tertiary orogen developed along the southern margin of the Moesian Platform.

Generally, the ideas concerning the composition, boundaries and evolution of the Balkanides, despite the new advances in understanding and interpretation of the geodynamic processes, follow the model of E. Bonchev (1971, 1986). Ivanov (1988, 1998) updated the characteristics of the evolution and subdivision of Balkanides in the light of the plate tectonics, especially for the internal parts of the belt (Rhodopes, Kraishte and Sakar-Strandzha). Georgiev, Dabovski (1997) and Dabovski et al. (2002) confirmed the idea that the Bulgarian territory is a part of the Alpine orogen and its foreland (Moesia). All these schemes are of a regional scale and have very general sense. While in the last two decades a number of studies were carried out in the internal parts of the Balkanides (e.g. Kounov et al., 2004, 2010; Burg, 2011), there is still a significant lack of data for the external units and especially for the Balkan Fold-Thrust Belt (BFTB). Yet, the characteristics of the lower-order units and their boundaries are arguable and for the western part of the belt the main dataset is 40-50 years old and rather incomplete. Mostly, all proposed tectonic schemes for the Balkanides are based on the Late Alpine evolution. Except for the better studied Eastern Balkan (Doglioni et al., 1996; Blunt, Vangelov, 1997; Bergerat et al., 2010; Stewart et al., 2011), the age constraints of the main fault activity and modern data for them were rarely reported.

This paper focuses on the Tertiary evolution of the BFTB, especially on its geometry and deformation style. Compiled stratigraphic, sedimentological and structural data have been used thus providing important

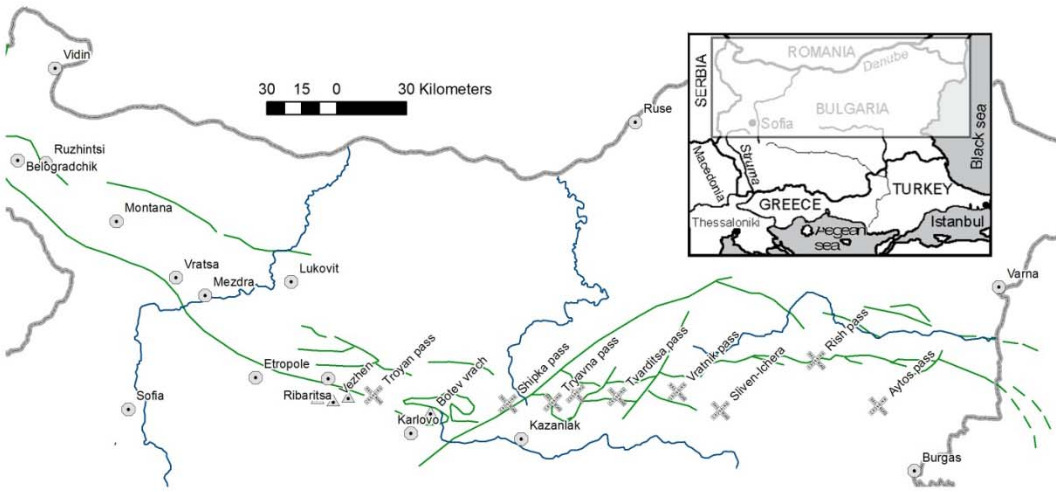

Fig. 1. Regional geographic scheme showing the position of the Balkan Fold-Thrust Belt and the location names used in the text.

evidence on the timing and effects of the Alpine evolution. Milestones of this contribution are several balanced cross-sections of the whole Balkan belt that allow deciphering the along-strike differences. The main idea is to characterize the frontal parts of the BFTB, main faults and fault zones formed during the Tertiary orogeny, the inherited, reactivated or inverted structures, the effect of the subthrust tectonics, the foreland basins and their importance in the interpretations.

REGIONAL TECTONIC FRAMEWORK

The Alpine orogen along the Balkan Peninsula has a complex polyphase evolution that at least since the Late Cretaceous was controlled by the northward subduction of several branches of the Tethys Ocean (Ricou et al., 1998; Stampfli, Borel, 2002). As a result, the main orogenic polarity is to the south and southwest (Dinarides, Hellenides, Rhodopes), whereas the northern branch (Balkanides) forms a retro-belt (e.g. Gochev, 1991).

The BFTB was formed along the southern margin of the Moesian Platform mainly during the Tertiary. The age of the platform consolidation and its attachment to the East European platform are still a matter of debate, but most probably these processes occurred during the Variscan and Early Alpine time. Northwestwards, the Balkanides link with the chain of the Southern Carpathians, thus forming one of the most spectacular orogenic curvatures – the Balkanide–Carphathian sigmoid (Karagjuleva et al., 1980; Burchfiel, 1980). Unlike the Carpathians, where for at least in the eastern part existence of Mesozoic oceanic crust was distinguished (Csontos, Vörös, 2004; Fügenschuh, Schmid, 2005), for the Balkanides it is clear that for the Paleogene there are no data suggesting a presence of large oceanic basin south of the Moesian Platform (except the Upper Cretaceous–Eocene arc/back-arc and the retro-arc/intra-arc basin systems during the Late Eocene-Oligocene in South Bulgaria).

South of the BFTB are located tectonic zones that recorded Early Alpine deformations and metamorphism (Kraishte, Strandzha, e.g. Dabovski et al., 2002; Kounov et al., 2010), or were involved in the Alpine synmetamorphic south-vergent tectonics, such as the Rhodopes (Burg, 2011). They represent the hinterland of the Tertiary BFTB.

PRE-TERTIARY EVOLUTION OF THE BFTB – BRIEF CHARACTERISTIC

Variscan orogeny and structural inheritance

Being still preliminary, our data suggest that the common for the Balkanides (*s.l.*) structural trends (E-W trending in Central Balkan, NW-SE trending in Western Balkan, partly in Eastern Balkan and Kraishte) resulted from inheritance and an Alpine reactivation of the Variscan fabrics. Being well-aware of the drawbacks of the lineaments and their reactivation hypothesis (e.g. Bonchev, 1986), we must admit that some of the ideas for the predestination of the Alpine structures, reported decades ago, can be revived on the basis of comparison between Variscan and Alpine tectonic elements.

Permian–Triassic evolution

During the Early Permian, deposition of a few hundreds of meters thick succession of coarse-grained continental sediments took place accompanied by an abundant bimodal magmatism. The Upper Permian to Upper Triassic sequence represents a complete transgressive/regressive cycle of several hundred meters of continental and shallow-marine sediments including both early- and late-stage evaporites. The initial (embryonal) rifting processes are indicated by the presence of mafic and intermediate volcanics hosted within the Lower Triassic succession. The facies distribution shows generally ESE-WNW expansion of the basin as the deposition was controlled mainly by sea-level fluctuations, reflecting in wide lateral transition and migration of the facies belts. Relatively deep-water sediments were deposited in the East Balkan area and they could be interpreted as a western prolongation of the Palaeo-Tethyan back-arc Küre Basin (Ustaömer, Robinson, 1997; Robertson et al., 2004). During the Norian, numerous tectonic events took place, causing the basin closure and formation of regional-scale unconformity at the Triassic–Jurassic boundary. The exact mechanism of the basin closure is still unclear.

Jurassic–Early Cretaceous basin evolution

The initial extension (dextral transtension) in Hettangian–Toarcian time resulted in the westward expansion of the Küre Basin (Ustaömer, Robinson, 1997; Robertson et al., 2004). The sediments were deposited only in the central parts and the southern periphery (northern board) of the Moesian Platform, East Balkan (depocenter) and Central Sredna Gora–Strandzha (southern board). Generally, the depositional rate was low except in the areas along the hanging walls of the echeloned master faults along the northern board. In the SW and SE parts of the Moesian Platform the sedimentation onset was at the beginning of the Middle Jurassic. Along the SE part of the platform, at the end of Early Jurassic a huge Gilbert-type delta was formed, which has existed until the Callovian and consequently was covered by shallow-marine carbonates (Sapunov et al., 1985).

The deposition of deep-water turbidites in the East Balkan reflected a fast subsidence and northward progradation of the system (proximal over distal facies, covered by slope chaotic deposits) until the end of Bathonian. The basin expansion continued during the Middle Jurassic when two important events took place. In both the Strandzha and the East Balkan, the depositional processes were strongly tectonically controlled as there was a northward migration of slope and shallow-water facies formations, which processes finally ceased at the end of Bathonian. At the beginning of Callovian, the sedimentary systems along the northern board of the basin show facial and bathial maturation, typical feature of the passive margin basins – a wide carbonate shelf, attached carbonate turbiditic ramp and deep-water turbiditic systems were formed. The carbonate shelf in Western Bulgaria occupied almost the entire accommodation space including the Western Balkan, Western Sredna Gora and parts of the Kraishte zone.

During the Tithonian–Valanginian time, the basin shortening caused the formation of a for-orogenic terrigenous wedge in front of the propagating thrust wedge. This resulted in the basin transformation from passive margin type into a foreland type in the area of the Central Balkans.

