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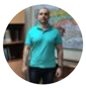

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MORPHOSTRUCTURAL PRECONDITIONS FOR THE SEISMIC SETTING IN THE RHODOPE MOUNTAIN

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***Key words**: Rhodopes, earthquakes, morphostructures, Plate tectonics.*

Abstract: The present study is a morphotectonics analysis of the spatial distribution of the earthquakes on the territory of the Rhodope mountain massif. The methodological basis of such a study is the mobilistic (Plate tectonics) model of the Neogene-Quaternary morphostructural evolution of the Rhodope lands. The analysis of the relation of the regional seismic processes with the local positive morphostructural generations is a significant step towards the construction of a generalized model of the endogenous morphogenesis in the Rhodope region.

МОРФОСТРУКТУРНИ ПРЕДПОСТАВКИ ЗА СЕИЗМИЧНАТА ОБСТАНОВКА В РОДОПИТЕ

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***Ключови думи:** Родопи, земетресения, морфоструктури, плейттектонски.*

Резюме: Настоящето изследване представлява морфотектонски анализ на пространственото разпределение на земетресенията на територията на Родопския планински масив. Методична основа на едно такова изследване се явява мобилистичния (плейттектонски) модел на Неоген-Кватернерната морфоструктурна еволюция на родопските земи. Анализът на връзката на регионалните сеизмични процеси с локалните позитивни морфоструктурни генерации се явява съществена стъпка към конструирането на един обобщен модел на ендогенната морфогенеза в района на Родопите.

Introduction

The Rhodopean Mountain Massif (λ = 23.8° – 26.3° E and φ = 41.2° – 42.0° N) is the largest mountain system in the eastern part of the Balkan Peninsula. It is elongated in WNW – ESE direction at the same longitude from 225 km by maximal width-130 km in South Bulgaria and North-East Greece. The total area of the Rhodope Mountain is about 18 000 km^2, as the Bulgarian part is 14,738 km^2 (81.88% of its entire area).

The Rhodope Mountain occupies a median position on the Balkan Peninsula and thus is close enough to the main tectonic processes in this part of the Eastern Mediterranean-transcontinental collision. The collision is between adjacent parts of the African continental macroplate (Gondwana) and the southern margin of Eurasian continental macroplate (Neo Europe). The Rhodope Mountain builds its northern front. This is an important prerequisite for the development of endogenous geodynamic processes reflected the risky phenomena (earthquakes). They have strict spatial determination and are concentrated around certain "locations". In this regard the main goal of this study is the morphotectonic analysis of regional conditions for the Neogene-Late Quaternary seismic processes in the Rhodope Mountain. This is an attempt to build up a general model of endogenous morphogenesis based on modern morphotectonic concepts and dominating at the present times Plate tectonics model.

Neogene-Quaternary morphotectonic evolution of the Rhodopes

The Rhodope Mountain is located in the eastern part of the Balkan Peninsula. Its surveyed parts are made of multiple tectonic microplates (Bulgarian, Moesian, Halkidiki, Pontic, etc.). These continental microplates are separated from Gondwana´s passive paleotethysian margin at different stages in its Phanerozoic evolution. During the closure of Tethys Ocean (Fig.1) they moved in north direction in the form of islands or archipelagos, which have different geological and tectonic history. Those Gondwana´s continental fragments reach the southern edge of the paleo European continental massif at the end of subduction of the Tethys´ oceanic crust. They are tectonicaly articulated and build up the recent northwestern and southern edge of the European continent- Neo Europe. These circumstances determine the mosaic nature of continental crust in the region. (*Tzankov, Iliev*, 2015)

