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# The Precambrian Metamorphic Complex in the Rhodope Massif – A Unified Stratigraphic System

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***Abstract***

*The high-grade Precambrian metamorphic complex in the Rhodope Massif is a clearly stratified and unified lithological system, with a relatively well-preserved and recognizable primary sequence. It is divided into two groups with different age and petrographic composition named: Prarhodopian - a lower infracrustal gneiss formation and Rhodopian - an upper Neoproterozoic supracrustal variegated formation. An Ophiolitic association, consisting of serpentinites, amphibolites and metagabbros occupies the lower stratigraphic levels of the Rhodope Group. The dominant structural plan of the complex is folded. Linear and domed anticlinal folds are clearly outlined, which in the Central Rhodope block have a southern vergence. Local tectonic deformations, mainly along the lithological boundaries of the rocks, do not destructively disturb the general stratigraphic sequence. The rock complex underwent three metamorphic changes of different nature and age: 1. general Precambrian regional metamorphism, reaching amphibolite facies, T=480-580oC / P= 5-7 kbar; 2. local HTP geotribometamorphism (eclogitization) in paleoseismic friction zones, T=800-1200oC / P=12-20 kblar and 3. Metasomatism, due to the penetration of pegmatite-aplite veins - derivatives of granitic magmas. The second and third types of metamorphism occur locally during the Precambrian and Phanerozoic.*

**Keywords:** Rhodope Massif, Prarhodopian, Rhodopian Groups, Ophiolites, Geotribometamorphism

## Introduction

The main issue in the characterization of each metamorphic complex is its general structure and petrographic composition. But while the composition of the rocks enables direct observation, fast and accurate determination, the clarification of the general structure of the complex is a problem requiring many years of field research, appropriate methodology and thoughtful interpretation.

The metamorphic complex of the Rhodope massif has been subject of research for more than 100 years, but controversies over its structure and stratigraphy continue. Cvijic was the first author who indicated more accurately the boundaries of the massif and divided the metamorphic rocks "into two parts – an upper low-grade metamorphic part of Paleozoic age, and a lower, high-grade metamorphic part of `Algonkian age" [1]. Later this subdivission was accepted by most authors. Str. Dimitrov notes two metamorphic groups differing in composition and stratigraphic position: a lower series of uniform crystalline rocks (gneisses), for which he assumed an Archaean age, and "a thick, variegated series of various gneisses, mica schists, amphibolites and marbles which occupies an unquestionably higher stratigraphic position" [2]. The lithostratigraphic method for subdivision of the crystalline was applied in national conditional geological mapping (1948-1962).

Subsequent individual studies on the construction and composition of the metamorphic complex in the Rhodope massif confirmed the lithostratigraphic research method as the most promising and successful by which the crystallite can be divided into lithostratigraphic units of different rank [3-5].

A general stratigraphic scheme of the metamorphites in South Bulgaria was publis, according to which the rocks were subdivided into three complexes named later supergroups Prarhodopian (Archean?), Rhodopian (Proterozoic) and Kulidzhic (Vendian-Lower Cambrian) [6-8]. The first two supergroups high-grade metamorphosed into amphibolite facies were subdivided into groups and formations. This stratigraphic scheme was adopted in the 1:100 000 scale geological map in 1990.

The general scheme was continuously refined and improved in terms of boundaries, spatial relationships and composition of the lithological units by additional detailed mapping, profiles and correlation studies [7]. Subsequent thematic developments on the stratigraphy are aimed at systematic checks, detailing, correction and improvement of the developed stratigraphic concept, which has retained its validity to this day [8-10]. In the process of refining (Kozhoukharova, 2008) the stratigraphic concept, some lithostratigraphic units were renamed or abbreviated which made it possible to more clearly discern the unity and sequence of the primary lithostratigraphic structure.

This lithostratigraphic concept is opposed by a later tectonic interpretation that presents the metamorphic complex as a thrust system consisting of a stack of discordant rock plates [11-16].

**Methods for Studying**

The Precambrian metamorphic complex of the Rhodope massif has been subjected to a long-term complex study involving field and laboratory methods. The main applied method is the lithostratigraphic code officially adopted in Bulgaria based on Hedberg's code [17].

**Field Research**

Field research is carried out along several lines:

**Areal mapping:** Conditional geological mapping on a scale of 1:25,000 was carried out between 1948 and 1962 over the entire area of the Rhodope massif, combined with profile studies of the stratigraphic sequence of the rock layers. Many areas with a more complicated geological structure are covered with detailed maps at a scale of 1: 10,000 and 1: 5000. The tectonic brittle and plastic deformations of the rock layers and local ruptures along the boundaries between them are noted.