In the western parts of the basin, where the entire accommodation space is occupied by a carbonate shelf or platform, series of depocenters were documented, infilled by turbiditic systems, indicating deposition in a piggy-back basin. The Hauterivian–Barremian sequences indicate general basin depocenter compensation, finning-up deposition and northward progradation of the facies from the southern board like the Urgonian reefal limestones. The deposition during Aptian-Albian time was restricted only in parts of Central and Western Moesian Platform and the Western Fore-Balkan with WNW migration of the depocenter.

During the final stages of the basin evolution, several hundreds of meters thick molasse-like, shallow-water sandstones have been deposited in front of the central and southeastern parts of the Western Balkan. Contemporaneously, a low-efficient sandy/clayey turbiditic system was developed north and east of the other parts of the Western Balkan and the Southern Carpathians. Only in this remnant basin on the territory of Bulgaria the deposition continued during the Early/Late Cretaceous boundary.

Early Alpine orogeny

As a general rule, the structures related to the Early Alpine orogeny were variously affected or even inherited by the Tertiary north-vergent compressional fabrics. Large parts of the Early Alpine orogen (especially the more internal ones, e.g. Kraishte, Strandzha) can be regarded as hinterland of the BFTB. The northern parts represent the hanging walls of the main Tertiary compressional zones and are variously affected by a Tertiary shortening.

The Early Cimmerian orogeny (~210-200 Ma) is still poorly understood. Nevertheless, the presence of a regional unconformity suggests a considerable change in depositional and geodynamic style around the Triassic/Jurassic boundary – development of a system of subbasins with contrast lithology, significant sedimentary fill and/or a lack of deposition at about a period of 10-20 Ma. The Late Cimmerian stage (~165-145 Ma) is more prominent, but also poorly studied, although it is very important to understand the evolution of more internal parts of the BFTB. It is generally of Late Jurassic age, but the basin evolution suggests a dominance of compressional tectonic regime since the beginning of Late Bathonian to the end of Early Cretaceous. The continuous tectonic control, the depositional systems, depocenters changes and migration do not allow to distinguish Late Cimmerian and Austrian orogenic phases and to accept the gradual dextral transpressional regime all along the Bathonian-Albian time span (~165-100Ma).

The deformation started in Strandzha, Eastern Sredna Gora and the Eastern Balkan at the end of Bathonian resulting in wide thrust belt formation with a thick-skinned internal southern part and a thin-skinned northern part. In the Central Sredna Gora and the

Balkan, where the major shortening took place and the metamorphic basement was involved in thrusting, Callovian–Oxfordian is the supposed time for the beginning of the compression according to the sedimentary record. The compressional events in the Kraishte, West Srednogorie areas, according to depositional system characteristics, started during the Late Kimmeridgian, causing a transformation of the wide carbonate platform into a piggy-back basin. At the end of the Early Cretaceous in the Kraishte, Western and Central Balkan several thrust sheets were formed in which the Paleozoic basement was involved. During the Late Cretaceous, the Kraiste, West and partly Central Balkans were a dry land, whilst along the other fragments of the Early Alpine orogen – Strandzha, East Balkan and Sredna Gora a volcanic arc - back-arc basin system was formed.

In terms of the Early Alpine evolution, it is important to note the presence of mainly E-W trending very low-grade shear zones of pre-Late Cretaceous age in the Central Balkan. Their occurrence was first established in Zlatitsa area (Gerdjikov, Georgiev, 2005) and later in Tvarditsa area (Gerdjikov et al., 2008). Similar structures we distinguished in Karlovo and Buzludzha parts of the Balkan Mountains. The zones commonly are up to tens of meters thick and with a pronounced north-vergent thrust-dominated kinematics. Such E-W trending anisotropies in the Variscan and Mesozoic basement are weak zones that are potentially easy to be reactivated during the Paleogene shortening.

Late Cretaceous–Paleogene basin system evolution

The Late Cretaceous–Paleogene basin system is a part of the Apusseny-Banat-Sredna Gora-Pontides Andean type active margin (e.g. Quadt et al., 2005). The Bulgarian part of the system – the Sredna Gora area (and partly the Eastern Balkan) is characterized by numerous en-echelon strike-slip and pull-apart basins developed in dextral transtensional regime over fragments of the Early Alpine orogen (Ivanov, 1998).

In the Eastern Sredna Gora and Eastern Balkan, the basin opening started at the end of Albian and the beginning of Cenomanian, followed by a westward expansion until the beginning of Turonian. Two basins are distinguished within the Moesian Platform. The first one has occupied its western part, representing an eastward expansion of the remnant Late Jurassic-Early Cretaceous basin. The second basin was developed in the southeastern part of the platform and was propagated westwards. It was closely related to Western Black Sea basin and was separated from the Sredna Gora basin by a dry land. During the Maastrichtian–Early Paleocene the entire BFTB was under the sea-level excepting the West Balkan and extensive parts of the Kraishte.

At about 93 Ma an intense synrift magmatic activity started that ceased gradually at 80-78 Ma (von Quadt et al., 2005; Georgiev et al., 2009). It had generally SSE migration, oblique to the basin system general orientation. The magmatic products are presented by intermediate volcanics in the northern part and granitoid intrusions in the southern. The basin system reached its postrift stage at Late Campanian–Maastrichtian time; this fact is well evidenced especially in the eastern part, where the facies zonation shows a transition from inner shelf to deep-water turbidites.

The compression started at the end of Campanian in the eastern part of the system where the biggest Emine basin was transformed into a piggy-back and later to a foredeep basin in the Forebalkan during the inversion stage at the beginning of Paleocene. In the western part of the Sredna Gora Zone, the Early Maastrichtian compression caused a rapid change in depositional style and finally a general fast basins closure by dextral transpression.

During the Bartonian (after the peak of compression during the Lutetian) the basin system was divided by the newly formed BFTB into two parts: a starved basin on the Moesian Platform, and a number of narrow basins south of it filled with clastic deposits, formed over the ramp zones of the main structures due to a post-compressional extension.

The evolution of the Late Eocene–Oligocene basin system developed in the internal parts of the BFTB and the Rhodopes will stay out of the scope of this study.

TERTIARY BFTB – MAIN STRUCTURES AND EVOLUTION

General subdivision

Two different parts of the BFTB are distinguished based on their geometry, general deformation style and kinematics – the Eastern and Western (Figs 2-4). The Eastern part shows structural characteristics of thin-skinned fold-thrust belt, but some features suggest a minor basement involvement in the Western part. The Western one has more complex structural patterns and could be further subdivided into four fragments. From east to west these are the Buzludzha (between Shipka and Sliven-Ichera passes, see Fig. 1), Botev Vrah, Ribaritsa and Plakalnitsa fragments (Fig. 4), each showing specific structural and basin evolution related to basement involving thrusting.

Along the BFTB we distinguish fault system typical of a fold-thrust belt along which both types of tectonic style have been revealed – thick- and thin-skinned. The BFTB represents the northernmost compressional tectonic zones that show largest displacement (Figs 5-10). These zones are well-known regional scale thrusts or/and reverse faults. These structures accommodated the most significant shortening during the Tertiary orogeny. In the western part the BFTB involves pre-Mesozoic basement, whereas in the Eastern part along the Chudnite Skali dislocation–only lower Mesozoic rocks (Fig. 5).