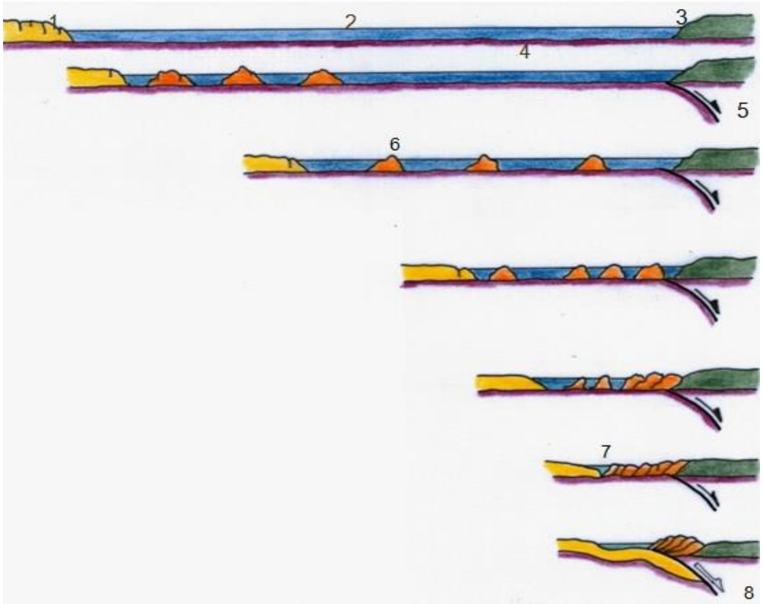

Fig.1 Stages from the closing of the Tethys Ocean and transcontinental collision between Gondwana and Neo Europe. 1- Gondwana continental massif, 2- Tethys Ocean, 3- Paleo Europe continental massif, 4- oceanic crust, 5- Phanerozoic subduction of the Tethys Ocean beneath the Paleo Europe continental massif, 6- fragments from the Gondwana's continental crust in the Tethys Ocean, 7- Mediterranean Sea building (after the closing of Tethys Ocean), 8- transcontinental collision between the Gondwana and the Neo Europe continental massifs (*Tzankov*, *Iliev*, 2015).

The ancient continental blocks of the Rhodopes is one of those fragments (terranes) genetically linked to the structural core of the Cyclades in the Aegean region (*Jacobshagen*, 1986). During its tectonic evolution they moved to the northern direction to its current geographical position at southern edge of Bulgarian tectonic microplate.

Neotectonic evolution of Neo Europe began in the Early Paleogene- the time of full closure of the Tethys Ocean. The significant recent Alpine deformations in the region were realized during the Paleocene and Eocene and early Oligocene too. This is a time of deep crustal folding and thrust deformation. These processes mark the end of the Alpine geotectonic era. During the Paleocene - Early Oligocene predominantly lowland or hilly topography in the region was associated with significant volcanic activity. Traces of these processes are found in the lithological formations of tuffs in the Eastern Rhodopes.

The contemporary morphotectonic setting in the Rhodopean Mountain Massif is a result from the morphotectonic processes in connection, as already noted above, to the transcontinental collision between the continental lands of Gondwana and Neo Europe. Those deformations started after the end of Early Pleistocene (before around 800 000 years) (*Tzankov*, *Iliev*, 2015). In that time the existing Post Early Pleistocene orthoplain was intensively destructed from the beginning of the orogenic uplifting of the area. There is remaining parts as little fragments (bottoms of the contemporary kettles and morphostructural passages) only.

The modern morphotectonic pattern of the Rhodope Mountain was formed by the compounded influence of the Neogene-Quaternary morphostructural generations, as follow:

✓ *Relicts from the late formed in this region alluvial plain – orthoplain*. They found its orographic expression in the vast savannah-like plains which has become the arena of Late Miocene braided rivers (*Tzankov et al.*, 2005). Modern remnants of it are block leveled bottoms of the kettle morphostructures in the area. Destruction and displacement of the orthoplain began in Early or Late

Pleistocene in connection to Quaternary mountain building processes in these places (*Tzankov et al.*, 2005).