**Vertical Profiling:** Numerous detailed vertical profiles were carried out, measuring the thickness of the strata to trace the stratigraphic sequence.

**Lateral Tracking:** Lateral variability is an important characteristic of high-grade metamorphic complexes, which is manifested in three directions: primary lithologic, metamorphic and tectonic. The lithology is expressed in a change of sedimentary or volcanic material, the metamorphic in uneven metasomatic manifestations of and the tectonic - in local folding, breaking or accumulation of layers. On this occasion, crawls and observations were undertaken along the layers.

**Comparative profile:** After analyzing and summarizing the areal and profile data, correlation tracings were carried out for the stability of the stratigraphic sequence from different terrane sections. All rock varieties are detailed petrographically described and sampled for microscopic and petrochemical laboratory studies.

**Sampling of Rocks for Laboratory Research:** The testing of the rocks is carried out according to a certain scheme that ensures uniform coverage of all petrographic varieties.

**Laboratory Studies**

Petrographic microscopic observation of the mineral composition and structure of the metamorphic rocks, in parallel with the geochemical analysis by various methods, was carried out on thousands of samples in specialized laboratories. They provided information on the degree of metamorphism, metamorphic facies, sequence of metamorphic events, and rheological properties of the rocks and their absolute age

A number of later scientific thematic studies supplemented the geological mapping data. All geological information from the conventional geological mapping and the additional thematic studies are generalized into a Geological Map of Bulgaria at a scale of 1:100,000, with each map sheet accompanied by notes with textual descriptions.

**Stratigraphy and Structure of the Metamorphic Complex**

The summarized and analyzed results of the complex geological mapping and the additional thematic confirmed several basic statements: i. the high-grade metamorphic complex in the Rhodopes is enough well and clearly stratified system; ii. the contacts of lithostratigraphic units are normal and consolidated, movements are rarely observed between steep layers of rocks with different rheological properties without causing large displacements; iii. the lithological sequence is stable and maintained in all parts of the Rhodope massif; iv. the Leptite gneisses Formation is an important stratigraphic marker due to its wide distribution and recognizable appearance; v. ophiolites and especially serpentinites also have significance as a lithostratigraphic benchmark that marks an old erosional surface.

These main features of the metamorphic complex allowed correlation studies to be carried out, documented in numerous stratigraphic profiles and columns [8]. The need for correlation studies is unquestionable, but it must be taken into account the lateral chance of the metamorphic rocks. It is due to primary lithological, metamorphic and deformation variability. The first type occurs most often in the metamorphosed volcano-sedimentary formations and is expressed in the ratio between amphibolites, slates and marbles. Metamorphic variability is related to the degree of patchy metasomatic manifestations and to the depth level of recrystallization to which the same lithostratigraphic unit falls under folding. The different rheological properties of the petrographic varieties in a plastic environment are the reason for a change in the thickness of the layers - from thinning to breaking of the layer or accumulation, especially common in marbles, calciphires and quartzites. The marbles that have the property of "flowing" in the flanks of the anticlines are thin, while in the synclinal spaces they accumulate as thick layers. Regardless of the listed unfavorable factors, a complete lithostratigraphic correlation has been established between the Eastern, Central and Western blocks of the Rhodope massif, which is a serious confirmation of the unity of the metamorphic complex.

With the first lithostratigraphic concept common to the entire massif, the notion that the metamorphic complex is a general stratigraphic system, which consists of two main Proterozoic groups with different age and composition: lower gneissic and upper with a variegated composition of amphibolites, serpentinites, mica schists, marbles and carbonate schists, was established [6]. The lower gneiss group is named as the Prarhodopian group, and the upper variegated one - as the Rhodopian group. The groups are divided into formations, and the latter in many localities of horizons [7, 9]. Tectonic detailed revisions established local repetitions of the sequence in recumbent fold structures in the Central and Eastern Rhodopes, which necessitated some correction in the range of the Variegated Formation.

Here we present the latest version of the lithostratigraphic scheme down to group and formation level [10].

| | |
|---|---|
| Rhodopian Group | Belashtitsa Formation of calk-silicate schists |
| | Dobrostan Formatiom of marble |
| | Lukovitsa Variegated Formation with ophiolites |
| Prarodopian Group | Konstantinova Formation of metaconglomerates |
| | Punovo Formation of porpyroblastic gneisses |
| | Bachkovo Formation of leptite gneisses |
| | Boykovo Formation of biotite gneisses |

Zagorchev distinguishes 6 types of Precambrian metamorphic complexes from different regions of Southern Bulgaria [18]. In the western part of the Rhodope massif they are: Arda ultrametamorphic, Rupchos variegated, Bachkovo gneiss and Asenovgrad complex, and in the eastern part of the massif - Strazhets gneiss, Boturche metaophiolitic and Tintyava gneiss complex. By applying the lithostratigraphic and correlation methods, taking into account the deformations and the specifics of the metamorphic rocks, the researcher is able to create a realistic geological picture. The structure of the metamorphic complex shows a distinctly dominant fold building.

