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SUPRASTRUCTURE OF THE METAMORPHIC TERRAINS IN SOUTH BULGARIA

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ABSTRACT. In Rhodope, Strandja and Sakar regions are exposed metamorphic rocks of different age and deformation history. Traditionally until the beginning of the eighties, these rocks were interpreted as a polymetamorphic and polydeformation terrain with Precambrian age. In the beginning of the eighties a progressively metamorphic model of Alpine development was proposed. During the nineties this model was synchronized with the modern concept of the metamorphic core complexes. The analysis of the literature indicates that in the environment of the Bulgarian academic practices the concept of the metamorphic core complex does not lead to valuable scientific ideas. For this reason, reexamination of the structure of the metamorphic rocks is proposed in this and in the next paper applying yet another philosophical concept, that is the concept for the supra- and infrastructure of the metamorphic terrains. Under suprastructure (superstructure in some works) a structural level in the crusts is understood in which upright folds and sub-vertical foliations predominate. Under infrastructure lower structural level is understood in which the folds are recumbent and the metamorphic foliation is shallowly dipping around domes. In Bulgaria the suprastructure has Alpine age.

СУПРАСТРУКТУРА НА МЕТАМОРФНИТЕ ТЕРЕНИ ОТ ЮГОИЗТОЧНА БЪЛГАРИЯ

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РЕЗЮМЕ. В Родопите, Странджа и Сакар се разкриват метаморфни скали с различна възраст и деформационна еволюция. Традиционно до началото на осемдесетте години тези скали бяха разглеждани като полиметаморфен и полидеформационен терен с докамбрийска възраст. В началото на осемдесетте бе предложен прогресивно метаморфен модел на алпийско развитие. През деветдесетте новият модел бе преработен и синхронизиран с модерната концепция за метаморфните ядрени комплекси. Анализът на литературата показва, че в условията на българската академична практика концепцията за метаморфните ядрени комплекси не води до развитие на качествени научни идеи, затова в тази и последващата я публикация се предлага преразглеждане на строежа на метаморфитите в рамките на друга философска концепция, а именно концепцията за супра и инфраструктурата на метаморфните терени. Под супраструструктура (суперструктура в някои работи) се разбира горен структурен етаж, в който преобладават изправени гънки и суб-вертикална фолиация. Под инфраструктура се разбира долен структурен етаж, където гънките са лежащи, а метаморфната фолиация потъва под малък ъгъл и формира куполообразни подувания. В България супраструктурата е с алпийска възраст.

Introduction

Until the early eighties of the last century the Rhodope massif and the high-grade metamorphic rocks of the Strandja zone (SZ) has been described using the philosophical framework of Eskola (1948) who introduced the concept of the mantled gneiss dome. This philosophy was thoroughly reflected in the geological map of Bulgaria in scale 1:100000, which was published in the beginning of the nineties. Later the concept of the metamorphic core complex (e.g. Coney, 1980) was introduced as it replaced the mantled dome philosophy.

In fact everywhere in the world the old massifs previously examined as mantled domes were later reexamined as metamorphic core complexes. In most of the cases, the newly defined metamorphic core complexes are taught to have poly-metamorphic history, like their predecessors the mantled domes, but in some cases the core complexes are believed to be monogenic edifices. The problem of interpretation, opposing poly-metamorphic against progressive metamorphic history of the core complexes, can be illustrated by the following citation of Armstrong (1982) who wrote: "Most confusion concerning core complexes arises because of differences in age of structures and multiplicity of deformation events. These differences are of two major types: From Canada to California the complexes are polygenetic – all contain evidence of Mesozoic metamorphism and deformation which is related to Cordilleran orogenic development in a setting of plate convergence. All the complexes have also been overprinted by an episode of crustal extension during the Cenozoic. In Arizona most complexes are monogenetic-exclusively the result of Cenozoic extension. Episodes of regional extension during the Mesozoic have not been clearly resolved, and potentially are further complexities of the polygenetic core complexes".

