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Structure and Alpine evolution of Bulgaria

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Introduction

The territory of Bulgaria covers parts of two major tectonic units — the northern part of the Alpine thrust belt on the Balkans and its foreland — the Moesian platform.

These two major tectonic units are generally recognized by all Bulgarian geologists but there has been and still is going on a considerable debate about their further subdivision into higher-ranking units, their structure and geodynamic interpretation.

Earlier tectonic schemes were based on the geosynclinal theory. According to the classical and most popular concept of Бончев (1971, 1986), the northern branch of the Alpine orogen in Bulgaria developed within the geosynclinal "mobile space" between two cratons — the Moesian platform and the Thracian "median massif". From this viewpoint, the territory of Bulgaria was divided into three major tectonic units: Thracian massif (Serbo-Macedonian and Rhodope massifs), Alpine orogen and Moesian Platform. The orogen was further subdivided into "morphostructural zones": Balkanides (with Fore-Balkan and Stara Planina zones), Srednogorie, Kraishtides and South Carpathians. The tectonic map of Йовчев et al. (1967, 1971) is based on a similar, slightly modified approach and portrays four major tectonic units: Rhodope massif, Moesian platform, Alpine fold belt (with seven zones) and Superimposed Tertiary depressions.

Since the advent of the plate tectonic theory three decades ago, numerous controversial and contradicting tectonic models for the structure and geological evolution of Bulgaria have been proposed (Boyanov et al., 1989; Dabovski et al., 1989, Dokov et al., 1989; Антова et al., 1996 and many others). They are based on the concept that the Alpine evolution and structure of the Balkan Peninsula were controlled by continuous subduction and multiple collisions along the south facing continental margin of Eurasia. These models differ in the approach to define tectonic units, but share one common point of view — the Alpine thrust belt is a mosaic of proximal and exotic continental fragments that accreted to Eurasia during the closure of Tethys. So far, however, a published modern tectonic map of Bulgaria is not available.

In order to arrive at the most objective tectonic model of any territory, it is necessary to compile and analyze as complete a range of geological parameters as possible, including lithology, palaeontology, stratigraphy, structure, volcanism, plutonism, metamorphism, radiometric data and geophysics. This approach has been adopted by the authors in an attempt to develop a new model for the Alpine structure and evolution of Bulgaria. The present paper is a summary of the main results.

Structure

In our model, tectonic units are understood as rock bodies that are usually confined between fault structures. Each unit is characterized by a specific rock assemblage (specific lithology, stratigraphy, magmatism, metamorphism) and deformational events (age, resulting structures), recording a geological evolution different from that of the adjacent units.

Tectonic units may be defined as independent entities or may be grouped into superunits (zones) on the base of common rock assemblages and deformational events. In some cases, tectonic units may be subdivided into subunits based on differences in the stratigraphy and composition of the rock successions.

Following this approach, the Alpine thrust belt and the Moesian platform on the territory of Bulgaria have been divided into zones (superunits), units and subunits. A simplified tectonic scheme of the defined zones and units is shown in Fig. 1.

Alpine thrust belt

The Alpine thrust belt is a stack of mostly north-verging thrust sheets that progressively developed during multiphase collisions and related compressional events, and namely, toward the end of the Late Triassic, and in Mid-Jurassic, Mid-Cretaceous, Late Cretaceous and Mid-Eocene times. The final stages in the evolution of the belt are recorded by a system of Tertiary intraorogenic extensional basins.

The Alpine thrust belt is conventionally divided into two orogenic systems — the South Carpathian and the Balkan system.

South Carpathian orogenic system

The South Carpathian orogenic system is poorly exposed in the northwestern corner of Bulgaria and includes two units. The western, *Kraina unit* is an extension of the Severin nappe in Serbia and Romania. It comprises Upper Jurassic-Lower Cretaceous flysch sequences that were deformed in Mid-Cretaceous time. Toward the end of the Late Cretaceous, this unit was thrust over the eastern, para-autochthonous *Koula unit.* The latter is represented by Turonian-Senonian flysch that covers unconformably Triassic to Lower Cretaceous carbonates from the southern margin of the Moesian platform.

