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Alpine Evolution of the Pre-Alpine Amphibolite Facies Basement in South Bulgaria

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Alpidische Entwicklung des präalpidischen amphibolitfaziellen Grundgebirges in Südbulgarien

Zusammenfassung

Das präalpidische amphibolitfazielle Basement in den zentralen Teilen der Balkanhalbinsel besteht aus zwei präkambrischen, metamorphen Komplexen. Die phanerozoischen Überprägungen begannen mit einer Schieferung, die gleich alt ist wie die altpaläozoische Faltung des grünschieferfaziellen Diabas-Phyllitoid-Komplexes und die Intrusion von ca. 500 Millionen Jahren alten Graniten.

Die jungpaläozoische Kollision verursachte die Entstehung und Intrusion der südbulgarischen Granitoide (340–240 Ma.). Das präalpine Basement wurde in verschiedene autochthone und allochthone alpine tektonische Zonen eingebaut. Die alpine Überprägung des Basements war besonders intensiv in der verdickten kontinentalen Kruste des Rhodopen-Massives und entlang von Scherzonen in der Sakar-Einheit. Beide Lokalitäten sind mit einer gleichaltrigen Metamorphose in Grünschiefer- bis Amphibolitfazies verknüpft. Die Deformationen wurden von einer Kreidesubduktion am nordöstlichen Rand des Vardar-Ozeans verursacht unter gleichzeitiger Überschiebung der Morava-Zone und der Ograzhden-Einheit über die Stuma-Zone und über die Pirin-Pangaion-Zone des Rhodopen-Massives in der Mittelkreide. Später entwickelte sich ein Inselbogen, die Srednogorie-Zone nördlich des Rhodopen-Massives, während sich gleichzeitig krustale granitoide Magmen im Massiv selbst bildeten. Paläogene Deformationen überprägten das alte Gebirge in einem relativ seichten Krustenniveau.

Abstract

The pre-Alpine amphibolite facies basement in the central parts of the Balkan Peninsula consists of two Precambrian polymetamorphic complexes. Phanerozoic superimposed deformations began with overprinting of a new schistosity coeval with the Early Paleozoic folding of the covering greenschist facies diabase-phyllitoid complex, and the intrusion of ca. 500 Ma granitoids.

The Late Paleozoic collision resulted in the formation and intrusion of the South Bulgarian granitoids (in the time interval between 340 and 240 Ma). The pre-Alpine basement was incorporated in several autochthonous to allochthonous Alpine tectonic zones. The Alpine reworking of the basement was particularly intense in the thickened continental crust of the Rhodope Massif, and along the shear zones in the Sakar Unit. Both localities are connected with coeval metamorphism grading from greenschist facies to amphibolite facies. The deformations were related to the Cretaceous subduction at the northeastern margin of the Vardar Ocean, with accompanying Mid Cretaceous thrusting of the Morava Zone and the Ograzhden Unit over the Struma Zone and the Pirin-Pangaion structural zone of the Rhodope Massif. Later, a volcanic island arc (Srednogorie Zone) developed to the north of the Rhodope Massif, while synchronous crustal granitoid magmas formed in the massif itself. The superimposed Paleogene deformations occurred at shallower crustal levels.

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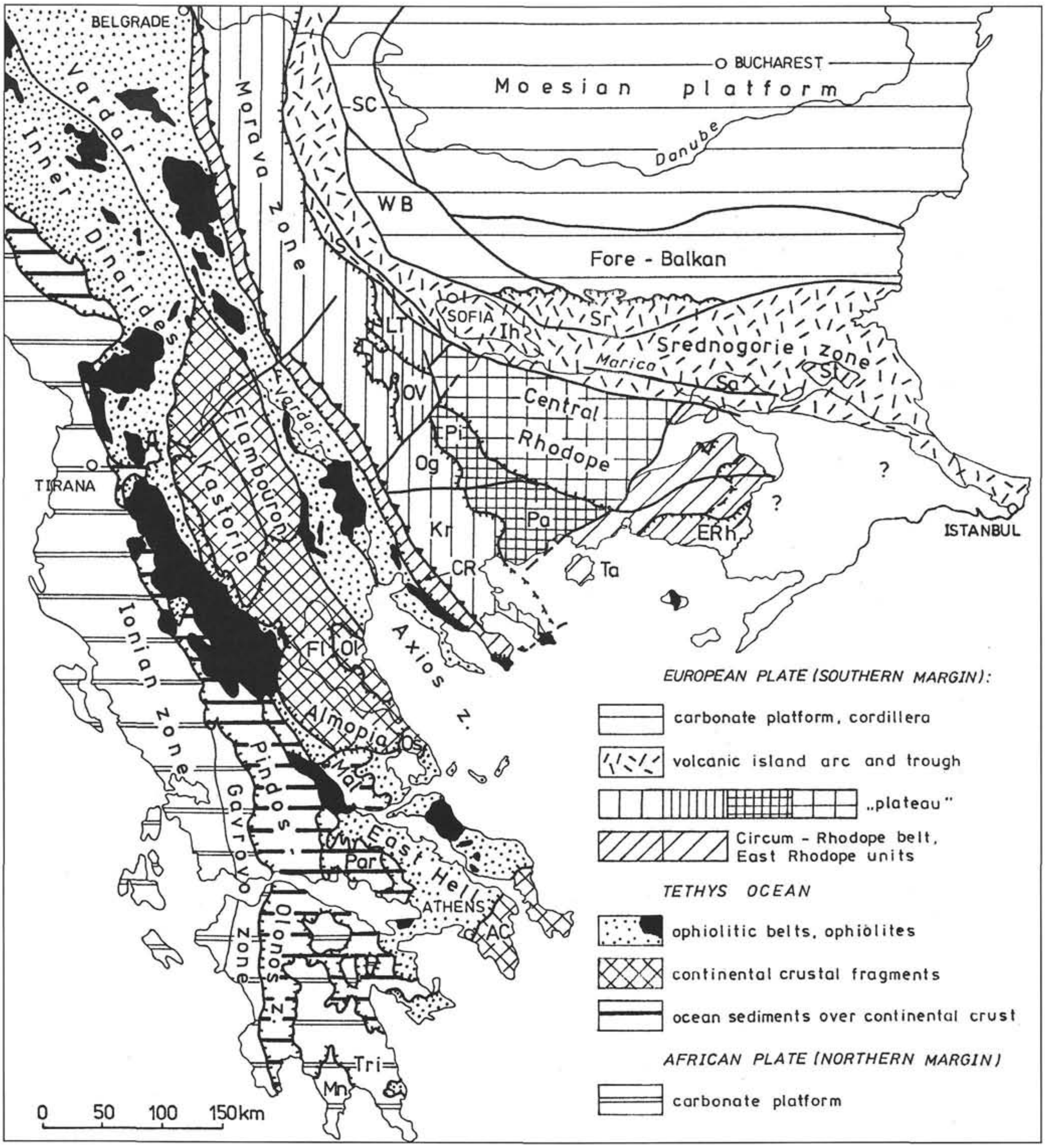


Text-Fig. 1.
Tectonic sketch map of the Alpine orogens on the Balkan Peninsula (based mainly on the Late Cretaceous orogen) on the basis of the Tectonic Map of the Carpathian-Balkan-Dinaric Region reworked after data of BOYANOV et al. (1989), PAPANIKOLAOU (1983) and ZAGORTCHEV (1993).
Southern margin of the European plate (with Eocene and Oligocene reworking and north-vergent thrusting): SC = South Carpathians (Kula flysch trough), WB = West Balkan (cordillera formed over former Mid Cretaceous units); relics from Mid Cretaceous and older units included in the Srednogorie Zone (volcanic island arc): Sr = Sredna gora crystalline block, Ih = Ihtiman Unit, Sa = Sakar Unit, St = Strandzha Unit, S = Suva planina, Lyubash, Radomir and Golo bardo units (covered by Upper Cretaceous limestone-marly and terrigeneous sedimentary formations at the southern margin of the volcanic island-arc basin); "plateau" (in the sense of DEWEY et al., 1986) with thickened continental crust (Morava-Rhodope Zone) formed from Mid Cretaceous and older units: Og = Ograzhden Unit, Kr = Kroussia Unit, LT (Luzhnica-Tran Subunit) and OV (Osogovo-Vlahina Subunit) = Struma Zone (Strumicum), Rhodope Massif s. s. (Central Rhodope Zone, and Pirin-Pangaion Zone with Pi = Pirin Unit, and Pa = Pangaion Unit); Circum-Rhodope belt (CR) and East-Rhodope Zone (ERh).
Tethys Ocean: Vardar (Axios) Zone and Inner Hellenides = Eastern Dinarides.
Continental crustal segments: Flambouron, Kastoria and Almopia partially thrusted over Olympos (Ol) and Ossa (Os) windows.
Mainly oceanic sediments over continental crust: Pindos-Olonos Zone, Parnassos (Par) and Maliac (Mal) zones.
Northern margin of Apulia: Ionian (including Paxos), Gavrovo, Tripolitza (Tri) and Mani (Mn) zones.
Main subduction zones (barbed line with triangles), main thrusts (barbed line).

