# MORPHOTECTONIC PREREQUISITES FOR EARTHQUAKE HAZARD IN THE RHODOPES

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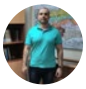

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# MORPHOTECTONIC PREREQUISITES FOR EARTHQUAKE HAZARD IN THE RHODOPES

# МОРФОТЕКТОНСКИ ПРЕДПОСТАВКИ ЗА ЗЕМЕТРЪСНАТА ОПАСНОСТ В РОДОПИТЕ

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***Abstract***

This study represents morphotectonic analysis of the spatial distribution of seismic processes in the Rhodopean Mountain Massif. Methodological basis of such a study is the mobilistic (Plate tectonics) model of the Neogene-Quaternary evolution of the Rhodope lands. The analysis of regional seismic processes is performed by the position of the theory of self-organizing nonlinear systems (synergy approach). Co-administration of these two complementary principle approaches is a significant step towards the construction of a general model of endogenous morphogenesis in the area.
***Key words:*** *Rhodopes, earthquakes, arched morphostructures, seismic hazard, Plate tectonics, synergy approach;*

***Резюме***

Настоящето изследване представлява морфотектонски анализ на пространственото разпределение на сеизмичните процеси в Родопския планински масив. Методична основа на едно такова изследване се явява мобилистичния (плейттектонски) модел на неоген-кватернерната еволюция на родопските земи. Анализът на регионалните сеизмични процеси е извършен от позицията на теорията на самоорганизиращите се нелинейни системи (синергетичен подход). Съвместното приложение на тези два взаимно допълващи се принципни подхода се явява съществена стъпка към конструирането на един обобщен модел на ендогенната морфогенеза в района.
***Ключови думи***: Родопи, земетресения, дъгови морфоструктури, сеизмична опасност, плейттектонски, синергетичен подход.

## 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 prolonged in WNW – ESE direction at one 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 its close enough to the main tectonic processes in this part of the Eastern

Mediterranean- transcontinental collision between adjacent parts of the African continental macroplate (Gondwana) and southern margin of Eurasian continental macroplate (Neo Europe). The Rhodopes build its northern front. This is an important prerequisite for the development of endogenous geodynamic processes with risky nature (earthquakes). They have strict spatial determination and are concentrated around certain "areas". In this regard the main goal of this study is the morphotectonic analysis of regional conditions for the Neogene-Late Quaternary endogenous risk processes in the Rhodope Mountain, which is an attempt to build a general model of endogenous morphogenesis based on prevailing today 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 move 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 palaeo European continental massif at the end of subduction of the Tethys´ oceanic crust. They are tectonic articulated and build modern 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)

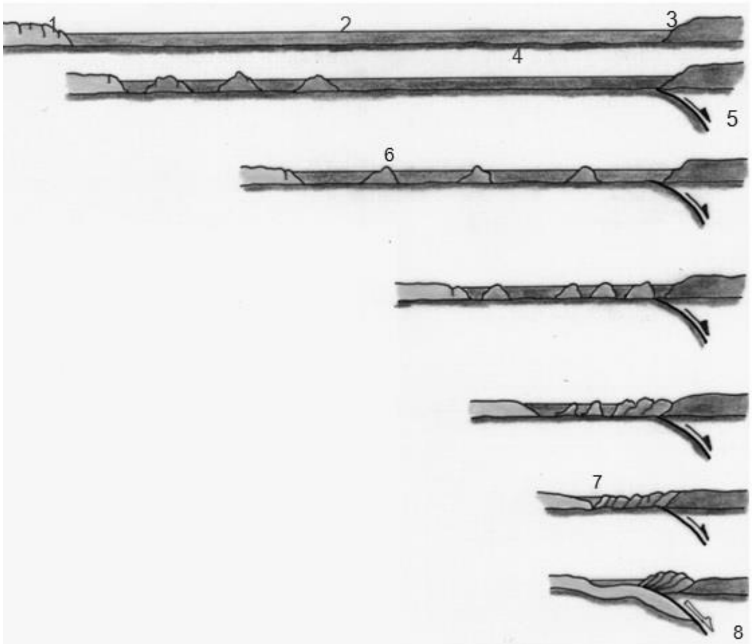


Fig.1 Stages from the closing of the Tethys Ocean and transcontinental collision between Gondwana and Neo Europe. 1- Gondwana continental massif, 2- Tethys Ocean, 3- Paleo Europe continental massif, 4- oceanic crust, 5- Phanerozoic subduction of the Tethys Ocean beneath the Paleo Europe continental massif, 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).

According to *Jacobshagen* (1986), the ancient continental block of the Rhodopes is one of those fragments (terranes) genetically linked to the structural core of the Cyclades in the Aegean region. During its tectonic evolution they moves in northern direction to its current geographical location 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.