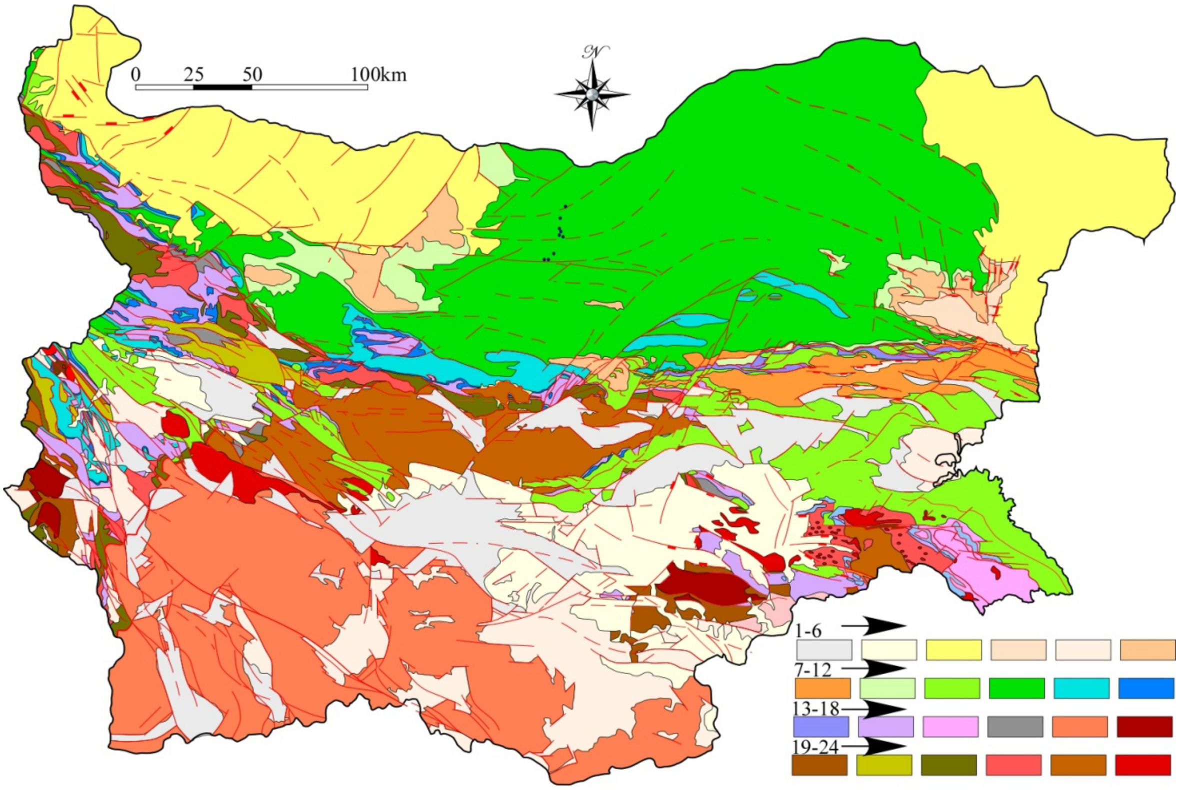

Fig. 2. Compiled geological map of Bulgaria based on the published information.
1–6 – Superimposed post-compressional basin systems: 1 – Quaternery; 2 – Plio-Pleistocene basin system; 3 – Miocene basins; 4 – Late Eocene–Oligocene basin system; 5 – Priabonian basin system south of the thin-skinned part of the thrust belt; 6 – Paleogene deposits on the Moesian Platform; 7 – Lower–Middle Eocene on the thin-skinned allochthone; 8 – Late Cretaceous basins on the Moesian Platform; 9 – Upper Cretaceous rocks (Srednogorie and Eastern Balkan – Emine basins; 10 – Early Cretaceous foreland basin; 11 – Upper Jurassic–Lower Cretaceous; 12 – Lower–Middle Jurassic; 13 – Triassic and Lower–Middle Jurassic basement of the Eastern Balkan; 14 – Triassic epi-platform type; 15 – allochthonous Triassic in Strandzha; 16 – Upper Carboniferous–Permian; 17 – high-grade metamorphitc rocks in the Rhodope–Serbo-Macedonian Massif; 18 – Early Alpine (?) syntectonic granitoids; 19 – metamorphosed Permian–Triassic complex in Sakar; 20 – Silurian–Lower Carboniferous low-grade rocks; 21 – green-schist metamorphic complex; 22 – Variscan plutons; 23 – high-grade metamorphic rocks from Strandzha, Srednogorie and Kraiste basement; 24 – Upper Cretaceous plutons.

Despite the uneven seismic data coverage (available mainly for the Eastern part) it is clear that the BFTB structures recorded different amounts of shortening. The balanced cross-sections suggest that along the exclusively thin-skinned eastern part of the BFTB the shortening was accommodated along several isolated thrust faults, whereas along the Botev Vrah fragment, a part of the western belt, almost all the shortening was accommodated along the main frontal thrust (Figs 6, 8 and 9). Further west, the amount of shortening increased and a larger internal deformation is observed in the Plakalnitsa fragment.

The restoration of the orogen-scale geometry of the Tertiary BFTB requires the existence of crustal detachments beneath. Following the model of Lacombe, Monthreau (1999, 2002) we can suppose an existence of two major detachments. The deep basal detachment underlays the thick-skinned hinterland-ward part and ramps to the surface as Frontal basement wedge. In the case of the Western Balkan (west of the Botev Vrah fragment), on the basis of the balanced cross-sections restorations, it could be suggested that this deep detachment underlays the subthrust zone and transmits the basement involved shortening to the platform margin. For the Eastern Balkan and Botev Vrah fragment, an existence of a shallow detachment could be suggested (in front of the Frontal basement wedge) that traces along the weak layers in the Mesozoic succession – either along Triassic evaporates, or along weak layers in the Jurassic–Cretaceous successions. The existence of such detachment levels is required not only in order to balance the cross-sections but also from the theoretical considerations about far-field transmission of the orogenic stress to the peri-platform areas (Lacombe, Monthreau, 2002).

In terms of major boundaries within the Tertiary

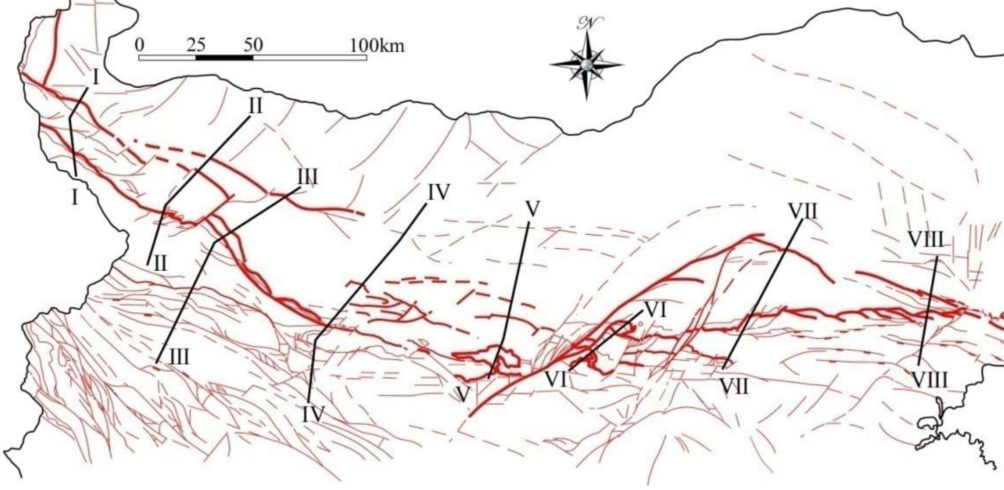

Fig. 3. Sketch map of the established faults (based on the published data and our investigations). With bold red lines are shown the main faults described as frontal line of the Balkan Fold-Thrust Belt. The black lines show the positions of the presented below geological cross sections.

BFTB, the following main structures are distinguished: the Frontal basement wedge, the shallow wedge front and the reactivation front. Their presence fits well with the tectonic model of Lacombe, Monthreau (2002). It should be noted that the occurrence of shallow wedge front is restricted only to the areas where the shallow detachment is presented (e.g. Botev Vrah fragment and Eastern part of the belt).

The Eastern Balkan thin-skinned part

The East Balkan part of the fold-thrust belt was first described by Kockel (1927) as the "Chudnite Skali" Dislocation (CSD). Along it the Triassic and Lower–Middle Jurassic rocks of the Eastern Balkan basement as well as the "Mediterranean" type of Upper Cretaceous and Paleogene sediments overthrusted the Paleogene deposits of the Forebalkan area. The thrust is well exposed in the area locked between the Tvarditsa Pass to the west and the Solnik village to the east (Fig. 4). Westwards the CSD continued at least up to the Hainboaz Pass along the Voynezha-Badevtsi thrust zone (Kanchev, 1962) and is limited by the Yantra fault zone to the west. To the east, the CSD traces up to the coastal part and offshore of the Black Sea, where the zone is covered mainly by syn-compressional sediments, which existence being evidenced by local outcrops or seismic data.

The total length of the CsD exceeds 200 km, including the offshore part. It has a general W to E onshore strike that changes to N-S in the offshore. The thrust front varies in width, but at least a few kilometers thick leading imbricate fan was documented in each of the studied transects.

The Eastern Balkan part of the BFTB was formed from the beginning of Paleocene until the closure of the Emine piggy-back basin in Eocene time (a back-arc basin in the initial stages of its evolution) by a sinistral transpression (Doglioni et al., 1996; Blunt, Vangelov, 1997; Bergerat et al., 2010; Stewart et al., 2011). The onset of the inversion and transpression were reflected in deformation and erosion along the master fault, changing of depositional systems, and angular unconformity between the Upper Cretaceous rocks and synchronous syn-compressional deposits. The end of the compression during the Middle Lutetian is constrained by the youngest sediments beneath the thrust plain and the oldest ones covering the thrust front. The amount of maximal displacement constrained by the distance between the possible root zone and the thrust front is difficult to be assessed. According to seismic data from transect along the Aytos Pass, it is at about 23-25 km, whereas the amount of the total shortening along the allochthone pile exceeds 45 km. Nevertheless, the true amount of shortening is hard to be accounted due to the dissemination of the shearings among the few km thick turbiditic sequence, in both the basement and cover, even locally in subthrust zone. Further obstacles are the small- to medium-scale back-thrusts, stacking of duplexes in similar lithology, the presence of oblique ramps, etc. The shortening along the leading imbricated fan is impossible to be estimated due to the above mentioned reasons, but in average it varies from few hundreds of meters up to 4-5 km (Fig. 5). The linear orientation of the thrust front is additionally complicated by a lateral overlapping related to the transpression tectonics. Due to these reasons the

