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FRACTALITY OF THE MOUNTAIN ARCHED MORPHOSTRUCTURES IN THE RHODOPE MOUNTAINS

Abstract: The research presents the results of fractal analysis of the arched mountain morphostructures in the Rhodope Mountains. For this purpose a methodology for surface fractals analysis was applied. The relationship between the arched mountain morphostructures and earthquakes was also investigated. In this study, a free earthquake catalog of the USGS Seismic Hazard Program for the period 1965-2016 was used. The results obtained confirm the self-organizing nature of the tectonic processes in the area and provide new guidance for analysis and interpretation.

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INTRODUCTION

The Rhodope Mountains occupies a median position within the Balkan Peninsula and thus it closes enough to the main tectonic processes in the Eastern Mediterranean. In this part of the world as a major geodynamic generator appear the transcontinental collision between adjacent parts of the African continental macroplate (Gondwana) and southern margins of Eurasian continental macroplate (Neo Europe) (*Tzankov*, *Iliev*, 2015). The Rhodope Mountains builds up its northern front.

The contemporary morphotectonics setting in the Rhodope Mountains is a result of the Plate tectonics processes beginning after the end of Early Pleistocene. In that time the existing Post Early Pleistocene orthoplain (savannah-like lowlands) was intensive destructed trough the orogenic uplifting of the area. They are rested some little fragments (bottoms of the contemporary kettles and morphostructural passages) only (*Tzankov, Iliev*, 2015).

The contemporary morphostructural pattern of the Rhodope Mountain was formed by the compounded influence of three Neogene-Quaternary positive morphostructural generations:

- ✓ *Early Pleistocene concentric circular morphostructures*. These are remnants of the early generation of the circular morphostructures that occurred on destroyed parts of post Middle Miocene orthoplain. Their traces are rarely preserved and in varying degrees secondary deformed.
- ✓ *Middle to Late Holocene dome-like morphostructures*. They are given the morphostructural aspect of the local contemporary topography. Their evolution is connected to the maximal uplifting centers, listric faulting and local fault network (*Tzankov*, *Iliev*, 2015).
- ✓ *Contemporary arched mountain morphostructures* (Fig.1). They are fragmentary distributed all over the territory of the Rhodope Mountains 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 area.