The contemporary morphotectonic setting in the Rhodopean Mountain Massif is a result from the morphotectonic processes in connection, as already noted above with the transcontinental collision between the continental lands of Gondwana and Neo Europe. Those deformations are beginning after the end of Early Pleistocene (before around 800 000 years) (*Tzankov*, *Iliev*, 2015). In that time the existing Post Early Pleistocene orthoplain was intensive destructed from the beginning of the orogenic uplifting of the area. They are rested some 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 (Fig.2)*. 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.

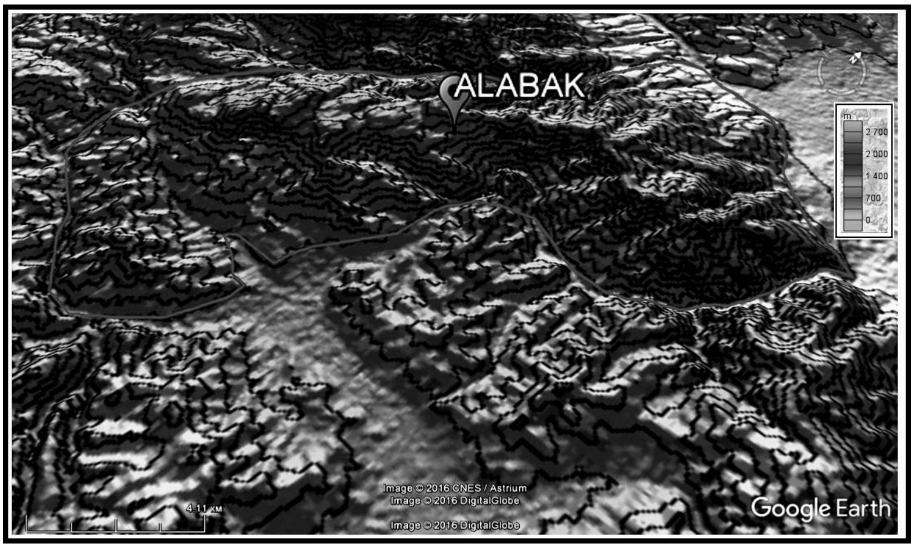


Fig.2 3d model of the arched mountain morphostructure of Alabak (northwest of the town of Velingrad)

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).

**Litosphere as a nonlinear self-organizing systems and endogenous risk processes as a function of this**

According to the principle of synergy the planet Earth is hierarchically structured in several open nonlinear systems at different levels of self-organization. In nature nonlinear are only those systems that in the course of its evolution have the ability due to an effect to take on alternative development paths, and the system is self-organizing if no specific external impact is able to acquire spatial, temporal and functional structure (*Haken, 1977*).

The Earth's hard shell- the lithosphere is a product of many complex interacting processes. They are caused almost entirely by the action of endogenous Earth's forces that raised some sections of the Earth's crust and contribute to the formation of small or large landforms. In distinction from exogenous processes, who owe their origin to the radiant solar energy, endogenous processes seeking its energy source deep in the Earth's bowels. According to the theory of Plate tectonics major endogenous energy generator is a redistribution of substance and energy between the Earth's crust and the asthenosphere (in upper mantle), which in turn ensures continuity of geotectonic crustal changes. Thus the lithosphere is open nonlinear system with fractal-hierarchical structure, constantly transform incoming energy and exchanging matter, information and energy with neighboring geospheres.

The most important evidence of geological medium being nonlinear and unstable and of the self-organization processes in the medium is an extremely wide range of geomorphological, tectonic, and petrologic objects characterized by dimensional invariance of structural geometry, in fact, fractal organization of the objects. It includes geometrical pattern of seismic delamination of the Earth, submarine topography, banks and channels of rivers, seismicity, fault systems and grains in rocks, lithospheric plates and blocks of various ranks, etc. These objects are quantitatively characterized by fractal dimension; furthermore, in many cases the scale self-similarity of structures is distinctly obvious under qualitative, phenomenological treatment. (*Mirlin*, 2011)

In essence, a crucially new view on rock characteristic and the whole lithosphere was established, in particular:

- hierarchical heterogeneity all over the scale range, from small mineral grains to planetary-scale irregularities;
- physical nonlinearity appearing in the interdependency of physical processes;
- energy activity, i.e. the ability to permanently produce energy as seismic, acoustic, and
electromagnetic emission, as well as heat;
- changeability of physical properties in time, as result of activity and physical nonlinearity; and
- ability of geophysical processes for interaction.

