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FRACTAL GEOMETRY OF TOPOGRAPHY IN THE RHODOPE MOUNTAIN

Abstract: The article presents the results of study of fractal properties of the relief in the Rhodope Mountain. A similar type of survey should be performed on the basis of the dominant landforms (morphostructural generations). For the mountain massif of the Rhodopes this is the dome-like morphostructures. They are a product of the Plate tectonics processes in connection to the transcontinental collision between Gondwana and Neo Europe. The relationship between local relief and earthquakes was also investigated.

Keywords: Rhodope Mountain, dome-like morphostructures, fractal, Plate tectonics, earthquakes..

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INTRODUCTION

The Rhodopes (λ = 23.8° – 26.3° E and φ = 41.2° – 42.0° N) is the largest mountainous 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 km², as the Bulgarian part is 14,738 km² (81.88% of its entire area).

The Rhodope Mountain occupies a median position on the Balkan Peninsula and thus it 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 Rhodope Mountain builds up its northern front.

The contemporary morphotectonics setting in the Rhodope Mountain is a result from the Plate tectonics processes in connection, as already noted above, to 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 morphotectonics pattern of the Rhodope Mountain was formed by the compounded influence of three Neogene-Quaternary positive morphostructural generations:

✓ *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 fragmentary 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 Rhodope morphostructural area most widespread are the remains (traces) of concentric morphostructures (60% of the total), followed by a dome-like morphostructures (35% of the total) and arched mountain morphostructures (5% of the total). The contemporary aspect of the relief in the Rhodope Mountain is entirely dominated by the dome-like morphostructures.

METHODOLOGY AND THEORETICAL BASICS

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" (introduced for the first time by Mandelbrot in 1975) 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:

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

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):

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

and the fractal is completely determined by D as its characteristic fractal dimension. Applying this definition for the elements of faulting and faults fragmentation, some authors use this idea to depict formal models of the Earth's crust fragmentation, which indicates the level of fracturing of the upper Earth's layers (*Ranguelov, Dimitrova, 2002; Ranguelov, Ivanov, 2017*).

According to the adopted methodology for surface fractals, the number and areas of the individual dome-like morphostructures in the studied area is taken as the basis. The methodology based on the correlation number-area is following the algorithm presented and effectively applied in a number of publications (*Ranguelov*, 2010; *Ranguelov et al.*, 2003, 2004):

- presentation of the data for each selected element (total number, investigated parameter, dimensions – (only linear (1D) and surface sizes (2D) are considered)

- calculation of the number for the graphics (selection of the calculation step for X and Y axes, scale on X and Y axes, values for each selected parameter).

- presentation of the results on the graphics – on the X axis the semi-logarithmic scale is most convenient, on the Y axis, z denotes in linear scale the numbers calculated for each element.

The methodology of morphotectonics research was developed in the monograph "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 various morphostructural generations through the Quaternary and the Late Neogene as well as a detailed morphostructural map.

RESULTS AND DISCUSSION

Verification and evaluation of the fractal geometry of the relief in the Rhodope morphostructural area should be done in morphostructural regions (as a basis for comparison). The complex local orohydrographic features of the mountain massif give grounds for its sharing in 5 morphostructural regions (*Tzankov*, *Iliev*, 2015), namely: Western (Devin), Southwestern (Xanthi), Central (Smolyan), Eastern (Krumovgrad) and Southeastern (Sape) (Fig.1)