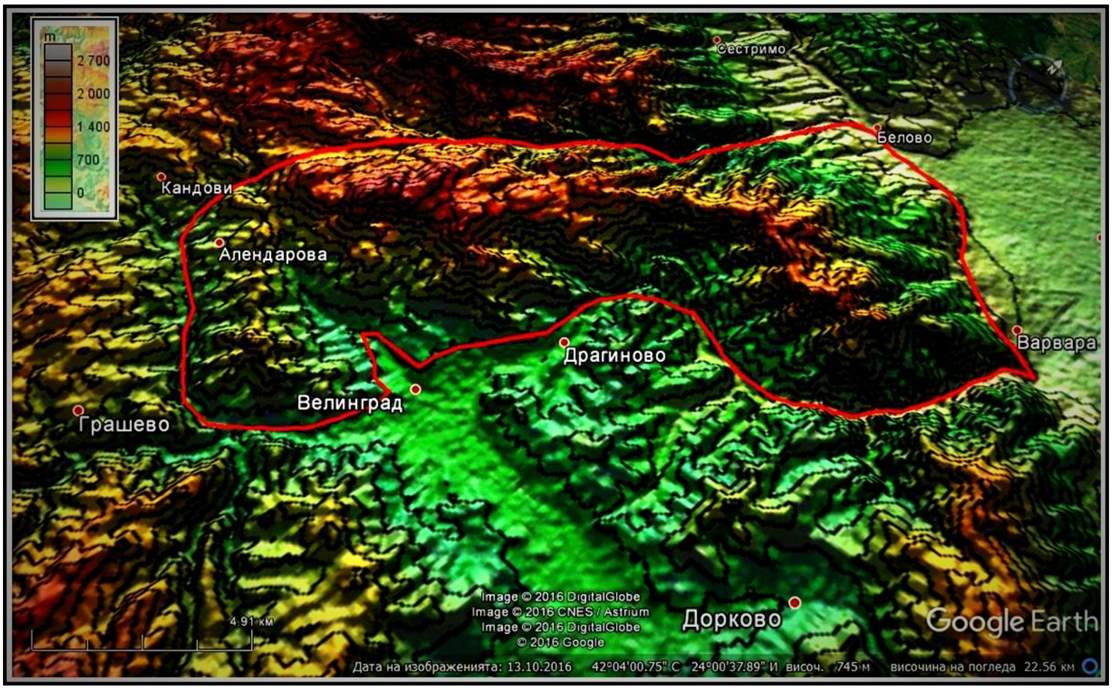

Figure 1. 3D model of the arched mountain morphostructure of Alabak (Bozhenets). The arched mountain morphostructures have a distinctly arc-like shape and mark the highest ridges within the mountain. (Mapping tool: Google Earth)

The main objective of the study is to verify and estimate the probable fractal geometry of arched mountain morphostructures within the Rhodope Mountains. For this purpose, an adopted methodology for the estimation of surface fractals has been used. An analysis of the relationships of the arched mountain morphostructures with the regional seismic hazard was made too.

STUDY AREA

The Rhodope Mountains (λ = 23.8° – 26.3° E and φ = 40.8° – 42.0° N) is the largest mountain system in the eastern part of the Balkan Peninsula. This complex mountain morphounit is geographically located within the boundaries of the Republic of Bulgaria (62% of the total area) and the Republic of Greece (28% of the total area) (Fig.2). The object of the study is the arched mountain morphostructures. They have a fragmentary distribution and are located mainly along the edges of the mountain massif (Fig.3).

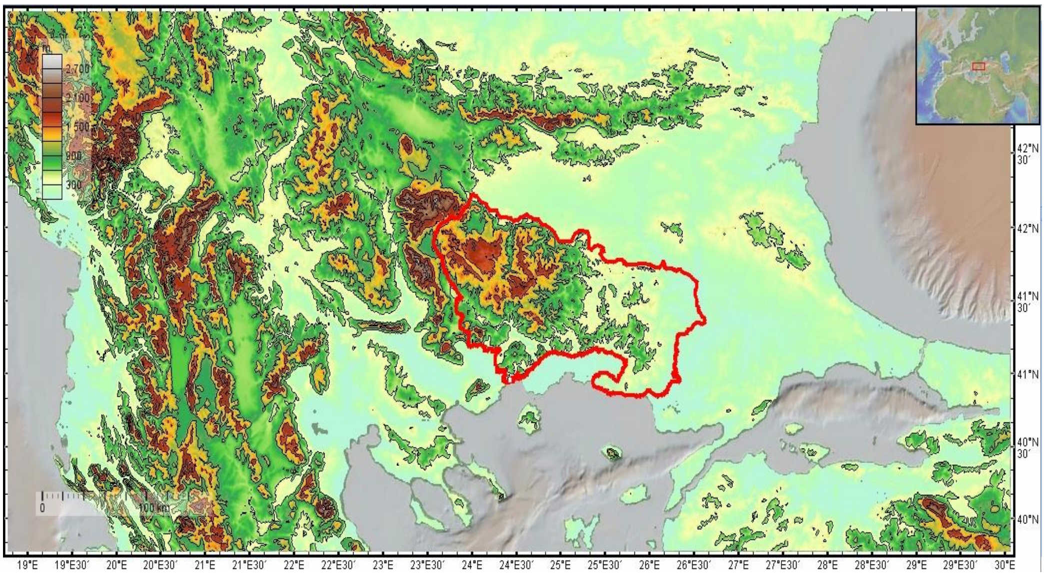

Figure 2. Geographical position of the Rhodope Mountains in the eastern part of the Balkan

Peninsula (Mapping tool: GeoMapApp-http://www.geomapapp.org)