The PRG and RG were subjected to folding at least twice. In the general structural plan, the diapiric raised domes and linear positive structures are clearly outlined by layers of the RG. The cores of anticlines are built of the Prarhodopian gneisses. The spaces between them are occupied by deeply sunk subvertical, inclined or recumbent synclines, filled by the rocks of the Lukovitsa Variegated and Dobrostan Marble Formations. The stratigraphic sequence is relatively well preserved, which allows through systematic study to restore the structure of the entire metamorphic complex.

On a macro scale, the largest positive folds in the Central Rhodopes are the Northern Rhodope linear anticline, the Madan-Davidkovo dom-anticline so the secondary Middle Rhodope anticline which have an east-west orientation and southern vergence. Vacha and Ardino (Fig. 1), synclines have a north-south direction. In the eastern Rhodopes, the direction of some of the fold structures (Kesebir - Kardamos anticline) change to the northeast, others as the Zaltichal syncline to the northwest, and others retain their north-south orientation (Avren syncline and Tintyava anticline). In the Western Rhodopes (Fig. 1), the orientation of the fold structures was influenced by the uplift of the Rilo-Rhodope batholith [19]. To the east of the batholith they have a pronounced northwesterly direction, but to the south of it a northeasterly direction is clearly manifested. The Debren recumbent syncline is particularly characteristic structure (Kozhuharova, 1976) for the western part of Rhodope Massif. At the meso scale of the outcrops, a variety of folds are observed, the configuration of which depends on the rheological properties of the rocks. From the nappe structures, it is worth mentioning the famous Middle Rhodope nappe, which Yaranov defined as epidermal, the Kulidjik nappe and several small clips in the Eastern Rhodopes [20-22].

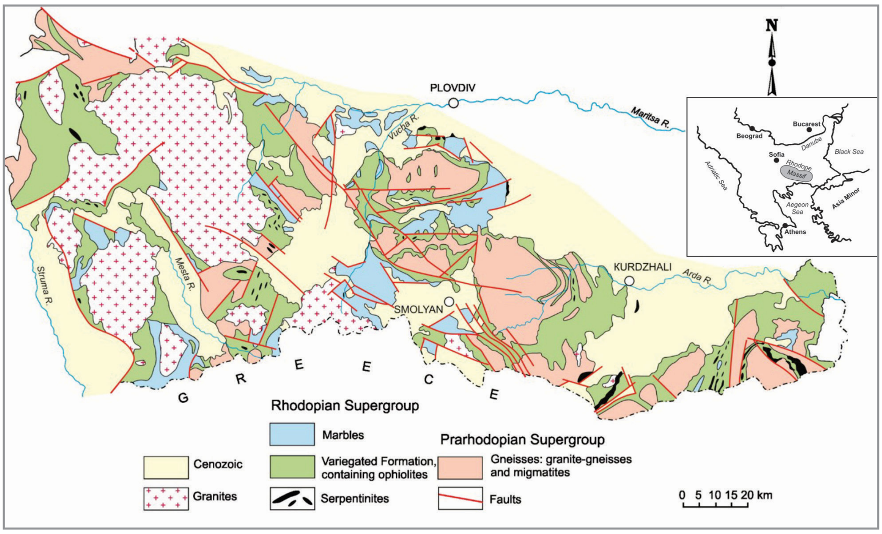


**Figure 1:** Geological map of the metamorphic complex in the Rhodope Massif.

**Metamorphic Complex of Rhodope Massif**

**Prarhodopian Group**

The lower Prarhodopian Gneiss Group (PRG) is widespread, forms the foundation of the Rhodope massif and everywhere fills the cores of the positive linear and dome fold structures (Fig 1). It shows features of an ancient infracrustal continental complex consisting of predominant fine- to mediumgrained gray biotite and yellowish-white leptite gneisses, rather monotonous in appearance and composition. Interlayers and packages of migmatic gneisses and granite-gneisses appear in the lower levels. The texture is foliated, flaser, thin striated, and in the migmatized varieties - small to large porphyroblastic, banded, augen, ptygmatic and others. The microstructure is usually grano- to lepidoblastic, porphyroblastic, glomeroblastic. The mineral composition is mainly represented by plagioclase, quartz, biotite, muscovite, biotite gneisses often contain orthite, and leptite gneisses are microcline bearing. The absence of marbles is a specific feature of PRG. Cadomian, Hercynian and Alpine granitoid magmas, fluids and several generations of aplite-pegmatite veins penetrated the rocks, causing local migmatization and reheating. As a result the whole rock complex obtained geochemical signature of granite-granodiorite.