Balkan orogenic system

The Balkan orogenic system is subdivided into three tectonic zones: Balkan, Srednogorie and Morava-Rhodope (Fig. 1). Sediments of Tertiary intraorogenic continental and shallow marine basins cover and mask large areas within the Srednogorie and Morava-Rhodope zone.

The Balkan zone includes four tectonic units: West Balkan, Central Balkan, East Balkan and Dolna Kamchya unit. They form a complex system of north-verging thrust sheets over the South Carpathian units and the margin of the Moesian platform. Key characteristics of this superunit are: widespread Mesozoic to Early Tertiary flysch, flysch-like and molasse successions typical of the external parts of orogenic belts; general lack of products of Alpine magmatic activity with the exception of scarce and small occurrences of Upper Cretaceous subvolcanic and volcano-sedimentary rocks; intense Mid-Eocene? compressional deformations in the central and eastern segments of the zone; relatively thick continental crust (38-34 km) gradually thinning toward the Moesian platform.

The West Balkan unit is composed of greenschist facies Vendian-Cambrian ophiolite, island-arc and olistostrome assemblages at the base, overlain by Ordovician, Silurian and Lower-Middle Devonian slates and clastic rocks, Upper Devonian to Lower Carboniferous flysch, Upper Carboniferous coal-bearing continental sediments and Permian clastics. The Mesozoic succession begins with Triassic clastics and platform carbonates, followed upward by Lower-Middle Jurassic continental to shallow marine sediments and a dominantly carbonate succession of Late Jurassic to Late Cretaceous-Palaeocene age. Lower-Middle Eocene continental to shallow marine clastic and carbonate sediments are locally exposed. The main compressional deformations are of Late Cretaceous age. Mid-Eocene thrusting over the Moesian platform affected the northern periphery of the unit.

The pre-Mesozoic basement of the *Central Balkan unit* is exposed mainly in the southern, topmost thrust slices and comprises Vendian-Cambrian greenschist facies ophiolite and island-arc assemblages, overlain by Permian clastics and acid volcanics. Upward follow Triassic clastics, platform carbonates and evaporites (in the eastern parts of the unit), Lower-Middle Jurassic continental and shallow marine clastic and carbonate rocks, and thick flysch and molasse successions of Late Jurassic-Early Cretaceous age. They are overlain by Upper Cretaceous-Palaeocene carbonates and Lower-Middle Eocene continental sediments. The unit experienced intense Mid-Cretaceous and Mid-Eocene compressional deformations.

The East Balkan unit is dominated by Upper Cretaceous to Middle Eocene clay-carbonate and clastic flysch successions. The underlying rocks are exposed within a narrow belt along the frontal thrust of the unit and comprise Triassic carbonates and Lower-Middle Jurassic shales,

