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Rhodope controversies

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Controversies in the interpretation of the geological evidence on the Rhodope region come mostly from restricted field and laboratory data and personal limitations in field experience. For to resolve important problems of European and world geology, the Rhodope massif needs a concerted action of the interested geological communities and complex implementation of modern methods and techniques.

Introduction

The Rhodope (Rodopi) Mountains are shared between Bulgaria and Greece, and form the Rhodope Massif s.s. The latter is a part (Figures 1, 2 and 3) of a larger Thracian (Rhodope mass s. l. according to Cvijic, 1901) Massif that occupies also parts (Moravides and Serbo-Macedonian or Dardanian Massif) of the former Yugoslav republics of Macedonia and Serbia. Many controversies concern important geological features relative to the role and place of the massif as an assemblage of older crustal fragments in the Alpine orogenic belt of Europe (Neubauer and v. Raumer, 1993). Stratigraphy, structure and tectonic evolution of the massif are often discussed rather at the background of pre-conceived ideas on the Tethyan geodynamic evolution than on the sound basis of detailed geological evidence. Results obtained by partial application of modern methods only opened new challenges to the geological and geophysical communities.

The present paper aims to expose the character of the principal controversies and to seek ways for a critical and independent evaluation of the existing hypotheses.

Lithostratigraphy and age of the protoliths of the amphibolite-facies metamorphics

The protoliths of the amphibolite-facies metamorphics are considered to be mostly of Precambrian age (Cvijic, 1901; Kozhoukharov, 1968; Kozhoukharov et al., 1988). These considerations have been recently supported by determinations of acritarchs (e. g., Kozhoukharov et al., 1988; Kozhoukharov and Timofeyev, 1989; Kozhoukharov and Konzalova, 1990) and problematica (Tchoumatchenco and Sapunov, 1989). Outside the Rhodope Massif s.s., metamorphism of formations of Vendian and Palaeozoic age in the Serbo-Macedonian Massif locally reaches amphibolite facies, too. In the Sakar unit north of the Rhodope Massif s.s., Precambrian amphibolite-facies metamorphics are covered (showing primary unconformable depositional contact) by amphibolite facies metamorphics that contain well-preserved Triassic fossils (Chatalov, 1985). Therefore, besides the Precambrian metamorphics, the presence of amphibolite-facies metamorphics formed at the expense of protoliths younger than the Precambrian cannot be excluded also in other tectonic units. However, the detailed lithostratigraphic work on continuous sections (Kozhoukharov, 1968; Kozhoukharov et al., 1988; Zagorchev, 1994a, and many others) points to the presence of two amphibolite facies complexes (Ograzhdenian Supergroup of amphibolites and migmatites of Figure 4, and Rhodopian Supergroup of varied gneisses, schists, amphibolites and marbles) of Precambrian age.

Another viewpoint is maintained by Kronberg et al. (1970), Papanikolaou (1984), Papanikolaou and Panagopoulos (1981), Burg et al. (1990, 1996) and other authors. They believe that the oldest protoliths are of Palaeozoic age and that each of the thrust sheets represents an individual terrane built up of Palaeozoic and/or Mesozoic rocks. The common degree of metamorphism was formed in the process of plate motions and thrusting in Alpine times.

Age and character of the metamorphic events

The age of the metamorphism is a subject of controversies. Two principal opinions have been outlined, namely:

1. Alpine tectonics and Mesozoic and Cenozoic erosion exhumed different levels of pre-Alpine and Alpine metamor-

Figure 1 Tectonic structure of the Balkan Peninsula (after Cvijic, 1902, 1924).