Due to the above-indicated characteristics, the medium acquires properties of fluid; and, with that, self-similar processes, producing structures adapted for the consummation of incoming energy, take place in the medium. (*Mirlin*, 2011)

In the process of evolution the lithosphere is subjected to phases of accelerated development and therefore to processes with risky character. These phases of sudden spontaneous events are different by genesis, mechanism of realization and spatial-temporal amplitude. To the group of risky processes with endogenous genesis should be attributed earthquakes and volcanic eruptions. For the Rhodope region main endogenous risk process appears only earthquakes. Therefore the lithological foundation in which develops seismic process should be seen as a self-organizing system, growing in state of unstable equilibrium. In this case the earthquake itself is an expression of sudden loss of stability (natural catastrophe). After releasing the energy lithosphere system restructure and adapt to new steady state.

**Spatial distribution of earthquakes in the Rhodope Mountain**

In terms of seismicity the Rhodope Mountain is part of the Rhodope zone of the Rila-Rhodope seismic area. The Rhodope seismic zone is located between the Struma seismic zone to the west and the Sredna gora seismic zone to the north within Bulgaria and the Xanthi seismic zone to the south in Greek territory. It includes the Rhodope Mountain as well as the easternmost edge of Rila Mountain.

Seismic hazard in the Rhodope Mountain is moderate (VII-VIII degree by MSK-64 intensity scale) and associated with seismically active fault systems along the western edge of the mountain (Kovachevitsa, Chepino, Middle Mesta), with located deeper in the mountain active faults around the towns Dospat and Devin and with the most seismically active nowdays fault structures in the region of the Arda complex morphostructural passage and the Varbitsa complex morphostructural passage (the lands around the towns of Kardzhali, Ardino and Momchilgrad). Several small seismic faults surround the edges of dome-like and arched mountain morphostructures.

The seismic picture in the Rhodope Mountain is characterized by a relatively high incidence of earthquakes, but mostly low magnitude (M≤3). For example, for the period 1980-2014, the share of micro earthquakes amounted to 97.29%. As for the last 35 years there has been an increase in seismic activity in the Rhodopes (*Tsekov* et al. 2015). About 90% of the epicenters of earthquakes in the Rhodope

Mountain are located in Bulgaria, while the remaining 10% on the territory of Greece.

The maximum observed earthquake in the 20th century is the event of 1905 with magnitude M=5.4. There is no information for larger events before 1900 in the Bulgarian territory of this zone, but the strong historical earthquakes of 1829 (magnitudes 7.2 and 6.9) in the Greek territory can be assigned to this zone (*Christoskov* et al. 1979). These quakes occurred at the southern margin of the Rhodope Mountain and are associated with the activity of the Middle Mesta fault bundle.

In spatial terms the basic seismic events in the Rhodopes are concentrated along the periphery of the mountain massif (Fig.3). There have registered the strongest earthquakes in historical perspective. This is explained by the fact that accumulated seismic energy can be most easily and smoothly be released into the environment with reduced resistance in order to drive the lithosphere to release the destabilizing effects aimed at putting her state of unstable equilibrium. Seismic events within the mountain that are less frequent and with lower energy than those at the periphery, followed by a similar mechanism, such as they are located along the boundaries of the individual tectonics blocks (active faults).

