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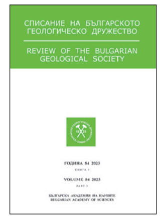

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The crustal thickness in the Rhodope Metamorphic Complex area from the perspective of the present-day geological knowledge

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Дебелината на кората в областта на Родопския метаморфен комплекс от перспективата на съвременното геоложко познание

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Abstract. The crustal thickness in the area of the Rhodope Metamorphic Complex decreases from west to east from ~50 km to ~30 km. This regional-scale feature is mostly due to the different rates of extension that the basement rocks experienced in different parts of the complex. In our model, we postulate that the crustal thickness in the area is an effect of the late Eocene zipper-like or hinge-like extensional tectonics that caused a larger amount exhumation of high-grade metamorphic rocks in the eastern parts of the area and lesser one in the west. This zipper-like orogen parallel extension caused a vast tectonic erosion and progressive thinning of the crust from west to east.

Keywords: Rhodopes, thrusting, detachment faulting, crust thickness.

Introduction

The thickness of the crust in the area of the Rhodope Metamorphic Complex (Internal Hellenides) varies considerably from west to east. In the eastern parts of the area (Eastern Rhodope Mountains) the crustal thickness is ~30–35 km, whereas in the western parts (Rila, West Rhodope and Pirin Mountains) it exceeds 50 km. This significant difference was studied, interpreted and reported mostly by means of geophysics (Georgieva, Nikolova, 2015 and references therein) and was only barely touched in terms of tectonic interpretations (Khrischev et al., 2020 and references therein).

Herein, we are drawing your attention to some well-known local and regional structural features that in our opinion control the commented phenomenon suggesting a generalized model with which we make an attempt to explain the differences in the crustal thickness in the Rhodope area; the lack of outcropping lower units in its western parts (excluding Pirin, Bozdag and Vrontou Mountains); east-west directed younging and composition change of the latest Eocene–Oligocene magmatic arc rocks; as well as the role of the syn- to post collisional extensional tectonics and related major low-angle extensional detachments for the rates of regional scale extension and different levels of tectonic driven erosion in the area.

General structure of the Rhodope Metamorphic Complex

The rocks that form the Rhodobe Metamorphic Complex (Rhodope Zone, Rhodope Metamorphic Province, Internal Hellenides in other studies) were subdivided for simplification in four large allochthonous tectonic units namely Lower, Middle, Up-

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per and Uppermost allochthons (Janák et al., 2011). The four allochthons merge together lithotectonic/tectonostratigraphic units that contain metaigneous rocks with common magmatic protolith ages, underwent similar metamorphic conditions, share same tectono-metamorphic history, etc. Thus, each of the allochthons can be considered as a distinct paleogeographic province. All these stacked together due to the Alpine orogenic processes from Latest Jurassic on and formed the nappe edifice of the Rhodope Metamorphic Complex (Jahn-Awe et al., 2012 and references therein). The Lower Allochthon represents a subducted margin of a south located continent (possibly Apulia). The Middle Allochthon derived from a former Jurassic volcanic arc with Jurassic ophiolite fragments that in the late Jurassic were first obducted onto the European passive margin (i.e., the Upper Allochthon) and thus, formed the present-day Uppermost Allochthon. In the course of the Late Alpine orogeny, parts of the Uppermost allochthon were sheared off and tectonically emplaced between the Lower and the Upper allochthons. The Upper Allochthon represents the European continental margin that contains parts of the Early Alpine orogen and was emplaced onto the Middle Allochthon in the Ypresian (Gorinova et al., 2019). The Lower, Middle and Upper allochthons consist of high-grade metamorphic rocks in some places, reaching granulite and eclogite facies conditions. Although some controversial opinions exist, it is widely accepted that the Uppermost Allochthon consists of low grade (reaching anchizonal to greenschist and rarely blueschist facies) metasedimentary to metavolcanic rocks with Middle to Late Jurassic protolith ages that contain Jurassic ophiolite fragments (Bonev et al., 2015 and references therein). This due to the Alpine collision and thrusting, quadruple tectonic "sandwich" increased the thickness of the crust involved and led to a significant isostatic instability. The latter, together with the onset of the relatively fast slab retreat that started by the end of Bartonian (38–37 Ma) triggered a vast extension that caused the reshaping of the Rhodope Nappe Edifice once in the late Paleogene and again in the middle Miocene. The extension was mostly controlled by the onset of regional scale detachment faults and caused the formation of metamorphic core complexes and related supradetachment (mostly) sedimentary basins. Each of the two extensional stages ended with the obliteration of the low-angle detachments by steeper normal faults. The latter acted also as drainage channels for rising magmas, so thus controlling the formation of the volcanic-sedimentary successions and hydrothermal ore systems formed in the latest Eocene and Oligocene and again in middle to late Miocene.