Figure 2 Tectonic structure of the central part of the Balkan Peninsula (after Kober, 1952).

phics in different tectonic units. Precambrian protoliths underwent deformations and amphibolite facies polymetamorphism during several tectonic cycles (Kozhoukharov et al., 1988; Zagorchev, 1994a,b). The first metamorphic event (high-pressure metamorphism) in the Ograzhdenian Supergroup was older than 1000 Ma (Zidarov and Nenova, 1996), and the last intense amphibolite facies event occurred at ca. 530–550 Ma (Zagorchev and Moorbath, 1986), thus corresponding to the Pan-African event (described also in the

Menderes Massif in Asia Minor, Sengor et al., 1984). In the Rhodopian Supergroup, amphibolite facies metamorphic events also occurred in the Precambrian, and Hercynian granitoids intruded (Figure 5) already deformed metamorphic basement (Kozhoukharov, 1968; Kozhoukharov et al., 1988). Numerous U-Pb (on zircons and inherited zircons) and Rb-Sr whole-rock isochron data (e. g., Peytcheva et al., 1992a,b; Peytcheva and Sarov, 1994; Peytcheva and v. Quad, 1995) about igneous and metamorphic

events between 296 and 377 Ma and inherited more than 575 Ma old zircons exist also for the East Rhodope Mountains in Bulgaria near the border with Greece. However, in some parts of the Rhodope region, superimposed metamorphic event in Alpine time (ca. 100 Ma) might reach also amphibolite facies conditions (Zagorchev and Moorbath, 1986). Young dates (mostly Palaeogene) obtained by the K-Ar method are the result of "rejuvenation" due to intense heating during the Priabonian-Early Oligocene extensive igneous activity, and the post-magmatic heating and still persisting high heat flow (discussion in Zagorchev, 1991). In the Sakar unit, Precambrian metamorphism in the Ograzhdenian Supergroup was followed by intrusion of 500 Ma old granitoids (Lilov, 1990), Hercynian granitoids, unconformable deposition of Triassic terrigenous and carbonate (with preserved Triassic fossils) rocks, Alpine metamorphism at 145–135 Ma B.P. (Chatalov, 1985; Kozhoukharov et al., 1988; Zagorchev, 1994b).

2. The Palaeozoic and Mesozoic protoliths of the Rhodope metamorphic complex were subjected to metamorphism during a single tectonic cycle: Mid and Late Cretaceous (Burg et al., 1990, 1996) or Cretaceous and Palaeogene (Liati and Mposkos, 1990; Dinter et al., 1995; Wawzenitz and Mposkos, 1997). This opinion is based mostly upon K-Ar and Pb-Pb data from northern Greece where the

Figure 3 Tectonic structure of the Balkan Peninsula according to modern ideas (interpretation by the author).

Figure 4 Intensely folded migmatites of the Ograzhdenian Supergroup, Ograzhden unit. Field photograph, Tsaparevchitsa River, Maleshevska Mountains.

Thracian (Rhodope s. l.) Massif (microcontinent) had been thrust over the oceanic crust as a separate terrane.

Vassileff (1993) also pointed out the theoretical discrepancies, and proposed a model of independent continental (Thracian) and oceanic (diabase-phyllitoid) terranes that had collided and accreted in early Palaeozoic times.

Bonev et al. (1995) proposed (Figure 8) the presence of a synmetamorphic nappe pile of Alpine age formed (from bottom to top) from three principal rock "groups" (or nappes): group I. amphibolite-facies (Ograzhdenian Supergroup) rocks; group II. greenschist-facies (diabase-phyllitoid) rocks; group III. non-metamorphic Palaeozoic of Balkan type, covered unconformably by the Alpine sequence (Triassic, Jurassic, etc.). The whole evidence about the age of the complexes is rejected a priori, without discussion. The first two "groups" are believed to be of Palaeozoic and/or Mesozoic age, and were subjected to Cretaceous regional metamorphism coeval with the south-vergent thrusting that formed the whole tectonostratigraphic pile.

Alpine thermal and tectonic overprint has been much more intensive than in the central and northern parts of the massif. Obviously, the bulk of observed geological field relations and stratigraphic evidence is overlooked or underestimated.