It can be added that recent high precision geochronology reported in numerous papers confirmed not only Mesozoic but also Paleozoic and Precambrian metamorphism and deformation for many of the core complexes. The geometry and mechanics of the core complex formation is also problematic. With respect to the extensional stage, it can be mentioned that nowhere in the world the amplitude of displacement along low angle normal (detachment) faults have been scientifically proven. The nature of the thrusts during the compression stage is even murkier.

The Balkan (Bulgarian) model of core complex was suggested for Osogovo-Lisets (Kounov et al., 2004), Rhodope (e.g. Bonev et al., 2006), and Strandja-Sakar (Ivanov et al., 2001) tectonostratigraphic domains (Fig. 1). Specific features of the Bulgarian style core complex is that it does not have polymetamorphic and polydeformational history like the Cordilleran core complexes and like all massifs in Europe, which have Caledonian and Variscan relict structures but it is interpreted as a single-stage, compression-extension alpine buildup in spite of the isotopic and stratigraphic evidence for older ages of the protholite, which in the case of Rhodope are reported to be Proterozoic (Kozoukharov, Timofeev, 1979). Such oversimplification results in mixing of old, say Hercinian or Caledonian structures with Alpine structures. Even if the idea for the metamorphic core complex correctly describes the latest extensional structures, formed during exhumation of an old massif, in the Bulgarian context this concept is severely compromised, because it ignores the polymetamorphic history. The evidence of polymetamorphic and polydeformation history of the high-grade metamorphic rocks, and part of the low-grade metamorphic rocks in Bulgaria are overwhelming.

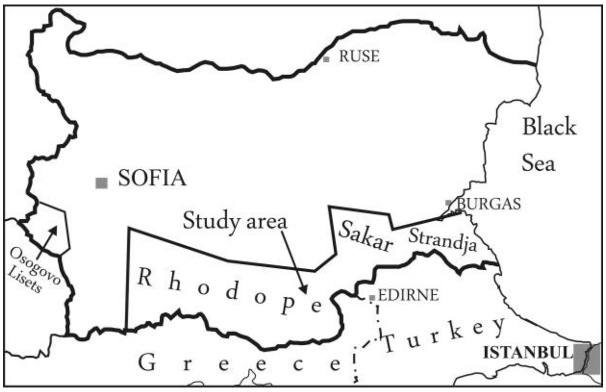

Fig. 1. Orientation map of the study area showing the regions of Rhodope, Sakar and Strandja, for which the supra – infrastructure relationships are discussed in this paper

In search of a philosophical framework capable of accommodating numerous evidence of multiple metamorphism, multiple intrusive activity and complex fold interference we are better to reinterpret the metamorphic rocks in terms of yet another tectonic concept. It must be suitable for explanation of polymetamorphic and polydeformational history, and should not allow room for oversimplification.

A replacement of the monogenic metamorphic core complex is easily available. It has common features with the polygenetic metamorphic core complex and with the mantled domes of Escola. Because, it is not so easy to digest in the "paper generator" it is not overused and corrupted yet. In this paper, which is split in two part, respectively part (I) Suprastructure and part (II) Infrastructure, the supra-infrastructure concept (e.g. Wegmann, 1935; Haller, 1956; De Sitter, Zwart, 1960; Haller, 1971; Higgins, 1976; Murphy, *1986;* Carreras, Capella, 1994; Culshaw et al., 2006) is delineated and reshaped in the context of the South Bulgarian metamorphic rocks. In the second paper (Infrastructure), comments are made from the point of view of the geometric structural geology and basic overprinting relationships in order to justify the need for a change in the research strategy.