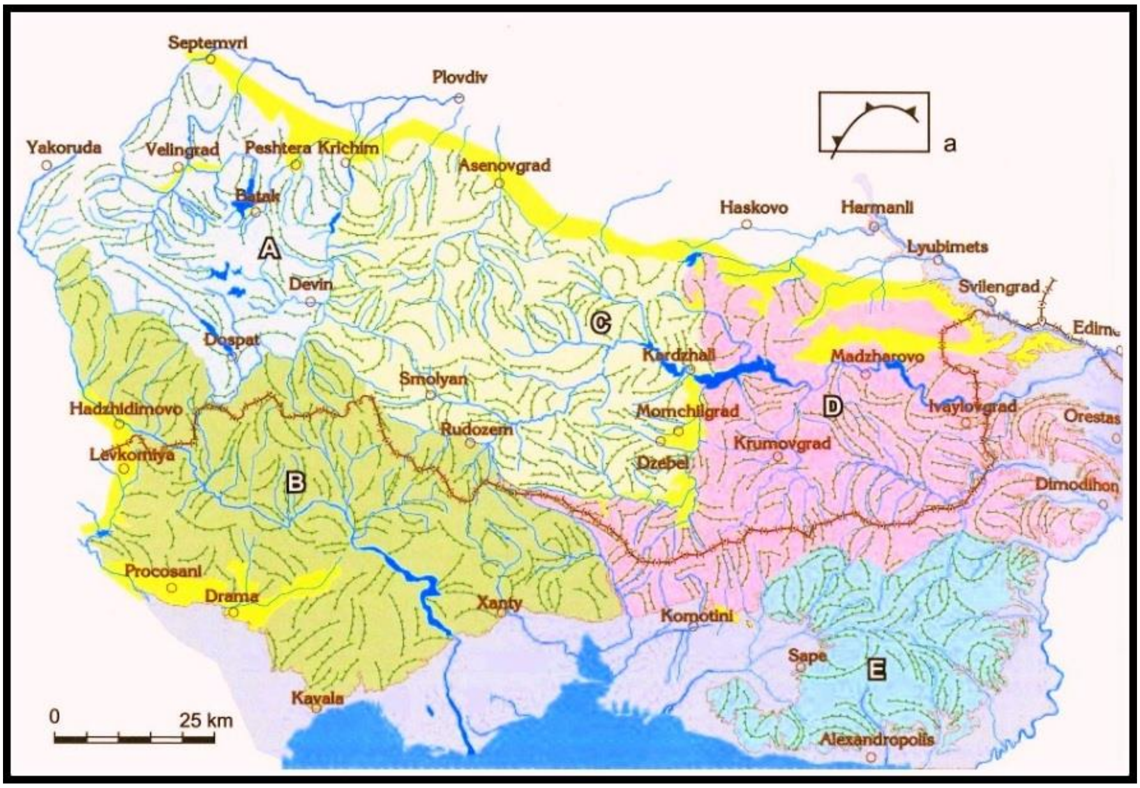
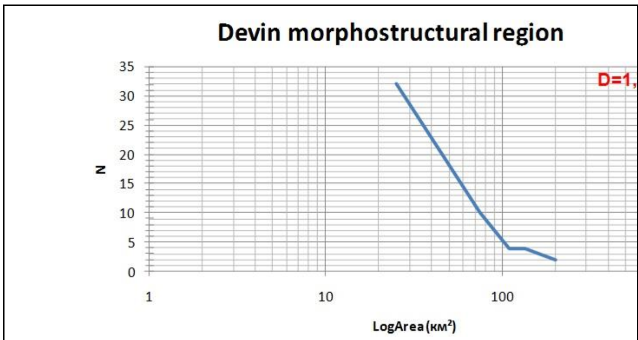
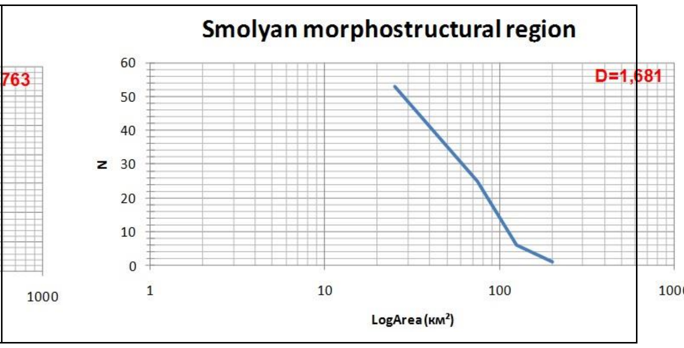