Age and origin of the diabase-phyllitoid complexes at the periphery of the Rhodope massif, and their relations to the amphibolite-facies basement

Beginning with Cvijic (1901), the pre-Alpine formations of the Rhodope "mass" are referred to as three principal groups, namely, high-grade (amphibolite facies) metamorphic basement (lower metamorphic complex) of presumed Precambrian age, volcano-sedimentary (diabase-phyllitoid) upper metamorphic (greenschist facies) complex of late Precambrian or/and early Palaeozoic age, and Palaeozoic (Ordovician-Lower Carboniferous) non-metamorphic or very low-grade rocks. In tectonic units that possess a full pre-Alpine section, i. e., at the periphery of the massif, all the three complexes (Cvijic, 1901) or at least the Precambrian and the diabase-phyllitoid complex are juxtaposed in their normal chronostratigraphic sequence. At the direct contact, the amphibolite-facies rocks are affected by superimposed schistosity subparallel to the contact (and to the foliation of the diabase-phyllitoid complex) accompanied by greenschist-facies diaphthoresis (Zagorchev, 1987; Bonev et al., 1995).

These relations are interpreted in different manners depending on more general considerations.

Zagorchev (1987), following many older authors, admitted a primary depositional unconformable contact that was later sheared during intense folding of the two complexes (Figure 6). The diabase-phyllitoid complex (Frolosh Formation) is regarded as an island-arc assemblage that has covered directly the continental crust (Precambrian Ograzhdenian Supergroup) at the periphery of the massif. As an alternative explanation, obduction process was proposed, too.

Haidoutov (1991) considered the diabase-phyllitoid complex as a sequence of ocean-floor ophiolites and volcanic island-arc complex, and therefore, excluded the possibility of oceanic crust "normally" covering the continental crust (objections made in the past also by A. Belov, V. Pouchkov, and others). Presuming that the ocean-floor crust was obducted over the Moesian continent situated to the north of the ocean, he believed that the continental crust of the

Age of the granites

The principal groups of granitoids belong to the so-called South-Bulgarian granites and were dated in the Sredna-gora unit to the north of the Rhodope region at 340, 300–320 and 240–270 Ma (Zagorchev et al., 1989). The same groups of granitoids are believed

Figure 5 Intensely folded and granitised migmatites of the Chepelare Formation, Rhodopian Supergroup (Pirin unit) intersected by the Hercynian Southbulgarian porphyritic granites. Field photograph, northern entrance of the Kresna Gorge.

to be present also in the Rhodope region although only scarce isotopic data confirm such ages. Thus, zircons from the Kavala (Symvolon) pluton were dated by the U-Pb method at about 335 Ma (Kokkinakis, 1980; Dinter et al., 1995). Cretaceous (86–90 Ma) and Palaeogene (30–35 Ma) granite plutons have been also proven with Rb-Sr isotopic studies (Zagorchev et al., 1987, 1989). However, researchers in Greece (e.g., Dinter et al., 1995; Kyriakopoulos et al., 1996) recently tend to explain the Palaeozoic and Cretaceous data with inclusions of older zircons in Tertiary magmas, and suggest a Palaeogene or even early Miocene age for all plutons on the basis of K-Ar and Ar-Ar dating of micas. Young (Palaeogene and Neogene) heating of older rocks over threshold temperatures (radiogenic rejuvenation according to Harre et al., 1964) are the alternative explanation for these data (e. g., Zagorchev, 1991, 1994).

Internal structure of the massif

The descriptions of the internal structure of the Rhodope Massif usually follow pre-conceived ideas and prejudice, rather than standard exact methods and procedures.

The block structure of the massif is mostly due to movements along normal faults in Palaeogene and Neogene times. It was believed traditionally (Cvijic, 1901; Jaranoff, 1938), that the internal structure of the metamorphic complexes in the massif consists of domes formed mostly during intrusion of Hercynian South-Bulgarian granitoid bodies. New information about the intimate structure of the metamorphic complexes brought a serious evaluation of the role and time of folding and thrusting.

Classical studies of foliation and schistosity, lineations, boudinage, folds, etc. show a polydeformational synmetamorphic evolution which can be correlated within the different structural units with the polymetamorphic

evolution (e. g., Papanikolaou and Panagopoulos, 1981; Ivanov et al., 1985; Zagorchev, 1994a,b). Most of the metamorphic and deformation events are of pre-Alpine, and even, pre-Hercynian age, as far as their products are sealed by Permian or Triassic, Cretaceous or Palaeogene sedimentary formations, cross-cut by Palaeozoic and later granitoid plutons, or intersected by pre-Palaeogene thrusts. The old (pre-Hercynian and Hercynian) structure of the massif was strongly influenced by Alpine thrusting (Figure. 7). Mid Cretaceous northeast-vergent thrusts are proven in the westernmost parts of the massif, and Late Cretaceous south-vergent thrusts, in its central and northern parts. Late Oligocene or/and earliest Miocene thrusts are observed along the northern periphery, and are numerous in the southern Greek part.