1. Introduction

Regions of complex tectonic history cannot be analysed in simple terms of strain partitioning and rock structure geometries typical of single-phase structures. The final results produced by different sequences of deformation events can be quite similar, and only the complex interpretation of the geological evidence can reveal the real structure and deformation history.

The pre-Alpine basement ("Thracian Massif") in the Central Balkan segment of the Alpine fold belt represents an intricate mosaic of tectonic units with different tectonic histories (Text-Fig. 1). Later zones of sedimentation and folding have been often unconformably superimposed over the earlier structures producing their partial reworking by completely unrelated new strain fields. In the cases of less intense Alpine reworking, the basement preserved traces of late Paleozoic (Hercynian) or early Paleozoic (Late Cadomian, or Panafrican) overprint, or even of the initial Precambrian structure.

The aim of the present paper is to trace the Alpine deformation history of the basement, and to show how the old (Precambrian and Hercynian) structures have been reworked or influenced by superimposed later deformations.

2. Precambrian Amphibolite Facies Complexes

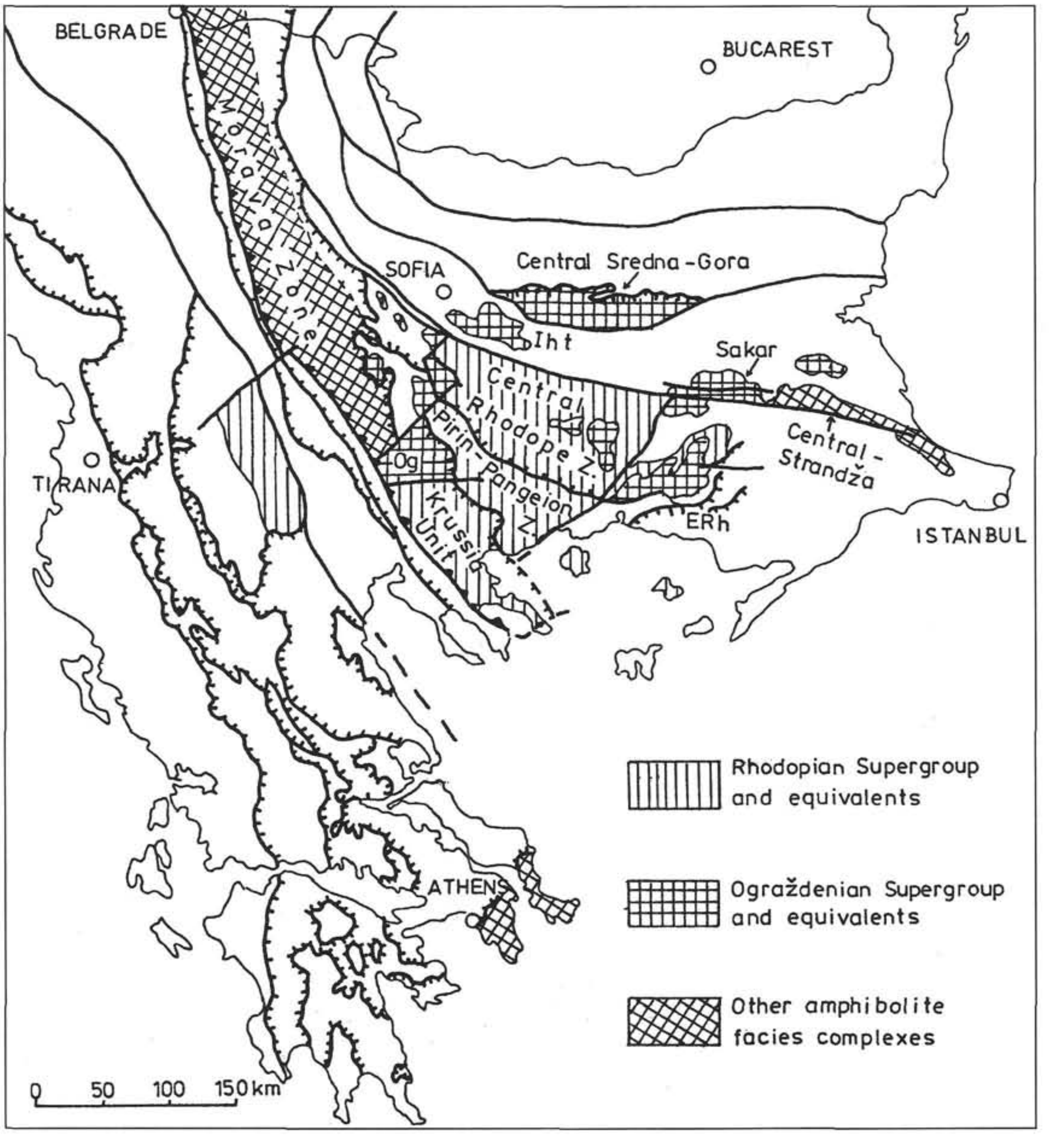
The Precambrian amphibolite facies complexes are widespread (Figs. 2, 3) in the Central Balkan segment.

Two main types of complexes have been distinguished:

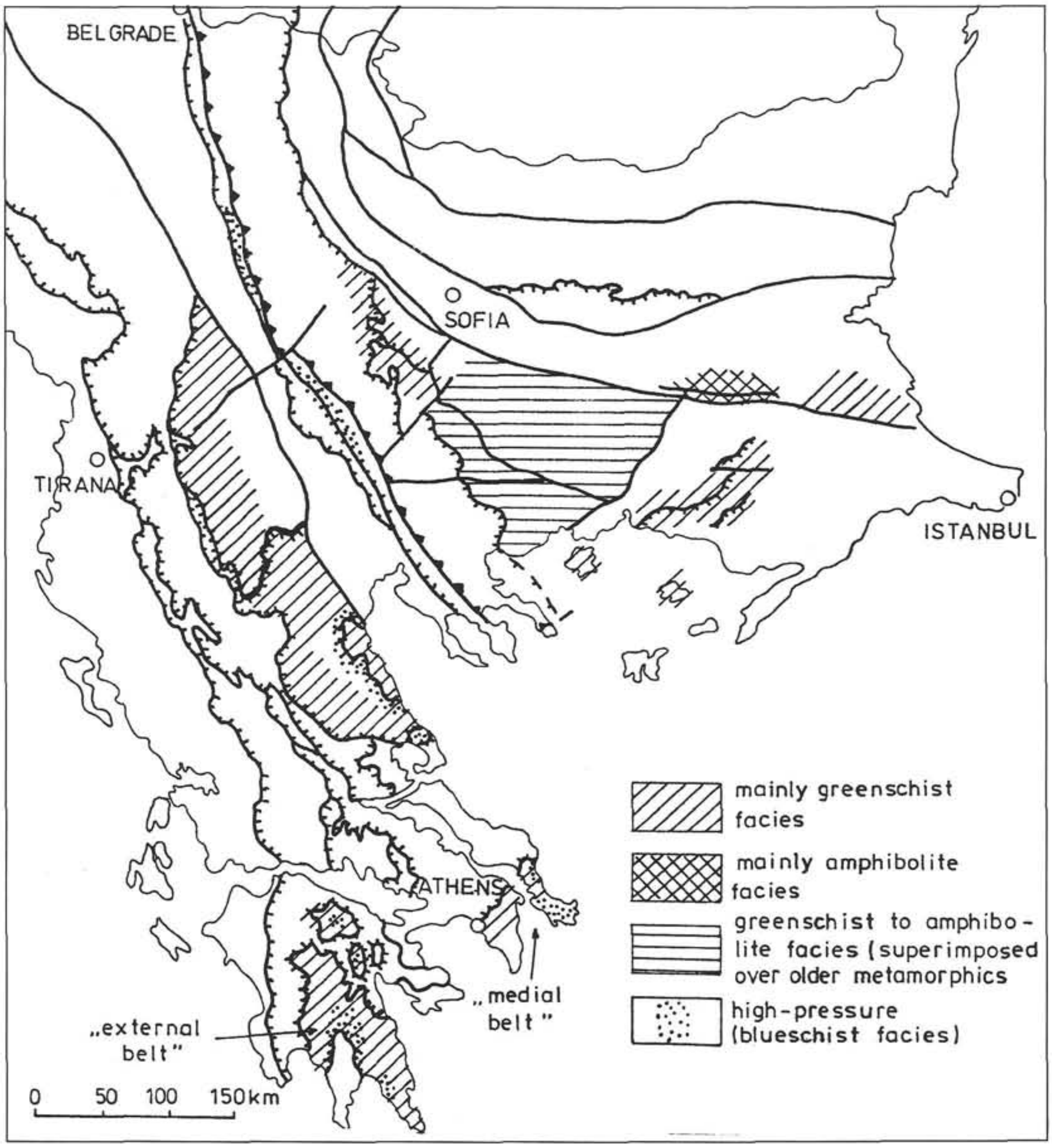
① **The Ograzhdenian ("Prarhodopian") Supergroup** is built up of biotite and two-mica gneisses and migmatites with amphibolite layers or rootless bodies (KOZHOUKHAROV, in ZOUBEK, 1988). Granite-gneisses (metagranites) are widespread. Other rock varieties (biotite and two-mica schists, graphite-, garnet-, staurolite- and sillimanite-bearing schists, muscovite quartzo-feldspathic gneisses etc.) are also present.