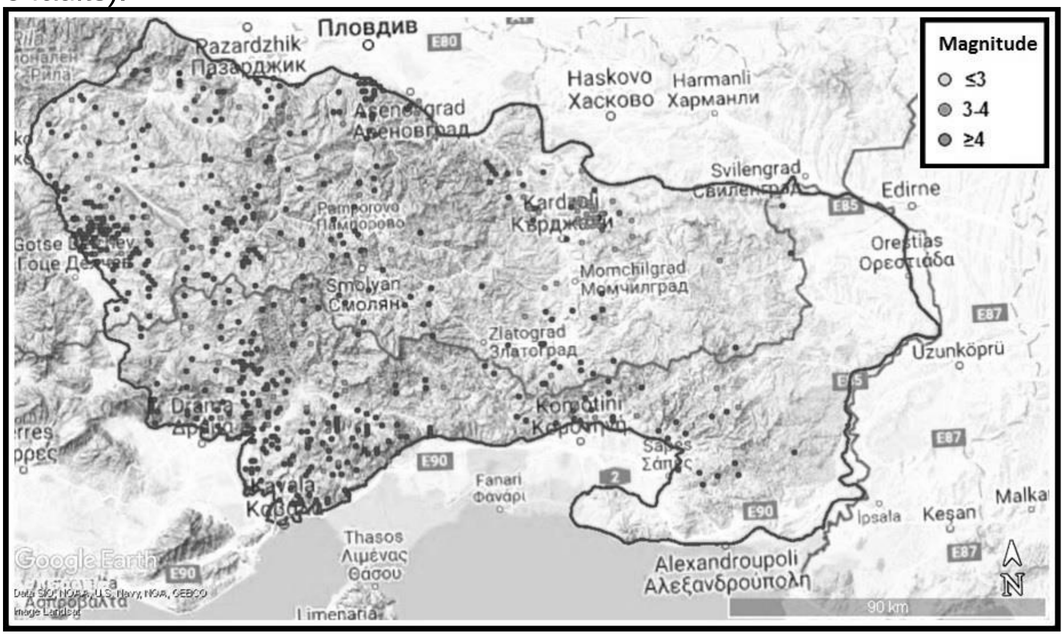


Fig.3 Map of the epicenters of earthquakes occurred on the territory of the Rhodope Mountain in the last 50 years (1965-2016). It is apparent that the major seismic effects in the study area are concentrated mostly on the periphery of the mountain massif. Exceptions are the lands between the towns of Pamporovo and Smolyan to the west and those around the Arda River and Varbitsa River to the east. (seismic data source: IRIS-http://ds.iris.edu/ds/; basemap: Google Terrain)

Based on seismic events occurred during the period 1965-2016 on the territory of the Rhodope Mountain can be separated 5 main areas of seismic activity (Fig.4). These are Kovachevitsa area (on the western edge of the mountain), Devin-Smolyan area, Drama-Kavala-Xanthi area (the largest one), Kardzhali area and Velingrad-Asenovgrad area. At present, the most active is the Kardzhali area. Here in 2006 occurred a number of earthquakes, the strongest of them with a magnitude of 4.5 on the Richter scale. Outside these areas seismic activity is very rare or simply missing.

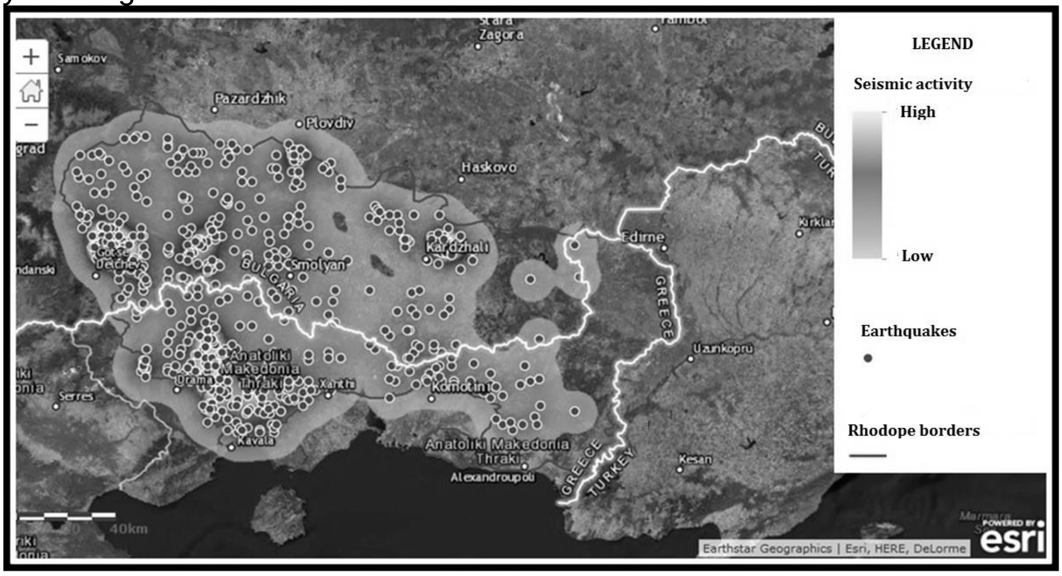


Fig.4 On the territory of the Rhodopes can be differentiated 5 areas of seismic activity. Historically the most dangerous of them are the Velingrad-Asenovgrad and Drama-Kavala-Xanthi areas. Nowadays most active, however, is the Kardzhali area. (seismic data source: IRIS-http://ds.iris.edu/ds/; basemap: ArcGIS-http://www.arcgis.com)

## Conclusion

The major destabilizing factor in the Rhodopes region- the intercontinental collision between the continental macroplates of Gondwana (Africa) and Neo Europe (Eurasia) gives rise to adverse endogenous phenomena - earthquakes. Lithosphere as a self-organizing system strive in every way to get rid of the destabilizing impact of such processes and through spatial hierarchical divisibility (fractality) expressed in the distribution of seismic events around certain "areas", that facilitate the release of stored energy and restoring the state of equilibrium. Within the Rhodope Mountain they are five in number and are located mainly along the peripheral areas of the mountain massif (excluding of Devin-Smolyan area). Given the specific geological and geophysical conditions these are the best "outlets" for the accumulated tensions in the Rhodopes. Along them the Earth's system and in particular its lithosphere subsystem are exempt from the adverse impacts that violate its unsustainable equilibrium. That is why the future strong seismic events in the Rhodope Mountain should be sought precisely therein.

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