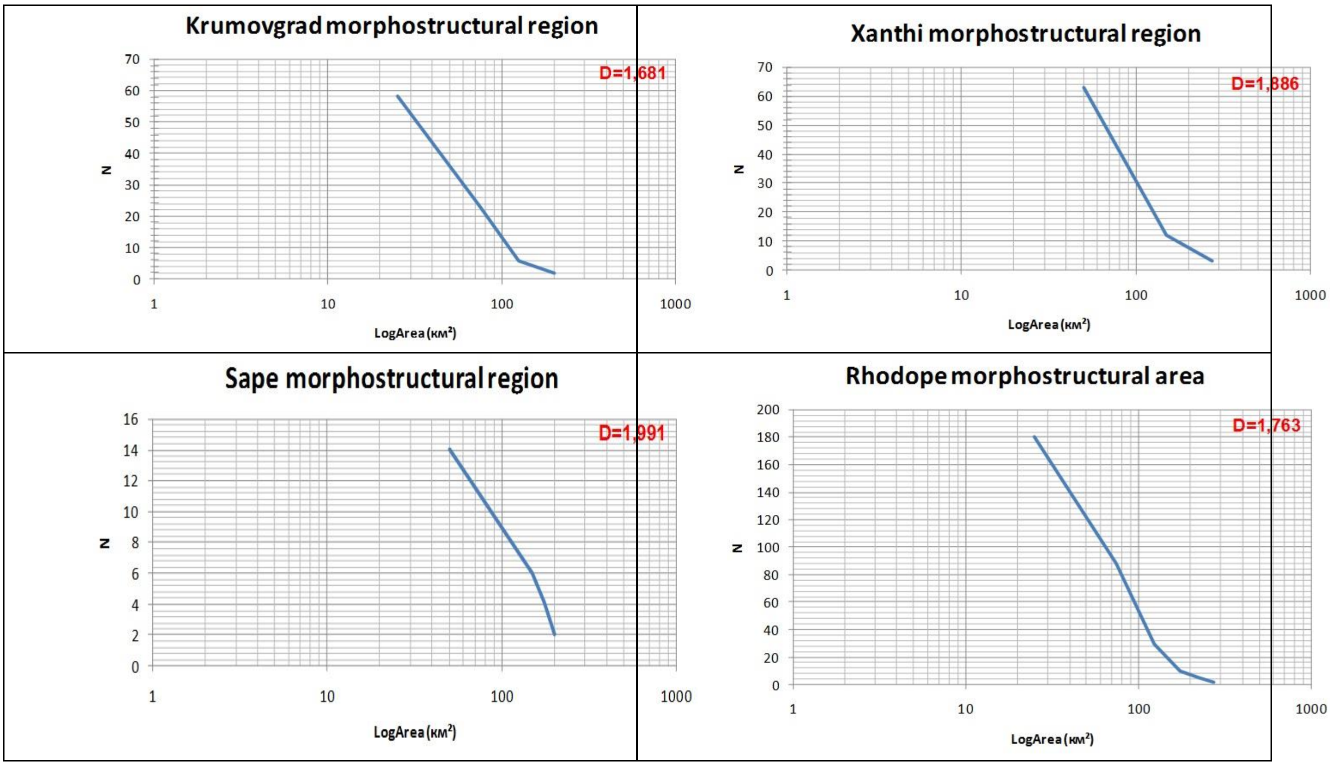
Figure 1 Morphostructural division of the Rhodope morphostructural area. A- Western (Devin), B- Southwestern (Xanthi), C- Central (Smolyan), D-Eastern (Krumovgrad), E- Southeastern (Sape) (after *Tzankov*, *Iliev*, 2015)

The results of the analysis of the degree of self-similarity (fractality) of dome-like morphostructures in the Rhodope morphostructural area are presented in graphical form in Table 1.

Table 1 Fractal analysis of dome-like morphostructures in the Rhodope morphostructural area (by morphostructural regions)







The results in Table 1 confirm the fractal character of the relief within the individual morphostructural regions and in the Rhodope morphostructural area as a whole. This unambiguously reflects the self-organizing nature of the endogenous processes that created and modeled the topography on the Earth’s surface. From an energy point of view, this is the most advantageous form of reorganization. The system seeks to reduce dissipation. The potential energy accumulated over time can be released not in one or two locations (centers), but in many. The main purpose of this is to reduce and, respectively, regulate the amount of energy emitted. This is clearly demonstrated by the distribution of earthquake epicenters (Fig.2). The most active in seismic terms are dome-like morphostructures with small to medium sized areas. For the period 1965-2016, the stronger earthquakes in the Rhodope Mountain (M≥4) occurred along the edges of dome-like morphostructures with areas between 12 and 415 km² (an average of 118 km²). In the percentage distribution of nearly 63% of cases, the most dangerous seismic dome-like morphostructures have an area of up to 100 km^2, while another 25% have an area between 100 and 200 km^2 and only 12% with an area of more than 200 km^2.The higher degree of fragmentation is a guarantee of faster and easier energy release.