Definitions for suprastructure and infrastructure

The literature review, suggests that the suprastructure – infrastructure concept has two very significant advantages with respect to the concept of the metamorphic core complex. The first advantage is that it is very flexible and can accommodate with ease polymetamorphic and polydeformational history. The second advantage is that by definition it requires detailed studies of the fold interference pattern and the recumbent folds in particular, which will compel the researchers to turn more attentions to the geometric structural geological and stratigraphic relationships instead of ignoring them as many prefer to do it now. Finally, this concept allows transition to other models, such as the channel–flow model (e.g. Williams et al., 2006), which is gaining repute at present, so it can allow "academic productivity and scientific longevity" of the workers who embrace it.

A suprastructure is usually defined as a higher structural level with greenschist-grade metamorphism, upright folds and vertical foliations, and an "infrastructure", as a deeper structural level with amphibolite-grade metamorphism, recumbent folds and dome-shaped, gently dipping foliations (Zwart, 1979; Murphy, *1986*).

The change from infrastructure to suprastructure is commonly attributed to rheological differences resulting from different grades of metamorphism (De Sitter and Zwart, 1960). Another view is that the transition from suprastructure to infrastructure involvs progressive increase of shear strain and consequent rotation, extension and reactivation, so the angle between the steep and shallowly dipping foliations, progressively decreases with depth until, eventually, only one schistosity is observed (Aerden, 1994). The foliation in the infrastructure is generally considered to be younger and to have formed during subsequent crustal extension; however, new data show that the gently dipping foliation in the infrastructure is commonly rotated and extended instead of being an younger one (Aerden, 1994). For the specific case with the high-grade metamorphic rocks in south Bulgaria Aerden's finding is of particular value, because evidences exists of large unconformities and multiple metamorphism, which separate alpine form pre-alpine basemen rocks in such a way that the foliation in the pre-alpine infrastructure can not be interpreted as younger than the foliation in the alpine suprastructure.

Different options exist for interpreting the recumbent and the upright folds in the infrastructure and suprastructure. The author prefer the model according to which most folds in the crust are formed originally as an upright folds, which are later transformed to recumbent folds by tilting and lateral shear due to doming of the underlying basement (e.g. Echtler, 1990). Some researchers would insist that recumbent folds can be formed directly by simple shear related to nappe emplacement in spite of the strong opposition to this model (e.g. Ez, 2000), however it is unlikely that most of the recumbent folds in the old massifs and especially in Rhodope and SZ are formed this way. The formation of recumbent folding requires lateral accommodation of space. If nappe-related simple shear is involved we have to allow it to happen by exhuming the massif high enough to allow space for lateral collapse of the rock above the doming segment. The above consideration leaves as with the conclusion that the recumbent folds and the upright folds in the old massifs are most likely of different age, and so are the associated with them shallowly dipping and sub-vertical foliations of the infrastructure and suprastructure. In the case of Rhodope existence of foliations of different ages can be