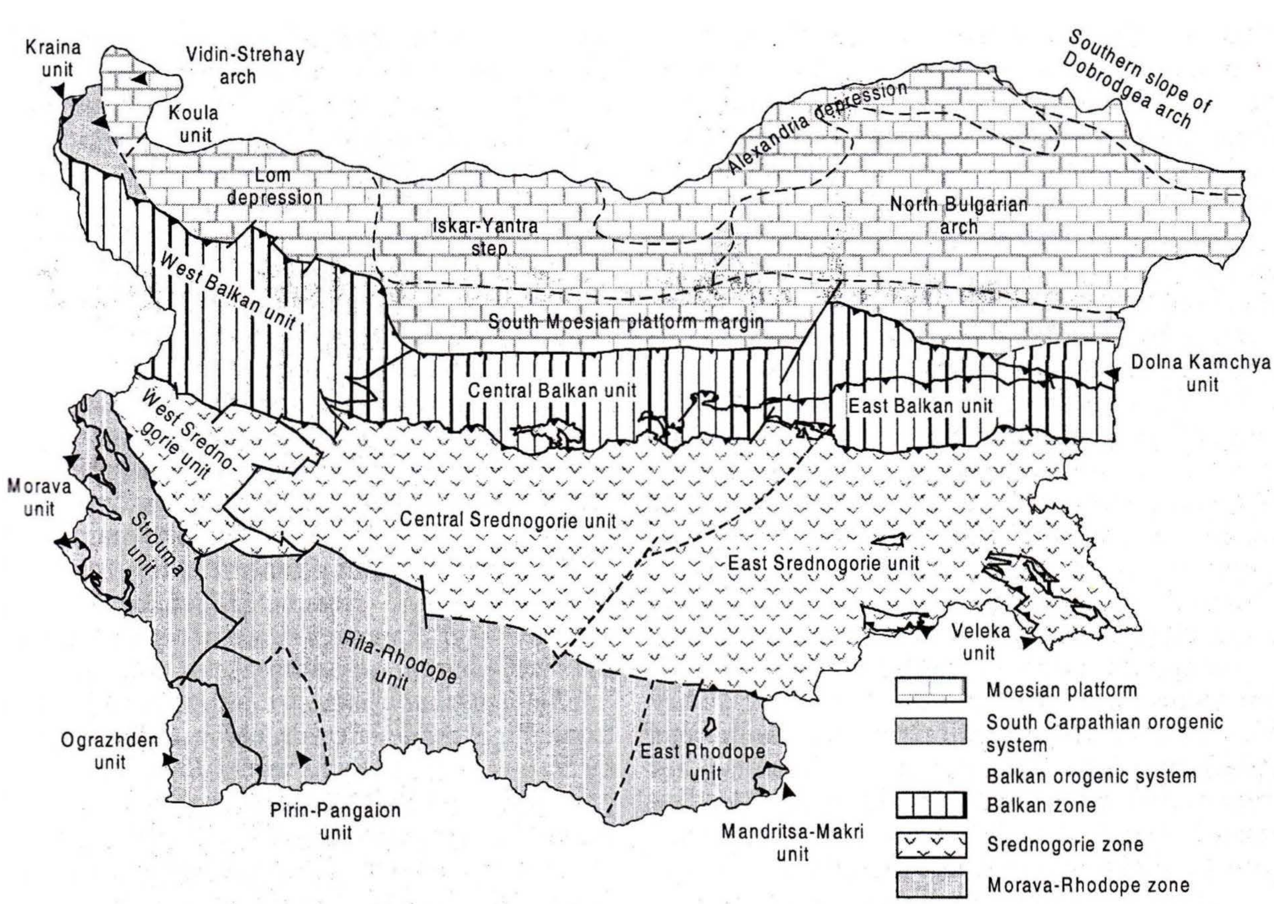

Fig. 1. Tectonic scheme of Bulgaria

locally associated with Upper Triassic flysch-like sediments.

The Dolna Kamchya unit is a late- to post-orogenic foredeep filled dominantly with thick Late Eocene-Oligocene and Neogene sediments.

The Srednogorie zone is defined on the base of the following key characteristics: thick Upper Cretaceous volcano-sedimentary successions and numerous intrusive bodies of island-arc signature; main Late Cretaceous compressional deformations followed by Mid-Eocene north-verging thrusting in the northern parts of the zone; relatively thin (35-28 km) continental crust.

Three tectonic units are divided on the ground of some specific features of the Upper Cretaceous successions and their basement: West, Central and East Srednogorie unit. Their northern boundaries are major E-W trending Mid-Eocene thrusts reactivated in some segments by later, Neogene and Quaternary normal faults. The lateral contacts are complex, NE-SW fault systems that are largely covered by Tertiary and Quaternary sediments.

The West Srednogorie unit is composed of locally exposed high-grade metamorphic rocks of Precambrian? age at the base, overlain by Devonian flysch, Permian clastics, Triassic platform carbonates, Jurassic shallow marine clastics and carbonates, Upper Jurassic-Lower Cretaceous flysch and Lower Cretaceous carbonate successions. The Upper Cretaceous section begins with Cenomanian-Turonian continental to shallow-marine clastics and shales, followed upward by an over 4 km thick Coniacian-Campanian volcano-sedimentary succession that is transgressively overlain by Campanian-Maastrichtian shales and carbonates. Typical magmatic rocks are basic to intermediate varieties of the calc-alkaline and high-potassium calc-alkaline series with shoshonitic trends in some polyphase plutons. The cover comprises Oligocene and Neogene continental sediments.