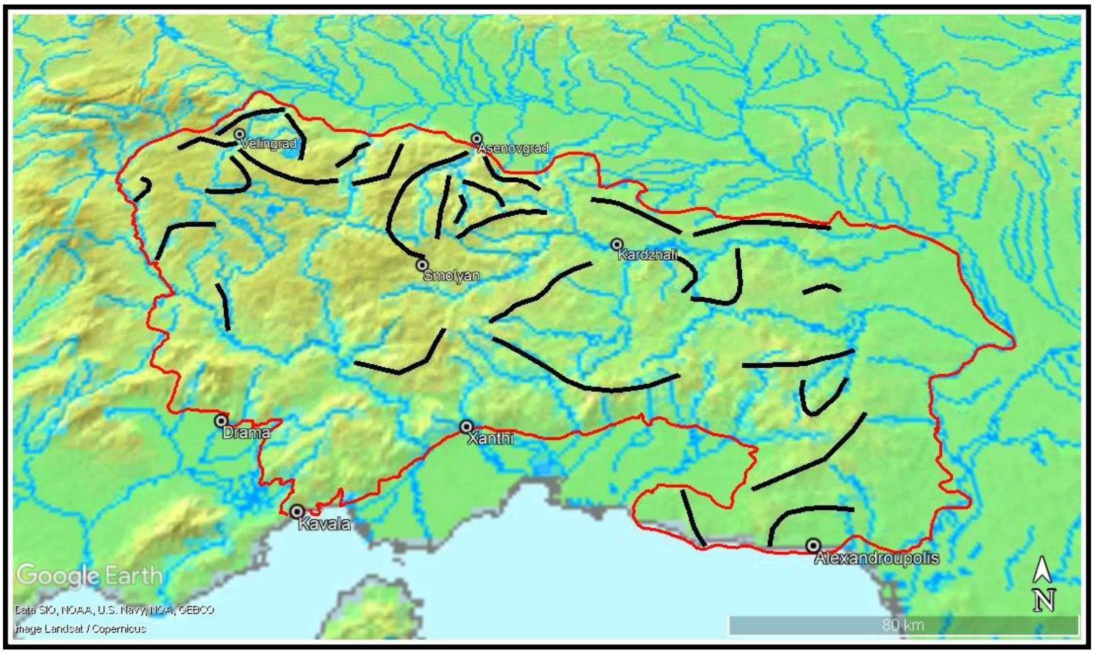

Figure 3. Distribution of the arched mountain morphostructures within the Rhodope Mountains (Basemap:http://www.gpsvisualizer.com/kml_overlay; Mapping tool: Google Earth Pro)

METHODOLOGY AND THEORETICAL BASICS OF THE STUDY

The classical example of a fractal object first is defined by French mathematician Benoit Mandelbrot in his book "*Fractal geometry of Nature*" (1982). The term "fractal" derives from the Latin „*fractus*", which means "a fracture". If the length of an object P is related to the measuring unit length *l* by the formula:

$$P \sim l^{1-D} \qquad (1)$$

then P is a fractal and D is a parameter defined as the fractal dimension. This definition was given by B. Mandelbrot in the early 60-s of the 20-th century. His ideas support the view that many objects in nature can not be described by simple geometric forms, and linear dimensions, but they have different levels of geometric fragmentation. In the field of Geosciences is accepted that definition of the different «fractals» as «real physical objects is most often connected to fragmentation» (*Korvin, 1992*). This reveals that each measurable object has a length, surface or volume, which depends on the measuring unit and the object's form irregularity. The smaller the measuring unit is, the bigger is the total value for the linear (surface, volume) dimension of the object and vice versa. The same is valid for 2D and 3D objects (*Ranguelov*, 2010).

Another definition of a fractal dimension is related to the serial number of measurement to each of the measuring units used and the object dimensions. If the number of the concrete measurement with a selected linear unit is bigger than r, then it might be presented by (*Turcotte*, 1997):

$$N \sim r^{-D} \qquad (2)$$

where D is the fractal dimension and N is the number of objects with a linear dimension r for a discrete distribution and the number with a linear dimension greater than r for a continuous distribution.