Another viewpoint (Figure 8) has been developed by Burg et al. (1990, 1996). Superimposed schistosity and lineation dated at ca. 100 Ma are considered as first synmetamorphic (amphibolite facies) s/c structures within the Rhodope s.s. massif coeval with large synmetamorphic south-vergent thrusting at deeper crustal levels. Later (Late Cretaceous) thrusts occurred already in greenschist-facies conditions but followed the same kinematics. Normal faulting occurred in Palaeogene and Neogene times.

Structural position of the massif in the Alpine orogenic belt

Ideas about the structural position of the Rhodope s.l. (or Thracian) massif depend largely on ideas about the nature and evolution of the Tethys and of the Alpine belt. Most of the ideas are subconsciously based upon a "rhodopocentrism" that comes from the first research performed in the 19th century by A. Boue, and later on, by Cvijic

Figure 6 Structural relations between the high-grade metamorphic basement and the diabase-phyllitoid complex (after Zagorchev, 1987; Vassileff, 1993; Haydoutov, 1989).

(1901) and Jaranoff (1938). The interpretation of the massif as a median or central massif is not necessarily a fixistic one. Moreover, the notions "fixistic" and "mobilistic" differ nowadays considerably from their content fifty or even thirty years ago. The principal difference comes from the interpretations of the Alpine orogen as a simple and single-process edifice or as an edifice formed as a result of superposition of separate basins (continental or oceanic) and fold and thrust belts throughout the Alpine (Cimmerian + Alpine s.s.) cycle.

The principal features and interpretations of the massif and its environment may be schematically classified into the following several hypotheses:

1. The Rhodopes represent a core built up of older (Precambrian) rocks centrifugally surrounded (wrapped) by "Circum-Rhodope zones" (Jaranoff, 1960). This Rhodope s.l. or Thracian Massif has been regarded as a median massif (Boyanov and Kozhoukharov, 1968; Bonchev, 1971, 1988) within a larger Thracian-Anatolian pre-Alpine continent. The interpretations range from a strictly fixistic (an elevated platform or shield that played the role of dryland during most of the Mesozoic and Cenozoic time) to a moderately mobilistic one.

2. The Rhodopes are a central massif (Figure 2) within the Centralides (Kober, 1952) and Metamorphides, i.e. a central and most compressed and uplifted part of the orogen (root zones of larger carriage structures) that suffered intense Alpine deformations and metamorphism.

3. A "middle branch of the Alpine orogen" (Brunn, 1960) of heterogeneous character is situated between the two centrifugally thrust branches: the northern (Balkanides) and the southern (Dinarides, Hellenides); this middle branch has been covered only occasionally by basins, and has suffered more limited deformations.

4. The Rhodope region is a part of the Cimmerian Continent formed through folding in Jurassic times.

5. Fragments of older crust (metamorphic and igneous rocks of Precambrian and Palaeozoic age) were partially covered by unconformably superimposed Mesozoic sedimentary troughs, and subjected to Alpine deformations and metamorphism (Boyanov et al., 1989); the Rhodope massif s.s. was comparatively weakly influenced by these processes.

6. Fragments of Precambrian?, Palaeozoic, Cimmerian and Alpine units that travelled through the Tethys (including those as transit plates) were accreted in different times (Vassileff, 1993) to the present jigsaw puzzle; the Rhodope area was a pile of thrust sheets that formed during this motion, and included several sutures (non-metamorphic formations with eclogite and ultramafic lenticular bodies) and carbonate platforms of Alpine age (Burg et al., 1990, 1996; Ricou, 1994).