The Central Srednogorie unit comprises Precambrian? high-grade metamorphic rocks and Palaeozoic granites, overlain by a thin cover of locally preserved Permian clastics, Triassic carbonates and Lower-Middle Jurassic clastic and carbonate shallow marine sediments. In contrast to the West Srednogorie unit, Upper Jurassic and Lower Cretaceous successions are lacking. The Upper Cretaceous volcano-sedimentary section in the western parts of the unit includes Turonian continental to shallow marine clastics, Coniasian-Santonian volcano-sedimentary successions and Campanian-Maastrichtian flysch. The eastern parts comprise Cenomanian clastics and shales overlain by not well constrained in age Turonian-Senonian sediments and volcanics (mostly pyro- and epiclastics). The magmatic rocks are intermediate to acid varieties of the calc-alkaline to shoshonitic series. Large areas of the unit are covered by thick Palaeogene and Neogene continental and shallow marine sediments.

The East Srednogorie unit is dominated by Upper Cretaceous volcano-sedimentary successions in the northern part and pre-Late Cretaceous rock assemblages in the southern. The section begins with Precambrian? high-grade metamorphic rocks and Palaeozoic granites, followed by locally preserved Palaeozoic greenschist facies rocks, Permian clastics, Triassic carbonates and Lower-Middle Jurassic shallow to deeper marine clastics and shales. They are tectonically overlain by allochthonous Palaeozoic and Triassic metasediments that were emplaced toward the end of the Mid-Jurassic? The Upper Cretaceous section begins with Cenomanian continental and shallow marine clastics, followed by Turonian deeper marine shales and argillaceous carbonates and an over 5-6 km thick Coniacian-Campanian volcano-sedimentary succession. They are overlain by Maastrichtian carbonates, Eocene-Oligocene and Neogene continental to shallow marine clastics and carbonate rocks. The products of the magmatic activity (volcanics, numerous intrusive bodies and dikes) range in composition from ultrabasic to acid and span from the tholeiitic to ultrapotassic series. The K-content increases from south to north indicating across-arc zonality typical of volcanic island arcs.

The Morava-Rhodope zone includes fragments of seven tectonic units: Morava, Ograzhden, Strouma, Pirin-Pangaion, Rila-Rhodope, East Rhodope and Mandritsa-Makri. They are integrated into one superunit on the base of the following common features: widely exposed high-grade metamorphic basement complexes typical of the internal parts of orogenic belts; frequent Late Cretaceous intrusive bodies of different size; development of isolated Palaeogene basins with continental and shallow marine sediments associated with dominantly acid and intermediate volcanic rocks; main Mid-Cretaceous compressional deformations followed by Late Cretaceous-Tertiary extension and exhumation; thick continental crust (50-52 km) in the central parts of the zone, thinning to 34-37 km in SE and NW direction. The northern boundary with the Srednogorie zone is a complex system of thrusts and normal faults with uncertain age and relationships.

In some units, the age of the high-grade metamorphic complexes is not well constrained and controversial. Conflicting alternatives suggest Precambrian and/or Palaeozoic age of the protolith, and Precambrian, Mid-Cretaceous or even Late Cretaceous-Early Tertiary age of the high-grade metamorphic event.

The Morava unit is a system of nappes that were thrust over the Strouma unit during the Mid-Cretaceous. The section comprises Precambrian gneisses and migmatites covered by Ordovician, Silurian and Devonian successions of Rheno-Hercynian signature. Mesozoic rocks are lacking and Eocene-Oligocene volcano-sedimentary sequences directly overlie the pre-Mesozoic basement and seal the thrusts.