The PRG group is divided into four lithostratigraphic units from bottom up: Boykovo Formation – biotite gneisses, Bachkovo Formation – leptite gneisses, Punovo Formation – porphyroblastic gneisses and Konstantinovo Formation of metaconglomerates (Fig.2). The first two formations maintain stable development throughout the Rhodope massif. They are completely mutually concordant and the boundary between biotite and leptite gneisses is a gradual lithological transition that demonstrates their genetic unity. Porphyroblastic gneisses of the Punovo Formation are developed in the Eastern Rhodopes and less often in the Western Rhodopes. They form thick-bedded packages in some places and lie discordantly on the leptite and biotite gneisses. The rocks are coarse-porphyroblastic, mica-poor and resemble porphyroid granites in appearance. Above them lies a thin layer of metaconglomerates, made up of large rounded lumps of feldspar rocks about 20 cm in diameter.

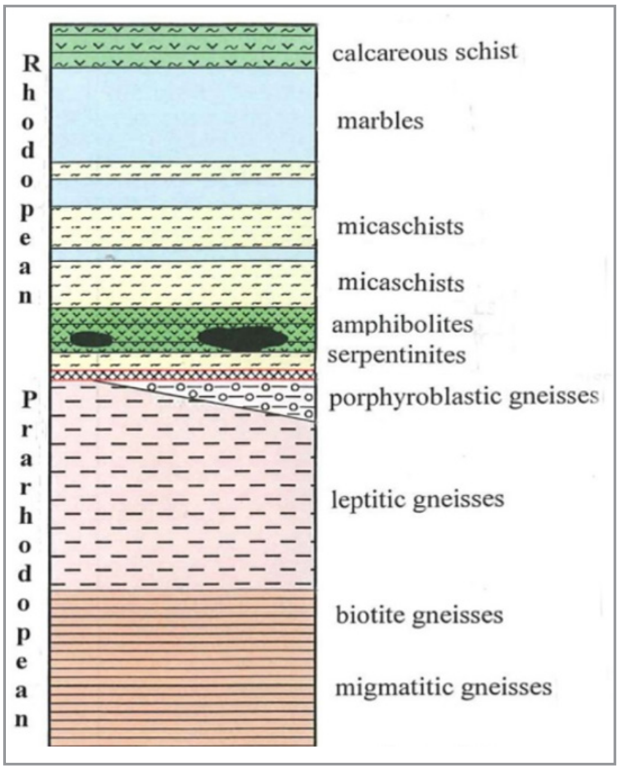


**Figure 2:** Common stratigraphic column of the metamorphic complex.

The analysis of the spatial and lithological features testifies to a later local appearance of the porphyroblastic and metaconglomerate rocks as a microcontinental margin facies that marks a new tectonic stage. This means that Punovo and Konstantinovo Formations only lithologically belong to the Prarhodopian group. However, they were created much later, immediately preceding the transgressive deposition of the Rhodope Group on the continental margins.

The available data on the absolute age of the rocks from the Prarhodopian group do not clarify their age. Absolute ages of 3000 Ma to 40 Ma have been recorded, indicating numerous metachronous influences on the rocks due to deep-seated collisions and granitic magmatism during the Proterozoic and Phanerozoic.

Various assumptions have been made about the origin of the protolith of the PRG gneisses: granites, volcanics, metasomatites. It is also possible that the PRG gneisses could have been a long-drifting fragment of some supercontinent such as Rodinia. During sliding, as a result of internal deformations and recrystallizations of the practicles, a schist and striated texture is created, accompanied by a gravitational separation of the components.

**Rhodopian Group**

The upper Rhodopian Group (RG) is an enough well stratified supracrustal variegated complex that has been transgressively deposited on the Prarhodopian one. Everywhere in well-exposed profiles the rocks of the Rhodopian Group normally overlie the gneisses and fill the synclinal spaces between the positive fold structures (Fig 1). The group is represented by metamorphosed ophiolites and volcanogenic-sedimentary rocks. The primary sedimentary sequence of alternating pelites, quartzites and carbonates was formed in marginal basins. It shows a clear tendency of a gradual increase of the carbonate component upwards. A moderate lateral variability is shown in the group mainly due to the varying amounts of ophiolites from different localities.

