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MORPHOSTRUCTURAL PRECONDITIONS FOR THE SEISMIC HAZARD IN THE RILA-PIRIN MOUNTAINS RANGE

Abstract: The study offers the results of the authors' investigations about the morphostructure of the Rila-Pirin Mountains Range (South Bulgaria- Northwestern Greece) and its relationship to the regional seismic hazard. There are analyzed morphological characteristics of the Quaternary positive landforms as a real criterion for the morphogenesis of the study area. The spatial distribution of earthquakes to morphostructural generations has been investigated with the aim of building a generalized model of regional seismic hazard.

Keywords: Rila, Pirin, mountain range, morphostructures, seismic hazard, earthquakes.

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INTRODUCTION

The Rila-Pirin Mountains Range is the highest mountain morphounit in the eastern part of the Balkan Peninsula. Her morphological evolution is directly related to the effects of the transcontinental collision between Gondwana and Neo Europe in the eastern Mediterranean (*Tzankov, Iliev*, 2015). This determines the levels of seismic hazard in the research area and the peculiarities in the spatial distribution of earthquakes. They are also analyzed the morphological characteristics of local positive landforms. For this purpose were studied and compared species, morphological traits, spatial dimensions, vertical displacement and relationships between the morphographic units. The investigation is based on a complex morphostructural map (scale 1:250 000) of the Rila-Pirin Mountains Range (*Tzankov et al.*, 2017), where are separated and mapped the different Quaternary (post Early Pleistocene) positive morphostructural generations. This is the basemap for the realization of different correlative studies between the landforms' peculiarities and the regional seismic hazard. In the future this study would be an important criterion for assessing of the near-surface lithospheric geodynamic processes and trends in the changes to the local relief.

STUDY AREA

The research area includes a row of high, medium high and low mountains, submeridional orderly on the both sides of the Bulgarian-Greek border (Fig.1). Includes from north to south the following mountain units: Rila Mountain, Pirin Mountain, Slavyanka Mountain, Stargach Mountain, Mavro vouno Mountain, Vrontous Mountain, Menoikio Mountain, Pangeo Mountain and Eleohorion Mountain. The investigated mountain range flanked from west and east by the Struma and the Mesta River Valleys and connected to them morphostructural passages.