The Ograzhden unit is composed of Precambrian high-grade metamorphic rocks intruded by Palaeozoic, Late Jurassic, Late Cretaceous granitoids and Palaeogene minor intrusions and dikes. The contact with the Pirin-Pangaion unit is a major east-verging thrust believed to be of Mid-Cretaceous age as suggested by an Upper Cretaceous intrusive body that intersects the thrust surface.

The Strouma unit is the only unit of the Morava-Rhodope zone with a relatively thick Mesozoic succession. The base of the section comprises Precambrian high-grade metamorphic rocks covered with tectonic (ductile shear zone) or tectonized contact by Vendian-Cambrian greenschist-facies island-arc and ophiolite assemblages. Upwards follow Ordovician metasandstones, Permian red beds, Triassic clastic and carbonate rocks, Jurassic to Lower Cretaceous flysch, Eocene-Oligocene sediments and volcanics. The entire succession experienced Late Triassic folding, followed by intense Mid-Cretaceous compressional deformations (folding and thrusting accompanied by low-grade metamorphism) and Palaeogene extension.

The Pirin-Pangaion unit is composed dominantly of high-grade metamorphic rocks (Rhodopian Supergroup) intruded by Palaeozoic, Late Cretaceous and Oligocene granitoids. Palaeocene?-Eocene terrigenous sediments are scarce. The contact with the Rila-Rhodope unit is believed to be a southwest-verging Mid-Cretaceous? thrust, masked by Eocene-Oligocene volcano-sedimentary successions and "stitching" intrusive bodies.

The Rila-Rhodope unit exhibits a similar section — high-grade metamorphic rocks (Prerhodopian and Rhodopian supergroups) intruded by several large Palaeozoic and Late Cretaceous granite plutons, followed by Eocene? – Early Oligocene "minor" intrusions. In contrast to the Pirin-Pangaion unit, the Palaeogene volcano-sedimentary cover is better preserved in several basins. This is the unit with thickest (40-52 km) continental crust in Bulgaria. The boundary with the East Rhodope unit is uncertain. It is placed along a steep regional gravity gradient that is possibly related to a major east-dipping shear zone fixed in seismic profiles.

The East Rhodope unit comprises high-grade metamorphic rocks referred to the Prerhodopian and Rhodopian supergroups and intersected by Late Cretaceous and Late Palaeogene "minor" intrusions. Upwards follow allochthonous Mesozoic rocks of the Mandritsa unit and a thick cover of Late Palaeogene volcano-sedimentary successions. The continental crust is relatively thin (34-37 km) as compared to the other units of the Morava-Rhodope zone.

The Mandritsa-Makri unit comprises diabase-phyllitoid greenschist-facies rocks of uncertain (Vendian-Cambrian or Triassic) age that are overlain by Jurassic black shales (with radiolarites and sandstones) and Upper Cretaceous sediments and volcanics. The unit is interpreted as a complex thrust slice emplaced between high-grade metamorphic rocks as a result of Mid- and Late Cretaceous compressional deformations.

Moesian platform

The Moesian platform is composed of relatively undeformed Mesozoic successions up to 4-5 km thick, resting unconformably upon a gently folded Palaeozoic basement and buried beneath Palaeogene, Neogene and Quaternary deposits. Major unconformities at the base of the Triassic, Jurassic, Upper Cretaceous and Eocene, record the main compressional events within the Alpine thrust belt.

Several major positive and negative structures of different geological history can be divided. In all of them, the Triassic sediments were affected by Early Cimmerian folding and thrusting, whereas the overlying younger successions were practically not deformed. Dominating structures are the Lom depression, the North Bulgarian arch and the South Moesian platform margin.

The Lom depression comprises an over 8 km thick, almost uninterrupted succession of Mesozoic and Cenozoic shallow to deeper marine sediments that record a continuous subsidence of the western part of the Moesian platform. The oldest rocks drilled are Lower Triassic clastics.