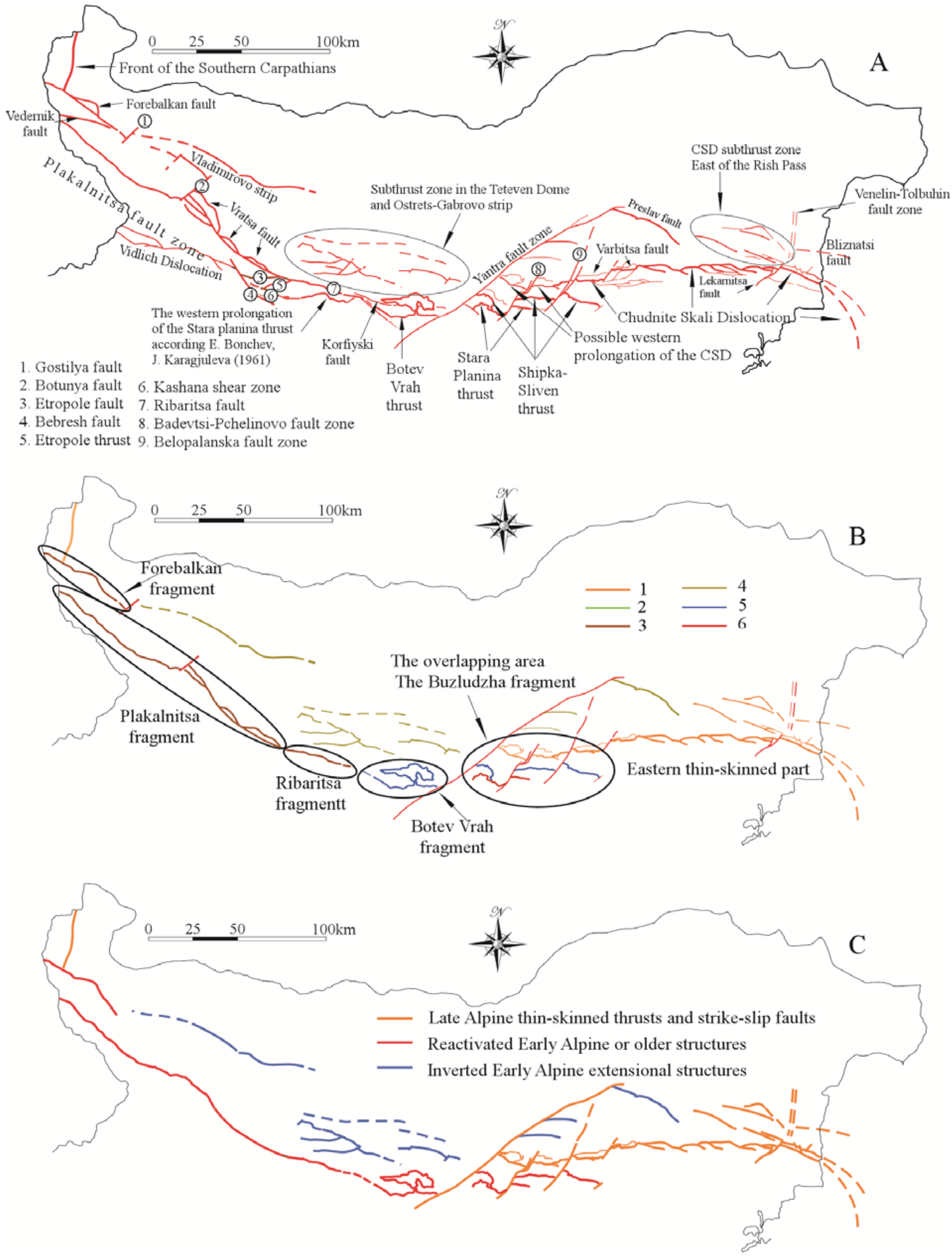

Fig. 4. A – Simplified map of the faults and fault zones outlining the front of the Balkan Fold-Thrust Belt. B – Subdivision of the BFTB frontal faults: 1 – Late Alpine thin-skinned thrusting; 2 – thick- to thin-skinned thrusting in the imbricated overlapping area; 3 – thick-skinned thrusting; 4 – reactivated Early Alpine (Early Jurassic) normal faults; 5 – thick-skinned thrusting indicating reactivation during Early and Late Alpine time (the Botev Vrah and Stara Planina thrusts); 6 – lateral and oblique ramps related mainly to the overlapping area. C – Distribution of the thick- vs. thin-skinned thrusting in the BFTB front and the most prominent subthrust zones.

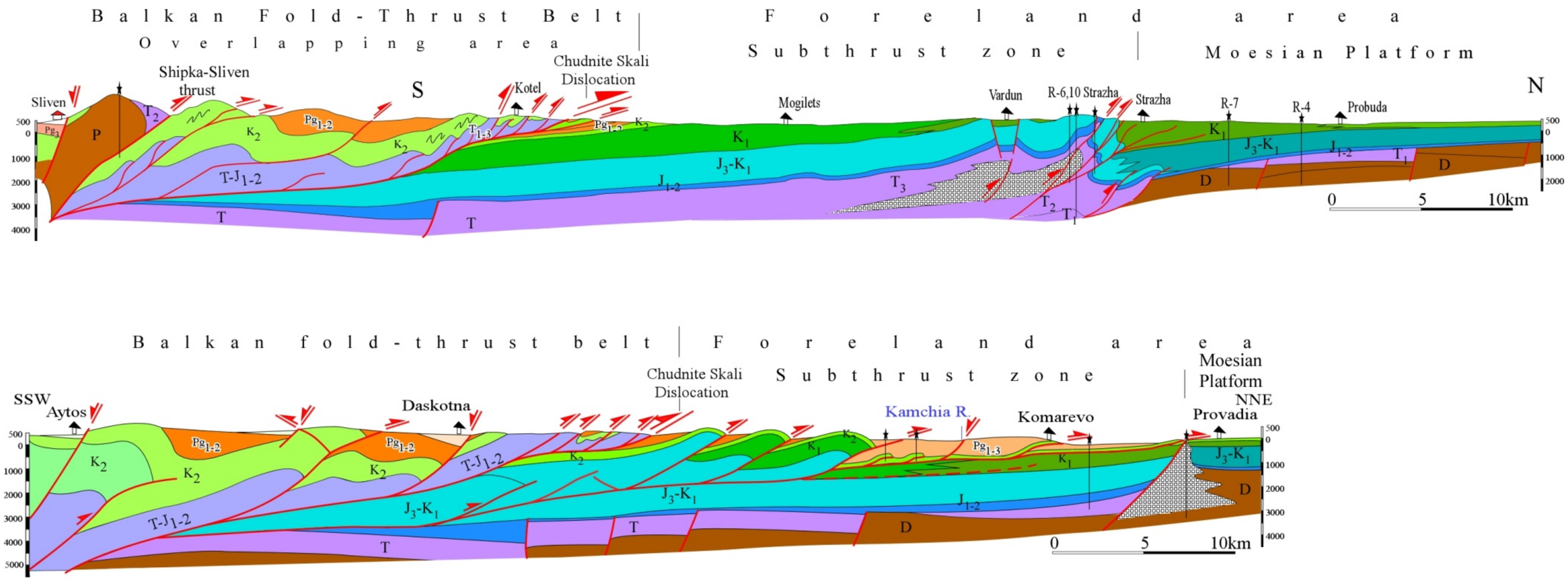

Fig. 5. Simplified cross sections across the East Balkan transects – VII-VII and VIII-VIII (in the Fig. 10), indicating thin-skinned thrusting and different behavior of the subthrust zone – from deformation only in the frontal part to deformation distributed in the entire affected zone. Note the position and the possible mechanism of formation of the salt diapirs.

characteristics of the belt vary along the different transects (Bergerat et al., 2010).

The Western Balkan thick-skinned part

Although basement-involving thrusting in the Balkan belt was previously reported (Bonchev, 1986; Ivanov, 1998), relatively little is known about the nature and the geometry of the individual thrusts and their fragments, as well as the timing of their emplacement and the regional geodynamic setting. Additionally, the western thick-skinned part of the BFTB shows more complicated structure compared to the eastern one. Such is the case in the Buzludzha fragment (Fig. 4) where the geometry of the belt is significantly disrupted due to the presence of several imbricated duplexes, a series of sinistral oblique ramps and the development of two main en-echelon basement involving structures along both the Stara Planina (Bonchev, Karagiuleva, 1961) and Shipka-Sliven (Kockel, 1927) thrusts.

Generally, three fragments can be clearly distinguished in the Western Balkan part of the fold thrust belt on the basis of differences in their geometry, internal structure and kinematics.

The Buzludzha fragment (eastern)

The Buzludzha fragment is the easternmost part of the thick-skinned part of the belt. It shares a lot of common stratigraphic and structural features with the Eastern Balkan part of the BFTB as it refers especially to the northern domain of the fragment. Here, the compression affected mainly the sedimentary cover under the thin-skinned tectonics. Nevertheless, considering the whole fragment, some distinction can be made accounting the significant involvement of the pre-Mesozoic basement into the north-vergent thrusting in other parts of the Buzludzha area.