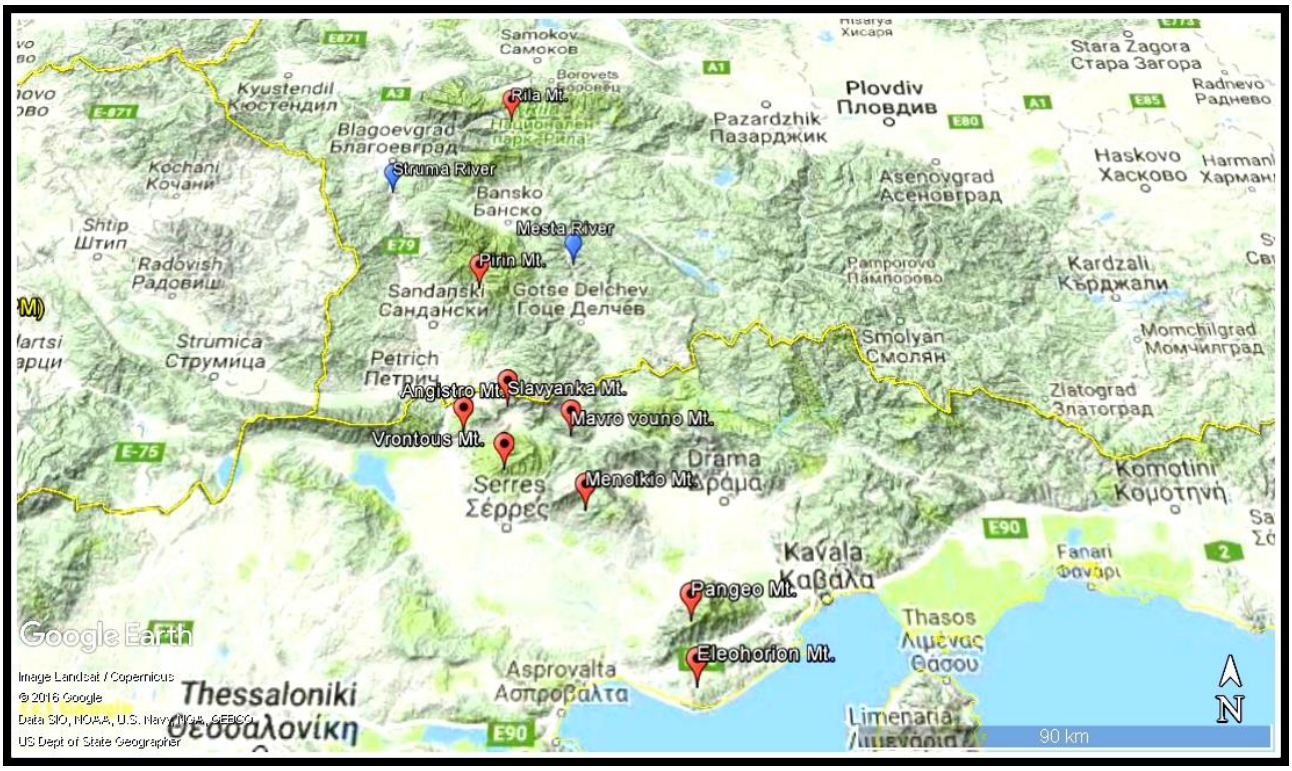

Fig.1

Survey map of the Rila-Pirin Mountains Range within the eastern part of the Balkan Peninsula (Base map: Google Terrain)

METHODOLOGY AND METHODS

The analysis of the Late Neogene – Quaternary morphogenic processes are based on modern concepts of the listric tectonics and Plate tectonics.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 Rila-Pirin Mountains Range“ (*Tzankov et al.,* 2017) 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 (scale 1:250 000). According to the adopted methodology for surface fractals, the possible fractal geometry of the dome-like morphostructures in the studied area is checked and evaluated. 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, 2017). Earthquake data for the study area is taken from the free online seismic catalog of the Incorporated Research Institutions for Seismology (IRIS) for the 1965-2016 statistical of period.

MORPHOSTRUCTURAL PATTERN OF THE RILA-PIRIN MOUNTAINS RANGE

The analysis of the morphostructural range shows that its relief was formed at the time of the emergence and growth of the Late Pleistocene-Holocene dome-like morphostructures and the simultaneous mapping of the expressive negative morphorstructures of the enclosed complex morphostructural passages (Fig.2). There are almost no negative morphostructures within the mountain range. An exception is the specific by location the Razlog and Petrich kettle morphostructures. The rest of the regional morphounit is occupied by more or less expressive predominantly high (alpine) and medium high mountainous morphorstructures (Fig.2). The mountain massifs of the mountain range clearly outline the general dome-like elevation of the relief around certain centers. This gives reason to believe that at present the Rila-Pirin Mountains Range is in the most intense uplifting regime in the eastern part of the Balkan Peninsula.