All rocks are metamorphosed in amphibolite facies. The sediments are transformed into a fine to medium grained variety of muscovite, biotite, kyanite and staurolite schists, often containing garnet, quartzites, jaspilites, gondites, marbles and calciphyres. Metamorphosed ophiolite rocks are represented by a variety of amphibolites, eclogites, garnet-lherzolites, serpentinites, chlorite and actinolite-tremolite schists.

The rocks of RG are grouped in three parts, up to top: Lukovitsa Variegated Formation, Dobrostan Marble Formation and Belashtitsa Calc-silicate Formation (Fig.2). An Ophiolite association appears in the lower levels of the Lukovitsa Variegated Formation and marks the boundary between the two groups. Subintrusive and volcanic basic magmatism cuts the rocks and connects the PRG and RG. Lukovitsa Variegaded Formation has been divided as an impotant stratigraphic level in the northern parts of the Central Rhodopes [4]. The presence of the same Variegated Formation was established throughout the Rhodope Massif being named Chepelare Formation and Vucha Formation [23, 7].

Because of the uneven areal distribution of the ophiolite association Lukovistsa Variegated Formation shows lateral changes and three types are distinguished from it: Western Rhodope (high presence of amphibolites), Central Rhodope (low presence of ophiolites) and Eastern Rhodope (high presence of serpentinites) (Fig. 3).

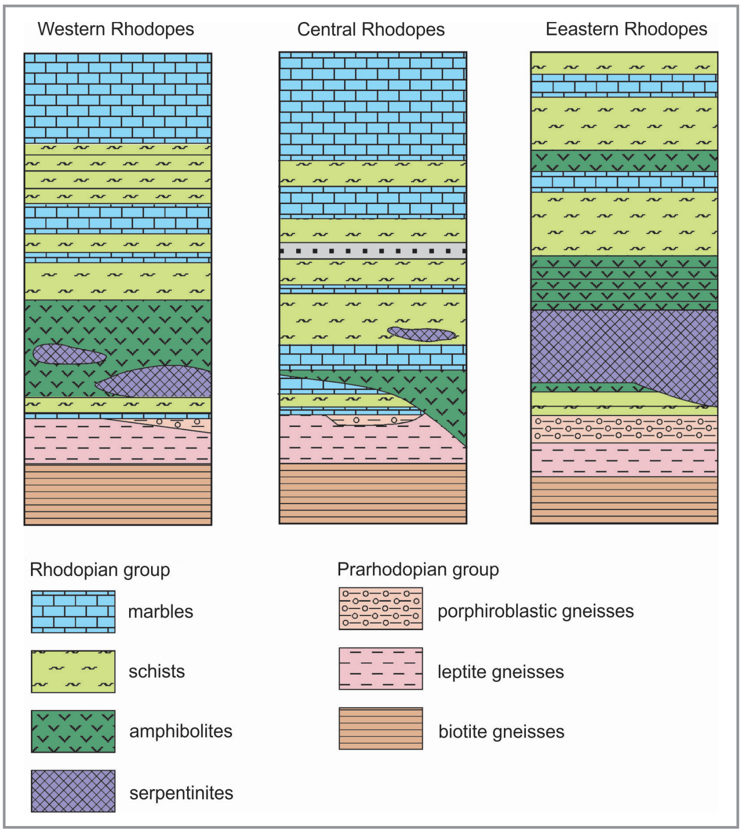


**Figure 3:** Stratigraphic columns of the Lukovitsa Formation in the Western, Central and Eastern Rhodopes

**Ophiolite Association**

The Rhodope Ophiolite Association (ROA) is an important stratigraphic, paleogeographical and metamorphic mark. The ophiolites occupy a clearly defined stratigraphic position in the lower stratigraphic levels of Lukovitsa Variegated Formation of the Rhodopian Group. The Ophiolite association is composed of: a. serpentinites; b. amphibolites - metamorphosed volcanic rocks and tuffs; c. metagabbros and metagabbrodiabases.

**The serpentinite bodies are placed concordantly between the lower layers of the Lukovitsa**

Formation, often directly on the gneiss sole of the Prarhodopian Group and are covered or included by amphibolites, schists and marbles. The largest serpentinite bodies up to 10-12 km long are found in the Eastern Rhodopes [24]. The serpentinites are composed of lysardite, chrysotile and antigorite, rare relics of olivine, pyroxene and chromite. Mineralizations of native copper, gold, pyrrhotite, pentlandite, laurite, sulfarsenides and elemens of platinium group: Os, Jr, Ru, Rh, Pt, Pd have been established in some serpentinite bodies [25].