Palaeogene evolution

The Palaeogene evolution is regarded as the result of gradual and irregular subsidence of the whole Macedonian - Rhodope (Morava - Rhodope) area formed during Mid Cretaceous and Late Cretaceous thrusting and crustal thickening. In Palaeocene to Middle Eocene times, a West Thrace marine basin covered the southern part of the region, and fast subsiding grabens in the central and northern parts were filled by thick olistostrome formations (Zagorchev, 1998). After erosion and lateritic weathering under tropical conditions (Moskovski, 1994), newly-formed grabens in Bartonian? and Priabonian time were filled with terrigenous continental sediments par-

Papanikolaou (1981, 1984)

Zagorchev (1981, 1994)

Figure 7 Late Alpine tectonics of the Serbo-Macedonian and the Pirin-Pangaion superunit (after Papanikolaou, 1981, 1984; Zagorchev, 1974, 1981, 1994a)

tially followed by marine transgression in Priabonian and Early Oligocene (Rupelian) time. In Late Oligocene and earliest Miocene time, after the regression, coal-bearing basins were formed along important fractures, and the sedimentation ended with folding and thrusting in earliest Miocene time. The principal igneous activity (volcano-plutonic associations of bimodal magmas) occurred almost simultaneously with the marine transgression although the first tuffs were probably of Bartonian age and the last outbursts were of Late Oligocene or even Neogene age.

Another viewpoint regards the Rhodope region as a pile of nappes formed in Palaeogene time, and exhumed in Miocene time. Some of the deeper nappes suffered metamorphism of amphibolite-facies grade (see above). This concept is not yet fully developed and exposed, and meets serious controversies in the well-established evidence (partially exposed hereabove) about Palaeogene sedimentary and volcanic formations that lack any metamorphism.

Neotectonic history and structure

The research on the Neogene and Quaternary evolution of the Rhodope region has a long tradition, some of the most outstanding workers being both distinguished geologists and geomorphologists (Cvijic, 1901; Jaranoff, 1938, 1960). Traditionally, the beginning of the neotectonic stage is placed at the formation of the principal peneplain in Early - Middle Miocene time, after the last important compression event in earliest Neogene time. Correlation of denudation (planation) surfaces in the neotectonic horsts with sedimentary formations in the adjacent grabens points to prevalent vertical block movements under the conditions of generalized extension (Zagorchev, 1992). The extension increased southwards in the Aegean region.

According to another viewpoint (Dinter and Royden, 1993; Sokoutis et al., 1993), the metamorphic rocks of the Pirin-Pangaion zone are a "Rhodope metamorphic core complex" that underwent Cretaceous to Tertiary folding and amphibolite-facies metamorphism as well as intrusion by Tertiary (Palaeogene to Pliocene) granitoids. The "core complex" is thought to have been exhumed very rapidly in Late Miocene or Oligo-Miocene time during enormous extension along a detachment surface. Several aspects of this hypothesis are inconsistent with the presence of pre-Priabonian Palaeogene non-metamorphic sediments that cover directly with unconformable depositional contact the pretended Tertiary metamorphic core complex (Zagorchev, 1998).

Conclusions

The importance of the Rhodope Massif for the geology of Europe and the world comes mostly from: 1) the place of the massif between the "two branches of the Alpine orogenic belt" and its role and behaviour during the consecutive phases of folding and thrusting and during considerable plate motions relative to closure of the Tethys

Figure 8 Generalized idea about the Late Alpine structure of the Rhodope region (after Burg et al., 1990, 1996; Bonev et al., 1995)

Ocean; 2) the presence of pre-Alpine metamorphic complexes and tectonic entities and their behaviours during the Alpine orogenies; 3) the present thickened continental crust and its evolution and recent behaviour with increasing seismicity and seismic hazard; 4) possibilities for application and perfection of existing methods in complexly built metamorphic terrains.

The solution of most of the problems may be achieved through a wider involvement of the international geological community. Joint geological field work in the border areas and field trips of international experts would remove the effects of prejudice and of imperfect field descriptions and contribute to a better understanding. Wider application of modern methods in the domains of radiogeochronology, deep seismic sounding, palaeomagnetism, deep structural boreholes etc. is also needed.

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