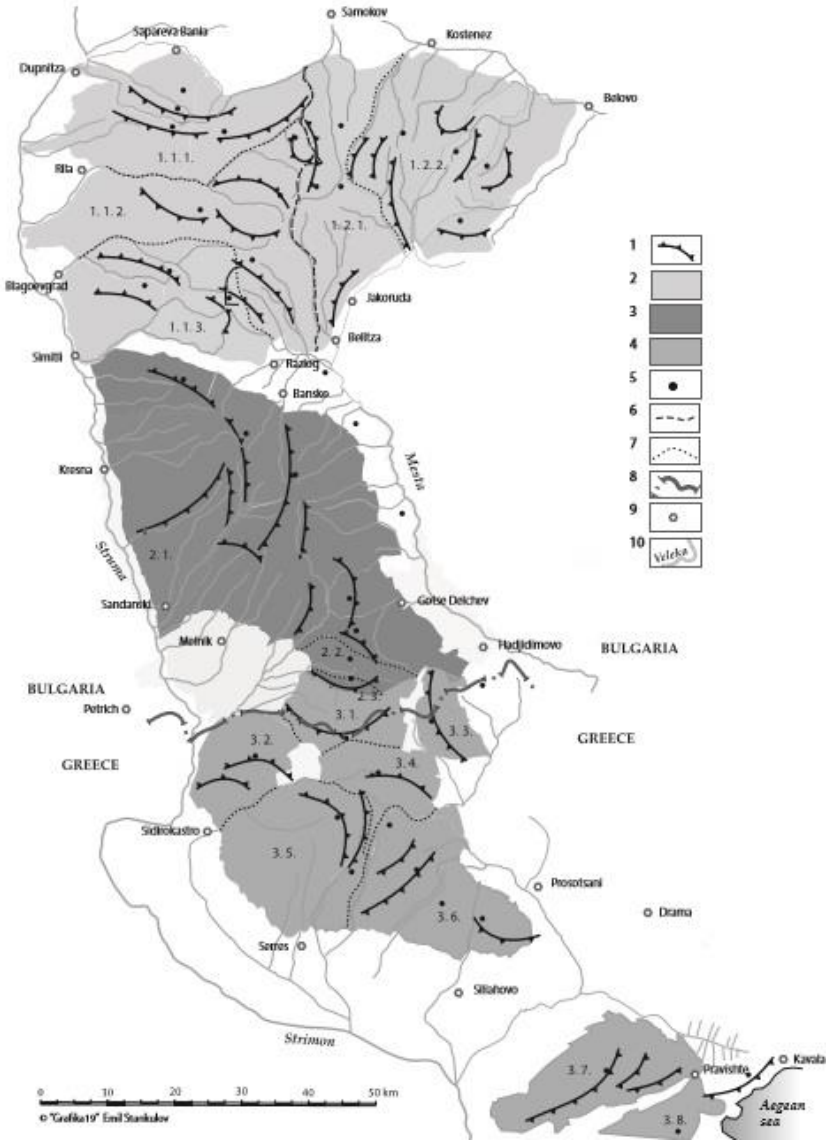

Fig 2

Morphostructural map of the Rila-Pirin Mountains Range

1- Rila morphostructural zone: 1.1 - West Rila Morphostructural area: 1.1.1 - Malyovitsa morphostructural region, 1.1.2 - Skakavets morphostructural region, 1.1.3 - Yakoruda morphostructural region; 1.2 - East Rila morphostructural area: 1.2.1 - Musala morphostructural region, 1.2.2 - Ibar morphostructural region; 2 - Pirin morphostructural zone: 2.1- North Pirin morphostructural region, 2.2 - Central Pirin morphostructural region, 2.3 - South Pirin morphostructural region; 3 - Slavyanka (Orvilos) morphostructural zone: 3.1 – Ali Botush morphostructural region 3.2 - Angistro (Sengelitsa) morphostructural region, 3.3 - Stargach (Strangats) morphostructural region, 3.4 - Mavro vouno (Cherna gora) morphostructural region 3.5 - Vrontous (Sharaliya) morphostructural region, 3.6 - Menoikio (Zmiynitsa) morphostructural region, 3.7 - Pangeo (Kushnitsa) morphostructural region, 3.8 - Eleohorion (Lyuti rid) morphostructural region.

Mountain arched morphostructures (black serrated lines)

Centers of maximal contemporary elevation (black points)

From Table 1 is evident that the contemporary relief of the Rila-Pirin Mountains Range depends roughly equally on the dome-like (12%) and the arched mountain (11%) morphostructures. The above-mentioned two types of morphostructures dominate the outline of the landforms over the otherwise widespread concentric morphostructures. This is an important feature of the Rila-Pirin Mountain Range, unlike the neighboring mountain massifs.

Table 1 Share of the positive morphostructural generations in the Rila-Pirin Mountains Range by morphostructural areas

Morphostructural area	Concentric morphostructures (number/share)	Dome-like morphostructures (number/share)	Arched mountain morphostructures (number/share)
Rila	86 (70%)	19 (16%)	18 (14%)
Pirin	60 (85%)	6 (8%)	5 (7%)
Slavyanka	6 (67%)	1 (11%)	2 (12%)
Angistro	5 (63%)	1 (13%)	2 (14%)
Mavro vouno	6 (74%)	1 (13%)	1 (13%)
Menoikio	21 (78%)	4 (15%)	2 (7%)
Vrontous	20 (84%)	2 (8%)	2 (8%)
Pangeo	19 (90%)	1 (5%)	1 (5%)
Eleohorion	5 (71%)	2 (29%)	0 (0%)
Overall	228 (77%)	37 (12%)	33 (11%)

Within the Rila-Pirin Mountain Range, the dome-like morphostructures shows fractal geometry (Fig.3) This is a testimony of the self-organizing nature of the tectonic processes shaping and modeling the relief in the area. The results from the analysis of the fractal geometry of the dome-like morphostructures in the Rila-Pirin Mountains Range (D=1.772) show almost identical values of Earth's crust fragmentation compared to the neighboring Rhodope mountain massif (D=1.763; *Iliev* et al, 2018).