**Amphibolites as layers (thickness of 0.5 - 15-20 m), alternate with amphibole-biotite schists**

quartzites, carbonate schists and marbles. They are composed of amphibole (tschermakite/hastingsite) and plagioclase (andesine to bytownite), with variable amounts of quartz, biotite, garnet, epidote, pyroxene, titanite, rutile, magnetite, ilmenite. Amphibolites generally correspond to low K, high-Mg toleiite basalts, locally enriched in Ti and Fe, and to a lesser extent to basaltic and peridotite komatiites.

The metagabbros form isolated small bodies. Rare dykes of massive amphibolites and subintrusive body of metagabbrodiabases in the northern part of the Central Rhodopes cut biotite and leptite gneisses of the Prarhodopian Group as well as the serpentinites [26].

We propose a possible scenario for the formation of the Ophiolite Association, which unites in a logical scheme all known geological and theoretical arguments (Fig. 4). During the Neoproterozoic, a situation of basin closure was created, which caused counter movement and collision between oceanic and continental plates. A microcontinent, the prototype of the Rhodope Massif, built from the gneisses of the Prarhodope Group, collides with an Archean-Paleoproterozoic oceanic mantle plate that is covered by clay-like soft serpentinites. A suprasubduction zone was developed at their convergent boundaries. The serpentinite fragments were scraped off from the serpentinite cover of the oceanic plate by the principle of the grater and obduced on the erosion plane of gneiss continental crust (Fig. 4). As a result of the strong friction on the contact surface between the huge continental and oceanic plates and the resulting high temperature and pressure at certain depths, foci of molten gneiss and ophiolite rocks appeared. The melt penetrated into the gneisses through channels. Along the way it builds subintrusive bodies and dykes and covered the serpentinites as lavas and tuffs, together with pelitic-carbonate sediments. The location of the large serpentinite massifs is a known indication of proximity to the coastline of the microcontinent from where the serpentinite fragments were obducted.

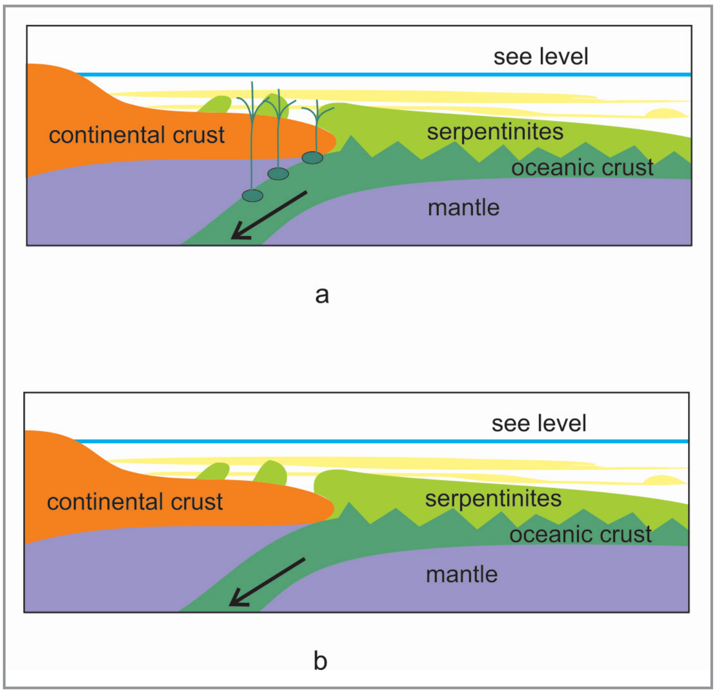


**Figure 4:** Drawing of formation of the Ophiolite Association.
1a. - subduction of the oceanic plate under the continental one and obduction of serpentinite fragments;
1b.- formation of melt and autochthonous magmatism;

The formation of the Rhodope ophiolite association had taken place in three stages: a. static – serpentinization of the oceanic ultrabasic plate; b. dynamic – ocean closure, plate subduction and obduction of serpentinite fragments, scraped from the hydrated coat of the sliding ultrabasic plate; c. constructive – autochthonous subintrusive magmatism and SSZ-type volcanism covering the serpentinite bodies. This determines the heterogeneous nature of OAR formation.

The oldest ages according to U-Pb dating of zircons from the chromitites of the Dobromirtsi serpentinite massif indicate Paleoproterozoic age - 2257 +/- 80 Ma and 1952 +/- 82 Ma (Gonzalez-Jimenez et al., 2013), which is the age of the oceanic plate in the ancient ocean, from which the serpentinite fragments have been torn off.