Two basement-involving thrusts are distinguished in this part – the Stara Planina thrust (Bonchev, Karagiuleva, 1961) and Shipka–Sliven thrust (Kockel, 1927; Ivanov, 1998). The Stara Planina thrust (SPT) crops out north of Kazanlak and traces out east of Tvarditsa (Figs 4, 5a, and 6) and to the west it is limited by the Yantra sinistral strike-slip zone (Vangelov, 2006). The thrust sheet overridded various in composition and structure rock complexes. In the Enina–Borushtitsa area the footwall consists of intensively deformed and imbricated Paleozoic metamorphics along with Triassic and Upper Cretaceous sediments. To the east, in the Tryavna Pass area, the footwall is composed only of Upper Cretaceous sequences of Eastern Balkan type. In its easternmost tip the SPT is emplaced on the Variscan basement, represented by the Tvarditsa granite and the high-grade metamorphics of Lazovo complex (Ivanov et al., 1984). The thrust zone shows clear flat/ramp geometry in the western part, where the dips vary from subhorizontal on the crest parts of the mountain up to 25-30° at the base of the southern slope. In the easternmost part, east of Tvarditsa, the thrust surface dips up to 70° to the south. The sense of shear criteria in the allochthone indicates a northward direction of the tectonic transport. We suggest that in this part of the Balkan belt the BFTB coincides with the above described fragment of Stara Planina Thrust.

The Shipka–Sliven thrust (SST) of Kockel (1927) is one of the least known structures and a number of authors (personal communications and discussions at meetings) put on doubt its existence as an independent structure. In the area between Shipka and Tryavna passes there are south-dipping fault zones displaying criteria of north-vergent thrusts, but their displacement cannot be estimated. In the area of Tryavna Pass the SST is covered by SPT and appears again east of Hainboaz Pass. Between Hainboaz and Vratnik passes displacement along north-vergent brittle faults can be evaluated to less than few hundreds of meters. On the other hand, northeast of Sliven, the Permian magmatic and Triassic sedimentary rocks were emplaced over the Upper Cretaceous sediments and the displacement is probably more than few kilometers, marked by the large width of the tectonic zone – up to tens of meters (Figs 5a, 6).

In fact, the SST (as defined by Kockel, 1927, and Ivanov, 1998) represents a north-vergent swarm of sub-parallel basement-involving thrust segments rather than a single structure. This compressional fault zone is one of the most prominent structures within the Buzludzha fragment.

We assume that in this part of the BFTB the latter is represented by the above described fragment of the Stara Planina Thrust. The intensive shearing, including duplex formation in the footwall of the SPT are result of the lithological and structural predestination. These features are also prominent in the Shipka and Tryavna parts of Stara Planina Mountains where the compatibly oriented foliation in the Paleozoic basement along with the presence of weak coal layers in the Cretaceous part of the sedimentary cover led to the formation of spectacular imbricate-duplex structure (Fig. 6).

Within the Buzludzha fragment two domains could be distinguished: a thick-skinned southern domain that was emplaced onto the northern thin-skinned one. The key argument to include the entire Buzludzha fragment into the thick-skinned part of the BFTB is the important role of the basement during the Paleogene compression. Our studies along the Shipka and Tryavna parts of Stara Planina suggest that the basement involvement was not only limited to the final stages of Eocene compression, but started already during the Paleocene. The uplift and north-directed transport of the pre-Mesozoic basement coincided with the syn-orogenic sedimentation and compression in the shallower parts of the fold-thrust belt. Moreover, in the Buzludzha fragment, the Upper Cretaceous and Paleogene sediments are different in comparison with those to the east due to the fact that in

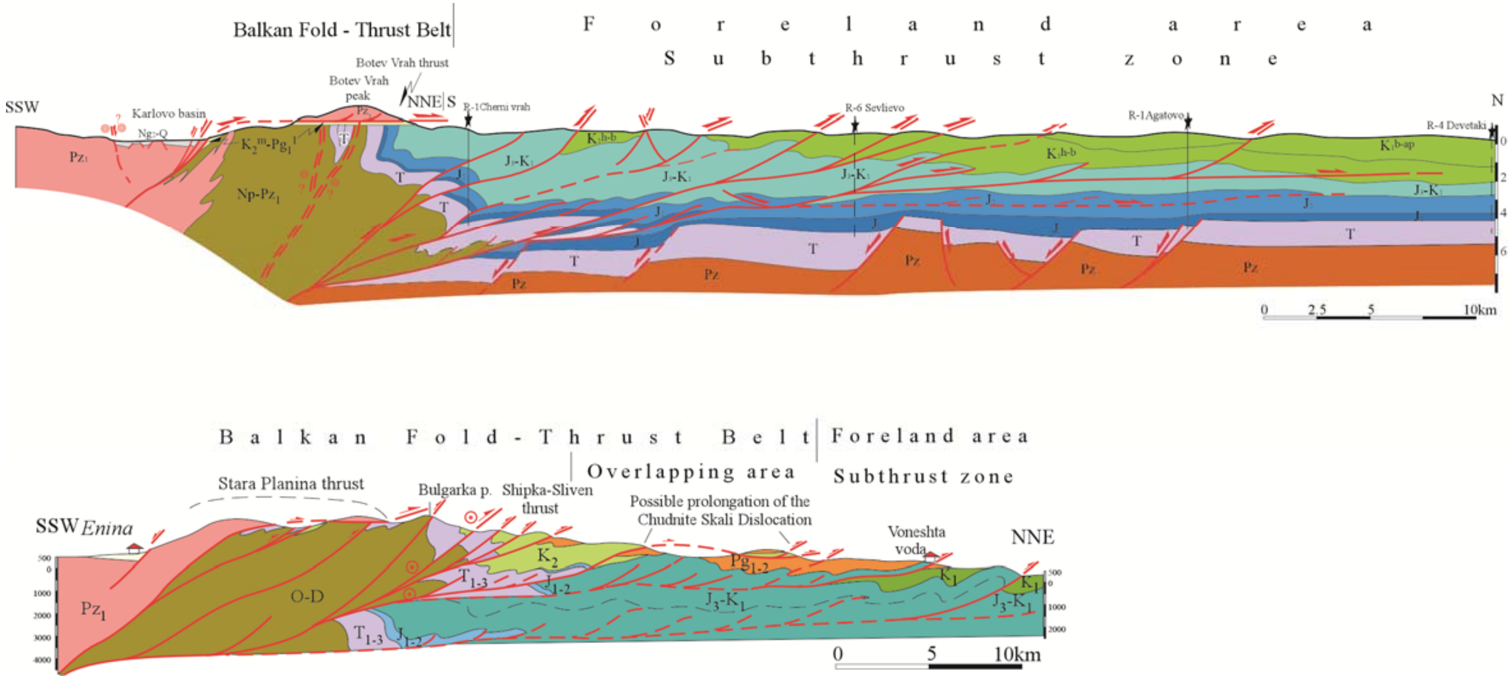

Fig. 6. Simplified cross sections across the Central Balkan and Sredna Gora, west of the overlapping area (V-V in the Fig. 10), within it (VI-VI in the Fig. 10), and the foreland area. Note the deep level of the Permian basement and the distinct low-angle and blind thrust in the Jurassic-Lower Cretaceous complex, most likely reactivated Early Alpine structures, and the significant displacement of the thick-skinned thrusting. For this area reactivation of Variscan and Early Alpine structures during Late Alpine time is typical (even current or recent). The imbrication of Paleozoic sequence is remarkable (presumed Variscan).

the western parts of the basin the depositional systems were shallow-marine.

The Botev Vrah fragment (central)

West of the Buzludzha fragment is situated a thick-skinned segment of the BFTB represented by the E-W striking Botev Vrah Thrust (BVT). This structure covers a great area of the Central Balkan Mountains and is one of the most impressive compressional structures along the entire Balkan belt (Cheshitev, 1958; Bonchev, Karagiuleva, 1961; Balkanska, Gerdjikov, 2010). Top to the north emplacement of the pre-Permian crystalline basement over various rocks of Paleozoic to Cenozoic age took place at shallow crustal levels (Balkanska, Gerdjikov, 2010). The footwall of the thrust exposed at the southern foot of Stara Planina Mountains displays multiple decameter-scale imbrications and duplexes. The available data suggest that the allochthone represents a single "monolithic" thrust sheet (Fig. 6), as the displacement is assessed at about 20 km, based on the map analysis (e.g. Cheshitev, 1958; Bakirov et al., 1984; our own data).

The Plakalnitsa fragment (western)

The Plakalnitsa fragment remains one of the most poorly studied parts of the BFTB as its geometry, kinematics and internal structure are still arguable. Especially problematic remains the easternmost part of the fragment.