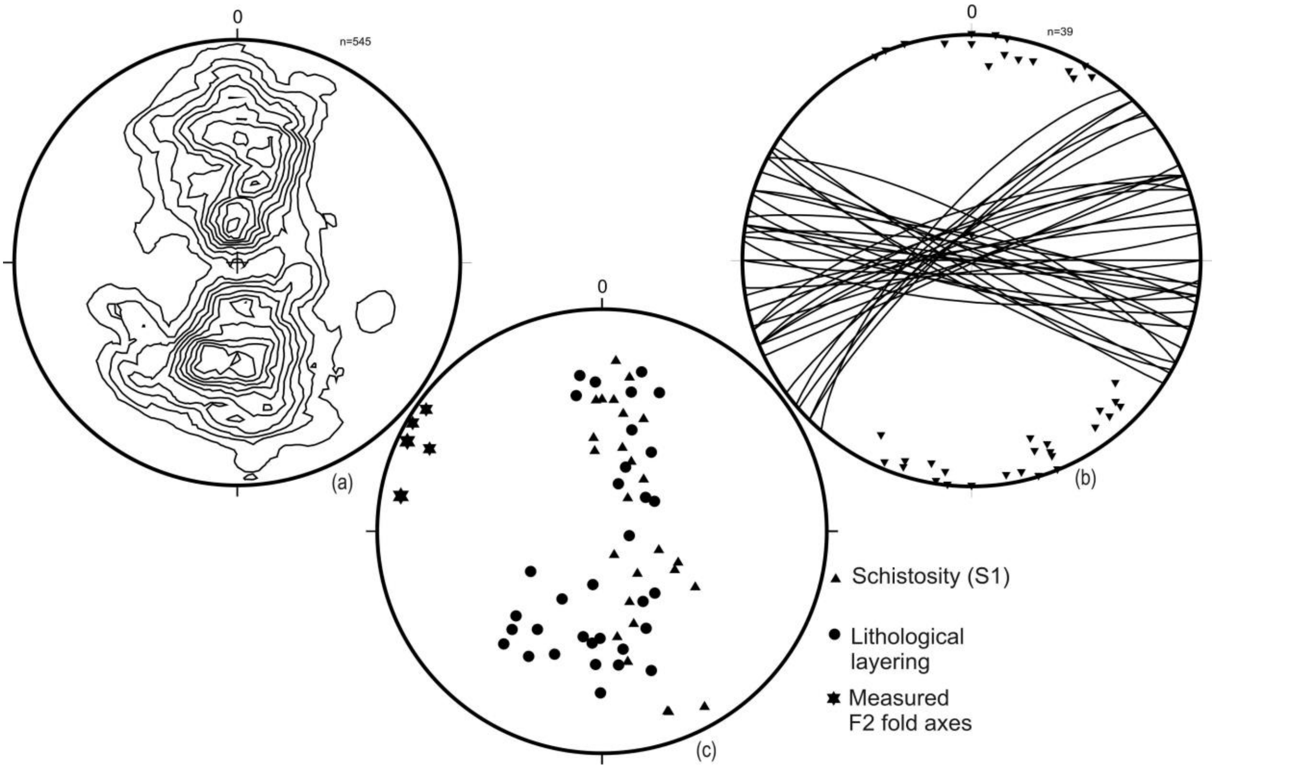

Fig. 2. Lower hemisphere equal area projections of metamorphic foliation and bedding from Sakar and east Strandja. (a) Bedding planes measured over area of approximately 4000 km^2 in SZ. (b) Enveloping surface to a folded (*F_3s*) dyke, quarry near village Drianovo. The axial surface of the steeply plunging fold is striking close to north south. (c) Simultaneously folded bedding and greenshist metamorphic foliation, south of village Crumovo, SZ. Both foliation and bedding participate in a recumbent fold (*F_1s*), which was later refolded by upright folds (*F_2s*) with east-west striking axial surface. Hinges of second order (*F_2s*) are shown on the same projection

proven with thin sections of fold hinges, and with variety of macroscopic overprinting relationships. In general in Rhodope and in SZ the entire high-grade sequence was folded by recumbent folds, which were later refolded by at least two generations of upright folds (Fig. 2-3).

Description of the suprastructure

Fold generations in the suprastructure

The geological structure of the metamorphic rocks in South Bulgaria is dominated by the interference of three regional alpine fold generations expressed in a similar way in the Sakar-Strandza Zone and in Rhodope (Figs. 2 and 3). The two younger generations (*F_2s, F_3s* in the SZ, and *F_2r, F_3r* in Rhodope) form the suprastructure but the older fold generation (*F_1s, in SZ and F_1r,* in Rhodope*)* contains the relics of a reworked (transposed) basement, which may have played the role of infrastructure for even older, variscan and pre-variscan deformations.

F_3s and F_3r folds

F_3s in SZ are sporadically developed. The strike of the axial planes is predominantly north-south and the fold hinges are steeply plunging because of fold interference. The *F_3s* folds were superimposed on older folds with east-west striking axial planes. In SZ *F_3s* folded upper cretaceous dykes. Folds with north-south striking axial planes were also described in the eastern Balkan as they were interpreted as Paleocen in age (Paskalev, 2005).