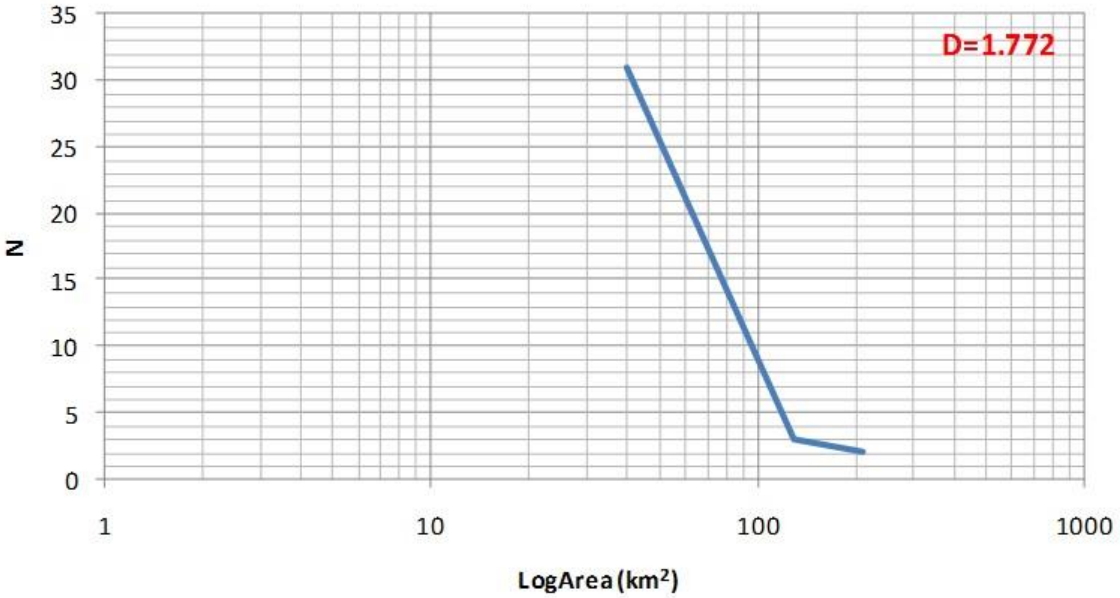

Fig.3

Fractal analysis of the dome-like morphostructures within the Rila-Pirin Mountains Range

SEISMIC HAZARD WITHIN THE RILA-PIRIN MOUNTAINS RANGE

TECTONIC PRECONDITIONS

In seismic terms the lands of the Rila-Pirin Mountains Range are part of the Aegean seismic zone of the Alpine-Himalayan seismic belt. In its length realize 5-6% of earthquakes in the world (*Koronovskiy*, 2003). The Aegean region is one of the most active parts of the Mediterranean region in geodynamic regard. Seismicity here is a specific reflection of the processes in the Earth´s crust and the uppermost part of the Earth´s mantle.

The Rila-Pirin Mountains Range is an element of Bulgarian continental microplate- a part from Neo Europe (*Tzankov*, *Iliev*, 2015). These lands are subject to ongoing intercontinental collision between the Eurasian (Neo Europe) and African (Gondwana) continental macroplates. In the region of the Eastern Mediterranean the morphotectonic situation is further complicated by the movement of Arabian continental plate to the northwest. This process activates the North Anatolian transform fault.

In his the West Anatolian continental microplate pressed the Aegean continental microplate and further increases seismicity in the Aegean region. A significant part of created in these processes seismic energy is "released" in the areas of the Middle Struma complex morphostructural passage and the Middle Mesta complex morphostructural passage. This explains the increased "secondary" seismic activity in this parts of the Balkan Peninsula.