According to the adopted methodology for surface fractals, the number and areas of the individual mountain arched morphostructures in the studied area is taken as the basis. The correlation number-area is following the algorithm presented and effectively applied in a number of publications (Meyback, 1995; Ranguelov et al., 2002, 2003, 2004, 2010, 2017). The presentation of the results is performed on semi-logarithmic graphs, where on the X axis in the logarithmic scale the area (LogArea) of arched mountain morphostructures is plotted, and on the Y axis in linear scale their number (N) is plotted respectively. This is the most convenient approach to displaying the data.

The methodology of morphotectonics research was developed in the book "Morphostructural analysis" (Tzankov, 2013). It provides the necessary basis for the research on Quaternary morphotectonics. The book „Morphostructure of the Rhodopean Mountain Massif“ (Tzankov, Iliev, 2015) offers a regional analysis of the manifestation of the different Quaternary morphostructural generations as well as a detailed morphostructural map.

The seismic analysis of arched mountain morphostructures within the Rhodope Mountains was performed on the basis of free earthquake catalogue of the USGS (United States Geological Survey) Seismic Hazard Program for the statistical period 1965-2016.

RESULTS AND DISCUSSION

The results of the fractal analysis of the arched mountain morphostructures in the Rhodope Mountains are presented in graphical form in Fig. 4.

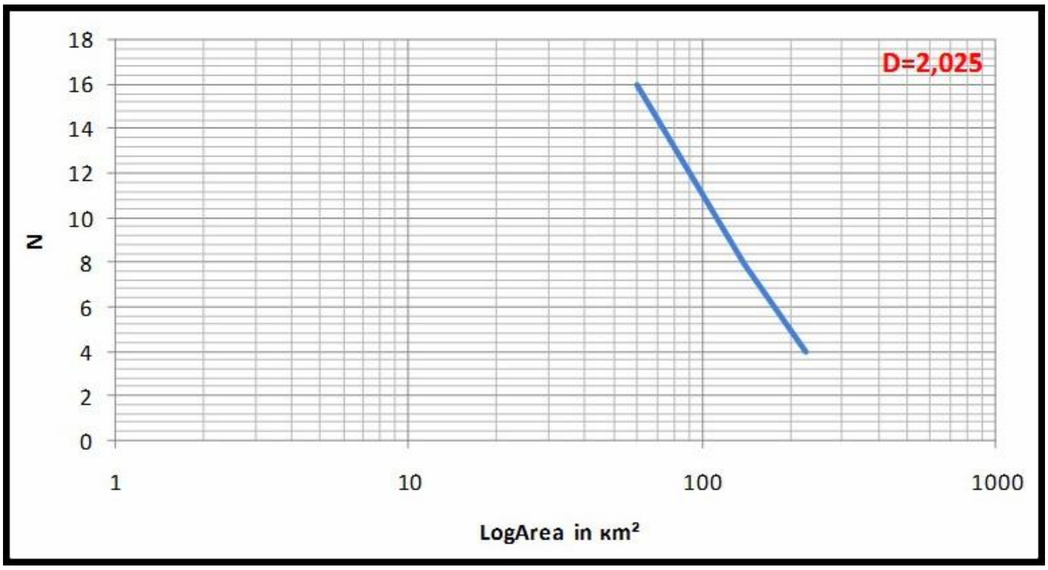

Figure 4. Fractal analysis of the arched mountain morphostructures within Rhodope Mountains

The relationship between arched mountain morphostructures and regional seismic hazard for the period 1965-2016 is reflected in Fig. 5