Most of the amphibolites are of igneous origin being formed at the expense of basic igneous rocks usually asociated with ultrabasics. The ophiolite associations probably represented pre-metamorphic ocean floor or volcanic island arcs obducted over the continental crust, and further modified by intense deformations and metamorphism (KOZHOUKHAROVA, in ZOUBEK, 1988).

The metabasic rocks (amphibolites, serpentinites) occur throughout the whole section but are concentrated mostly in its middle part (Boturche and Troskovo Groups).



Text-Fig. 2.
Simplified tectonic sketch of the Balkan Peninsula showing the distribution of Precambrian amphibolite facies complexes.
After data published in ZOUBEK (1988) and other sources.



Text-Fig. 3.
Simplified tectonic sketch of the Balkan Peninsula with the occurrences of Alpine metamorphism (in the Phanerozoic complexes, or superimposed over older amphibolite facies complexes).
After data of PAPANIKOLAOU (1983), CHATALOV (1985, 1990), BOYANOV et al. (1989) and other sources.

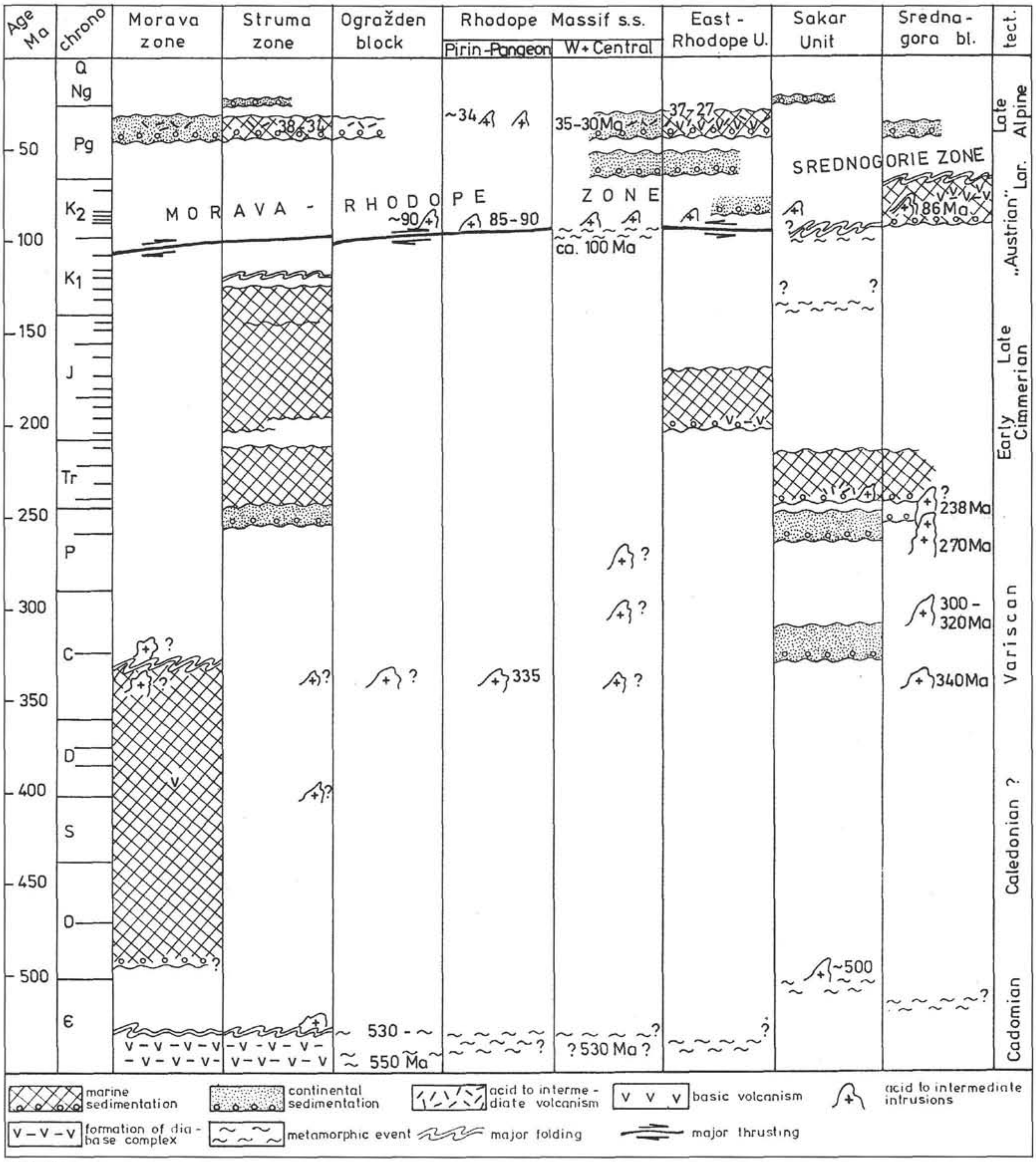
② **The Rhodopian Supergroup**
consists of three groups situated in superposition (KOZHOUKHAROV, in ZOUBEK, 1988).
The basal Rupchos Group consists predominantly of biotite gneisses and migmatites interbedded with amphibolites, kyanite-, garnet-, staurolite-, and graphite-bearing micaschists, calcareous schists, marbles, quartzo-feldspathic gneisses (leptynites) etc. with rootless bodies of metabasites and metaultrabasites. The sequence has in places a flysch-like character (rhythmic interbedding of biotite gneisses, quartzo-feldspathic gneisses, quartzites, amphibolites, calcareous schists and marbles).
The Sitovo Group begins with banded biotite gneisses and quartzo-feldspathic gneisses, and its uppermost Lukovica Formation marks the transition (through interbedding of different micaschists, calcareous schists, amphibolites and other metavolcanics, marbles etc.) towards the topmost Asenovgrad Group. Metabasites and metaultrabasites associate usually with formations consisting of interbedding rocks of varying composition often containing basic metavolcanics (amphibolites).

Different opinions about the age of the protoliths have been published. KOZHOUKHAROV & TIMOFEYEV (1989), TCHOUMATCHENCO & SAPUNOV (1989) and KOZHOUKHAROV & KONZALOVA (1990) reported acritarchs, ichnofossils and problematica confirming a Proterozoic age for the protolith of the Rhodopian Supergroup while IVANOV (1988) pleaded for a Paleozoic age as more probable from his general point of view, and on the basis of doubtful fossil remains (discussion in ZAGORTCHEV, 1993). On the basis of the existing evidence, a late Proterozoic age seems most probable (ZAGORTCHEV, 1993).

The Rhodopian Supergroup covers the Ograzhdenian (Prarhodopian) Supergroup in the Central Rhodope with a metamorphic unconformity (e.g. KOZHOUKHAROV, in ZOUBEK, 1988) although IVANOV (1988) maintains the opinion about the existence of a continuous section. The evidence about the age of the amphibolite facies regional metamorphism of the two supergroups is scarce.

The radiometric evidence (Table 1) points at an age of ca. 560–500 Ma for the last intense metamorphism in the Ograzhdenian Supergroup and its equivalents in the Morava Zone and Ograzhden and Sakar Units, and probably in the Rhodope region (whole-rock Rb-Sr isochrons cited by ALEKSIC et al. in ZOUBEK, ed., 1988; ZAGORTCHEV & MOORBATH, 1986a; LILOV, 1990).

The metamorphism was older than the intrusion of the Paleozoic granitoids (folded and metamorphosed Ograzhden-



Text-Fig. 4.
Chart for the main superimposed Phanerozoic events in different structural zones and units.

ian and Rhodopian rocks are discordantly cross-cut by the granitoid plutons) dated as late Cadomian (LILOV, 1990) or Hercynian (ZAGORTCHEV & MOORBATH, 1986b).