SEISMIC PROFILE WITHIN MOUNTAINS RANGE

The Rila-Pirin Mountains Range region is characterized by a moderate frequency of earthquakes. During the period 1965-2016 dominates the weak and moderate earthquakes (Fig.4). The strongest seismic event happened in 1985 on the eastern edge of the Mavro vouno morphostructural area and has a magnitude of 5.4 on the Richter scale. This is a seismic center from the Middle Mesta active fault system. The other seismic events in the region has a magnitude below 5.0 on the Richter scale.

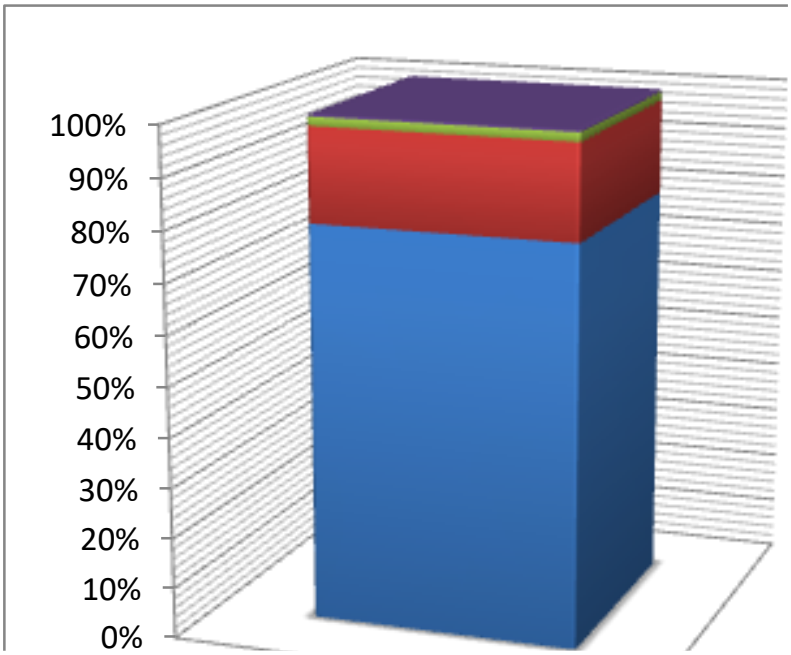

Fig. 4

Distribution of the earthquakes by magnitude in the Rila-Pirin Mountains Range for the period 1965-2016 (Seismic data source: https://www.iris.edu/hq/)

Almost 97% of all earthquakes on the territory of the mountain range occurring for the period 1965-2016 have focal depths of up to 20 km (shallow and very shallow earthquakes) (Fig.5).

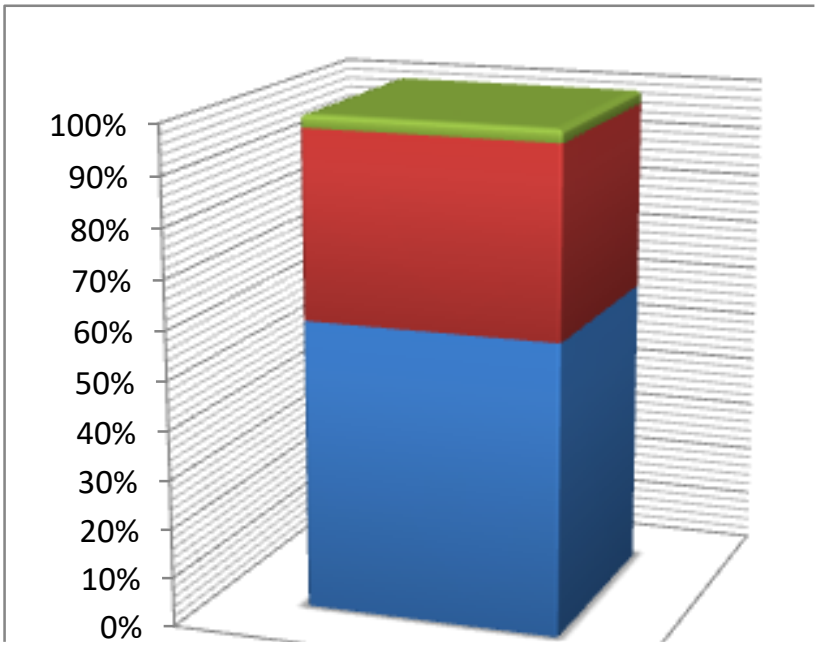

Fig 5

Distribution of the earthquakes by focal depths in the Rila-Pirin Mountains Range for the period 1965-2016 (Seismic data source: https://www.iris.edu/hq/)