In Rhodope the F_3r have mostly north-south striking axial planes (Ivanov, 1961) but wider variations to northwest and northeast are present. These folds are visible on the structural maps (Kozoukharov, 1965), where trajectories of the metamorphic foliation are shown. The age of F_3r is most likely the same as that of *F_3s*.

F_2s and F_2r folds

This is the dominant fold geometry in Rhodope, SZ and the Balkan. F_2s's axial planes are striking east-west or southeast-northwest. The fold hinges are horizontal or shallowly plunging. The scale of folding is hundreds of meters or kilometers. The initiation of the folding is protracted in the time. In West Bulgaria they are generally considered to be Austrian (middle cretaceous) (e.g. Antonov, 1978), however in East Bulgaria upper cretaceous volcanic strata are folded by F_2s. Recent review suggests that in Central and East Bulgaria some of these folds are discordantly covered by priabonian, while others are pre-maastrichtian in age (Nachev, Nachev, 2001). It is likely that the east-west trending folds were developed during the entire alpine orogenesis, however in different pulses. In general these folds are roughly synchronous to the formation and erosional destruction of the upper cretaceous volcanic ark in Bulgaria. In the SZ, locally penetrative axial planar cleavage S_2 is related to these folds (Fig. 3b).

F_1s and F_1r folds

Interpretations about folds and thrusts of upper Jurassic-lower Cretaceous age are common in the Bulgarian literature (e.g. Savov, 1962; Cankov, 1983). These alpine structures are recumbent and form the alpine infrastructure. The existence of such structures has justified the hypothesis for the nappe edifices of the Rhodope and SZ (e.g. Burg, et al.,1990; Gocev, 1991; Burg et al., 1996;). So far, however clear distinguishing between nappes and recumbent folds are not made, so it is vary likely, that the flat lying structures are in fact recumbent folds that repeat the same sequence, rather than nappes or thrusts with large displacement that juxtapose different rock sheets. In reality the time of initiation and the stratigraphic control of these structures are not clear. It can only be said that they are superimposed on Triassic and Jurassic rocks but are injected and disrupted by the upper cretaceous magmas (e.g. Ivanov, 2000).

In the pre-upper cretaceous rocks of SZ are developed two metamorphic foliations. The older foliation So-1 is penetrative and of greenschist to lower amphybolite facies grade. Commonly it is close to parallel with the lithological layering and nearly always is folded together with the layering in recumbent F1s folds (Maliakov, 1976).

Because the folds are recumbent and the lithological layering is transposed in their limbs both are folded together by later upright folds (F_3s, F_3r, F_2s, F_2r) and participate in complex structures, such as antiformal synclines of synformal anticlines (Fig. 3a,b). Because of which their geometry is difficult to study and understand. Sub-vertical fracture or crenulation cleavage is usually related to the upright folds. Only small number of F_1s and F_1r folds is directly observable on the field (e.g. the Marvodol synformal anticline in Southwest Bulgaria) but their widespread presence is indicated by structural analysis, when cleavage bedding relationships are studied or structural diagrams of cleavage and bedding in which both cleavage and bedding participate in the girdles of later folds (Fig. 2c).

In high-grade rocks such as the rocks in Rhodope F_1r folds are distinguished from older pre-alpine recumbent folds because in their hinges the pre-alpine high-grade metamorphic foliations are folded or week axial planar foliation related to regressive metamorphic alteration (diaphtoresis) transects the hinge area. The low-grade metamorphic foliation in Rhodope is analogous to the So-1 in the SZ. Nearly everywhere, except in the fold hinges this foliation is parallel to older high-grade foliations (Ivanov, 1961). The fact, that the low-grade foliation is transposed to shallow dips and is parallel to the older schistosity suggest that the limbs of all folds older than F_1r are also transposed are now dipping at shallow angles forming recumbent folds of microscopic to kilometer scale.