The *North Bulgarian arch* formed as a result of continuous uplift of the eastern part of the Mosian platform during Mesozoic and Cenozoic times. In the central topmost parts of the structure, the thickness of the Mesozoic succession is reduced to about 1 km and commences, directly over the Palaeozoic basement, with Middle Jurassic clastics, followed upwards by Late Jurassic to Hauterivian-Barremian carbonates. Tertiary cover deposits are lacking. Block faulting, horst and grabens of different rank are typical structural features of the arch.

The South Moesian platform margin includes the south dipping subsided part of the Moesian platform in front of the Alpine orogen. The Mesozoic section comprises thick Triassic to Late Cretaceous clastic and dominantly carbonate sediments, locally interfingering with deep marine foredeep successions (Late Jurassic-Early Cretaceous). They are overlain by Palaeogene and Neogene deposits. The structural pattern is dominated by southern monoclinal dips.

Evolution

The Alpine evolution of Bulgaria is closely related to the Mesozoic and Cenozoic history of the Northern Tethyan margin in the Eastern Mediterranean region. The geologic evolution of this region has been subject of extensive studies in recent years (Dercourt et al., 2000, Stampfli et al., 2001, and others) but still remains not well constrained and controversial. Most of the proposed regional plate tectonic reconstructions do not fit well to the preserved sedimentary, magmatic and structural record on the territory of Bulgaria.

The following major Alpine stages can be tentatively reconstructed (Fig. 2).

Late Permian-Late Triassic (Fig. 2a, b): development of a south facing passive continental margin with carbonate platform (Palaeo-Moesian platform) and pelagic (slope?) sediments to the South (sediments of the Mandritsa-Makri and Veleka units), failed rifting (Chiren, Sakar, South-Moesian rifts), followed by Early Cimmerian (Norian-Rhaetian) compression and inversion of the rift basins.

Early-Mid Jurassic (Fig. 2c): subduction of Tethyan oceanic crust and initiation of a Juras-

