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Assessment of the Geotouristic Values of Devil's Town, Serbia

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Abstract

Serbia is a country rich in geoheritage with eighty geomorphological sites now under protection. Although a canyon, the site of Devil's Town is a unique geomorphological site in Serbia and deserves special attention. The geotouristic values of Devil's Town were assessed based on the analysis of its present state and comparison with three similar and nearby geosites on the Balkan Pennisula (the Sand Pyramids in Bosnia and Herzegovina and the Stob and Melnik Earth pyramids in Bulgaria). The assessment was performed using a 'modified geosite assessment model' (M-GAM), which includes estimation of the main indicators and sub-indicators. Devil's Town has an average level of major and additional values. Indicators show that this geosite has great tourist, scientific and aesthetic value, as well as enough space for improving the ecological and functional values, as a basis for the development of tourism. Devil's Town displays a higher touristic value than the Sand pyramids and slightly lower than the Stob pyramids. However, in comparison with the Melnik Earth pyramids in Bulgaria, its touristic value is significantly lower. This study could serve as a guide for managing development strategies concerning decision-making and engagement in tourism of the analysed geosite, addressing the needs of modern tourists.

Keywords: Geotourism, Geosite assessment, M-GAM, Comparative analysis, Devil's Town, Sand Pyramids, Stob Pyramids, Melnik Pyramids, Serbia

1. INTRODUCTION

Although Serbia is a small European country, it has a rich geoheritage. There are numerous geological and geomorphological sites, which are excellent representatives of geodiversity. The current inventory of eighty protected geoheritage sites includes about 650 geological, hydrogeological, palaeontological, geomorphological, spelaeological and neotectonic phenomena (DJUROVIĆ & MIJOVIĆ, 2006, VASILJEVIĆ, 2015). There are numerous geosites with unique diversity, which can provide authentic and unforgettable experiences to tourists. Such an environment possesses an outstanding opportunity regarding geotourism development. Devil's Town is an excellent representative of rich natural heritage and it can potentially represent high geotouristic values being as one of the protected geomorphological geoheritage sites (STANKOVIĆ, 2004) and the most important geomorphological monument of nature in Serbia formed by erosion (RISTIĆ et al., 2018). Concerning major geostructures designated to geodiversity, Devil's Town considers "geomorphological occurrences, erosion and depositional proccesses and landscapes'' (DJUROVIĆ & MIJOVIĆ, 2006). The site is classified into the First category of protected sites, i.e. the category of natural monuments of outstanding importance, and has been declared a geological monument of nature. Regarding topography, the area is highly diverse. The occurrence of 202 stony topped Earth pillars (French term ''demoiselle''; North American term ''hoodoo''; including universal terms: ''pedestal rocks'', ''rock pinnacles''; ''Earth pinnacles'', Earth pillars'', ''rock pillars''; Earth pyramids) is noteworthy. These are rare natural phenomena resembling very attractive denudation relief forms (gullies are the most dominant forms, including ground-water seepages and scars). However, the geotourism potential and geoturist values of this geosite remain partially hidden.

The promotion of geological and geomorphological heritage is growing in importance when it comes to cultural tourism and landscape valorisation as thematic excursions and itineraries (REYNARD, 2009). The first official definition of geotourism was given by Thomas Hose, (1995,1996), and later reformulated (HOSE, 2000). Geotourism, as a geoscience-based tourist activity, is a process of recognizing and giving a wider meaning to geoheritage objects in order to preserve them more effectively (HOSE, 2005a). A straightforward definition was given by JOYCE (2006), who defines geotourism as a situation where "people go to certain places to observe one or more aspects of geology and geomorphology and learn about them." The definition of geotourism given by GRAY (2008), takes a view on the need for geoconservation; "Tourism is based on geological and geomorphological resources of an area that attempts to minimize the (negative) impact of this tourism through geoconservation and sustainable management". Under geoconservation, BUREK & PROSSER (2008) include active site management in order to preserve the original state and prevent any changes. Geoconservation measures in combination with the promotion of tourism are the most important elements of geotourism (HOSE, 2005b). SADRY (2009) states that geotourism is in fact knowledge-based tourism, interdisciplinary integration of the tourism industry with conservation and interpretation of the attributes, abiotic in nature, in order to bring the geosite closer to the general public. NEWSOME & DOWLING (2010) have come to the conclusion that geotourism promotes tourism at geosites as well as the conservation of geodiversity and understanding of the geosciences by means of respect and understanding (learning). The latest definition of modern geotourism was developed by HOSE & VASILJEVIĆ (2012): “Providing interpretative content and services at geosites, geomorphological sites and the surrounding topography, together with related in-situ and ex-situ artifacts, in order to conserve them, improve their appreciation, education and scientific work both [by, and] for, the present and the future generations.”

The basic principles of the fundamental importance for geotourism are: geological basis, sustainability, geointerpretation, benefit to the local community and tourist satisfaction (DOWLING, 2011). The economic perspective should also be taken into account. Geosites as a basis of geotourism development contribute to both the original and the additional tourist offer (PRALONG, 2006). In the context of geotourism, geoheritage provides the original offer. The additional offer consists of the infrastructure, goods and services offered to tourists in order to complete, improve and facilitate their visit. These can be informative and interpretative boards, the construction of paths and lifts to hard-to-reach places, or the organization and training of the guides (PRALONG & REYNARD, 2005; REYNARD, 2008). Tourist exploitation of geography can have a negative impact on Earth systems (NEWSOME & DOWLING, 2006; HOSE, 2008; HOSE et al., 2011; HOSE & VASILJEVIĆ, 2012) which can lead to degradation and an increase in the vulnerability of the geodiversity. Thus, it is necessary to create such an offer that will bring geological and geomorphological knowledge and scientific achievements to all visitors, as well as enabling the undisturbed and improved development of tourist activities.

Numerous methods which were used for evaluating geosites were focused on the scientific value of the geosite, and only later included additional values (GRANDGIRARD & SZEPESI, 1997; BRAGA, 2002; BRUSCHI & CENDRERO, 2005; PANIZZA & PIACENTE, 2003; CORATZA & GIUSTI, 2005; GRAY, 2013; PRALONG, 2005; BRILHA, 2005; REYNARD, 2009; REYNARD et al., 2016; REYNARD & BRILHA., 2018; PEREIRA et al., 2007; REIS & HENRIQUES, 2009; TOMIĆ, 2011; VUJIČIĆ et al., 2011; ROCHA et al., 2014). Evaluation of geodiversities and geoheritage in Serbia was carried out mainly using a descriptive method until the last decade of the 20th century when eminent experts from all geodisciplines established and proposed scientific and educational criteria for geoheritage evaluation, while planning the protection of natural areas (NOJKOVIĆ & MIJOVIĆ, 1998; MIJOVIĆ & MILJANOVIĆ, 1999). In the last few years, a lot of authors from Serbia have contributed to the foundation of modern thought on the need and significance of protecting and promoting geodiversity and geoheritage (LJEŠEVIĆ, 2002; MIJOVIĆ, 2002; MIJOVIĆ et al., 2005; DJUROVIĆ & MIJOVIĆ, 2006; BELIJ, 2007; 2008; 2009; VUJIČIĆ et al., 2011; VASILJEVIĆ et al., 2011; TOMIĆ, 2011; BOŽIĆ & TOMIĆ, 2015; BOŠKOV et al., 2015; TOMIĆ & BOŽIĆ, 2016; ANTIĆ & TOMIĆ, 2017; VALJAREVIĆ et al., 2017; VUKOIČIĆ et al., 2018; ANTIĆ et al., 2019; ANTIĆ et al., 2020).

Serbia has the potential for an increase in geotourism but is obviously lagging behind countries with developed tourism. Hence, the main goal of this study is to assess the geotouristic values of Devil’s Town and its comparison with the three similarly featured and nearby geosites in the Balkans (Sand Pyramids in Bosnia and Herzegovina and Stob and Melnik Earth pyramids in Bulgaria) by applying the M-GAM model. The results obtained should point to the potential advantages and disadvantages in these analyzed localities as well as to the main future tasks of management during the planning and development of a tourist offer aiming to adjust these to attractive tourist destinations.