Seismic intensity of the lands of the Rila-Pirin Mountains Range is around VIII-th degree on MKS-64 Intensity scale and for the region around the Krupnik fault to IX-th grade on MKS-64 Intensity scale. Higher seismic hazard should be expected in the northern parts of the morphostructural sequence in relation to the front of intercontinental collision in these places. In this sense, these lands from the morphostructural sequence (the Rila and Pirin morphostructural areas) represented one of the most dangerous in seismic sense zones not only in the Balkans, but also in whole continental Europe.

Earthquakes in the Rila-Pirin Mountains Range have strict spatial determination. Seismic events are realized primarily in the periphery of separate morphostructural areas (Fig.6). Some earthquakes mark the boundaries between the individual dome-like morphostructures. This is explained by the fact that accumulated seismic energy most easily and smoothly can be released into the environment with reduced resistance, namely the edges of the separate morphounits. Therefore, in the future it should be expected that the major seismic phenomena will follow the same spatial configuration.

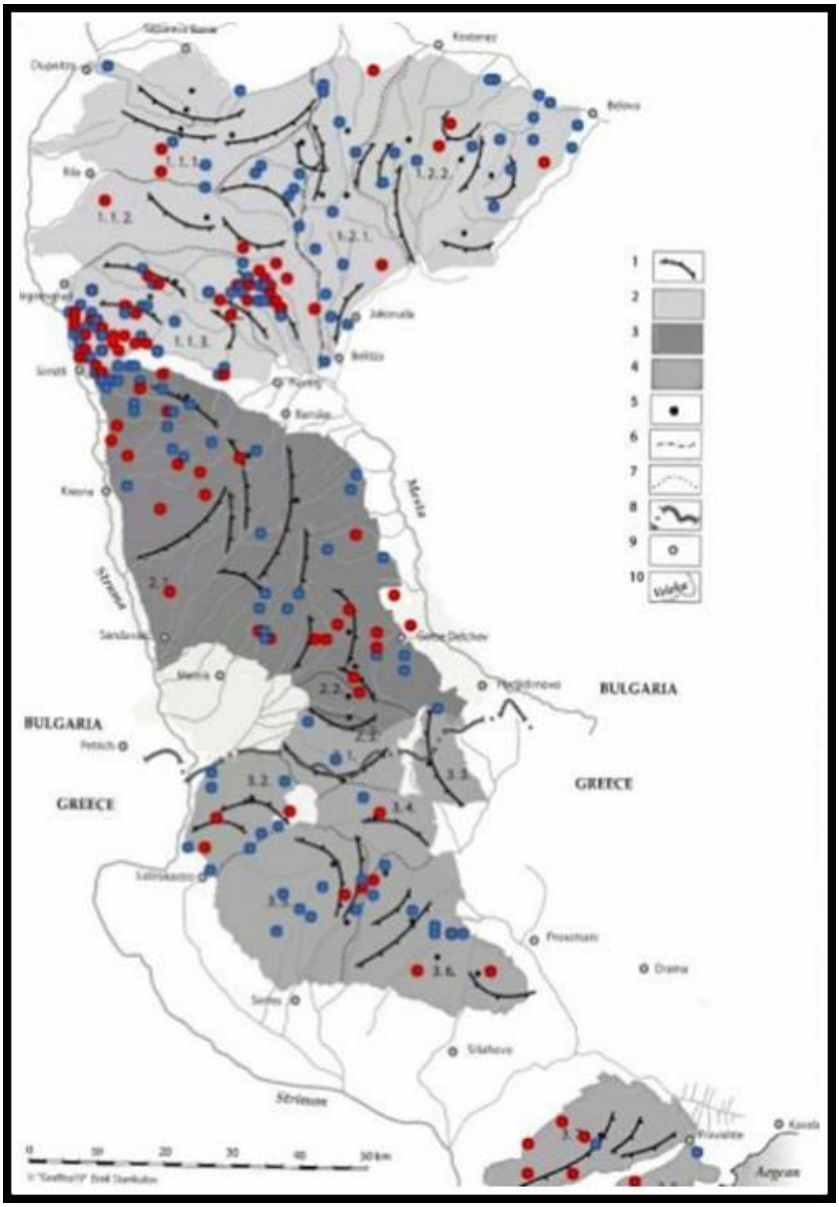

Fig. 6

Survey morphostructural map of the Rila-Pirin Morphostructural Range and earthquakes (Seismic data source: https://www.iris.edu/hq/)

1- Rila morphostructural zone: 1.1 - West Rila Morphostructural area: 1.1.1 - Malyovitsa morphostructural region, 1.1.2 - Skakavets morphostructural region, 1.1.3 - Yakoruda morphostructural region; 1.2 - East Rila morphostructural area: 1.2.1 - Musala morphostructural region, 1.2.2 - Ibar morphostructural region; 2 - Pirin morphostructural zone: 2.1- North Pirin morphostructural region, 2.2 - Central Pirin morphostructural region, 2.3 - South Pirin morphostructural region; 3 - Slavyanka (Orvilos) morphostructural zone: 3.1 – Ali Botush morphostructural region 3.2 - Angistro (Sengelitsa) morphostructural region, 3.3 - Stargach (Strangats) morphostructural region, 3.4 - Mavro vouno (Cherna gora) morphostructural region 3.5 - Vrontous (Sharaliya) morphostructural region, 3.6 - Menoikio (Zmiynitsa) morphostructural region, 3.7 - Pangeo (Kushnitsa) morphostructural region, 3.8 - Eleohorion (Lyuti rid) morphostructural region.

Mountain arched morphostructures (black serrated lines)

Centers of maximal contemporary elevation (black points)

Earthquakes with magnitude below 3 for the period 1965-2016 (blue points)

Earthquakes with magnitude over 3 for the period 1965-2016 (red points)

RESULTS AND DISCUSSION