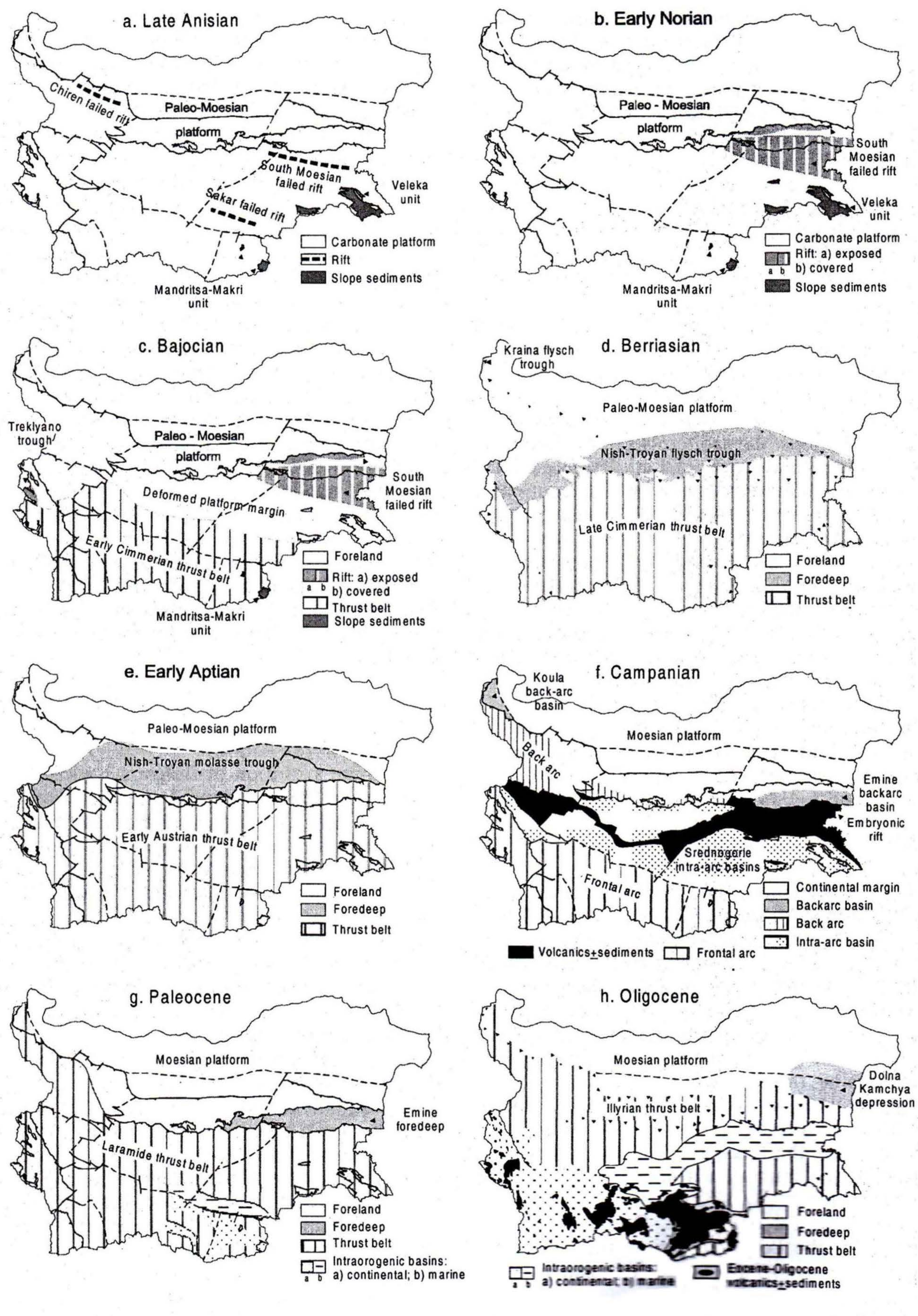

Fig. 2. Triassic to Oligocene evolutional model of Bulgaria. Fragments of different in age palaeotectonic elements (rifts, foredeeps, thrust belts, etc.) are shown in their present position without palinspastic reconstructions

sic volcanic island arc to the South (on the territories of Greece and Macedonia) of the Early Cimmerian thrust belt; resumed epicontinental deposition and rifting within the Palaeo-Moesian platform (South-Moesian rift, Treklyano trough), followed by Mid-Cimmerian (Bathonian) compression, thrusting of Veleka unit over the southern margin of the platform and inversion of the South-Moesian rift with formation of the Matorides.

Late Jurassic-Early Cretaceous (Fig. 2d, e): development of a convergent continental margin, further growth and northward propagation of the Cimmerian (Late Cimmerian) thrust belt, initiation and development of flexural foredeeps (Nish-Troyan, Kraina troughs), successive Early (Valanginian-Hauterivian) and Late Austrian (Aptian-Albain) compression, intense folding and thrusting, total consumption and inversion of the foredeeps and the Palaeo-Moesian platform epicontinental basins.

Late Cretaceous (Fig. 2f): northward subduction of Tethyan oceanic crust, initiation, development and extinction of a Turonian-Campanian volcanic island arc system with frontal arc, intra-arc (Srednogorie) basins, back-arc rift and back-arc basins (Emine, Koula), followed by Laramide (Late Maastrichtian) collisions and compression, folding, thrusting and inversion of the Srednogorie and Koula basins.

Palaeocene-Mid Eocene (Fig. 2g): further growth and northward propagation of the Laramide thrust belt, development of a flexural (Emine) foredeep over the Emine back-arc basin, initiation of intra-orogenic basins, terminal Illyrian (Mid-Eocene) collisions and compression, intense folding thrusting and inversion of the foredeep.

Late Eocene-Oligocene (Fig. 2h): progressive growth of the Alpine thrust belt, crustal thickening, exhumation of core complexes in the internal parts of the belt, extension and further development of intra-orogenic basins with local Eocene-Oligocene collision-related magmatic activity, initiation and northward propagation of a new post-orogenic (Dolna Kamchya) foredeep.

The marine regressions in Late Oligocene and earliest Miocene time were followed by compressional and transpressional movements. A new geodynamic pattern initiated in Middle Miocene times, evolved in conditions of prevalent extension and this neotectonic development (s. Zagorchev, 1992) is continuing up to our days.

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