2. MATERIAL AND METHODS

2.1. Study area

Devil’s Town spatially belongs to the municipality of Kuršumlija, and the village of Djake on Radan Mountain (central part of Southern Serbia). It covers an area of 8.31 ha, at an altitude of 660 – 796 m a.s.l. The Devil’s Town is located 290 km from Belgrade,

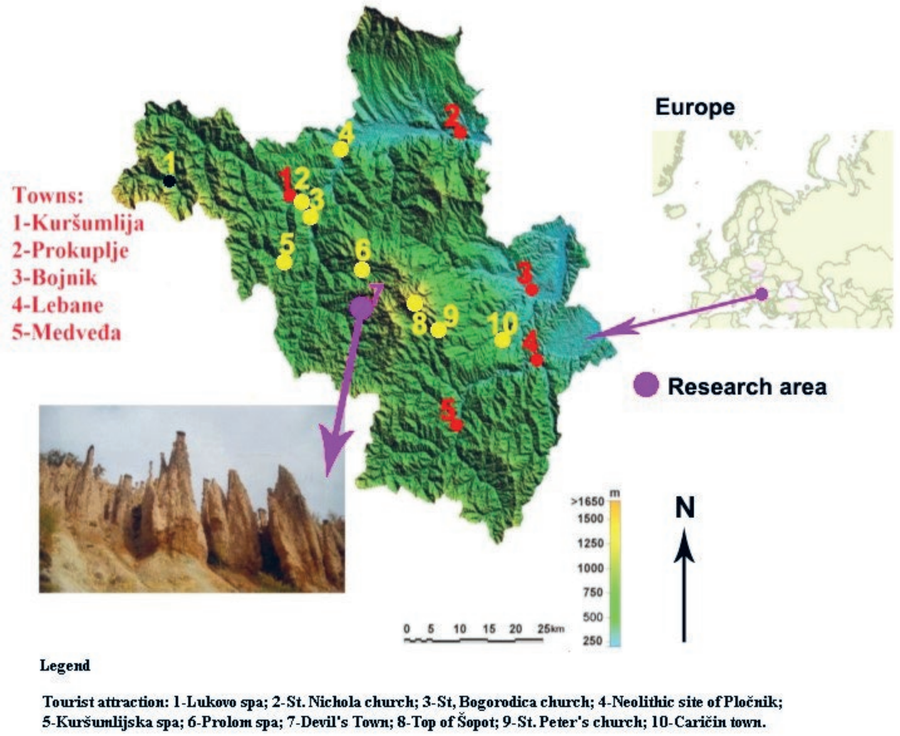

Figure 1. Location map of Devil’s Town (Source of hypsometry: CGIAR Consortium for Spatial Information, 2017).

29 km from Kuršumlija, and 9 km from the state road IB category no. 35 Niš-Priština. Beside this state road, there is also the Niš - Prokuplje - Kosovo Polje railway. The closest airports are Slatina in Priština (57 km) and the airport in Niš (92 km). Prolom Banja, which is one of the most visited spas of great touristic value in Serbia (TOMIĆ & KOŠIĆ, 2020), is located nearby, 28 km from Devil's Town. These two tourist-attractive destinations are connected by a well-built hiking trail. Parking for vehicles is 850 m away from Devil's Town, and the hiking trail leads to the top of the erosive fountain with a viewpoint that allows sightseeing and photography of the stone formations. At the beginning of the hiking trail, several ethno-style mountain lodges were built, one housing a restaurant with food prepared in the traditional Serbian style and an art galery where the photo-contest "Devil's Town" is traditionally held in May each year (Fig. 1).

Regarding geology, Devil's Town is located within the Lece volcanic complex, which is one of the largest Tertiary volcanic provinces in Serbia. It is, (observing the geotectonic setting), situated along the boundary between the Serbo-Macedonian mass (SMM) to the east and the Eastern Vardar zone to the west (Fig. 2). These two units are delineated by the Propolac–Medvedja and Tupala dislocation (STAJEVIĆ, 2004). The former unit has been interpreted as part of the deformed margin of the Eurasia continental plate, while the latter is considered a remnant of the vast Tethys Ocean (e.g. SCHMID et al., 2008).

According to the generally accepted explanation, the volcanic complex of Lece was formed in response to the Dinaride collapse. Magmatism took place along dextral strike-slip faults that resulted in transpressive crustal shortening and collision of the SMM as a part of the European plate within a short time frame, from about 33 to 31 Ma (DRAGIĆ et al., 2014; TOSDAL, 2012).

The unique geomorphological phenomenon in Serbia contains about 202 stone formations formed on steep slopes of two deep, parallel cut gullies. The formations are of different shapes and sizes. The oldest ones are the highest, up to 17 m high, and they are placed at about 670 m a.s.l., while smaller forms are up to 2 m high and are placed at about 680 to 700 m a.s.l. Today, it is very easy to find videos of Devil's Town on the internet.

These specific natural formations are the result of an erosive process that lasted for at least two hundred thousand years, during which those formations evolved and passed through different stages of development. The Devil's Town rocks are andesitic volcanic and volcaniclastic rocks and have been protected since 1959. In 1995, the Decree of the Government of the Republic of Serbia proclaimed a site of National importance“ and placed into the highest category of protection. A total area of 67 hectares is protected, although there is a requirement to increase the protected area to 1014 ha.

2.2. Geological background

The geology of the broader area is presented on the Basic Geological Map 1:100.000, sheets Kuršumlija and Podujevo (MALEŠEVIĆ et al., 1974; VUKANOVIĆ et al., 1975). The oldest rocks are Cambrian gneisses and subordinate Devonian metamorphosed limestone. Broad areas cover Cretaceous products, conglomerate and flysch sediments associated with members of the Jurassic ophiolite mélange (previously known as the "diabase-chert formation" DIMITRIJEVIĆ & DIMITRIJEVIĆ, 1974). The most dominant lithological units are products of Oligocene volcanism with a formation age of 32–28 Ma (KARAMATA et al., 1992; KOSTIĆ et al., 2017). These volcanic products are andesites and volcaniclastic rocks including lava flows, pyroclastic breccias, crystalline and lapilli tuffs (DIMITRIJEVIĆ & DRAKULIĆ, 1958; DRAGIĆ et al., 2014). Andesite displays a porphyritic texture, and contains plagioclase (Fig.3a), amphibole-hornblende (Fig.3b), biotite (less frequently) and monoclinic and orthorhombic pyroxenes as phenocrysts. Accessory constituents are apatite and opaque minerals. Their uniform chemistry suggests uniform volcanism within the entire complex (JOVANOVIĆ et al., 1972). Negligible variations in chemistry could be a consequence of