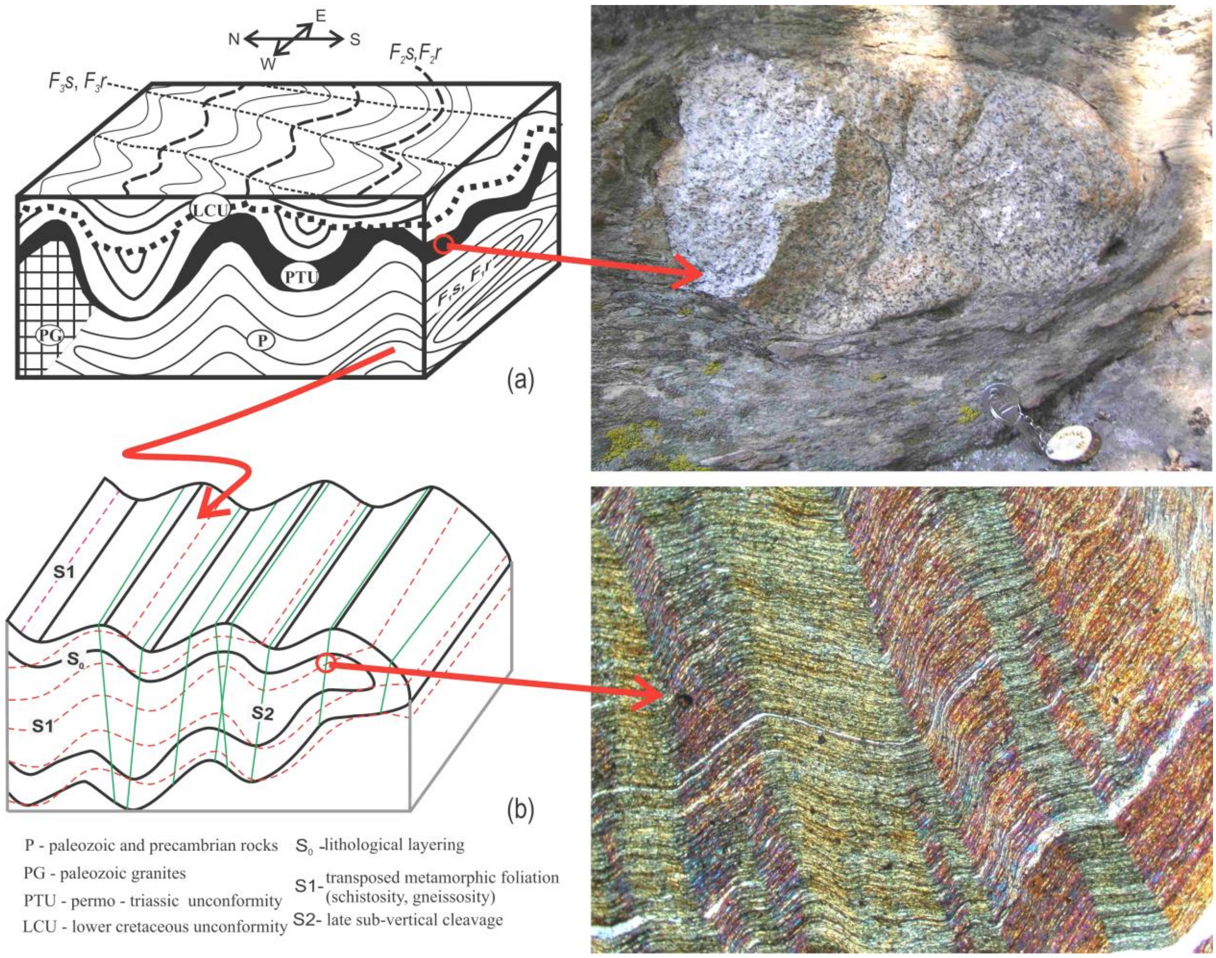

Fig. 3. Schematic block diagrams of the main stratigraphic and structural geological relationships in south Bulgaria. (a) Block diagram showing two unconformities and two upright fold systems (*F_2s, F_3s, F_2r, F_3r*) overprinting a recumbent fold system (*F_1s, F_1r*). The photograph to right shows meta-conglomerate from the permo-triassic unconformity in Sakar. The meta-conglomerate comprises deformed blocks of Paleozoic granite included in metamorphosed matrix, locality "Chernite kamany", south of Topolovgrad. (b) Block diagram of refolded recumbent folds in Rhodope and SZ. In the recumbent folds lithological layering (S_o) and metamorphic foliation (S_1) participate. The upright folds have sub-vertical axial planar crenulation cleavage (S_2) shown on the photograph to right

Fold interference

Together the folds with north-south and east-west striking axial planes form dome and basin interference pattern. The domes are slightly elongated in east-west direction and their limbs are dipping between 20-45°. The upper age boundary of the dome formation in the Rhodopes is given by the age of the unmetamorphosed but folded breccia-conglomerates of the Central and East Rhodopes (Goranov, Atanasov, 1991; Boyanov, Goranov, 2001). The breccia-conglomerates are covered by sub-horizontal strata of priabon-oligocen age. The geometrical superposition of fold generations F_2r, F_2s, F_1r and F_1s results in such an interference, that the beds from the inverted limbs of the recumbent folds outcrop in the cores of the domes.

Geodinamic setting during the suprastructure formation

In present day coordinates, the lithotectonic boundaries in Bulgaria are striking mainly east west-and to a lesser extend northwest-southeast (100-120SE). The boundaries of the modern continental basins, the major faults and the boards of the large intrusions also have this strike, which coincides with the axial plane orientation of the main alpine folds from the suprastructure (F_2s and F_2r). It can be argued that the sediments up to the Upper Jurassic time have been deposited in basins, which were also elongated in this direction (e.g. Nachev, Nachev, 2001). During folding lateral shortening perpendicular to this direction and shear parallel to it