In the Morava and Struma Zones, the amphibolite facies metamorphism and migmatization of the Ograzhdenian Supergroup and its equivalents pre-dated the deposition of the covering diabase-phyllitoid complexes (Vlasina complex in Serbia, Frolosh Formation in southwest Bulgaria) which both had a pre-Ordovician, and most probably, Vendian – Cambrian age (ALEKSIC et al., in ZOUBEK, 1988).

The Precambrian amphibolite facies basement complexes underwent a complex Phanerozoic metamorphic and deformation history. Superimposed Paleozoic and Alpine events are usually related to discrete ductile shear zones or to contacts with younger sediments, and the resulting retrogressed (diaphthoritic) metamorphic rocks developed mostly in greenschist-facies conditions (Text-Fig. 6).

In cases when the superimposed metamorphism reached amphibolite facies conditions, the distinction between late Precambrian events and superimposed Phanerozoic events is difficult or even impossible.

Table 1.
Rb-Sr whole rock isochron data from South Bulgaria.

Geologic body; locality; source	Age, Ma	($^{87}Sr/^{86}Sr$)0	MWSD
Migmatites, Ograzhdenian Supergroup, Maleshevska Mts. (ZAGORTCHEV & MOORBATH, 1986a)	531 ± 13	0.70 2	0.2
Sakar granitoid pluton (LILOV,1990)	499 ± 70	0.7028	12
Southbulgarian granitoids, Sredna gora Mts. (ZAGORTCHEV & MOORBATH, 1986b):			
Smilovene pluton, I granitoid complex	342 ± 27	0.7060	2.5
Hisar pluton, I granitoid pluton	337 ± 14	0.7057	2.6
Koprivshtitsa pluton, II granitoid complex	320 ± 58	0.7092	0.4
Koprivshtitsa pluton (aplite included)	301 ± 7	0.7096	0.4
St. Georgi granitoids, III granitoid complex	271 ± 26	0.7090	1.3
Strelcha pluton, III granitoid complex	238 ± 37	0.7096	0.7
Alpine events			
Bachkovo Formation, Rhodopian Supergroup (ZAGORTCHEV & MOORBATH (1986a)	96 ± 6	0.7102	1.0
North-Pirin pluton (ZAGORTCHEV et al., 1987)	92 ± 20	0.7121	
Bezbog pluton, Pirin (ZAGORTCHEV et al., 1987	88 ± 9	0.7099	2.9
Vitosha pluton (ZAGORTCHEV & MOORBATH, 1987)			
monzonites	91 ± 10	0.7042	0.4
leucogranosyenites*)	78 ± 6	0.7043	
Aplite-granites, Central-Pirin pluton (ZAGORTCHEV et al., 1987)	34 ± 2	0.7130	6.2
***) Best-fit line on 3 samples analysed in Oxford, and 3 samples (data of P.Monchev) analysed in St. Petersburg**			

3. Paleozoic Evolution of the Precambrian Amphibolite Facies Basement

The Ograzhdenian basement is covered (Text-Figs. 4, 5) in the Morava Zone, Struma Zone and the Ihtiman block by diabase-phyllitoid complexes (e.g. Vlasina complex, Frolosh Formation) of Vendian – Cambrian age (ALEKSIC et al., in ZOUBEK, 1988; ZAGORTCHEV, 1974, 1987).

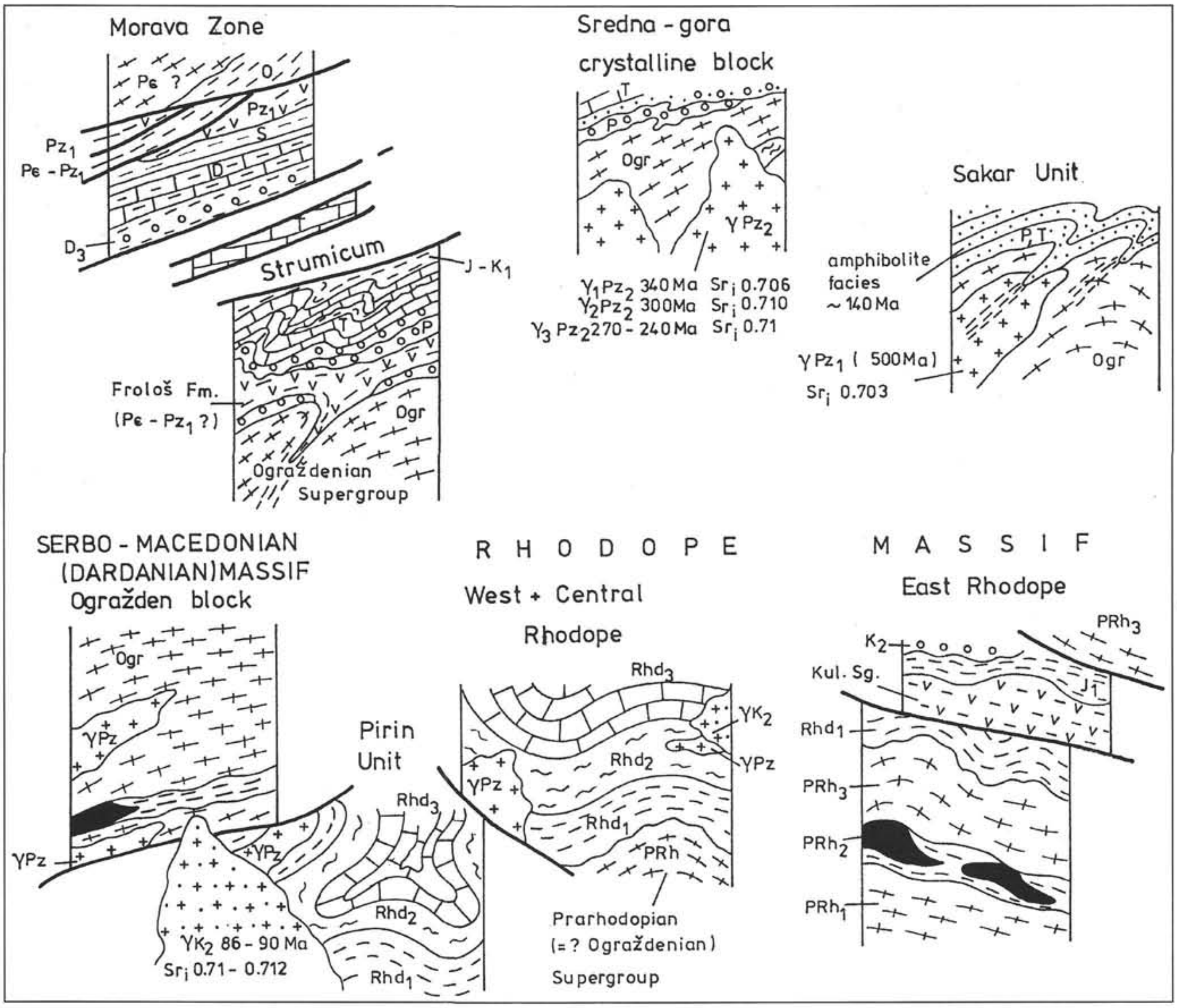
Locally, basal conglomerate and arkosic sandstone have been preserved at the base of these complexes (TENCHOV & ZAGORTCHEV, 1989) which consist mainly of metamorphosed diabases and tuffs interbedded with phyllites, sandstones and calcareous schists.

Basement and cover were folded together into typical cuspate-lobate folds with coeval greenschist-facies metamorphism in the cover, and formation of blastomylonites, diaphthorites and phyllonites in greenschist-facies conditions at the expense of the Ograzhdenian migmatites and amphibolites near the contact. The deformational and diaphthoritic overprint was particularly intense in Ograzhdenian rocks preserved as inliers within the diabase-phyllitoid complex. The age of these events is most probably early Paleozoic (late Cadomian).

Another concept (HAYDUTOV, 1989, 1991) regards the Ograzhdenian Supergroup and the diabase-phyllitoid complexes as products of different environments (continental and oceanic, respectively) which collided in Hercynian times with formation of the so-called Thracian suture.

In the Sakar Unit, the Ograzhdenian Supergroup and the intersecting older (Lesovo) gneiss-granites are cross-cut by the Sakar granitoid pluton (KOZHOUKHAROV, in ZOUBEK, 1988). The Sakar pluton is built up of late Cadomian (ca. 500 Ma) granitoids with a very low (about 0.703) initial $^{87}Sr/^{86}Sr$ ratio (LILOV, 1990) intersected by younger (Hercynian and Alpine) granitoid bodies.