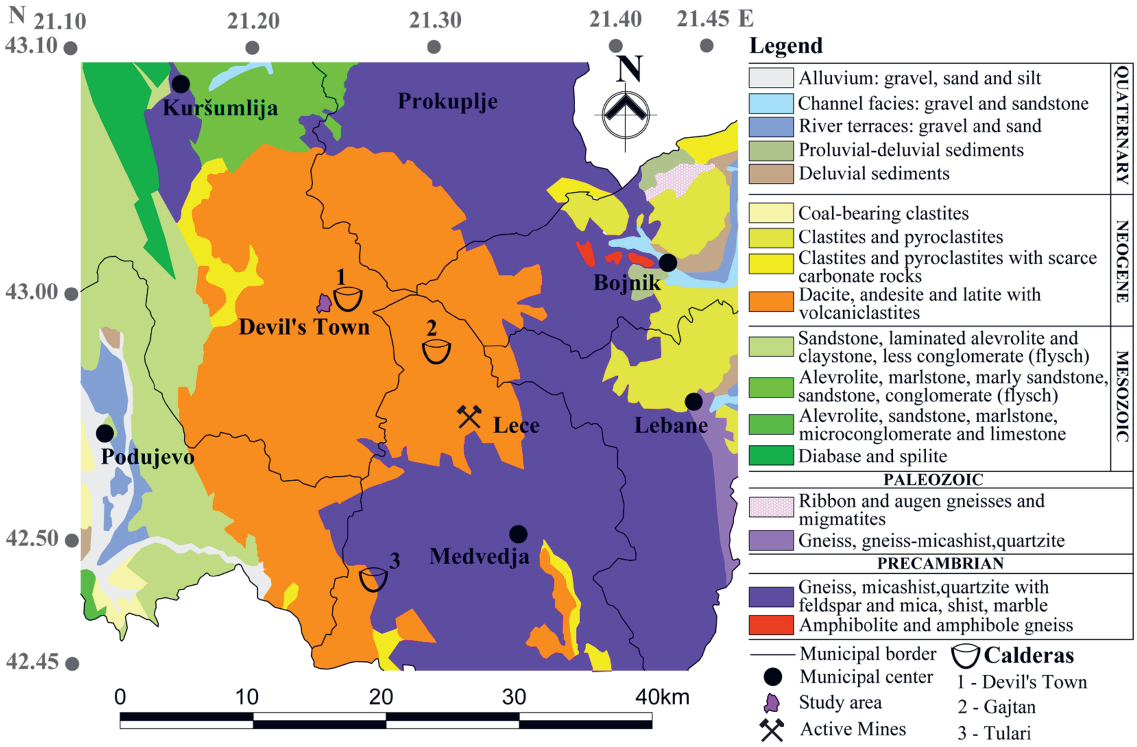

Figure 2. Geological map of research area. **Source:** Map processed by authors based on data of GEOLISS, 2020).

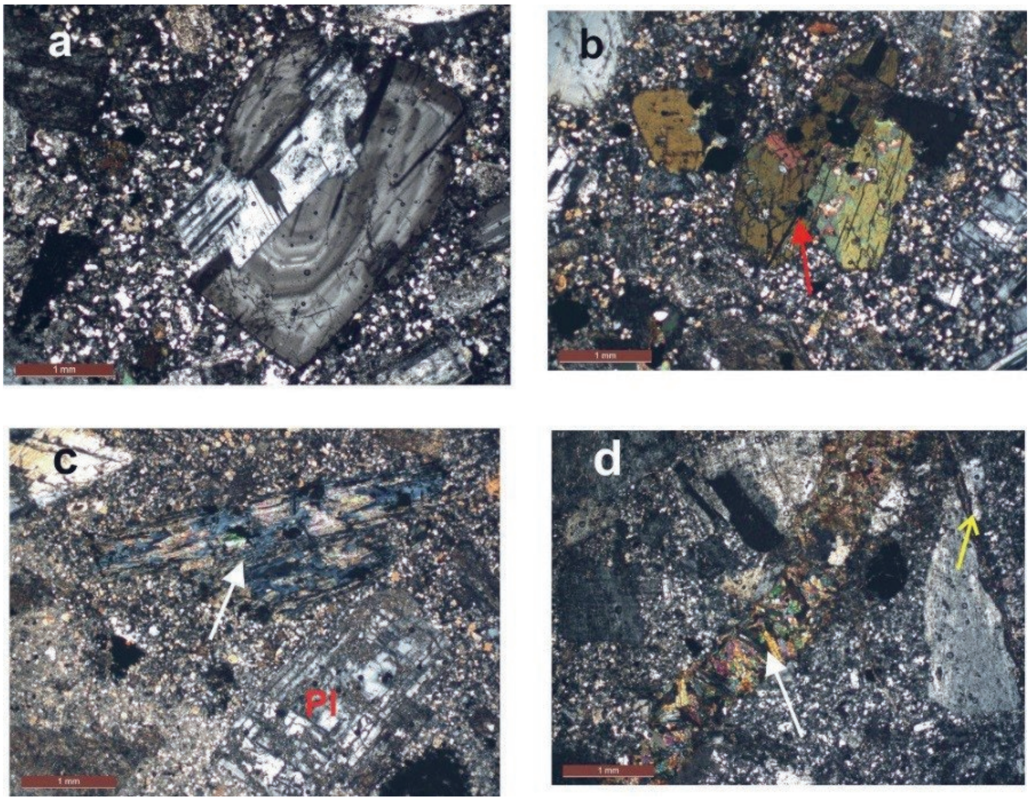

Figure 3. Microphotographs of porphyritic andesite: a) phenocryst of zoned plagioclase - andesine; b) phenocryst of hornblende (red arrow); c) bluish chlorite formed over amphibole (white arrow: pl-plagioclase); d) epidote vein, thick (white arrow) and thin one (yellow arrow) in hydrothermally altered sample.

minimal changes of steam pressure inside a volcanic vent or internal diffusion during peaceful phases as well as hydrothermal action and subsequent alteration (JOVANOVIĆ et al., 1972). Pyroclastic rocks, including some well-bonded ignimbritic types, comprise horizons from a few - 100 m thick. Hydrothermally altered rocks are most abundant in the area of interest occurring as reef zones due to their higher resistance (Fig. 3c, d). The most intensive hydrothermal process is silicification revealing the remarkable, several kilometers long zone of silicification known as the “quartzose-brecciated zones” (PEŠUT, 1976). At higher elevation, intense phyllic alteration occurs, which encompasses the mineralized rocks (DRAGIĆ et al., 2014). Hydrothermal alteration developed along favourable volcanic-tectonic and tectonic rupture systems (STAJEVIĆ, 2004). Fissures about 1km in length prevail, although some exceed a few km. In the same fracture zones precious minerals occur together with galena, sphalerite, pyrite and gold (e.g. the Rasovača, Vrtače, Kameno rebro and Bučumet deposit). Precious silicate minerals include amethyst, amethyst-agate, agate, fibrous chalcedony, granular quartz and relic opal, which display very heterogeneous colour varieties (MILADINOVIĆ et al., 2010). Although gemstone deposits became the subject of interest after World War II, on the basis of certain archaeological finds it is known that the amethyst and agate had been exploited by the Ancient Romans. Numerous poorly explored occurrences, mostly placer deposits (eluvial, deluvial, proluvial and alluvial), distributed outwith the volcanic complex, i.e. on its eastern rim also exist. Volcanic products affected by siliceous and/or siliceous-mineralized hydrothermal fluids were later exposed to further weathering and erosion along the already existing fissures.

Volcanoes in this area undoubtely exceeded 1000 m in height (Gajtan caldera in spite erosion and shortenning reaches approximately 700 m a.s.l.). Devil’s Town is the largest and most complex caldera with a diameter of about 25 km. The best preserved parts are at Sokolovica (in the north) and at Markov Vis (in the south).

2.3. Relief shaping

Volcanism initially sculpted this area in the Palaeogene, i.e. Upper Oligocene (DIMITRIJEVIĆ & DRAKULIĆ, 1958). According to JOVANOVIĆ et al. (1972) and VALJAREVIĆ et al. (2015) volcanic activity evolved throughout three phases:

1. Development of stratovolcanoes (emitting both tephra and viscous lava, building steep conical mounds),
2. Formation of calderas, and
3. Subsequent processes inside the calderas and consolidation of the entire complex.

1. Stratovolcanoes (complex, composite or gray volcanoes) are large, long-lived volcanoes, particularly those of andesitic composition that emit a combination of lava flows and tephra, building steep-sided volcanic cones. A growing lava dome might exceed 1000 m in height, as lava flows resist or slow down erosion and loss of tephra. The beautiful steep-sided cones of stratovolcanoes are among Earth’s most picturesque sights (e.g. Mount Fuji in Japan, Mount Rainier and Mount St. Helen in Washington, former volcanoes in East Serbia etc.). The height of volcanoes in this area undoubtely exceeded 1000 m (as the Gajtan caldera is now, although eroded and shortened, nearly 700 m), with a basal diameter greater than 30 km. Stratovolcanoes are often transformed over time as calderas – roughly circular basins, the diameter of which can vary between 1 - 25 km, some of which are still preserved as relics. In general, a caldera develops by collapse after the partial or complete emptying of a magma chamber. The unsupported roof of the empty chambers sinks slowly under its own weight.