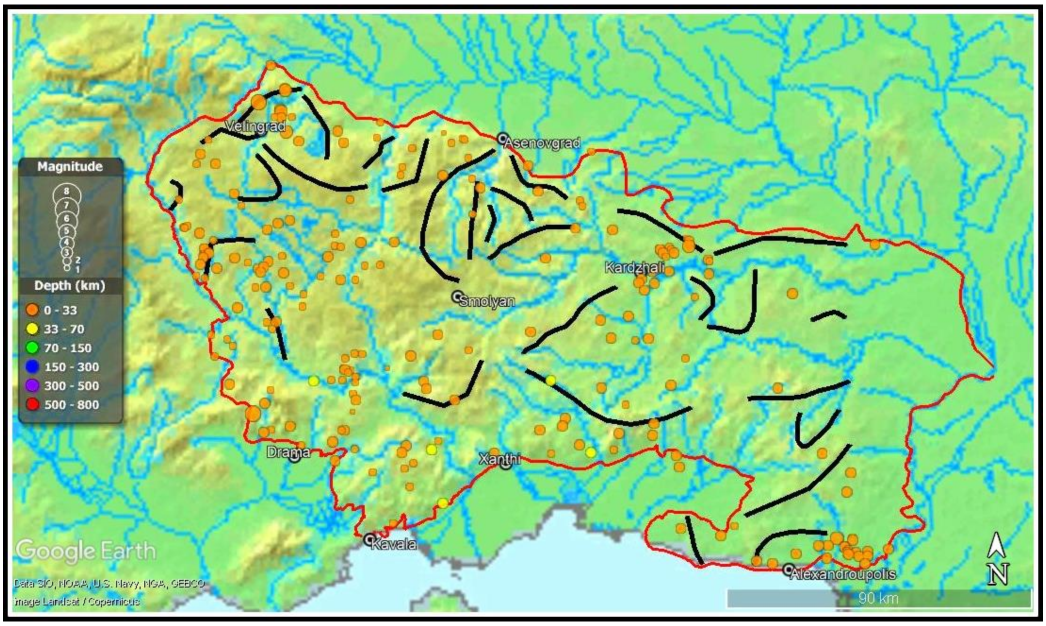

Figure 5. Relationship between the arched mountain morphostructures within the Rhodope Mountains and the spread of the earthquakes for the period 1965-2016 (Seismic data source: USGS

Seismic Hazard Program, Online available from https://earthquake.usgs.gov/earthquakes/search/;Basemap:http://www.gpsvisualizer.com/kml_overlay; Mapping tool: Google Earth Pro)

The results obtained in course of the study can be summarized as follows:

1) The arched mountain morphostructures in the Rhodope Mountains is characterized by a distinct fractal geometry (D=2.025). The degree of fragmentation has relatively high value.
2) There are signs of self-organization of the tectonic processes creating and shaping the relief in the Rhodope region. This also reflects the seismic activity in the area.
3) Fragmentation is observed in the spatial distribution of earthquakes, especially the stronger ones. The majority of seismic events are spread mostly on the edges of the mountain.
4) The earthquake epicenters as a whole are located primarily along the edges of the arched mountain morphostructures on the border with adjacent dome-like morphostructures.
5) For the period 1965-2016, the stronger earthquakes in the Rhodope Mountains ($M \geq 4$) are directly related to the activity of arched mountain morphostructures. Moreover, there is no seismic event whose epicenter is separated more than a few kilometers from them.

The obtained results give a new insight into the activity of the endogenous processes in the Rhodope mountain massif area. This, in turn, necessitates the identification of areas with increased seismic hazard. As a basis for this, the spreading of the arched mountain morphostructures can be used.

CONCLUSION

The results of conducted analysis unequivocally confirmed the fractal geometry of the arched mountain morphostructures within the Rhodope Mountains. Their fragmentary nature is clearly expressed and interconnected. On the other hand, there is a direct link between the evolution of arched mountain morphostructures and seismic activity in the area. This serves as a solid evidence of the self-organizing nature of endogenous geodynamic processes in this part of the Eastern Mediterranean. The results obtained give a better understanding of the geodynamic evolution of the Rhodope Mountains and especially for the interpretation of regional seismic hazard.

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