The link between the tectonostratigraphy and the crustal thickness of the Rhodope area

When discussing the compressional history of the Rhodope Metamorphic Complex, we mostly rely on relics of older structures or prograde mineral assemblages preserved. The main issues with the recognizing of structures related to the nappe stacking are their kinematic and metamorphic condition similarities with those from the later extensional stages. Moreover, when postulating the formation of the nappe edifice of the Rhodopes we always refer to orogen scale thrusts however, due to the dominance of the later extensional tectonics these are either reactivated but rather obliterated by the detachment faults. Therefore, we may in general discuss the orogen-scale tectonostratigraphy of the nappe edifice however, it is rather speculative to discuss on the original tectonostratigraphic features of the four allochthons which in different parts of the Rhodope Metamorphic Complex may vary considerably. For example, in the Central Rhodope area the Middle Allochthon represents a complex thrust sheet that is composed of two groups of units – a lower migmatized high-grade section and an upper unit that consists of rocks that underwent upper greenschist to moderate amphibolite facies metamorphism. However, in most of the places the shear zones that bound the allochthon and the shear zones that separate the two sections are interpreted as extensional low-angle regional structures (Jahn-awe et al., 2012 and references therein). In the east, in some areas the units of the Middle Allochthon are excised so the Lower Allochthon underly directly the units of the Upper Allochthon. In some other parts however, the units of the Middle Allochthon form larger-scale boudin-like bodies enclosed between the Lower and the Upper allochthons. In the western parts of the complex, the rocks of the Middle Allochthon are in general similar to the those in the Central Rhodopes (i.e., units composed of either migmatized or lower-grade rocks) but the section is more complex due to the presence of tectonic duplications. Another example is the structure of the Lower Allochthon in the area of South Pirin Mountains and Central Rhodopes, where duplications in the allochthon's section are reported (Jahn-Awe et al., 2010; Petrik et al., 2016 and references therein). The units of the Upper Allochthon in the western areas build up a significant part of the nappe pile. In contrary, these units are rather absent in the Central Rhodopes and in the eastern areas they represent dismembered extensional allochthons of the late Eocene detachments.

Different crustal thickness – a compression or extension induced phenomenon?

The presence of structural complexities may explain the differences of the crustal thickness in different parts of the Rhodope Metamorphic Complex however, the particular mechanisms of the thickening/thinning are yet to be clarified. It is well known that due to the convergence and collision the crust in the areas of the orogens experiences thickening. Due to the different character of the crustal fragments that are involved in such a convergence, in different parts of the orogenic belts the crustal thickness will vary (microcontinental fragments involved or formation of larger tectonic duplexes, etc.). On the other hand, different rates of syn- to post collisional extension would reflect on the amount of exhumation of the lower hot crust in different parts of the orogens and thus having a direct impact on the rates of tectonic erosion and final crustal thickness.