The Hercynian ("Southbulgarian") granitoids are widespread (Text-Figs. 4, 5) in South Bulgaria. The fold structures of the Ograzhdenian or Rhodopian rocks of the basement are intersected or modified by the Hercynian granitoids with superposition of pluton-related symmetrical or inclined domes. In the Sredna gora crystalline block (Text-Figs. 4, 5), three granitoid complexes with different age and composition have been distinguished (DABOVSKI et al., 1965; ZAGORTCHEV & MOORBATH, 1986b). The first complex consists of I-type granitoids (quartz diorites to plagiogranites with numerous enclaves from early basic rocks) with lower (ca. 0.706) initial $^{87}Sr/^{86}Sr$ ratios and an age of ca. 340 Ma until the later (320–300 and 280–240 Ma) granite complexes have comparatively high (about 0.71) initial $^{87}Sr/^{86}Sr$ ratios, and represent S-type peraluminous granites to leucogra-nodiorites. The plutons of the three com-



Text-Fig. 5.
Schematic columnar sections of some of the tectonic zones and units in the central parts of the Balkan Peninsula.
Ogr = Ograzhdenian Supergroup; Prh = Prarhodopian Supergroup: Prh_1 = Strazhets Group, Prh_2 = Boturche (Sakar) Group, Prh_3 = Arda Group; Rhd = Rhodopian Supergroup: Rhd_1 = Rupchos Group, Rhd_2 = Sitovo Group, Rhd_3 = Asenovgrad Group; Kul.Sg. = Kulidzhik Supergroup (Bryagovo Formation).

plexes were intruded in the Sredna gora crystalline block consecutively at shallower crustal levels, the later granites cross-cutting the older plutons (DABOVSKI et al., 1965.)

4. Jurassic– Mid Cretaceous Events

The Alpine tectonic events in the region (Text-Figs. 1, 4) took place mainly in the Norian–Hettangian, Mid Cretaceous, Late Cretaceous, Paleogene (Middle Eocene, Late Eocene–Oligocene) and Early Miocene times. Some of these events have not been recorded in the basement.

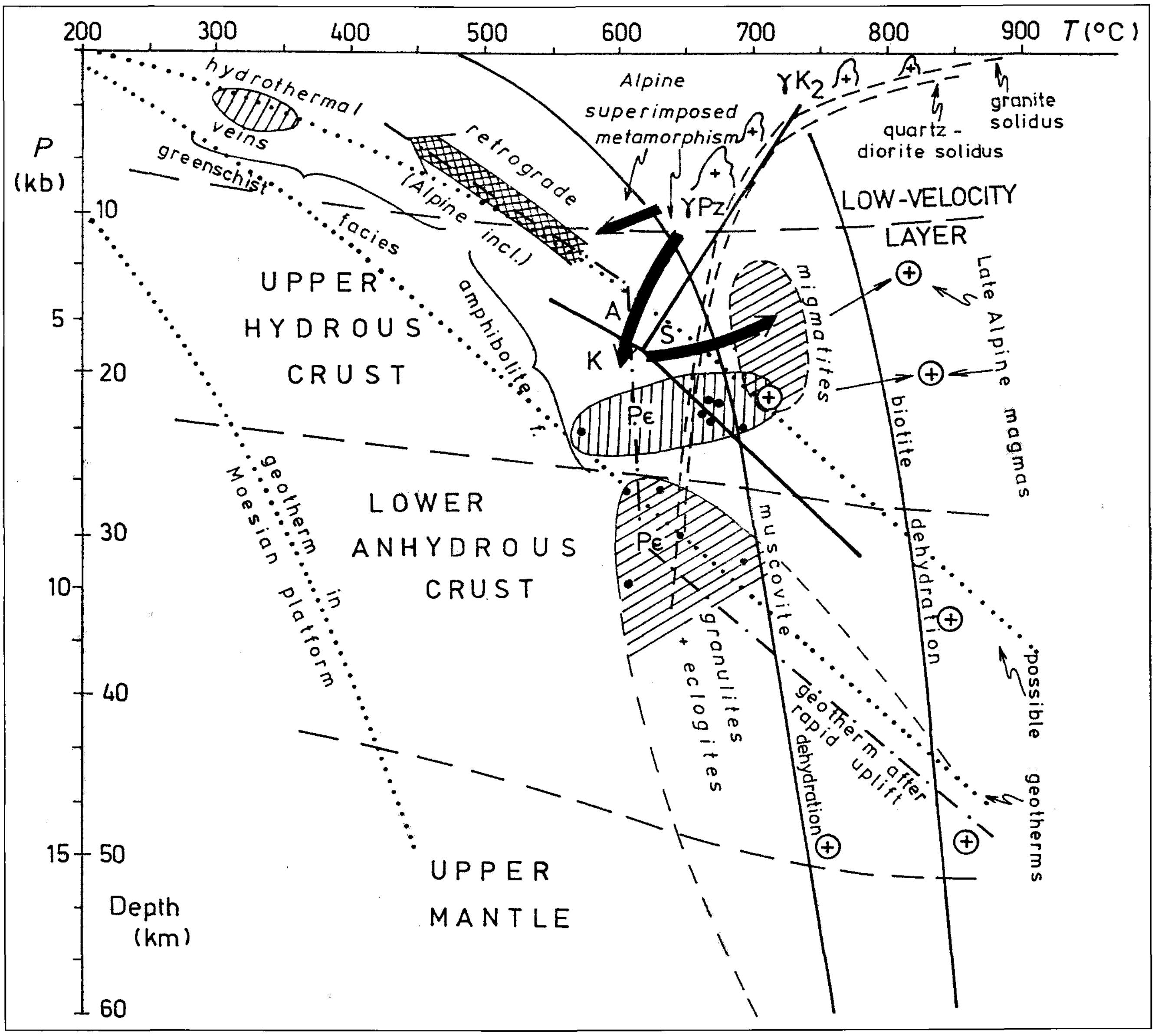
The first intense Alpine events overprinted in the basement occurred probably diachronously in Jurassic–Mid Cretaceous times (before the Turonian). The Mid Cretaceous tectonic units are now exposed by the erosion to different depths. The Alpine cover is preserved only in some of them, and is covering different time intervals. In some units, the Triassic to Lower Cretaceous cover and the basement were not affected by Alpine metamorphism, and the basement suffered brittle deformation.

In other units, the Alpine prograde metamorphism of the Mesozoic (Triassic) cover reached amphibolite facies conditions (Text-Figs. 3, 4, 7), and ductile deformations in the Precambrian to Paleozoic basement proceeded in the same conditions. In the most uplifted units, the Alpine sedimentary cover has not been preserved or was lacking, and the presence and age of superimposed Alpine ductile deformations and coeval metamorphism are subject to controversial opinions.

The Mid Cretaceous (post-Aptian and pre-Turonian) deformations in the Struma Zone (Text-Figs. 4, 5) occurred at shallow levels, in several phases of intense folding and thrusting.

No Alpine metamorphism (except for very low-grade to greenschist-facies metamorphism related to strain concentration zones) has been recorded both in the Alpine (Triassic to Berriasian) cover and its pre-Alpine basement (ZAGORTCHEV, 1986).

The thrusting of the Ograzhden Unit over the Pirin-Pangaion structural zone of the Rhodope Massif along the Strimon thrust occurred also in Mid Cretaceous time. The thrust



Text-Fig. 6.
Diagram for the conditions of the Precambrian metamorphism and the superimposed Alpine metamorphic events in parts of the Central Rhodope structural zone.
After data of KOSTOV et al. (1986), KOZHOUKHAROVA (in ZOUBEK, 1988), GROZDANOV(1989) and other sources.

surfaces are accompanied by greenschist-facies mylonites. The Late Cretaceous North-Pirin (Dautov) granite pluton cross-cuts (ZAGORTCHEV et al., 1987) both the thrust surfaces, and the footwall (Pirin Unit) and hanging-wall (Ograzhden Unit) (Text-Fig. 5).

The Ograzhdenian basement of the Sakar Unit together with the Early Paleozoic Sakar pluton is covered (Text-Figs. 4, 5) by Upper Carboniferous, Permian and Triassic (the latter with bivalves and conodonts) terrigeneous and carbonatic formations (BOYANOV et al., 1965; KOZHOUKHAROV et al.,1968; CHATALOV, 1985, 1990) with granite-porphyries as layer-parallel bodies. Together with the Ograzhdenian basement, they were subjected to deformations and amphibolite facies metamorphism, being transformed into metaconglomerates, metaarkoses, amphibolites, marbles, and staurolite- and kyanite-bearing garnet micaschists.

The synmetamorphic structure of the Upper Paleozoic and Triassic formations is characterized by a complex interference pattern dominated by two major generations of northeast- and east-plunging folds. Although the Ograzhdenian metamorphics preserved locally their older structure, their present pattern was greatly affected by the Alpine movements.

A ductile shear zone was formed simultaneously with the metamorphism of the Triassic cover folded in the tight cuspate Lisovo syncline (Text-Figs. 8, 9).