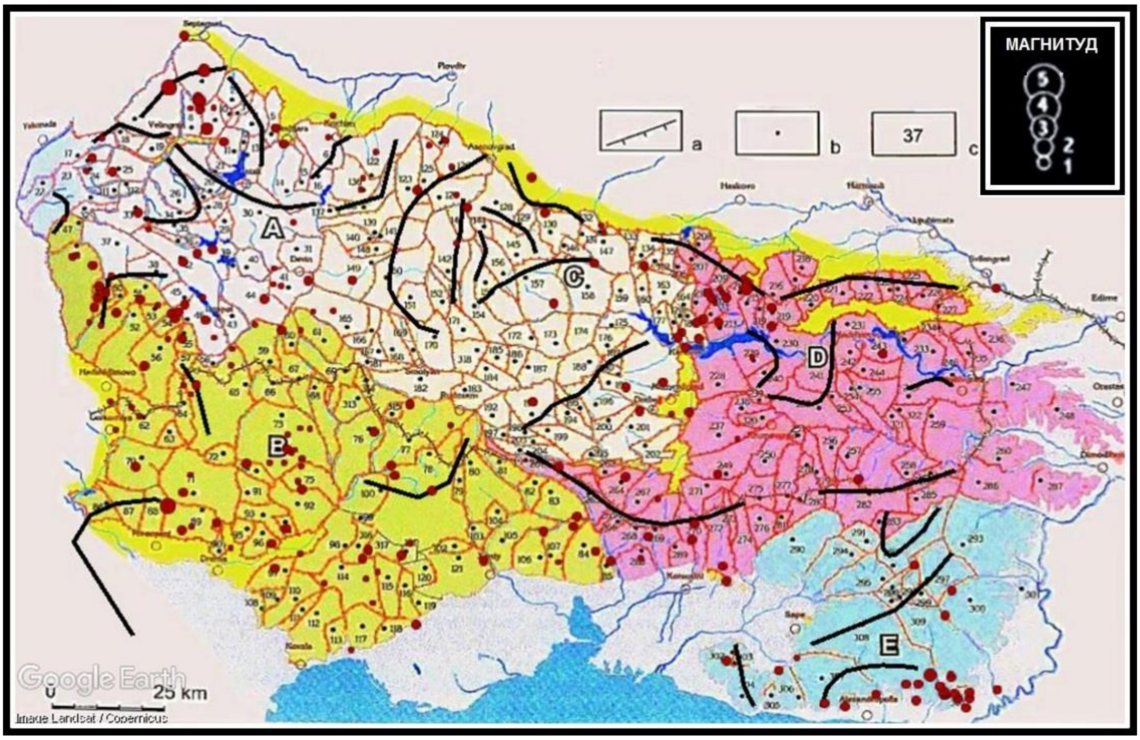


Figure 2 Map of the spatial distribution of earthquakes in the Rhodopes compared to the dome-like (with brown outline) and arched mountain (dense black lines) morphostructures for the period 1965-2016. The seismic phenomena are mainly located along the edges of dome-like morphostructures with mainly small areas; a- faults; b- centers of maximum contemporary elevation. (Seismic data source: Iris Earthquake Browser, Online available from http:// www.iris.edu/hq/)

The results obtained can generally be summarized as follows:

1) Given the local physiographic conditions, the Rhodope morphostructural area is divided into 5 morphostructural regions.

2) The relief in the Rhodope Mountain is characterized by a distinct fractal geometry (D=1.763) Overall, the degree of fragmentation in the Rhodopes has moderate values.

3) Fragmentation is also observed in the spatial distribution of earthquakes, especially the stronger ones.

4) The earthquake epicenters are located primarily along the edges of dome-like and arched mountain morphostructures.

CONCLUSION

The results of conducted analysis unequivocally confirmed the fractal geometry of the relief on the territory of the Rhodope morphostructural area. The fragmentary nature of the morphostructural elements is clearly expressed and interconnected. This serves as a solid evidence of the self-organizing nature of endogenous geodynamic processes in the eastern part of the Balkan Peninsula and especially in the Rhodope Mountain region. The results obtained give a better interpretation of the geodynamic development of the relief in the Rhodope morphostructural area and become the basis for different correlative studies on this base in the future.

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