The absolute age of the metamorphous basic protolith is determined by U-Pb dating on zircon as Neoproterozoic – 610 Ma in eclogites from Central Rhogopes 678-572 Ma - metagabbro Bubino (Carrigan et al) and 566 Ma - metagabbro Bela Reka [27- 29]. These dates coincide with the time of ocean closure preceding the amalgamation of the Gondwana supercontinent.

**Metamorphism**
Three main types of changes are distinguished on the metamorphic complexes in the Rhodope Massif:

a. regional metamorphism; b. high pressure mineralizations; c. metasomatism. They differ in their spatial, temporal and thermodynamic features and develop in distinctly diverse geological settings.

**Regional Metamorphism**

The regional metamorphism is a widespread, long-time lived process of comprehensive recrystallization of primary rocks. The temperature-pressure conditions of crystallization are controlled by the geothermal gradient and lithostatic (confining) pressure which keep a horizontal isotropy and a gradual increase to depth. The degree of metamorphism is within the amphibolite facies - T = 480-600oC and P=5-7 kbar. The presence of serpentinite massives with preserved lizardite, limits the temperature to 600oC. Otherwise, all the serpentinites would have turned into pyroxenite masses and being in a dry continental crust, they could not by any diaphthoritic processes revert to serpentinites again. All rocks underwent a regional metamorphism of amphibolite facies: basic volcanic rocks were recrystallized into amphibolites, subintrusive ones – into metagabbros or metadiabases. The large serpentinite bodies were only peripherally metamorphosed in antigorite, talc-chlorite and chlorite-actinolite-tremolite schists, while in the inner parts they retained the lizardite-chrysotile aggregate in mesh cells.

**High Pressure Mineralizations (HPM) or Geotribometamorphism**

High pressure mineralizations (HPM) or geotribometamorphism possess completely opposite characteristics. They appear locally for a short-time only within the range of geotribological or seismotectonic zone of friction where, thanks to the obtained kinetic energy the temperature and pressure rise to high values: T - 800-1000oC and P over 20 kbar. While the regional metamorphism is a prolonged state of certain conditions, the HPM geotribometamorphism is a short-living event.

Earthquake events cause movement and friction between rock blocks and bedrock layers. The temperature and pressure rapidly rise to high values, causing recrystallization or melting of the zone's wall rocks. The main factor in this metamorphism is friction, which is why we call it geotribometamorphism. In petrology HPM is also known as eclogitization - sensu lato which affects different rock varieties, manifested in new mineral paragenesess depending of the chemical composition of the host rock. Typical eclogites, consisting of garnet, omphacie and rutile occur on a basic substrate among amphibolites, while garnet-lherzolites of pyrope, enstatite, olivine, spinel, augite, diopside are formed on serpentinites. Calcifieres are found among marbles as thin (0,5-3 mm) layers, composed of fine-grained: garnet, scapolite, diopside, zoisite, spinel, calcite, dolomite, phlogopite, plagioclase, titanite, quartz. HPM in metapellites are represented by kyanite and phengite schists in some cases with microdiamond-bearing garnet [30].

Local HPM metamorphism can occur during the Proterozoic and Phanerozoic and affects rocks of different composition, resulting in eclogites, garnet lherzolites, phengite and kyanite schists and calciphyres. Eclogites in the Rhodope Massif were formed in situ in local geotribological crustal zones. Eclogites have been found in thin 5 cm cracks that intersect a gabbronorite body in SW Bulgaria [31].

**Metasomatism**

Metasomatism is a process of bulk chemical change in which substantial amounts of deep derivatives from anathectic and granitoid magmas, as pegmatite-aplite veins, penetrate the regional metamorphic rocks, enriching them with Si, Al, K, Na. Processes of replacement and hybridization develop between rocks with contrasting chemical composition, as well as "rejuvenation" of the age of the rocks. Metasomatic pegmatite-aplite pulses have occurred repeatedly during Proterozoic and Phanerozoic times of granitic magmatism, respectively. Ophiolites are strongly affected by metasomatism due to the contrasting chemistry between them and pegmatite-aplites resulting in hybrid rocks such as metasomatic gabbroides and gabbro-norites with a corona-structure are created [19, 32]. The genesis of the gabbro-norites with corona-structure is s ill a matter of debate. In our opinion, the most plausible version is the metasomatic one. It is likely that small serpentinite bodies, included in the amphibolite layer, reacted with the quartz-feldspar mineral composition of the surrounding migmatization environment. However, the metasomatic version is supported by findings of serpentinite inclusions in pegmatite veins in Ograzhden metamorphic rocks that show the same corona structure during recrystallization [33].