To the west of the syncline, the shear zone is traced by the intensely deformed (ductile shear, with multiple rotation of old clasts, and of Alpine synmetamorphic fragments, boudins, mullions and rods of pegmatite, aplite and quartz veins) Ograzhdenian rocks, and metaconglomerates and pseudoconglomerates of the so-called (KOZHOUKHAROV, 1991) Konstantinovo Formation which may correspond to the Upper Paleozoic metapsephytic formations deeply involved in the major shear belt (Text-Fig. 8).

Parallel shear zones within the Sakar granitoid pluton are characterized by ductile simple shear of xenoliths, aplite and pegmatite veins identical in morphology to the shear zones described in the Hercynian granitoids of the Alps (RAMSAY & ALLISON, 1979). Numerous small bodies and dykes of aplitic granites were probably intruded into these shear zones after the main shear event.

The possible age of the main Alpine folding and superimposed simple shear and amphibolite facies metamorphism may be deduced from the thermally reset K-Ar ages ("mixed dates") on biotites (CHATALOV, 1990; LILOV, 1990) which range from 140 Ma (Late Jurassic) to 105–110 Ma (Mid Cretaceous).

The Central Rhodope Zone of the Rhodope Massif (Text-Fig. 1) is built almost exclusively (Text-Figs. 4, 5) of metamorphic rocks of the Prarhodopian (Ograzhdenian) and Rhodopian Supergroups intruded by Hercynian and Alpine igneous rocks (KOZHOUKHAROV in ZOUBEK, ed., 1988). Superimposed Mid Cretaceous deformational and metamorphic events have been recently described (ZAGORTCHEV & MOORBATH, 1986a; BURG et al., 1990; ZAGORTCHEV, 1990) in the northern part of the zone. Tight to isoclinal folds developed in the previously folded and granitized metavolcanic and metasedimentary rocks of the Sitovo Group (Rhodopian Supergroup) folding also quartz, pegmatite and aplite veins (Text-Fig. 9). The coeval axial-plane parallel schistosity is widespread, and the ENE-trending mineral lineations are parallel to the intersection (superimposed schistosity over previous foliation) and stretching lineations thus forming a composite lineation. The new schistosity is also intersecting the Paleozoic Dobrolak granitoids. Due to the intersection of foliation and superimposed schistosity, to the anostomosing character of the latter, and to conjugated shear zones, the massive Precambrian amphibolite facies metavolcanic and metatuffaceous rocks (quartzo-feldspathic gneisses of the Bachkovo Formation) and the Dobrolak granitoids obtained a lozenge structure (Text-Fig. 9). The age of this event is determined by a Rb-Sr whole-rock isochron (ZAGORTCHEV & MOORBATH, 1986a) and by the U-Pb method on zircons (ARNAUDOV et al., 1990) at about 90–100 Ma (Mid Cretaceous). The P-T conditions of the superimposed Alpine deformations corresponded in different areas to the greenschist facies grading up to the amphibolite facies.

Mid Cretaceous deformations occurred in the Central Rhodope Zone during several distinct episodes (e.g., ZAGORTCHEV, 1990), and the metamorphic conditions changed from amphibolite to greenschist facies. The complex movement history is best recorded at the boundaries between formations with contrasting rheological properties (KOZHOUKHAROVA & ICHEV, 1989). The south-vergent movements inferred by BURG et al. (1990) on shear-sense indicators are probably related to comparatively late movements (Text-Fig. 10) post-dating the formation of the superimposed schistosity and intersection lineation during a major folding event. These deformation events were followed by the Late Cretaceous intrusion of the Yugovo granitoids which are not affected by the superimposed schistosity and lineation.

5. Late Cretaceous Events

The Late Cretaceous tectonics of the central parts of the Balkan Peninsula is dominated by the formation of a volcanic island arc (Srednogorie Zone), and of a thickened crustal segment (Morava-Rhodope Zone) underthrusted by the Vardar Ocean (Text-Fig. 1), and playing the role of "plateau" in the sense of DEWEY et al. (1988). The magmatic rocks in the Srednogorie Zone are products of complex differentiation processes, and belong to tholeiitic, Ca-alkaline, high-K Ca-alkaline, shoshonitic, high-K transitional, and bulgaritic (hyper-K transitional to alkaline) series (DABOVSKI et al., 1991). The intrusive rocks are characterized (ZAGORTCHEV & MOORBATH, 1987) by a low (about 0.704) initial $^{87}Sr/^{86}Sr$ ratio. In the Morava-Rhodope Zone, typical metaluminous granites with a high (0.710–0.712) initial $^{87}Sr/^{86}Sr$ ratio were formed at the same time (ZAGORTCHEV et al., 1987). The formation of the initial magmas was probably related to the isotherm uprise within the thickened continental crust of this zone, above the subducting Vardar oceanic slab, and the features of the rock association can be compared to the characteristics of a continental arc. The intense igneous activity lasted for about 10 Ma: from the Coniacian–Santonian to the late Campanian or Early Maastrichtian.

Compressional movements resulted in the formation of south-vergent thrusts in the Rhodope Massif, in continuation of the south-vergent movements recorded by BURG et al. (1990) by shear-sense indicators for the previous phases. The Late Cretaceous thrusts were sealed and buried by Palaeocene–Middle Eocene lacustrine sediments (KOZHOUKHAROV et al., 1991).