✓ *Traces of Late Holocene - Early Pleistocene concentric circular morphostructures*. These are remnants of the early generation circular morphostructures that occurred on destroyed parts of post Middle Miocene orthoplain. Their traces are rarely preserved, most often torn to varying degrees and secondary deformed.

✓ *Middle to Late Holocene dome-like morphostructures*. They are given the morphostructural aspect of the local and regional contemporary relief. Its evolution is connected to the maximal uplifting centers, listric faulting and local fault network. (*Tzankov*, *Iliev*, 2015)

✓ *Contemporary arched mountain morphostructures*. They are distributed all over the territory of the Rhodope Mountain marking the highest mountain ridges. These are the largest morphounits in the area. Its origin is connected to the basic contemporary tectonic processes in the Eastern Mediterranean and therefore they are the youngest and most actively developing morphostructures in the region.

On the territory of the Rhodopes most widespread are the remains (traces) of concentric morphostructures (62% of the total), followed by a dome-like morphostructures (34% of the total) and arched mountain morphostructures (4% of the total).

Spatial distribution of earthquakes in the Rhodope Mountain

In space the most seismic events in the Rhodope Mountain are concentrated along the periphery of the mountain massif (Fig.2). Here the strongest earthquakes in history occurred. Seismic events in the interior of the mountain are less frequent and with lower energy than those at the periphery.

Fig.2 Map of the epicenters of earthquakes occurred on the territory of the Rhodope Mountain in the last 50 years (1965-2016). It is apparent that the major seismic effects in the study area are concentrated mostly on the periphery of the mountain massif. Exceptions are the lands between the towns of Pamporovo and Smolyan to the west and those around the Arda River and the Varbitsa River to the east. (seismic data source: IRIS-http://ds.iris.edu/ds/; basemap: Google Terrain)

Seismic hazard in the Rhodope Mountain is moderate (VII-VIII degree by EMS intensity scale) and is primarily associated with seismically active fault systems along the western edge of the mountain (Kovachevitsa, Chepino, Middle Mesta), some located deeper in the mountain active faults around the towns Dospat and Devin and with the most seismically active nowadays fault structures in the region of the Arda and the Varbitsa Rivers. Several small seismic faults are around the edges of dome-like and arched mountain morphostructures.

The seismic picture in the Rhodope Mountain is characterized by a relatively high manifestation of earthquakes mostly with low magnitude (M≤3). For example, for the period 1965-

2016, the amount of micro earthquakes is 97.29%. For the last 35 years there was recognized an increase of the seismic activity in the Rhodopes (*Tsekov* et al. 2015). For the period 1965-2016 about 66% of the epicenters of earthquakes in the Rhodope Mountain are located in Bulgaria, while the remaining 34% on the territory of Greece. In the range of the Rhodopes the shallow earthquake sources are predominant. For the period 1965-2016, 59% of the seismic events have a depth of 10 km (near surface earthquakes), 35.5% - between 10 and 20 km (very shallow earthquakes), 3% between 20 and 30 km, 2% between 30 and 40 km and only 1% of earthquakes have a depth of more than 40 km (maximum to 47 km). This clearly highlights the crustal nature of seismic processes in the region.

Seismic activity in the Rhodope Mountains shows a strict spatial determination in connection to the positive morphostructural generations. The earthquake manifestations on the territory of the mountain massif are concentrated mainly on the edges of the dome-like morphostructures and, to a lesser extent, to the arched mountain morphostructures (Fig.3). These morphounits are surrounded by low angular (listric) faults or by high angular (normal) faults and reflects positive tectonic movements.