The western tip of the Botev Vrah fragment is locked between Rozino village and Yumruka peak (Fig. 7) and its westward continuation is a subject of ongoing controversy. According to the classical views (Bonchev, Karagiuleva, 1961; Ivanov, 1998), the major Late Alpine thrust is traced along the southern slope of the Stara Planina Mountains where it is distinguished as the Vezhen Thrust. Nevertheless, the current detailed mapping and structural analysis did not confirm such view. In this area a co-existence of Late Alpine brittle fault zone as well as Variscan and Early Alpine ductile zones has been documented (Gerdjikov et al., 2007). In contrast, the main Late Alpine zone traces along the northern contact of the Vezhen pluton coinciding with the Ribaritsa reverse fault (Kujkin et al., 1971) along ca. 25 km from the Yumruka peak up to the Divchovoto village. This segment is of NW-SE–trending which is a common feature of the western parts of the Balkan belt (in Fig. 4B marked as Ribaritsa fragment). An exception is made in the area of Yumruka peak where the fault is E-W oriented due to some internal imbrications (Kujkin et al., 1971). In fact, the Ribaritsa fault zone is a single fault without significant imbrications, thus resembling the geometry of the Botev Vrah fragment. Only along the crest line around the Yumruka peak the tectonic zone is shallow-dipping, but east- and westwards the dips are steeper. We suggest that the Ribaritsa fault represents the easternmost part of the Plakalnitsa fragment (Figs 4B and 8).

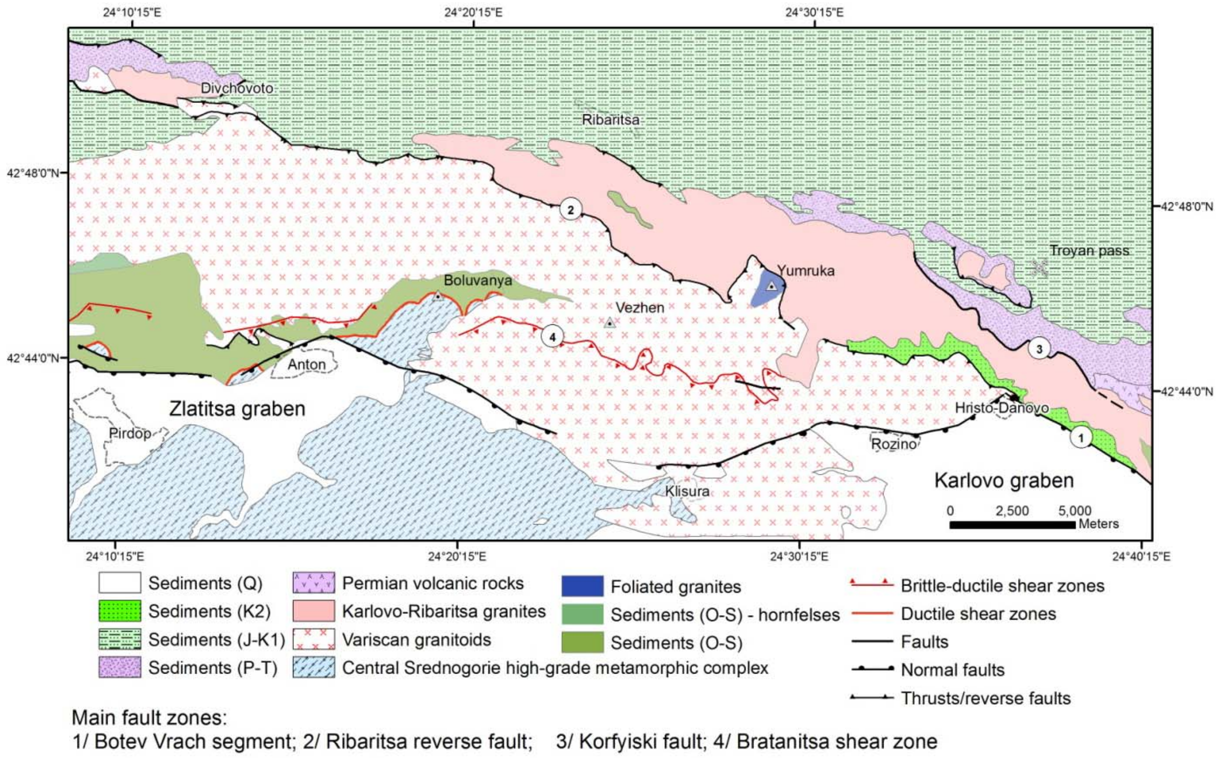

Fig. 7. Schematic geological map of the area between the Botev Vrah fragment and the Plakalnitsa fault zone with the supposed connection via Ribaritsa reverse fault.

West of the Divchovoto village the single thrust surface splits into several faults, forming a wider zone along which the Paleozoic basement rocks override the Mezozoic cover. This is the well-known Plakalnitsa fault system (PFS, e.g. Ivanov, 1998) which represents the westernmost zone of BFTB. The PFS is more than 150 km long and can be traced further west in the Eastern Serbia where it is truncated by the Timok fault. Despite its importance, this tectonic structure is poorly studied and needs to be revised and re-interpreted (e.g. Ivanov, Haydutov, 1971). Kockel (1927) considered the PFS as the major thrusting in the Western Balkans and correlated it eastwards with the Shipka–Sliven thrust and "Chudnite Skali" Dislocation. It could be speculated that the zone inherited the trace of a pre-existing Variscan shear belt, additionally reactivated during the Early Alpine time (Figs 8-10).

In the area between the towns of Etropole and Vratsa, PFS represents a complex NW–SE trending zone including both north-vergent thrusts and north-dipping top-south back-thrusts, as well as some sub-vertical dextral strike-slip faults. The main motions along the zone are related to the northward emplacement of the pre-Mesozoic basement onto the Mesozoic cover. The translations along the PFS additionally led to the formation of regional scale imbrication in the footwall known as the Vratsa reverse fault (Ivanov, 1998).

West of Berkovitsa, the PFS traces as a single fault or as a wide zone including several faults in front of the pre-Mesozoic Stakevtsi, Cherni Vrah and Berkovitsa complexes (Fig. 10). It is difficult to define whether these structures are of Variscan, Early or Late Alpine age. The low amount of shortening and dextral strike-slip movements along the zone most likely occurred during the post-Lutetian development of the Carpatho-Balkan sigmoid, after the main compressional events in the Balkan belt.

At the northwestern tip of the Balkan belt, the most prominent north-vergent structure is the Forebalkan fault (Tsankov, 1961). In fact, it is a thick-skinned fault and could be considered as a part of the BFTB (Figs 4, 9). The basement rocks include both the intensively sheared Cadomian and Variscan fragments (Sredogriv complex, e.g. Kiselinov, 2011) and the mafic rocks in the Belogradchik-Kiryaevo strip between the Belogradchik and Rayanovtsi Variscan granitoid plutons. The geometry of the Forebalkan fault indicates dextral transpression. It is generally assumed that the SE tip of the structure is marked by the Gostilya sinistral fault that to NW is truncated by Timok fault (Fig. 4A).

Subthrust tectonics

Towards the Moesian platform, the Tertiary compressional structures are unevenly distributed in front of the BFTB and its fragmentation influenced the subthrust tectonics in the foreland realm (Fig. 4).

In front of the East Balkan thin-skinned part of the BFTB, the Late Alpine faults can be subdivided into eastern and western domains. The eastern domain includes shallowly penetrating and narrow faults within the Upper Cretaceous–Paleogene rocks with decollement levels into the Upper Jurassic–Lower Cretaceous turbidites of the basement forming numerous fault-related folds. In the western "deeper and wider" domain the deformation affected the Triassic evaporite levels. It is of higher intensity in front of the subthrust zone – the Preslav fault, while the rest of the hanging wall rocks are almost undeformed (Vangelov et al., 2013).

Specific feature of the frontal part of the western domain is the presence of prominent fault-propagation fold – the Preslav anticline with a salt diapirism in the core. This structure is most probably an Early Alpine extensional fault reactivated as reverse fault during the Late Alpine tectonic activity. The faults are side-limited by the large oblique-slip Tertiary Yantra and Belo-palanska fault zones (Figs 4, 5).

North of the Buzludzha and Botev Vrah fragments, the surface evidence on intense tectonics are scanty. Nevertheless, according to the seismic and well data an existence of numerous duplexes, low-angle and blind thrusts was documented. Their occurrence can be related to the presence of several detachment levels in the very thick and dominated by mudstones Jurassic–Lower Cretaceous turbidite sequence. In this area the subthrust zone is the widest in the entire foreland realm (Fig. 6).

In front of the Ribaritsa fault (the eastern continuation of Plakalnitsa fault zone) the deformation was probably localized in the "Teteven dome" that shows characteristics of pop-up zone and the array of echeloned faults along the Ostrets–Gabrovo strip, both with discrete but persisting dextral strike-slip component (Figs 4, 6a, and 8).

Further northwest, in front of the Plakalnitsa fault zone, a system of reverse faults was documented in the foreland realm (Vladimirovo strip, Bonchev, 1971). In this area the fault surfaces are relatively steep, whereas in front of the Botev Vrah fragment the low-angle and blind thrust predominate. The geometry of the structures inside the Vladimirovo strip, as well as in the Teteven dome indicates reactivation and inversion of Early Jurassic extensional faults (Figs 8, 9).

Foreland basins

The thrust wedge/foreland basin system analysis is very important to restore the deformation, evolution and syntectonic deposition processes. The facies distribution and migration in the foreland basins, the architecture of prograding (or not) terrigenous wedge, subsidence history, erosion/sedimentary flux and factors controlling them as well as the syn- to/or post-depositional tectonics provide important information on the onset, growth, steady state and decay of thrust wedge evolution. Up to now, the tectonic aspects of the foreland basin evolution during the Tertiary along the Balkan belt were almost completely overlooked.