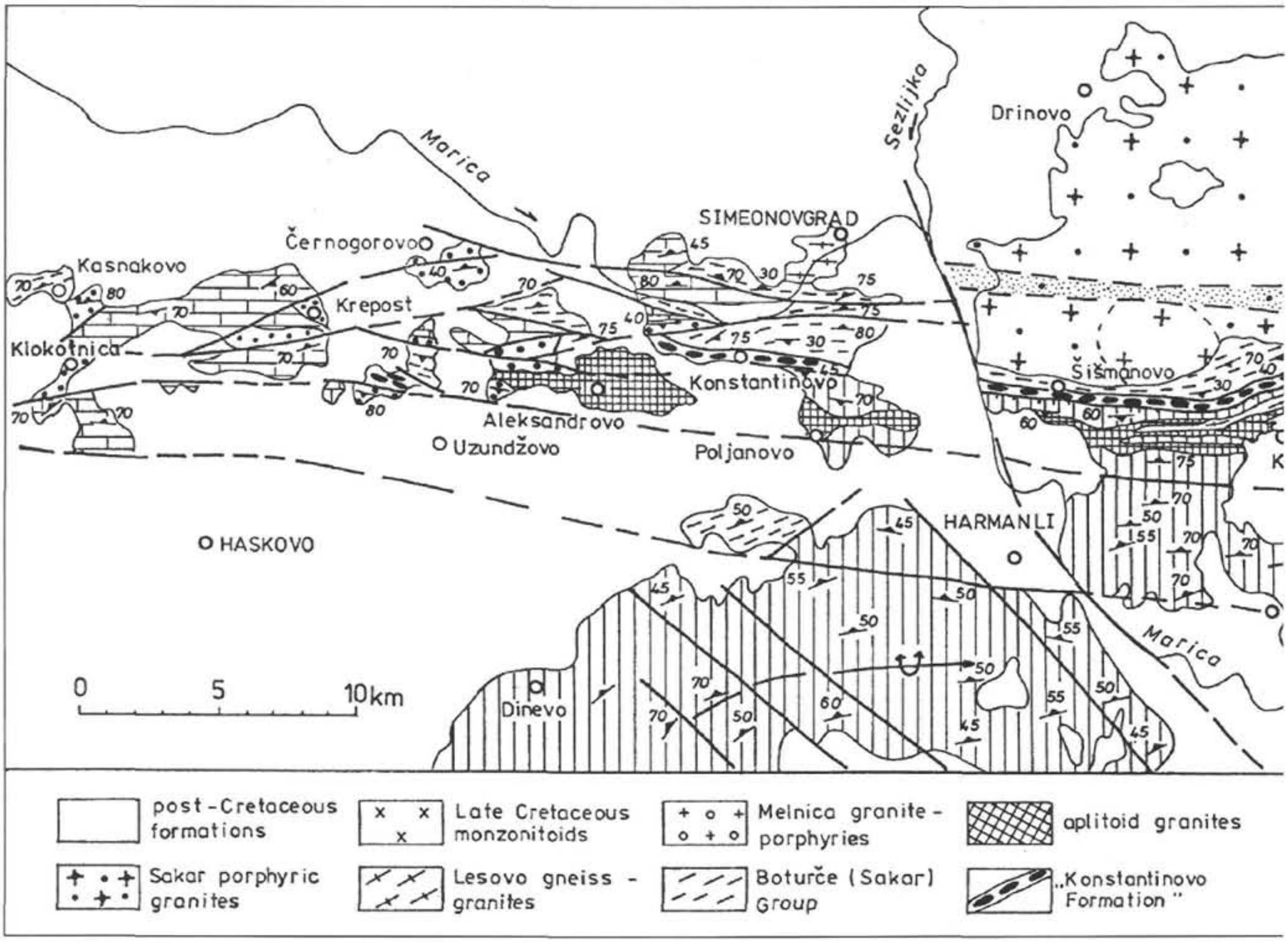
6. Paleogene Events

The Palaeogene deformational and tectonothermal events have been recently overestimated due to attempts to correlations with the Alps, and to young (usually "mixed") K-Ar dates obtained. In fact, the deeply eroded structure of the Rhodope Massif is sealed by the non-metamorphic Paleocene–Eocene lacustrine deposits (KOZHOUKHAROV et al., 1991; GORANOV& ATANASSOV, 1992). These deposits begin usually with thick breccia followed by sandstones and limestones. Their section is covered unconformably by coal-bearing or red continental deposits of the Upper Eocene. The latter are followed in the central parts of the massif by lacustrine sediments of Upper Eocene–Lower Oligocene age, and west and east, by marine sediments of the same age. The distribution of the accompanying collisional igneous rock associations is controlled by the thickness of the crust (DABOVSKI et al., 1991; ZAGORTCHEV, 1991, 1993), acid rocks with a high initial $^{87}Sr/^{86}Sr$ ratio being formed in the central thickened parts, and rocks of intermediate composition and lower initial $^{87}Sr/^{86}Sr$ ratios, in the peripheral thinned parts. Considerable rock volumes have been undoubtedly heated (locally to temperatures reaching and exceeding 300°), but the lack of penetrative deformations in the predominantly extensional environment did not favour the occurrence of widespread metamorphism. The whole Late Eocene–Oligocene evolution was accompanied by normal faulting, and subvolcanic sill-like bodies often penetrated along former Mid Cretaceous thrust surfaces. This environment can be considered as indicative of overall extension during orogenic collapse (DEWEY, 1988).

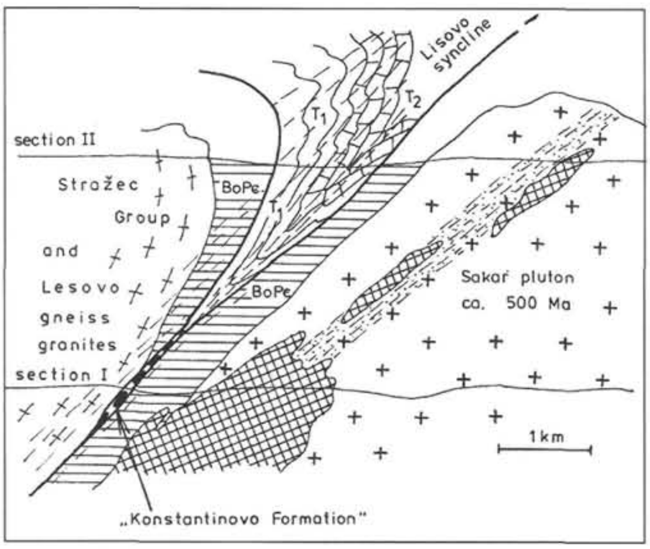
Lacustrine deposits formed locally in grabens along important fault zones during Middle and Late Oligocene and Early Miocene times (e.g., ZAGORTCHEV, 1992), and were followed by south- and southwest-vergent thrusting conjugated with right-lateral strike-slip along some of the faults of the NNW–SSE striking Struma (Kraishtid) lineament.

7. Discussion and Conclusions

The Central Balkan segment of the Alpine fold belt of Europe is an example of incorporation of old rock complexes into younger, Hercynian and Alpine tectonic units, with a different degree of reworking of the old structure geome-



Text-Fig. 7.
Simplified structural-geological map of a part of the Sakar Unit. After data of BOYANOV et al. (1965), KOZHOUKHAROV et al. (1968), KOZHOUKHAROV (in ZOUBEK, 1988), unpublished data of VERGILOV et al. (1985) and own observations.



Text-Fig. 8.
Idealized section through the Lisovo syncline and the shear zone beneath it.
Based on sections I and II shown on Text-Fig. 7.

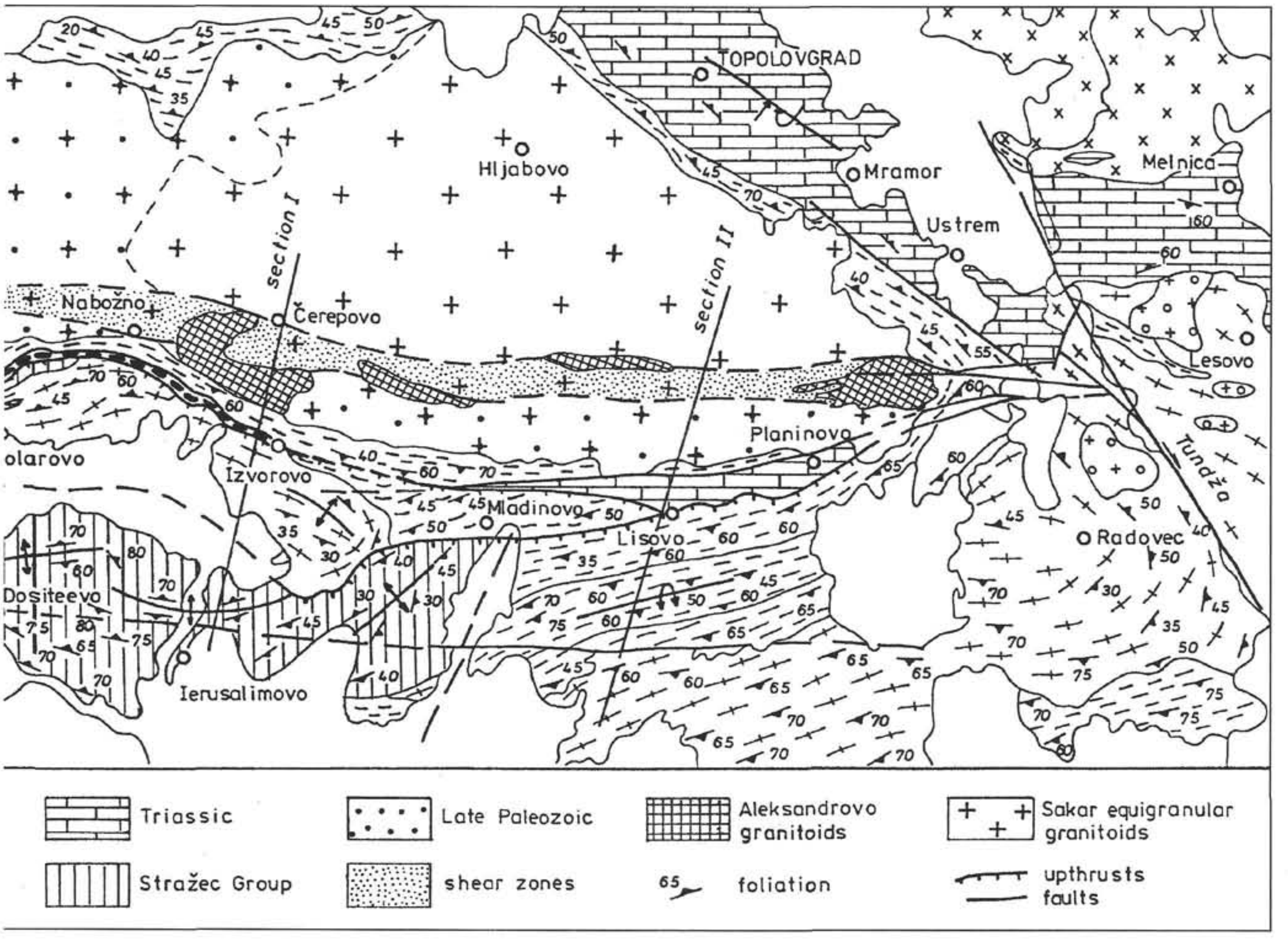
tries. Intense reworking took place in the most thickened crust of the Central Rhodope Zone of the Rhodope Massif which in Alpine times played the role of "plateau" (in the sense of DEWEY et al., 1986).

The most intense tectonothermal events occurred in late Cadomian (Panafrican – 500–550 Ma BP), Hercynian (340–240 Ma BP) and Alpine (100–80 and 35–30 Ma BP) times (Text-Fig. 4). The metamorphic rocks which formed at the expense of the Precambrian protolith were subjected several times to deformations in different metamorphic regimes (Text-Fig. 7).