2. Caldera dimensions exceeded the dimensions of the former volcanic cones. Pyroclastic rocks as well as lava flows in the relics of former stratovolcanoes generally dip towards the volcano periphery, if not affected by subsequent tectonic events. Devil's Town is, as mentioned above, within the volcanic complex of Lece, a sub-volcanic Pb-Zn deposit, which consists of three large calderas: Gajtan, Devil's Town and Tulari. However, at present, a significantly larger number of smaller calderas and volcanic vents are being observed (SERAFIMOVSKI, 1990; DRAGIĆ et al., 2014). As a result of pronounced erosion accompanied by the effects of endogenic (volcanic) movements within the calderas. Their height can not be precisely determined. The Gajtan caldera is the oldest one with only the eastern part preserved at Petrova gora. The southern part was eroded, whereas the western and northern parts were destroyed during development of the Devil's Town caldera. The Tulari caldera is the smallest and the best preserved suggesting that it is the youngest one. It has a complex fabric with a recognizable northward migration of the centre of effusion. The youngest effusion centre is still preserved in the form of the neck (Braina) from where a radial dyke stretches towards the north. Devil's Town caldera with a diameter of about 25 km is the largest and most complex, consisting of three smaller calderas: Devil's Town, Ivan Kula and Kravari. Tectonic activity and faulting during the northward migration of its eastern part additionally destroyed and reworked it. The best preserved parts are at Sokolovica (in the north) and at Markov Vis (in the south). Their marginal parts are composed of pyroclastic rocks, while the internal parts (morphologically higher and closer to the inner caldera) are of alternating pyroclastic rocks and lava flows. The outer zone is marked with well sorted material, according to grain size. Tuffaceous sandstone and volcanic gravel overlie crystalline schists and Cretaceous flysch in the footwall. Volcanic breccias and agglomerates build the highest levels. The interior is composed of coarser volcanic products: agglomerates, breccias, volcanic bombs (20-30 cm in diameter), and boulders reaching a few metres in size. Volcaniclastic rocks are represented by a mixture of coarse-grained blocks (from a few decimetres to a few metres in size) and fine-grained material explosively ejected from volcanoes. The pillars roofs are of andesite or dacite lava, which like umbrellas either protects them or slows down further erosion and destruction.
3. The presence of sinterized tuffs and younger lava flows in the Gajtan caldera, including repeated volcanic activity in the Tulare caldera, reflects the continuation of volcanic activity within the previously formed calderas. During the final volcanic phases, after consolidation of the magmatic masses, basal uplift in the form of domas took place enabling the development of radially distributed fissures through which hydrothermal solutions percolated. Hydrothermal solutions, meso- to epithermal, affected the host rocks which were subjected to physical and chemical weathering and erosion. These processes finally shaped this area. The stone formations were dissected into twenty metre thick layers of weathered delluvial material (i.e. debris flow) and their growth was enabled by the existence of "caps or roofs" of more resistent material (lava flows) (Fig. 4).

Similar forms have been noted in the high mountain ranges of the Andes and Alps (e.g. both sides of the Brenner pass, in

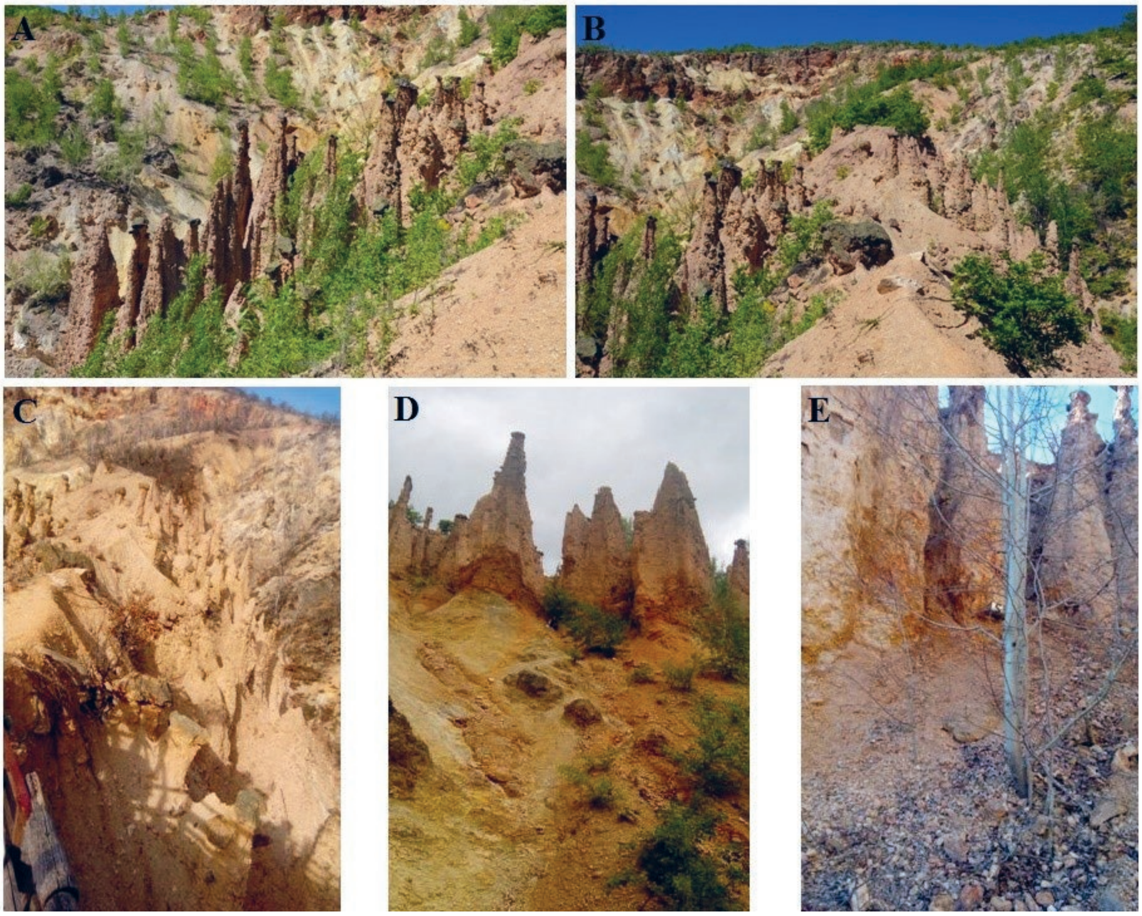

Figure 4. A - Devil's Town; B - The reef between Devil's Town and Hell's Gully; C - Hell's Gully; D - Earth pillars in Devil's Town; E - Earth pillars in Hell's Gully.

Figure 5. The bird's-eye view photograph of the Devil's Town.

Austria, Italy and France etc.), where they were formed through leaching of glacial (moraine) material. Spectacular forms in the Garden of the Gods (Illinois, USA) were formed within sediments (red and white sandstone, limestone and conglomerates of Carboniferous age, about 320 Ma old) that were deposited horizontally, but later have been tilted vertically and faulted by immense mountain building forces (SKINNER & PORTER, 2000). In the Sahara desert, the Memuniat formation was created within the Ordovician sandstone. However, in Devil's Town, stone formations are more abundant, larger in dimensions and more resistant, providing a representative example of the diverse erosive action of water supported by lithological differences and rare hydrothermal occurrences (Fig. 5).