happened. It is difficult to argue to what extend transpression and to what extend simple shear are responsible for the deformation but it is known that both can produce the same final result. It is also clear that the shear on a regional scale was channeled predominantly east-west. In this sense the dominant deformation mechanism responsible for the suprastructure formation is most likely wrenching. The folds formed during multiple shear episodes of wrenching are "cross-folds" in the sense of O'Driscoll (1964). This mechanism can explain their orientation, the interference pattern between the upright folds as well as the "an echelon" (e.g. Antonov, 1978) arrangement.

Conclusions

The brief review of the supra-infrastructure relationships in Bulgaria indicate that the folds and foliations of the supra and infrastructure were formed at different times. The folds of the suprastructure have been superimposed on the infrastructure, and refolded its foliation. The supra-infrastructure division is not strict but relies on general trends in the tectonic development. It is known that recumbent structures have been formed in upper cretaceous time and even in the paleogen but in general for infrastructure here are understood recumbent structures, which were refolded by the upper cretaceous and later upright folds. These structures affected triassic and lower-middle jurassic rocks, so obviously they predate the main alpine deformation. Recumbent structures however are present in the Paleozoic and Precambrian, where they form pre-alpine infrastructure. The separation of the alpine from the pre-alpine infrastructure is one of the main problems of the Bulgarian geology. One of the strongest time criteria still not used in the Bulgarian geology is separation of metamorphic rocks with one, two or more foliations. Particularly useful is this criteria in the SZ, where low grade metamorphic rocks with one cleavage and with two cleavage can be observed. The other main problem is the age of the folding events of the suprastructure. All evidence indicates that there were not single-phase, time-constrained folding events. The upright folds have been formed at different times, when different alpine basins have been closed.

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