The superimposed deformations produced different structure geometries:

1) Superimposed fold structures with a complicated interference pattern or with conical geometry due to constraints of the previous structure (ZAGORTCHEV, 1993).
2) New structures with transposition of the old ones, and formation of a new composite foliation.
3) New superimposed schistosities related to strain concentration (pure shear) or to simple shear along ductile shear zones.
4) Intersection lineations (new schistosities intersecting the old foliation) combined or coinciding with stretching and mineral lineations and the hinges of new folds, thus forming composite lineations;
5) Lozenge structures due to development of conjugated shear zones, etc.

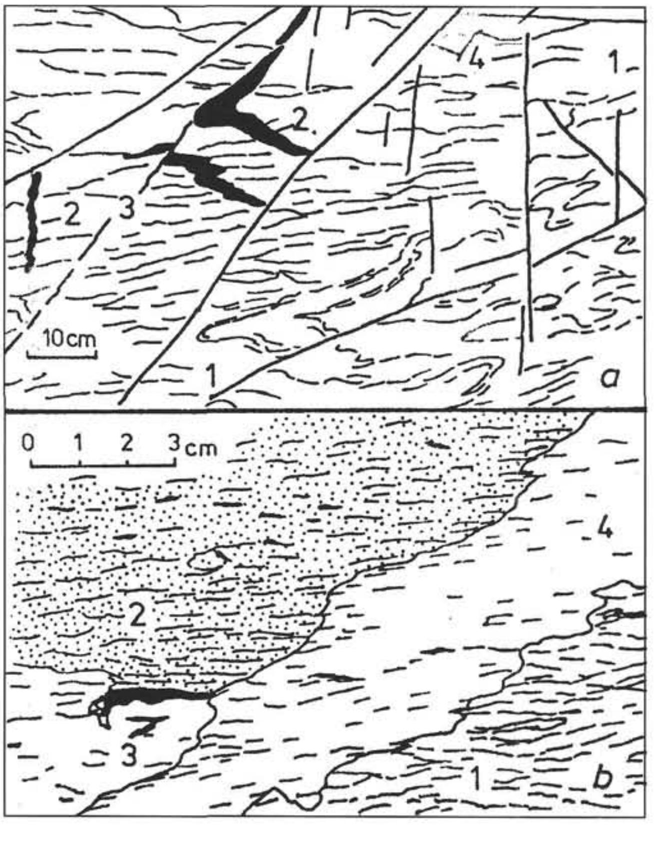
The most important controversies arise from the interpretation of the Alpine development. Thus, IVANOV (1988) considered the Rhodope Massif as a nappe pile composed of north-vergent thrust sheets inferred from the general northern vergence of the "northern branch of the Alpine



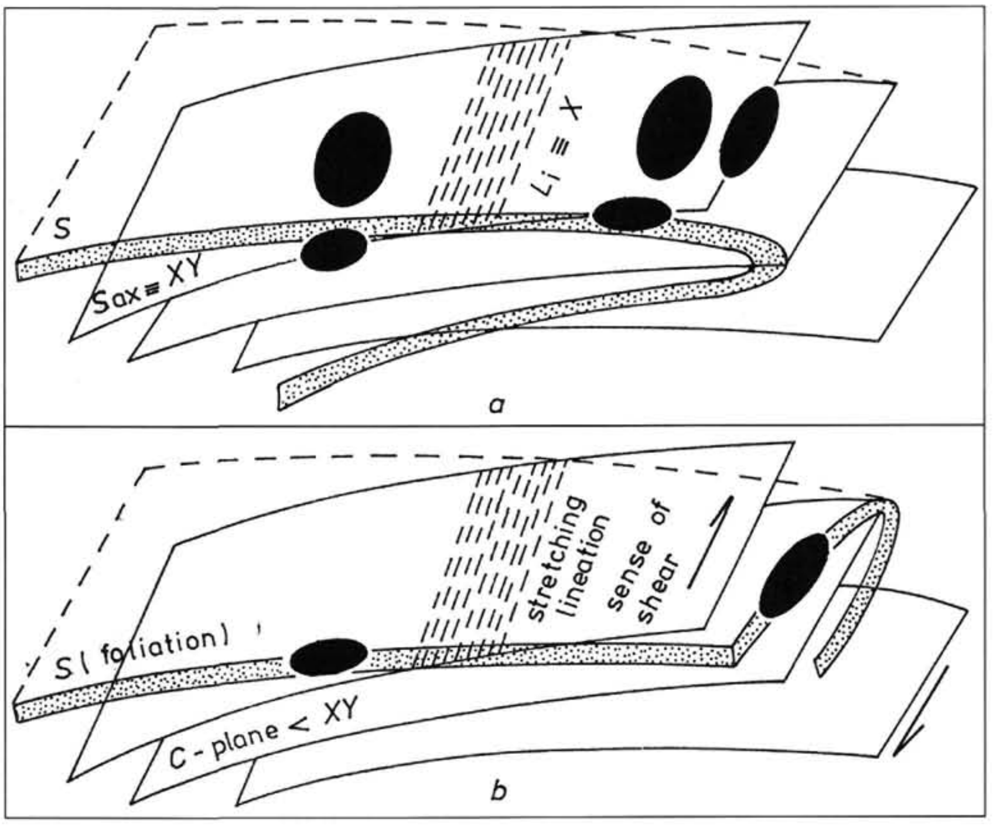
orogen". On the contrary, BURG et al.(1990) proved through observations on shear-sense indicators that south-vergent movements were dominant in the Central Rhodope, during presumed Cretaceous amphibolite facies regional metamorphism and coeval deformation. In both cases, the protolith is supposed to be of Paleozoic (or even Mesozoic) age, and to contain both metasedimentary and metagranitoid rocks.

These interpretations could be further extended towards a closer analogy with the internal zones of the Alps (as implicitly made by BURG et al., 1990, who supposed the tectonic insertion of Mesozoic ophiolites), and towards a tectonostratigraphy of alternating pre-Mesozoic and Mesozoic terranes and formations subjected to Alpine amphibolite facies regional metamorphism. Such interpretations do not take into account the evidence obtained on the stratigraphy and structure of the basement in the whole Central Balkan segment.

The Mid Cretaceous tectonic events occurred in all tectonic zones and units (Text-Figs. 1, 4). They took place in different P-T conditions (metamorphic facies) varying from



Text-Fig. 9.
Structures in the quartzo-feldspathic gneisses of the Bachkovo Formation.
Field sketches of outcrops near the village of Bachkovo, Central Rhodope Mts.
Sketch a: 1 = Bachkovo folded quartzo-feldspathic gneisses, 2 = folded quartz veins, 3 = late faults.
Sketch b: 1 = clearly foliated quartzo-feldspathic gneisses, 2 = granitized quartzo-feldspathic gneisses, 3 = lens of pegmatoid material, 4 = aplite dyke.



Text-Fig. 10.
Sketches for the formation and development of superimposed schistosity and lineations in the Bachkovo Formation.
a) Folding with formation of axial-plane parallel schistosity, and intersection lineation coinciding with the stretching lineation and local X-axis.
b) Formation of S/C structure (after BURG et al., 1990) and south-vergent simple shear.

non-metamorphic to very low-grade (Struma Zone) to the amphibolite facies (in the Sakar Unit, and partially, in the Central Rhodope Zone).

Faulting and brittle thrusting at the shallower crustal levels have been gradually replaced by formation of superimposed schistosity, irregular folding and ductile simple shear at the deeper crustal levels.

The position of the Rhodope Massif as a relatively rigid crustal fragment underthrusted by the northward-subducting Vardar oceanic crust, and the north-vergent retrocharriage events both in the Morava Zone and in the units north of the Rhodope Massif (Text-Fig. 1) were the main reasons for the diversity of the superimposed metamorphic phenomena and deformation structures. The general lithostratigraphic sequence remained surprisingly constant over large areas (e.g., KOZHOUKHAROV, in ZOUBEK, 1988), and the internal movements within the relatively rigid crustal blocks or lenses were concentrated mainly along the boundaries between formations with different rheological properties without involving large-scale movements of big nappes.

Observations in different parts of the Rhodope Massif (the East Rhodope Zone and the Pirin-Pangaion Zone included) show that the comparatively late south-vergent movements were almost ubiquitous. The movements in amphibolite facies conditions in Mid Cretaceous times produced mainly folds and superimposed schistosity and intersection lineation with local feldspar porphyroblast growth. The south-vergent movements were related mostly to deformations of the pre-existing porphyroblasts in greenschist-facies conditions, and they corresponded to the south-vergent movements recorded along the brittle thrust zones of Late Cretaceous (pre-Palaeocene) age. South-vergent movements occurred also during the last compression phase in the Early Miocene. Therefore, no simple picture of the Alpine structure and tectonic evolution can be obtained, and the complex tectonic and metamorphic evolution of the basement should be taken into account in the study of any particular region.

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