The wider area of Devil's Town is rich in ore (iron, aluminum, gold and silver), and demonstrates mines dating back to the 13th century and the arrival of German Saxon miners (Fig. 6). In fact, the Saxon miners restored mines and the ore-forming sites known from the Ancient and the Prehistoric ages. The nearby Neolithic site (5500 to 4700 B.C.) in the village of Pločnik, near Prokuplje, preserved a significant number of prehistoric metal-made weapons and copper tools. These artifacts suggest that this site was a centre of metallurgy in Europe dating back to 5500-4800 B.C., i.e. that the Copper Age started in Europe earlier than previously understood. It is also thought that the ore was obtained from an azurite and malachite deposit from the site in the vicinity of Toplica and Kosanica, as neither immediate locations of ore excavation nor slag residues resulting from smelting were discovered (ĆUZOVIĆ et al., 2004). Additionally, the remains of the medieval fortification constructed on the basement of the former Roman settlement of Hammeum (second half of 1st century), were discovered at Hisar hill (Prokuplje). This site is also under state protection and considered to be a monument of great cultural importance.

The entrances to the mine shafts are very narrow, which is characteristic of the castle mines. One of the three preserved mine shafts has been explored. Its entrance is expanded and its length is about 800 m (http://www.djavoljavaros.com/).

There are two rare hydrological phenomena in Devil's Town, related to the last phases of vulcanism. Extremely cold and acidic water (pH 1.5), highly mineralized (15 g / l, most of Si, Al, Fe and S) with a hardness of about 21,050d springs in the upper part of the Devil's Gully. This spring is known as the "Devil's Water".

Figure 6. Investigated mining shaft in Devil's Town.

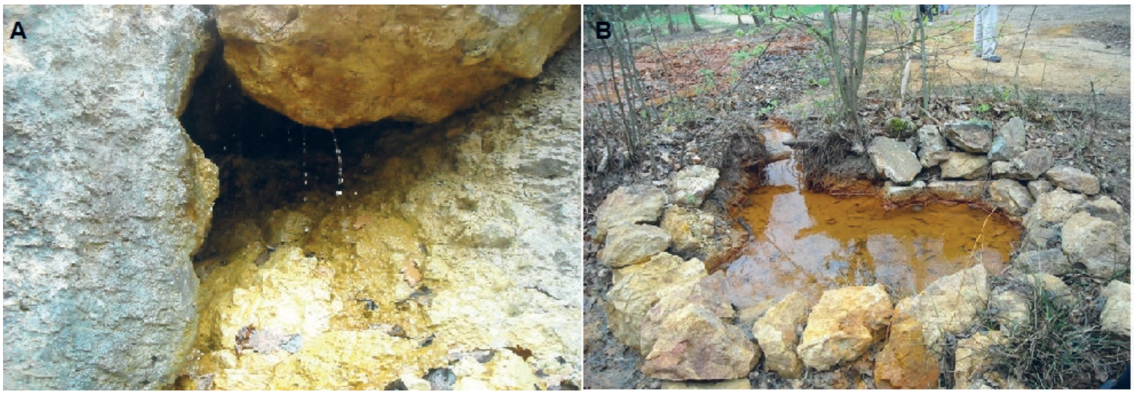

Figure 7. A- Devil's Water; B- Red Spring.

One litre of water contains over 1.5 g of metal (Al, Fe, K, Cu, Ni) and 2.63 g of sulfur. Due to its very low pH, this water is also a good solvent, suggesting that some amounts of Al, Fe and K were probably extracted from the surrounding rocks. Water in the spring called "Crveno Vrelo (the Red Spring)" (to the right side of the Yellow Stream, about 400 m from the previously mentioned spring) is less acidic (ph 4.0) and iron-rich (198.8 mg / l). The oxidized iron along with substances which came from the surrounding rocks led to changes in the water properties in the stream revealing its name "Žuti Potok (Yellow Stream)". The waters of both springs have no healing properties, but they are a natural poison to the living world (PROTIĆ, 1995; http://www.izjz-nis.org.rs/; SREĆKOVIĆ-BATOĆANIN, D. et al., 2010) (Fig. 7).

2.4. Examples of similar localities in the Balkans

Geolocalities in structure and origin similar to Devil's Town (GS$_1$) in the Balkan area include: the Sand Pyramids (GS$_2$) in Bosnia and Herzegovina and Stob (GS$_3$) and the Melnik Earth pyramids (GS$_4$) in Bulgaria (Fig. 8).

Small peaks called "pyramids" appear in the southeasternmost part of the macro region Bosansko Sredogorje near the village of Daničići (location *Šljivovice*, 9 km from Foča in Bosnia and Herzegovina). Similar landmarks are noted in the vicinity, too. These forms consist of alternating Pliocene clastites – conglomerate, gravel and sand derived in eluvial relief from the former Miocene basin under the triggered action of proluvial and gravitational processes during the Quaternary. The sand pyramids represent a classic example of selective denudation due to the existence of more resistant layers of Pliocene conglomerates in the hanging wall (LEPIRICA, 2013). Continual erosion facilitates their persistent growth.

Sculptured sand columns rise from a broad base and narrow towards the top revealing amazing geomorphological phenomena within the area. These sand pyramids were protected by a declaration of the Commission to Preserve the National Monuments of Bosnia and Herzegovina in 1959. At present the Institution is revising the inventory of localities that have been protected up to 1992. Due to its outstanding importance, specific protection measures are suggested for this locality. It needs to be evaluated in the sense of tourism, bearing in mind that it is commonly compared to the Devil's Town in Serbia (LEPIRICA, 2010).

The Stob pyramids, known as hoodoos, are located between the western foothills of Rila Mountain and the eastern localities of Kulski rid and Tsarkvishteto near the village of Stob, about 5 km from the city of Kocherinovo (Kyustendil Province) in Bulgaria. This site is very popular, in many ways like the Melnik pyramids on the slopes of Pirin Mountain, (Bulgaria) and Devil's Town in Serbia. The site is insufficiently explored and information concerning it remains far behind similar localities elsewhere in the world (e.g. the Wheeler geological area in the USA and Cappadocia in Turkey). These erosive landmarks, up to 12 m in height with a stony top, up to 120 cm in diameter, occupy an area of about 7.4 ha at 600 to 750 m a.s.l. The pyramids are composed of weakly bonded Neogene-Quaternary sandstones and conglomerates deposited within the last 1–2 Ma on the slope in a lacustrine environment.

Figure 8. Position of geosites on the Balkan Peninsula.

Table 1. The structure of the Geosite Assessment Model (GAM) (VUJIČIĆ et al., 2011).

Indicators/Sub-indicators	Description
Main values (MV)	
Scientific/Educational value (VSE)	
1. Rarity	Number of nearby identical sites
2. Representativeness	Didactic and exemplary characteristics of the site due to its own quality and general configuration
3. Knowledge on geoscientific issues	Number of published papers in journals, thesis, presentations and other publications
4. Level of interpretation	Level of interpretive possibilities on geological and geomorphologic processes, phenomena and shapes and level of scientific knowledge
Scenic/Aesthetic (VSA)	
5. Viewpoints	Number of viewpoints accessible for pedestrians. Each must be situated less than 1 km from the site.
6. Surface	Whole surface of the site. Each site is considered in quantitative relation to other sites
7. Surrounding landscape and nature	Panoramic view quality, presence of water and vegetation, absence of human-induced deterioration, vicinity of urban area, etc.
8. Environmental fitting of sites	Level of contrast to the nature, contrast of colours, appearance of shapes, etc.
Protection (VPr)	
9. Current condition	Current state of geosite
10. Protection level	Protection by local or regional groups, national government, international organizations, etc.
11. Vulnerability	Level of vulnerability of the geosite
12. Suitable number of visitors	Supposed number of tourists on the site at the same time, according to surface area, vulnerability and current state of geosite
Additional values (AV)	
Functional values (VFn)	
13. Accessibility	Possibilities for approaching the site
14. Additional natural values	Number of additional natural values in the radius of 5 km (geosites also included)
15. Additional anthropogenic values	Number of additional anthropogenic values in the radius of 5 km
16. Vicinity of emissive centers	Closeness of emissive centers
17. Vicinity of important road network	Closeness of important road networks in the radius of 20 km
18. Additional functional values	Parking lots, gas stations, mechanics, etc.
Touristic values (VTr)	
19. Promotion	Level and number of promotional resources
20. Organized visits	Annual number of organized visits to the geosite
21. Vicinity of visitors centers	Closeness of visitor center to the geosite
22. Interpretative panels	Interpretative characteristics of text and graphics, material quality, size, fitting to surroundings, etc.
23. Number of visitors	Annual number of visitors
24. Tourism infrastructure	Level of additional infrastructure for tourist (pedestrian pathways, resting places, garbage cans, toilets etc.)
25. Tour guide service	If exists, expertise level, knowledge of foreign language(s), interpretative skills, etc.
26. Hostelry service	Hostelry service close to geosite
27. Restaurant service	Restaurant service close to geosite