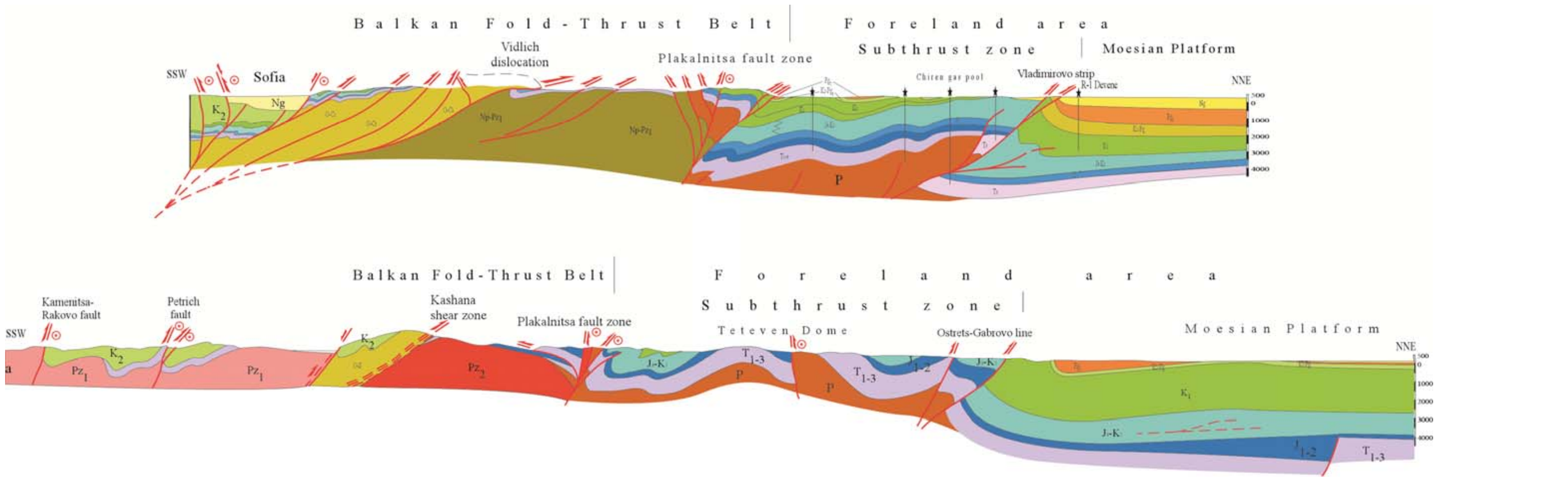

Fig. 8. Simplified cross sections across the western parts of the Central Balkan, Sredna Gora and their foreland areas (out of scale for the southern part) – III-III and IV-IV in the Fig. 10. Note the differences in the subthrust zone deformations and the composition of the Plakalnitsa fault zone. The changes in the Lower and Upper Cretaceous and Paleogene sequences are significant, despite the expected low-angle and blind thrust in the pre-Late Alpine rocks.

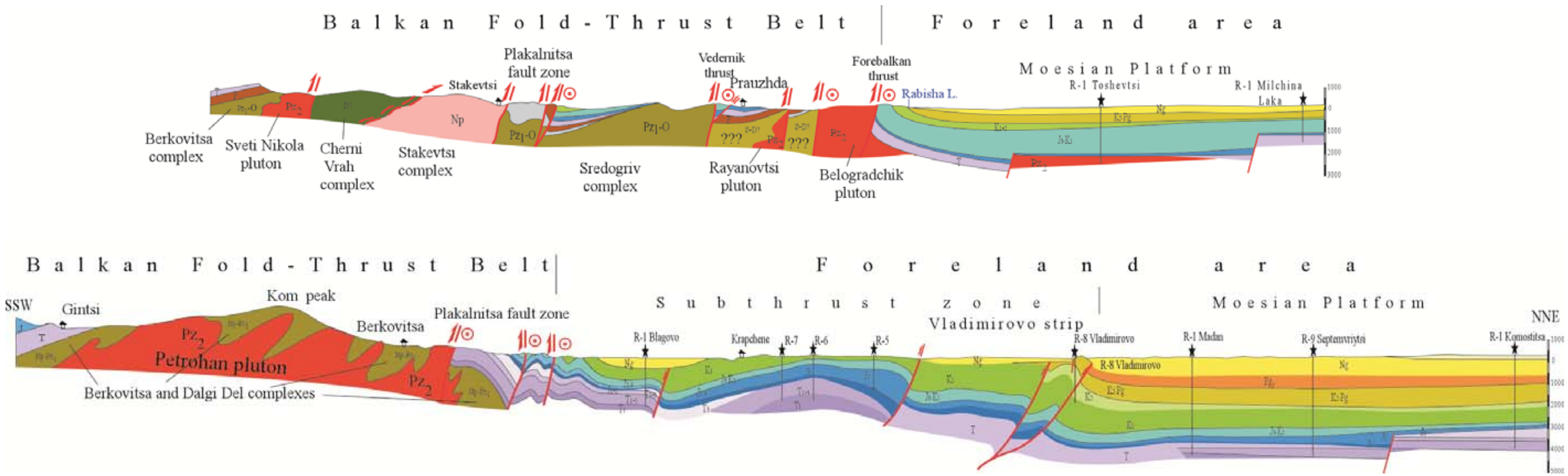

Fig. 9. Simplified cross sections across the Western Balkan and the foreland area (out of scale for the southern part). Note the differences between the westernmost part (I-I in the Fig. 10) where the frontal part of the belt is represented by the Forebalkan thrust, and the internal composition of the Balkans that is built up of imbricated piles of Cadomian (Stakevtsi complex), Variscan green schist complex, ophiolites, and syn- to post-metamorphic granitoids, in most cases with dextral striking component of the tectonic boundaries and the cross section (II-II in the Fig. 10), with frontal part represented by the Plakalnitsa fault zone, but with well-developed subthrust zone (Vladimirovo strip).

The syn-orogenic foreland basins formed in front of the BFTB show significant variations along strike in their evolution and particular characteristics (Fig. 10). Undoubtedly, this fact reflects the significant differences in the crustal architecture between the Eastern and Western parts of the belt.

The Eastern part of the foreland basin is closely genetically related to the Black Sea evolution and some of its characteristics do not coincide with the classical examples. Along the front of the thin-skinned thrusting (Eastern) terrigenous wedge was formed. This was a foreland (foredeep) basin which is almost entirely preserved in the Eastern part of the belt (east of the Rishki Pass). The syntectonic coarse-grained sedimentary pile (up to 600 m thick) indicates distinct north to northeast progradation and deposition in narrow depocenter in front of the thrust. The progradation is accounted at about 15 km over the shallow-water deposits of the northern slant and passive board.

The direction of the paleotransport indicates sourcing from the Eastern Balkan, including volcanic clasts from Sredna Gora, whereas it changes from S-N to W-E direction along the foredeep basin axe toward the Black Sea. Voluminous terrigenous material was transported eastwards since larger part of the source area was composed of poorly consolidated Paleogene rocks of the Emine piggy-back basin and redeposited in the Black Sea, thus forming a coalescent turbiditic fan system (Stewart et al., 2011). The width of the basin is expected to exceed 50 km. The basin closure indicates sinistral transpression, whereas the tectonic activity ceased in the Middle Lutetian. It is evidenced by an onlapping of the terrigenous wedge by younger mudstones of Middle–Late Eocene age. This is proved by the bulges orientation, oblique to the thrust front and the subthrust folds configuration.

West of the Rishki Pass, the foredeep sediments are restricted only in isolated outcrops in front of the thrust belt. On the other hand, in the Kotel–Stara Reka and especially in the Hainboaz Pass–Gabrovo areas (overlapping area) they cover a wide area showing sequence thickness up to several hundred meters. The sediment characteristics are very similar to the eastern ones (distribution of redeposited material from the thrust wedge, changing the direction of transport eastward along the basin axe, propagation north-eastward, etc.), but the clast content is slightly different. This is due to the fact that part of the source area is represented by the easternmost fragments of the thick-skinned thrust.

A recent re-examination of the Maastrichtian–Paleocene rocks from the immediate footwall of the Botev Vrah thrust (Balkanska et al., 2012) suggests the existence of foreland basin deposits in this part of the Central Balkan. Previously they were interpreted as platform-type Maastrichtian and coarse-clastic Eocene deposits (e.g. Bakirov et al., 1984). Therefore the sedimentary sequence in the Central Balkan area is now described as continuous Maastrichtian–Paleocene prolongation of the foreland basin in front of the Eastern Balkan (Balkanska et al., 2012).

In front of the Plakalnitsa fragment of the BFTB, the foreland basin sediments are unevenly exposed and/or preserved. North of the Ribaritsa fault zone, the Upper Cretaceous and Paleogene sediments are lacking. Paleogene middle to distal turbidites, common in a foreland basin, crop out at about 30 km north of the BFBW in the Lukovit syncline. Northwestwards, in front of the Plakalnitsa fault, the foreland deposits crop out in the Mezdra syncline. They are presented by relatively shallow-water deposits in the lower part of the sequence and a proximal turbiditic system developing in the upper part. There are scarce indications to the top-to-the-east direction of the tectonic transport and are probably related to the turbidites in Lukovit syncline, presumably with subthrust tectonic control on the deposition.