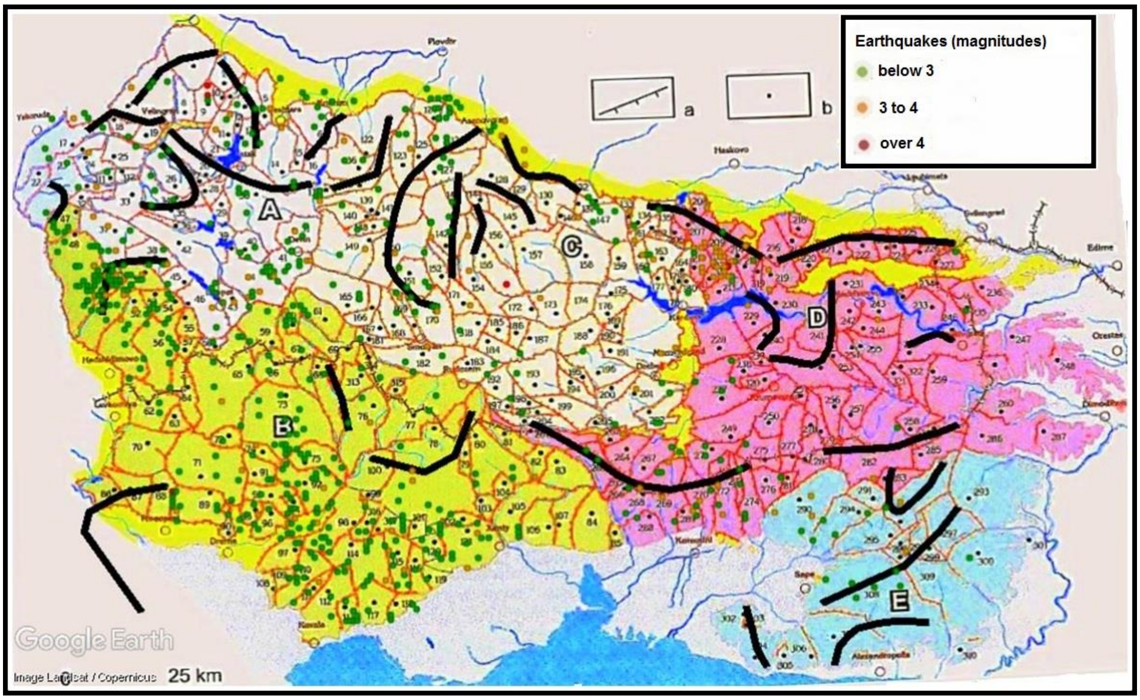

Fig.3 Map of the spatial distribution of earthquakes in the Rhodopes compared to the dome-like (with brown outline) and the arched mountain (dense black lines) morphostructures for the period 1965-2016; a- faults; b- centers of maximum contemporary elevation.

Seismic events are mainly located along the morphostructural edges (71% of cases), on the borders surrounded by fault structures, 24% of earthquakes are attached to the listric prisms and the remaining 5% to the most elevated and at the same time the most active in geodynamic parts of the dome-like morphostructures - the centers of maximal contemporary elevation.

The stronger earthquake events (M≥4) in the Rhodope Mountain are related to the development of arched mountain morphostructures. It is explained by the fact that arched mountain morphorstructures are the youngest, the largest and the most active morphounits in the region. They are centers of highly positive tectonic movements and mark territories with elevated values of the regional gravitational field. These positive movements activate the neighboring dome-like morphostructures and surrounding faults, making them seismogenic.

Conclusions

The results from the conducted investigation of the spatial distribution of seismic processes in the Rhodope Mountain lead to the following main conclusions:

- ✓ The majority of earthquakes in the Rhodopes are concentrated on the periphery of the mountain massif. Exceptions are areas of Pamporovo-Smolyan to the west and those along the Arda River and the Varbitsa River to the east;

- ✓ Most earthquakes are located along the edges and listric prisms of the individual dome-like morphostructures, and to a lesser extent along the centers of maximal contemporary elevation and at the edges of arched mountain morphocructures;
- ✓ Stronger earthquakes (M≥4) on the territory of the mountain massif are directly related to the activity of arched mountain morphorstructures;
- ✓ All earthquakes in the Rhodopes are shallow or very shallow (95%), which means that their focal mechanisms are fully attached to the Earth's crust and with the manifestation of the listric fault network;

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