Grades (0.00-1.00)					
0.00		0.25	0.50	0.75	1.00
1.	Common	Regional	National	International	The only occurence
2.	None	Low	Moderate	High	Highest
3.	None	Local publications	Regional publications	National publications	International publications
4.	None	Moderate level of processes but hard to explain to non-experts	Good example of processes but hard to explain to non-experts	Moderate level of processes but easy to explain to common visitor	Good example of processes and easy to explain to most visitors
5.	None	1	2 to 3	4 to 6	More than 6
6.	Small	-	Medium	-	Large
7.	-	Low	Medium	High	Utmost
8.	Unfitting	-	Neutral	-	Fitting
9.	Totally damaged (as a result of human activities)	Highly damaged (as a result of natural processes)	Medium damaged (with essential geomorphologic features preserved)	Slightly damaged	No damage
10.	None	Local	Regional	National	International
11.	Irreversible (with possibility of total loss)	High (could be easily damaged)	Medium (could be damaged by natural processes or human activities)	Low (could be damaged only by human activities)	None
12.	0	0 to 10	10 to 20	20 to 50	More than 50
13.	Inaccessible	Low (on foot with special equipment and expert guide tours)	Medium (by bicycle and other means of man-powered transport)	High (by car)	Utmost (by bus)
14.	None	1	2 to 3	4 to 6	More than 6
15.	None	1	2 to 3	4 to 6	More than 6

16.	More than 100 km	100 to 50 km	50 to 25 km	25 to 5 km	Less than 5 km
17.	None	Local	Regional	National	International
18.	None	Low	Medium	High	Utmost
19.	None	Local	Regional	National	International
20.	None	Less than 12 per year	12 to 24 per year	24 to 48 per year	More than 48 year per
21.	More than 50 km	50 to 20 km	20 to 5 km	5 to 1 km	Less than 1 km
22.	None	Low quality	Medium quality	High quality	Utmost quality
23.	None	Low (less than 5000)	Medium (5001 to 10 000)	High (10 001 to 100 000)	Utmost (more than 100 000)
24.	None	Low	Medium	High	Utmost
25.	None	Low	Medium	High	Utmost
26.	More than 50 km	25–50 km	10–25 km	5–10 km	Less than 5km
27.	More than 25 km	10–25 km	10–5 km	1–5 km	Less than 1 km

The Stob Earth Pyramids were declared a natural landmark in 1964. Their formation, evolution and destruction are taking place in repeated stages driven by groundwater, temperature inversion and wind. At the immediate site, two evolutionary stages could be recognized. The site is easily accessible to visitors via designated pathways and viewpoints, which offer a panoramic view over the whole geosite and nearby settlements (Stob, Porominovo, Barakovo, Kocherinovo, Rila). In the immediate vicinity of Stob village, there are also ancient ruins that should be evaluated in terms of tourism (https://www.andrey-andreev.com/en/stob-pyramids-bulgaria/).

The Melnik pyramids are considered to be the most interesting natural wonder in Bulgaria, as well as on the Balkan Peninsula. These pyramids are similar to those at Stob, but are much greater in size and spatial distribution. The Melnik pyramids are located on the southwestern slope of Pirin Mountain at about 180 km south of Sofia, in the Blagoevgrad Province and the municipality of Sandanski. The exact sites are Melnik, Gorna Sushitsa, Karlanovo, Rozhen and Sugarevo. This geosite has been protected since 1960 (enlarged and redeclared in 1978) over an area of 1165.6 ha. Rock formations resembling pyramids are located from 350 - 850 m a.s.l. Their variable colours and heights offer an amazing, very attractive image. The increasing number of visitors from all over the world required a number of buildings and recreation centres to be built in Melnik.

The Melnik region consists of grayish-white Pliocene sand, mixed with clay layers. It was deposited at the bottom of a shallow lake 3–5 Ma ago. Folding caused by the collision of continental plates led to the formation of mountain ranges, such as Pirin, Ograzden and Belasica. The lake water flowed to the south and discharged into the Aegean Sea. In the newly formed valley, terrigenous material was brought by mountain rivers and streams leading to the formation of about 500-600 m of alluvial deposits of weakly cemented and reddish sedimentary rocks. Over the next thousands of years, sediments accumulated up to 120 m thick, nourished from the Pirin range by mountain rivers and streams. In the variously shaped valleys the pyramid formation was additionally supported by wind action and temperature inversion.

The Melnik pyramids are of noteworthy shapes and of various sizes that are subjected to changes due to the decomposition and decay of plants, such as deciduous trees, bushes and grasses that thrive there. The most visited pyramids are those located near the Rozhen Monastery. They are easily accessible by constructed pathways from the city of Melnik to the Rozhen monastery. The other attractive group of pyramids is in the village of Karlanovo. Although there are only four pyramids, they look impressive exceeding 100 m in height, having slopes barren of vegetation and with flattened peaks. The stony caps have the same protective role against erosion, as in the previously mentioned localities. The small city of Melnik, additionally contributes to the attractiveness for tourists. Renowned for its authentic architecture from the renaissance era it is declared an architectural reserve. Additional anthropogenic tourist values include: the Kordopulov House – a large house from the Bulgarian national revival period, Wine Museum, Rozhen monastery – the biggest Orthodox Church in the Pirin Mountain area.

2.5. Methodology

Andesite samples were optically analyzed using a petrographic polarized microscope for transmitted light (Leica DMLSP), which is connected to a Leica DFC290 HD camera over the program LAS V4.

2.5.1. M-GAM model

Previous geosite assessment models involved geosite assessment criteria adjusted for tourists (PRALONG, 2005; SERRANO & GONZÁLEZ-TRUEBA, 2005; HOSE, 2007; PEREIRA et al., 2007; ZOUROS, 2007; REYNARD, 2008; REYNARD, 2009; REYNARD et al., 2016; REYNARD & BRILHA, 2018) and experts (BRUSCHI & CENDRERO, 2005; CORATZA & GIUSTI, 2005; HOSE, 2007; WHITE & WAKELIN-KING, 2014). VUJIČIĆ et al. (2011) proposed a model for the evaluation of geolocalities (GAM) based on the experts' opinion, whereas TOMIĆ & BOŽIĆ (2014) modified the GAM model into the M-GAM model, and based it on both the opinions of experts and visitors.

This study includes the values of experts for all 27 sub-indicators in GAM (Table 1) along with the tourist values (Im) (Table 2), which have already been presented by BOŽIĆ & TOMIĆ (2015). In the original GAM model two important indicators are included: Main Values and Additional Values, and then divided into 12 and 15 indicators respectively, each scored between 0 and 1. This kind of model is made according to two general kinds of values: main – mostly generated by the geosite's natural characteristics; and additional – mostly generated by modifications for its use by visitors. The Main Values are conducted by three groups of indicators: scientific/educational (VSE), scenic/aesthetical values (VSA) and protection (VPr) while the Additional Values are divided into two groups of indicators, functional (VFn) and touristic values (VTr). The Main and Additional Values are presented in Table 1.