These three radically different types of alterations with a different thermodynamic characteristics should be describes by distinct terms corresponding to the nature of the processes. In practice however we call them by the common name metamorphism which leads to misinterpretation of their origin relating especially to HPM.

## Discussion

There are two main conflicting versions about the structure and formation of the metamorphic complex: a. stratigraphic (presented here) and b. tectonic one.

The stratigraphic concept considers the metamorphic complex as a single building formed by successive deposition of rock formations. The initial stratigraphic sequence has been broadly preserved despite later Caledonian-Hercynian and Alpine tectonic dislocations. This is reflected in the general stratigraphic column, in which two groups different in age and composition are divided: Prahodopian and Rhodopian, detailed in lithological units formations and members. The concept is substantiated on rich abundant facts documented in numerous maps, profiles, sections, correlation columns and therefore claims to represent a highly objective realistic geological situation.

The tectonic concept suggests the idea that the metamorphic complex is ”an Apine nappe stack consisting of several metamorphic units emplaced on each other by thrusting” [15]. The idea appeared suddenly when Zh. Ivanov, who until 1984 firmly supported the unified stratigraphy and Precambrian folding of the Rhodope metamorphites, by suprise published a sketch with drawn discordant plates separated by septa of Jurassic-Cretaceous sediments „containing fossiles “and Paleogene sediments also [11, 23]. This situation has been rejected by all geological studies and revisions as a invalid report. J. P. Burg actively supports the idea of a nappe complex, arguing with contradictory reasoning about “pile of thrusts” “mylonitic gneisses...deformed under amphibolite facies condition”(?) and “sense-of-shear criteria” [12, 13]. Zones of ductile mylonitized gneisses that separate thrust units are also not found or shown by the authors in standard geological documentation. "Deformation asymmetric microstructures” also cannot serve as evidence of thrust structure because similar ones are created during ordinary folding movements. Contrary to the actual geological facts is the statement that "eclogites, ophiolitic and magmatic arc protoliths are found in various units of the crustal-scale duplex structure and delineate a suture zone” [14]. An evolution in views represents the recognition of the existence of an anticlinal and "crustal-scale duplex" in the Kesebir anticline, forgetting to mention that the named anticline and its composition were already described more than five decades ago [34, 35].

A terminological modification of the tectonic concept for “a nappe stack” is the idea of the existence of several allochthons in the Rhodope massif [2, 15, 36, 16, 37, 30, 38]. On the attached sketches on a scale of 1: 2 000 000, the delineated areas of the so-called allochthons, rocks incompatible in terms of lithological and stratigraphical characteristics are included. The mentioned "allochtons" more precisely represent alpine terrains with a distinct tectonic development, rather than trusts, whatever meaning is attached. A more realistic and terminologically close interpretation is given by N. Bonev and P. Filipov, who in the Eastern Rhodopes name the Prarhodope group as "Lower high-grade basement unit" and the Rhodope group as "Upper high-grade basement unit" [39]. Three contradictory features should be noted in the "tectonic concept" of the mentioned authors: a. discordant slabs separated by Phanerozoic sedimentary septa with fossils, piles of encrustations, and a few allochthons were nowhere identified in subsequent geological investigations; b. the authors themselves never submitted the mandatory graphic and textual material where the hypothetical covers are properly depicted and described; c. reviewing of the literature referenced shows that some authors failed to read, even to touch the vast preceded geological information, which is an annoying omission.

The tectonic concept as such is still an idea, presented and spoken as an axiom, that needs more factual argumentation, documentation and terminfological revision [40-43].

## Conclusion

The metamorphic complex of the Rhodope Massif is a unified stratigraphic system consisting of two different in age and lithology rock groups: lower Prarhodopian and upper Rhodopian. A Neoproterozoic Ophiolitic association occupies the lower levels of the Rhodopian Group in alternation with metasediments. Serpentinites mark a stratigraphic level and the boundary between the two groups. Eclogites were formed in situ in seismic geotribological friction zones during different epochs. A leading defining lithostratigraphic unit is also the Bachkovo Formation because of its recognizable appearance and its wide distribution throughout the Rhodope Massif.

The main arguments for the unity of the stratigraphic system in the Rhodope massif are the following:

- The well-preserved layering and normal stratigraphic sequence of the lithological units.
- The repeatability and complete correlation of the lithostratigraphic units from all parts of the massif.
- Presence of reference well-recognizable lithounits such as the Bachkovo formation of leptite gneisses, the ophiolite formation, the obducted serpentinites, marking an old erosional surface.
- Normal consolidated boundaries, often with a gradual lithological transition between stratigraphic units.
- The clear fold structure of linear and domed anticlines and narrow compressed synclines between them.

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