The widely exposed parts of the Lower Allochthon in the eastern and central parts of the complex and lack of exposed lower units in its western parts (except Pirin, Slavyanka, Bozdag and Pangaion Mountains that were exhumed in the course of the Middle Miocene extensional event) show that the rate of late Eocene–earliest Oligocene exhumation in the west is considerably lower than in the central and eastern areas of the complex. That, combined with the fact that the Middle Allochthon in the western and central parts of the complex appear as a coherent thrust sheet but in the eastern parts of the complex as larger separate boudin-like bodies supports the idea that the eastern parts of the complex were affected by more intense extensional processes. In addition, the Eocene–Oligocene sedimentary basins are broader and deeper in the eastern areas, transiting from continental to marine environment, whereas in the Central Rhodopes and to the west these are mostly isolated continental basins. Everywhere in the field, the present-day boundaries between the four allochthons represent extensional detachment faults. Therefore, we state that some compressional peculiarities in the overall structure of the Rhodope nappe edifice might have had some impact on the crustal thickness in the area however, it is more likely that the late Eocene–early Oligocene extensional tectonics and its varying intensity in different parts of the complex is the actual driven force for the irregular crustal thinning increasing from west to east.

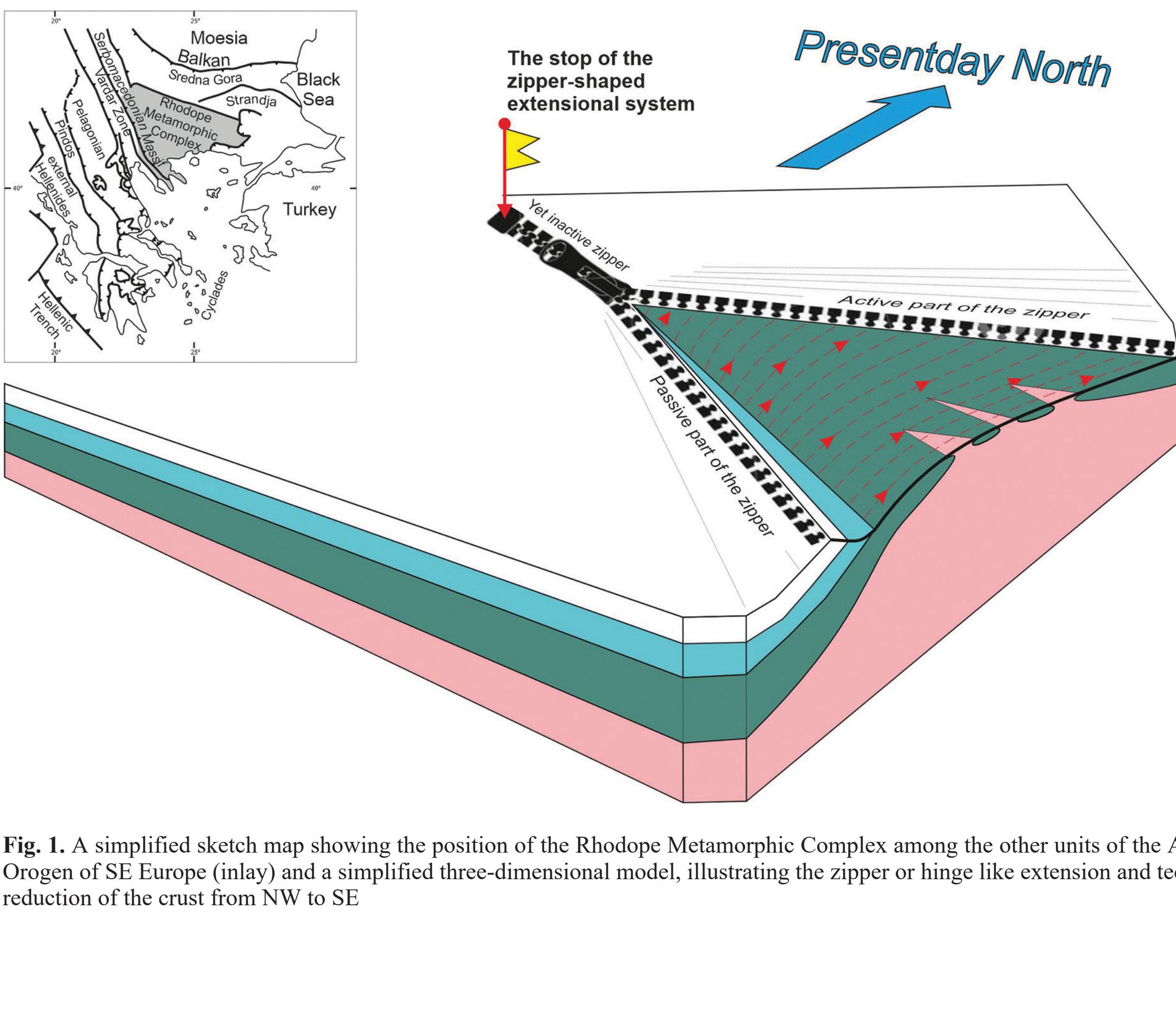

Fig. 1. A simplified sketch map showing the position of the Rhodope Metamorphic Complex among the other units of the Alpine Orogen of SE Europe (inlay) and a simplified three-dimensional model, illustrating the zipper or hinge like extension and tectonic reduction of the crust from NW to SE

Geometrically, in a regional scale map view this process can be presented as a development of large wedge-shaped metamorphic core complex with its tip located farther northwest of the Rhodope area (see also Georgiev et al., 2010) and the wider part located to the east-southeast. The vast regional scale orogen parallel extension and attendant doming and exhumation of the lower crustal high-grade metamorphic rocks was controlled by two opposing in their kinematics series of detachment faults (a top-to-the North and top-to-the Southwest one). It is difficult to estimate if these were active at the same time. There are some evidences for an earlier top-to-the North detachment