The GAM is defined as a simple equation, a sum of 12 sub-indicators of the Main Values, and 15 sub-indicators of the Additional Values which are graded from 0 to 1:

$$GAM = MV + AV \tag{1}$$

where *MV* and *AV* represent the symbols for the Main and Additional Values. We derive these two equations, because Main and Additional Values consist of three or two groups of sub-indicators,

$$MV = VSE + VSA + VPr \tag{2}$$

$$AV = VFn + VTr \tag{3}$$

Now that we know that each group of indicators consists of several sub-indicators, equations (2) and (3) can be written as follows:

$$MV = VSE + VSA + VPr = \sum_{i=1}^{12} SIMV_i,\ where\ 0 \leq SIMV_i \leq 1 \tag{4}$$

$$AV = VFn + VTr = \sum_{j=1}^{15} SIAV_i,\ where\ 0 \leq SIAV_i \leq 1 \tag{5}$$

Here, $SIMV_i$ and $SIAV_j$ represents 12 sub-indicators of the Main Values ($i = 1\ldots,12$) and 15 subindicators ($j = 1,\ldots,15$) of the Additional Values.

A matrix of Main (X axes) and Additional Values (Y axes) is created according to the results. The matrix is divided into nine fields represented by Z(i,j), (i,j=1,2,3). Depending on the final score, each geosite will fit into a certain field. For example, if a geosite's Main Values are 7 and additional are 4, the geosite will fit into the Z_{21} field (Figure 9).

High precision and applicability at several geolocalities (TOMIĆ et al., 2015; JONIĆ, 2018; ANTIĆ et al., 2019; VUKOVIĆ & ANTIĆ, 2019; TOMIĆ et al., 2020) were the main reasons to introduce the importance factor (Im) that has been presented by BOŽIĆ & TOMIĆ (2015). The importance factor (Im) is the mean value for each sub-indicator given by tourists. A few more papers concerning the use of M-GAM (PĂL & ALBERT, 2018; ANTIĆ

Table 2. Values given by experts and visitors for each sub-indicators in the GAM model.

Main Indicators / Sub-indicators	(GAM) Expert's estimation (0-1)				Im	(M-GAM) Total estimation			
	GS_1	GS_2	GS_3	GS_4		GS_1	GS_2	GS_3	GS_4
I Scientific/Educational values (VSE)						2.12	1.58	1.47	1,88
1. Rarity	0.75	0.50	0.25	0.25	0.89	0.67	0.45	0.22	0.22
2. Representativeness	1.00	0.75	0.75	1.00	0.79	0.79	0.59	0.59	0.79
3. Knowledge on geoscientific issues	0.50	0.25	0.50	0.50	0.45	0.23	0.11	0.23	0.23
4. Level of interpretation	0.50	0.50	0.50	0.75	0.85	0.43	0.43	0.43	0.64
II Scenic/Aesthetic (VSA)						2.22	1.72	2.79	2.96
5. Viewpoints	0.75	0.50	1.00	1.00	0.79	0.59	0.40	0.79	0.79
6. Surface	0.75	0.50	1.00	1.00	0.54	0.41	0.27	0.54	0.54
7. Surrounding landscape and nature	0.75	0.75	1.00	1.00	0.95	0.71	0.71	0.95	0.95
8. Environmental fitting of sites	0.75	0.50	0.75	1.00	0.68	0.51	0.34	0.51	0.68
III Protection (VPr)						1.8	1.31	1.90	2.09
9. Current condition	0.75	0.75	0.75	0.75	0.83	0.62	0.62	0.62	0.62
10. Protection level	0.75	0.25	0.75	1.00	0.76	0.57	0.19	0.57	0.76
11. Vulnerability	0.50	0.50	0.50	0.50	0.58	0.29	0.29	0.29	0.29
12. Suitable number of visitors	0.75	0.50	0.75	1.00	0.42	0.32	0.21	0.42	0.42
IV Functional values (VFn)						1.66	2.28	2.89	3.24
13. Accessibility	0.75	0.75	0.75	0.75	0.75	0.56	0.56	0.56	0.56
14. Additional natural values	0.25	0.50	0.75	1.00	0.71	0.18	0.36	0.53	0.71
15. Additional anthropogenic values	0.25	0.50	0.75	1.00	0.70	0.18	0.35	0.53	0.70
16. Vicinity of emissive centers	0.25	0.50	0.75	0.75	0.48	0.12	0.24	0.36	0.36
17. Vicinity of important road network	0.75	0.75	0.75	0.75	0.62	0.47	0.47	0.47	0.47
18. Additional functional values	0.25	0.50	0.75	0.75	0.59	0.15	0.30	0.44	0.44
V Touristic values (VTr)						3.9	1.66	4.67	5.78
19. Promotion	1.00	0.25	0.75	0.75	0.85	0.85	0.21	0.64	0.64
20. Organized visits	1.00	0.25	0.75	1.00	0.56	0.56	0.14	0.42	0.56
21. Vicinity of visitors centers	0.25	0.25	0.50	0.75	0.87	0.22	0.22	0.44	0.65
22. Interpretative panels	0.00	0.25	0.75	0.75	0.81	0	0.20	0.61	0.61
23. Number of visitors	0.75	0.25	0.50	1.00	0.43	0.32	0.11	0.22	0.43
24. Tourism infrastructure	0.75	0.25	0.75	1.00	0.73	0.55	0.18	0.55	0.73
25. Tour guide service	0.50	0.25	0.75	0.75	0.87	0.44	0.22	0.65	0.65
26. Hostelry service	0.50	0.25	0.75	1.00	0.73	0.37	0.18	0.55	0.73
27. Restaurant service	0.75	0.25	0.75	1.00	0.78	0.59	0.20	0.59	0.78

GS_1 – Devil's Town (Serbia), GS_2 – Sand pyramids (Bosnia and Herzegovina), GS_3 – Stob pyramids (Bulgaria), GS_4 – Melnik pyramids (Bulgaria)
Im – importance factor.

et al., 2020; BRATIĆ et al., 2020; TOMIĆ et al., 2021) have been published in the most recent few months.

The importance factor (Im) is defined, as:

$$Im = \frac{\sum_{k=1}^{k} Iv_k}{K} \tag{6}$$

Where Iv_k is the assessment/score of one visitor for each sub-indicator and K is the total number of visitors. Note that the Im parameter can have any value in the range from 0.00 to 1.00. Finally, the modified GAM equation is defined in the following form:

$$M - GAM = MV * AV \tag{7}$$

$$MV = \sum_{i=1}^{n} Im_i * MV_i \tag{8}$$

$$AV = \sum_{i=1}^{n} Im_j * AV_j \tag{9}$$

As it can be seen from the *M-GAM* equation, the value of the importance factor (*Im*), which is rated by visitors (for each sub-indicator separately) is multiplied with the value given by experts (also separately for each sub-indicator). This is done for each sub-indicator in the model. Therefore, the values of *M-GAM* sub-indicators are always less or equal to the *GAM* values (Table 2).

3. RESULTS AND DISCUSSION

The unique geomorphological phenomenon in Serbia, the Devil's Town, (GS_1), was being considered with respect to three similar localities on the Balkan Peninsula, the Sand pyramids (GS_2) in Bosnia and Herzegovina, and the Stob (GS_3) and Melnik pyramids (GS_4) in Bulgaria. Geosites were evaluated using the above mentioned methodology (M-GAM). Values for the Main indicators and sub-indicators are given in Table 2, whereas the final results of these values are presented in Table 3 and Figure 9.

According to the results obtained, Devil's Town (GS_1) displays the highest scientific/educative value of the analyzed geosites, being particularly emphasized by its representativeness. This could be explained by the high didactic and educational characteristics of the locality itself. The Melnik pyramids (GS_4) are also known by their representativeness due to features of the geosite. However, the Sand pyramids (GS_2) and Stob pyramids (GS_3) geosites are of significantly lower scientific value. The knowledge on their geoscientific issues has the lowest value within the analyzed sub-indicators of scientific value of all of the analyzed geosites. The lowest number of publications relates to the Sand pyramids (GS_2), while articles for the rest of geosites were commonly published in local publications, less commonly in regional and national journals. The Stob (GS_3) and Melnik pyramids (GS_4) also record low values for rarities, as both geosites are in Bulgaria in the circled area of 100 km.