In front of the Forebalkan fault, in the area of Ruzhintsi village, the foreland basin sediments are distinguished only in several wells. On the basis of the drilling diaries (National Geofund reports) we can interpret them as local turbiditic fan oriented towards the Carpathian foreland and limited to the east by Gostilya fault. Another turbiditic fan with similar characteristics was documented to the northwest in the area of the Gramada village (wells Toshevtsi and Milchina Laka). There are also some local outcrops near Staropatitsa village, but they are in the realm of the most prominent Carpathian foreland basin.

Important fact is that the synchronous deposits between the Mezdra syncline and the area of Ruzhintsi village are presented mainly by clayey-limy sequence without any evidence of terrigenous input.

In the case of the Balkan Belt there are some different features when comparing it with the classical models of foreland basins. In front of the Eastern thin-skinned part of the BFTB, a very narrow foredeep basin was formed including up to 600 m thick sedimentary sequence indicating top-to-the-east direction of paleotransport along the basin axe towards the Black Sea. It is preserved in three locations (Gabrovo and Stara Reka synclines and east of the Aytos Pass) separated by areas with poorly developed syntectonic deposits overlaying shallow-marine sediments with long-term hiatuses. This facts could be explained by: (1) the thinner ~30-31 km crust in the eastern part of the foreland vs. up to 37 km in the western part (Boykova, 1999); (2) a thin thrust pile (1-2 km) and shallow depocenter; (3) existence of front forebulges (areas of erosion) oblique to the main thrust separating local depocenters which are now buried beneath the thrust plain; and (4) uplifting of the subthrust zone.

The deposition in the foreland basin started at the beginning of Middle Paleocene in the Gabrovo area (lasting at about 15 Ma), during the Late Paleocene in the Stara reka area (lasting at about 10 Ma) and in the coastal part at the Early Eocene (lasting at about 6-8 Ma).

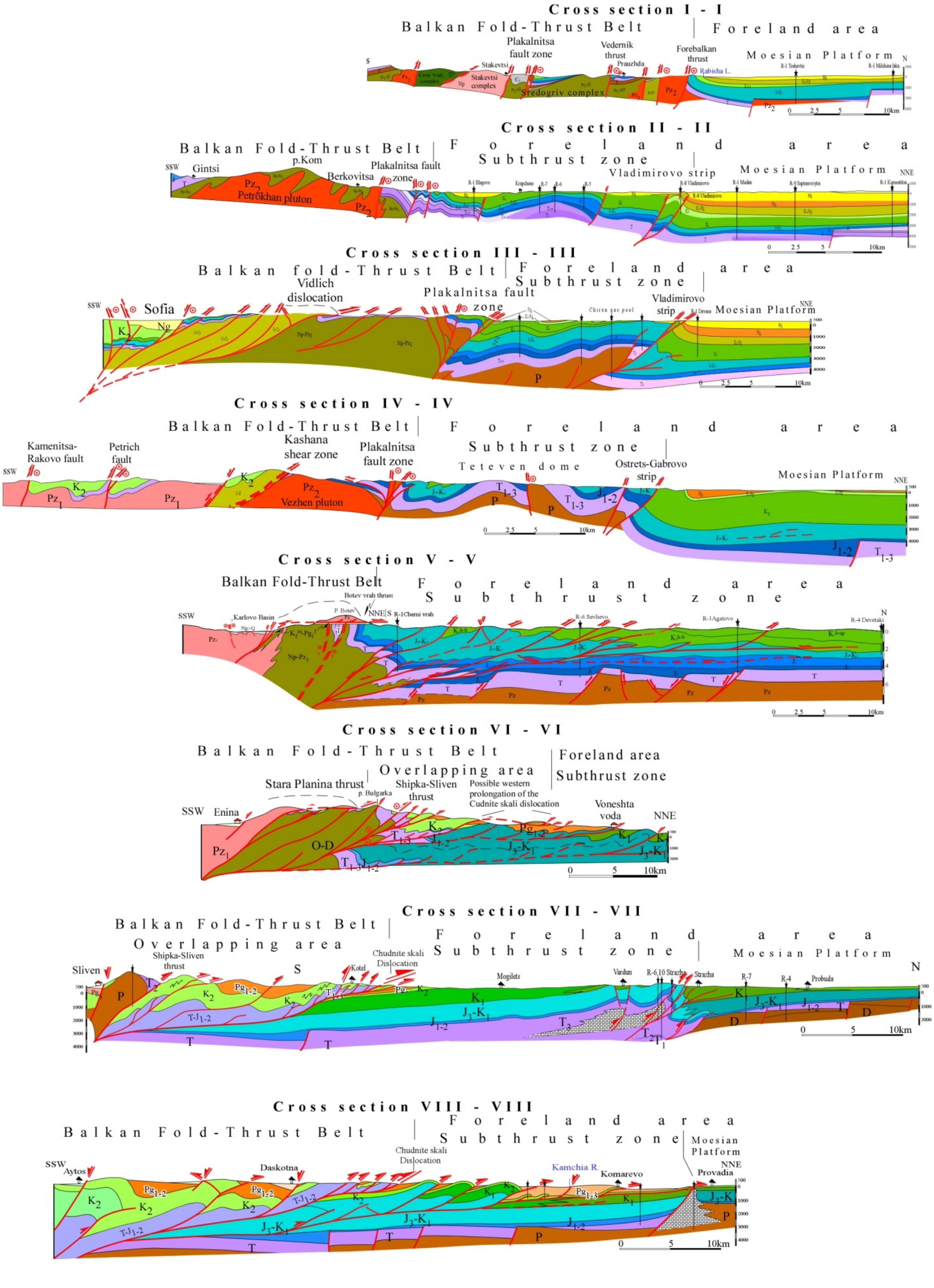

Fig. 10. Overview of the cross sections across different parts of the BFTB showing specific features and style of deformation.

In front of the Western thick-skinned part of the Balkan Belt, typical foreland basin was not formed. The isolated turbiditic fans cannot be considered as remnants of such a basin. Beneath the Botev Vrah fragment (the only one with significant displacement of ~20 km) remnants of foreland shallow-marine sediments (few tens of meters) were preserved. The Botev Vrah thrust plane follows the Maastrichtian–Paleocene level, demonstrating low-angle thrusting that cannot produce significant amount of foreland deposits. The eroded material was presumably redeposited in the eastward existing depocenters, e.g. Gabrovo syncline.

The other parts of the thick-skinned fragment of the Balkan Belt indicate very low amount of shortening. The synchronous deposits in the foreland basin are dominated by silty-limy-clayey sequences. Relatively larger turbiditic system was developed in the frontal part of the subthrust zone, now preserved in the Mezdra and Lukovit synclines, orientated almost parallel to the thrust belt. This could be explained by intensive subthrust deformation in the pre-Upper Cretaceous successions, causing relatively high relief existing even today. Two other turbiditic fans were formed in front of the Forebalkan thrust but they are related to the south Carpathians foreland realm.

Strike-slip component

Although there is no evidence on existence of major orogen parallel strike-slip faults along the Tertiary Balkan Belt, there are some indications of lateral translations. They are well-documented for the Eastern Balkan, where the Paleocene–Eocene shortening occurred in sinistral transpression regime (Doglioni et al., 1996; Blunt, Vangelov, 1997; Bergerat et al., 2010). Also, in the Eastern part there are important strike-slip fault zones oblique to the orogen. The sinistral Yantra zone is the most prominent structure of this type. It limits the domain of sinistral transpression from the west. Other important zones are Voynezha–Pchelinovo, Belopalanska and Kotel fault zones along which the displacement is from 2 to at least 10 km.

While the Central Balkan part (Botev Vrah fragment) recorded pure orthogonal convergence during the Paleogene (Balkanska et al., 2012), there is evidence suggesting some dextral strike-slip component along the steep faults in the Western Balkan, probably related to the formation of the Carpathian–Balkan sigmoid (orocline). Tertiary strike-slip tectonics is typical of the Southern Carpathians. Moreover, in the Western Balkan there are numerous steep faults with compatible orientation that accommodated some dextral strike-slip shearing (e.g. Petrov, 2009).

CONCLUSIONS

The Tertiary Balkan Fold-Thrust Belt consists of two clearly distinct parts: an Eastern one dominated exclusively by a thin-skinned thrusting, and a Western one with considerable basement involvement. The basement-involved tectonics requires an existence of deep detachment levels in the crust. A wide transitional area occurred at the zone of the overlapping of these distinctive deformational styles. For the Western thick-skinned part, the lack of syn-orogenic flysch is a characteristic feature that along with the modest and very limited development of foreland basin suggests a rather limited orogenic shortening compared to the Eastern part of the BFTB. The proposed re-definition of the Balkan Frontal system and internal structures of the peri-platform margin also call for significant revision of the existing tectonic subdivision schemes.

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