The results of the present study can be summarized as follows:

1) The relief within the Rila-Pirin Mountains Range is dominated to the same extent by dome-like and arched mountain morphostructures.
2) Dome-like morphostructures shows clear fractal geometry. The fractal dimension (D) of 1.772 is indicator for moderate levels of Earth's crust fragmentation in the area. This is a complete similarity to the neighboring Rhodope mountain massif (D=1.763).
3) The seismicity of the Rila-Pirin Mountain Range is a "reflection" of the tectonic processes in the Aegean region. The seismic energy is released mainly through the morphostructural passages of the Middle Struma and Middle Mesta, which surrounds the mountain range from the west and east.
4) The lands of the Rila-Pirin mountain range are characterized by moderate seismic activity. Low magnitude earthquakes prevail. For the last 50 years there is no seismic phenomenon much higher than 5.4 on the Richter scale.
5) Almost all earthquakes in the area are surface or near surface (up to 20 km deep). This clearly demonstrates the crustal nature of the seismic processes in the region.
6) The focal mechanisms of the earthquakes within the Rila-Pirin Mountains Range are predominantly dominated by the action of the listric tectonics.
7) In spatial terms, epicenters of earthquakes are localized mainly along the edges of dome-like and / or arched mountain morphostructures.

The obtained results for the seismic pattern allows better interpretation of the crustal geodynamic processes in the Rila-Pirin Mountains Range region. The results refute some old ideas about the mechanisms of development and spatial distribution of seismic phenomena in the area. This may serve as a basis for various comparative studies in the future.

CONCLUSION

The overall review of the evolution and construction features of the Rila-Pirin Mountain Range shows that it is a spatially very well-placed Earth's crust area with respect to the geodynamics of the surrounding lands. This gives reason to believe that the endogenous processes of transcontinental collision are controlled by the deep Earth's mosaic block structure. Obviously it is a heavily pushed up Earth's block that contrasts with the neighboring mountain areas. This in turn means that the transcontinental collision in depth is hardly carried out in a uniform manner on a large area. Obviously, the mosaic crustal structure has a distinct impact on the geodynamic evolution of this part of the Balkan Peninsula and in the regional seismic hazard in particular.

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