Concerning scenic/aesthetic values, the Melnik pyramids (GS_4) exhibit the highest values due to the amazing landscape and beautiful natural scenery in the vicinity: a number of designated viewpoints, contrasting colours and shapes, as well as the overall appearance of the geosite. The Stob pyramids (GS_3) geosite has a lower aesthetic value in spite of the breathtaking panoramic view, plenty of easy accessible pathways and viewpoints and contrasting colour with the surrounding nature. The geosite Devil's Town (GS_1) is of exceptional scenic/aesthetic value regarding nature and its vicinity. The lowest value is ascribed to its spatial distribution in comparison with the area of other geosites (GS_4 and GS_3). The lowest aesthetic value within the analyzed geosites relates to the Sand pyramids (GS_2) due to a smaller area and a lesser number of landscape areas.

Considering protection, which is a very important indicator of the main values, only small differences were noted between these four geosites. The lowest level of protection goes to the Sand pyramids (1.31). Some higher values were exhibited at Devil's Town (1.80) and the Stob pyramids (1.90). The geolocality Melnik is reasonably the highest ranked (2.09) as it has been under protection much longer than the other three geosites. The biggest differences among the sub-indicators were recorded for the level of protection and accommodation capacities. The largest areas are occupied by the geosites Melnik (GS_4) and Stob (GS_3), hence their values are the highest. In contrast, the geolocality Sand pyramids (GS_2) covers the smallest area and thus displays the lowest value.

Considering the additional values, particularly the natural and anthropogenic ones, the best results were indicated by the geosite Melnik (GS_4). Being well-known for its natural values and surrounding settlements of rich cultural-historical heritage, Melnik (GS_4) displays the highest additional, natural and anthropogenic values. Stob pyramids (GS_3) are also surrounded by plenty of natural and anthropogenic values, whereas the remaining two geosites (GS_1 and GS_2) are less worthy due to their distance from other attractive tourist destinations. The vicinity of emissive centers is among the functional values of the lowest value in all of the analyzed geosites. However, some higher values

Table 3. Overall ranking of the analyzed geosites using M-GAM.

Values					
	Main		Additional		
	VSE+VSA+VPr	Σ	VFn+VTr	Σ	Field
GS_1	2.12+2.22+1.80	6.14	1.66+3.90	5.56	Z_{22}
GS_2	1.58+1.72+1.31	4.61	2.28+1.66	3.94	Z_{21}
GS_3	1.47+2.79+1.90	6.16	2.89+4.67	7.56	Z_{22}
GS_4	1,88+2,96+2,09	6,93	3,24+5,78	9,02	Z_{22}

GS_1 – Devil's Town (Serbia), GS_2 – Sand pyramids (Bosnia and Herzegovina), GS_3 – Stob pyramids (Bulgaria), GS_4 – Melnik pyramids (Bulgaria)

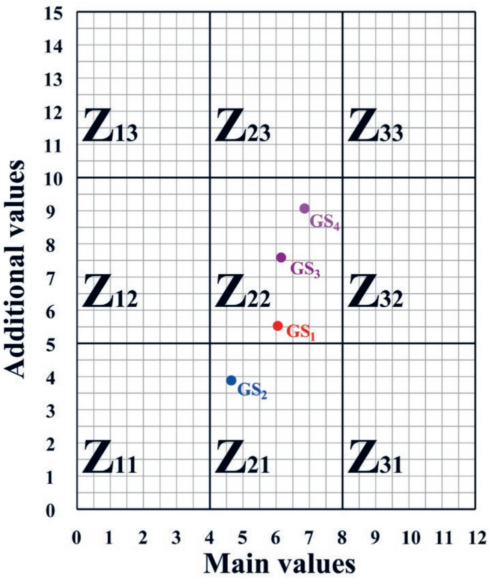

Figure 9. Position of evaluated geosites in M-GAM matrix.

were displayed by geosites Melnik and Stob in comparison with Devil's Town and the Sand pyramids. The important emissive centre in Melnik (GS_4) is the city of Sandanski, approximately 20 km distant. This city in Blagoevgrad Province is the third biggest city and one of the famous spas in Bulgaria. The nearest emissive centre to the Stob pyramids (GS_3) is Blagoevgrad, at about 15 km. Sarajevo, some 60 km away, is the nearest emissive centre to the Sand pyramids (GS_2). Finally, the cities of Niš and Kruševac, being about 90 km distant, are the nearest to Devil's Town.

Melnik (GS_4), has the highest touristic value among the analyzed geosites, being particularly noteworthy for its touristic infrastructure among the sub-indicators (designed long pedestrian pathways, resting places at viewpoints), hostelry and restaurant services placed next to the pyramids. However, the number of visitors is not in accordance with promotional activities, remaining insufficient and at a low level. Slightly lower touristic value displays Stob (GS_3), whereas the geosite Devil's Town (GS_1) remains far behind Melnik and Stob due to insufficient interpretative panels, the distance from visitor centers and hostelry services. The advantage of Devil's Town in comparison to the other analyzed localities is the significant level of promotional activities. The lowest touristic values exhibited by the Sand pyramids (GS_2) having low values of all the sub-indicators.

According to the final results for all the analyzed geosites, given in table 3, are the determined positions in M-GAM matrix (Fig. 9).

On the basis of the final results (Table 3) it could be concluded that in the future attention should be paid to the additional values at geosites GS_1 and GS_2. Sub-indicators obtained low values due to the distance from broadcasting centres as well as visitor centres, and the geosite lacked accommodation services, interpretative boards and additional functional values. In addition to these elements, there is a high level of sensitivity of geosites to natural and human interferences.

In spite of all the geo-tourist values that the site of the Devil's Town has, the manager of AD "Planinka" from Kuršumlija must be ready for the development of competition in the wider area, while at the same time tightening the criteria for assessing the load on the environment. This company must improve the quality of the resulting solutions, innovate procedures and learn to continue the improvement of activities and successful achievement in competitive surroundings (SÜTŐOVÁ et al., 2018).

4. SUMMARY AND CONCLUSION

It could be concluded that the highest differences within the analyzed geolocalities display touristic values that rely on tourism development in the country where the geosite is located and on tourist valorization of geosites. Sub-indicators from this group, such as promotion, organized visits, interpretative panels, tourism infrastructure, guidelines, accommodation and restaurant services, could be easily changed and improved by human activity and investment in tourism development.

According to the position of the evaluated geosites in the GEM matrix, along with the final results presented in Tables 2 and 3, the absolute domination of Melnik (GS_4) among the analyzed geosites is apparent. However, the inevitable upgrading of additional values for a better position in the matrix is necessary.

The Sand pyramids (GS_2) occupy the lowest position in the matrix, having significant main values, but unfortunately displaying the lowest additional values. This suggests the high potential of the Sand pyramids and direct progress in geotourism development with the improvement of additional values, particularly touristic ones.

Devil's Town (GS_1) is most similar to the Stob pyramids (GS_2) regarding the main values. Concerning the additional values, both geosites belong to the moderate level. Nevertheless, the Stob pyramids occupy a higher position in the matrix due to higher additional values. Thus, the appropriate increase of functional and touristic values would contribute to a better position in matrix.

Furthermore, the management of each geosite should focus on a specific market segment shaping and directing the development of the site towards the specific needs and preferences of tourism segments. Therefore, this research indicates what is important for the different segments when visiting a geosite so it can be used as a framework for tourism planning. Having said this, the management of each geosite should develop a tourism strategy depending on whether it intends to become a destination for mass tourism or to attract smaller specific tourism segments such as pure geotourists and thus base the development of a geosite according to their needs and preferences. In order to strike the right balance between the offer for general tourists and pure geotourists in the future, we should keep tourism development in a sustainable form, taking care of the protection of geosites and reducing the negative impact of tourism, which can be triggered by mass tourist visits.

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