faulting and consequent top-to-the Southwest one in the area of the Eastern Rhodopes. On the other hand, the temporal development of detachment faults that are responsible for the exhumation of deeply seated rocks of the Central and Western Rhodopes show that the top-to-the North extension is younger than the top-to-the Southwest one. It is clear however, that as farther east or southeast the detachment faults are located as wider the related mylonitic zones are and vice versa, the detachment faults that are located close to the western (northwestern) tip of the Rhodope Wedge show rather thinner mylonitic zones. Therefore, the low-angle shear zones located to the east accommodated larger movements and thus, contributed to the exhumation of the lower parts of the crust (Lower Allochthon). In contrary, the detachment faults located in the northwestern part of the complex accommodates lesser amount of offset and thus, smaller exhumation and crustal thinning respectively.

General conclusions and some open questions

In summary, we can suggest a model in which due to lesser amount of late Eocene detachment faulting, relic of compressional structures in the western parts of the complex were preserved. In the central parts, the extension was more intense and led partly to the obliteration of some of the compressional structures and reduction of the nappe pile section (especially the section of the Middle Allochthon). In the eastern area, due to the extremely intense extensional shearing the thickness of the nappe edifice was considerably reduced, and the area is nowadays occupied mostly by units of the Lower Allochthon. All these processes led to the more progressive thinning of the crust in the eastern areas of the complex and lesser one in its western parts. The main question arising is what triggered the zipper or hinge-like extension in the area (Fig. 1)? For the moment such a question remains unanswered however, we can suggest two possible scenarios: 1) different speed of the slab rollback and thus faster and larger amount of delamination of the lower crust in the eastern parts of the nappe stack; 2) presence of linear vertical crustal scale faults/shear zones that in a manner of large transforms controlled the amount of convergence, thickening as well as the extension and the thinning in different parts of the orogen. A good candidate for such a structure is the Avren Fault described as a regional scale strike-slip; 3) a combination of the two scenarios.

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