

Article

Preliminary Assessment of the Geological and Mining Heritage of the Golden Quadrilateral (Metaliferi Mountains, Romania) as a Potential Geotourism Destination

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Abstract: The Metaliferi Mountains (Western Romania) are known worldwide as the richest gold region in Romania and hosts for numerous porphyry and epithermal deposits. In these mountains, mining for gold dates back to Roman and even pre-Roman times. The Golden Quadrilateral constitutes a remarkable example of an area having a significant geological and mining heritage. The main purposes of this work are to emphasize this heritage, to present, for the first time, an assessment of the geological and mining heritage of the Golden Quadrilateral as a possible geotourism destination, and to point out the important role that geotourism could have in the sustainable development of local communities. To achieve our goals, the features of thirteen sites are presented, and two geotourism itineraries are proposed. A quantitative assessment of the geosites' capacity to support scientific, educational, and geotourism/recreational uses indicates that the Golden Quadrilateral presents a high potential not only for scientific studies but, also, for enhancement of the public understanding of science; geotourism could be part of the development strategy of rural areas. The two museums (Gold Museum and Gold Mining Museum) can have an important contribution both to the geo-education of visitors and in promoting the sustainable development of the region.

Keywords: geoheritage; mining heritage; geotourism; sustainability; ore deposits; Golden Quadrilateral; Apuseni Mountains



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1. Introduction

Over the last three decades, a rapidly increasing number of studies focusing on geodiversity, geoheritage, and geotourism has been published (e.g., References [1–15]). Geodiversity is a term that was defined by Sharples [1,2] as “the range (or diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes”. The definition of this term has evolved over time, and it is now commonly used as “the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes” [7]. In 1996, Wimbledon [4] proposed the term of geosite to refer to “any site that contains significant geodiversity”. According to Brocx and Semeniuk [5], geoheritage encompasses the “features of geology, at all scales that are intrinsically important sites or culturally important sites offering information or insights into the evolution of the Earth”, concentrating on the diversity of minerals, rocks and fossils, and the petrogenetic indicators related to them. Geomorphological features (e.g., landforms) illustrating Earth and climate processes are also included in this concept. Mining heritage is a comprehensive term that includes anything related to active and inactive mining, “such as minerals and rocks that are being (or were) extracted, industrial facilities, historical documentation of old mines”, mining processes and technology, “and even mining communities’ stories and traditions” [10]. Mining heritage is viewed as being at the interface between geoheritage (georesource) and cultural heritage [16]. As regards the term geotourism, it is relatively new. Geotourism is

considered a geosite-based activity focused on geology and landscape and meant to promote geodiversity conservation and facilitate the understanding of Earth Sciences [17,18]. It is a form of tourism that contributes to the discovery of “geological peculiarities of the visited territories, combined with other natural and human resources” [19]. As for the inventory and quantitative assessment of the geosites, different methodologies have been proposed over the past two decades. Thus, there are methodologies that focus on the assessment of: geomorphosites (e.g., References [8,20,21]), geodiversity and geodiversity loess [22], the planning and management of the natural heritage sites as potential tourist attractions [23], geoheritage and geodiversity sites [10,11], etc.

Our study area is located in the Apuseni Mountains (Western Romania), namely in the Metaliferi Mountains (Metaliferi means Metalliferous in Romanian), an area with a significant geological and mining heritage. In Romania, a major step in direction of regulation in the domain of natural heritage was made in 1930 by the promulgation of Law no. 213/1930 for the protection of the natural monuments of Romania [24–26]. Since then, more and more natural areas have been protected. For instance, in 1935, the first natural park was declared in the Retezat Mountains (South Carpathians). The first Romanian natural monument of geological interest, established in 1938, was Detunata Goală [24,27], one of the protected areas presented in this work. Nowadays, the Romanian’s National Network of Protected Natural Areas contains 975 protected natural areas of national interest and 18 protected natural areas of international interest [28–30]. In Romania, a member state of the European Union, the legislation on natural protected areas reflects the transposition of the European legislation directives in the country’s legislation. The National Agency for the Protected Natural Areas (ANANP) provides the framework for the management of protected natural areas [29]. Likewise, the Romanian National Institute of Heritage (under the authority of the Ministry of Culture) is in charge, with the activities of inventory, protection, and enhancement of cultural heritage [31,32].

Considered an important part of heritage, in Europe, there are hundreds of tourist caves and tourist mines [33], some of them being visited by a huge number of tourists every year (e.g., Postojna Caves, Slovenia; Drach Caves, Spain; Castellana Caves, Italy; Wieliczka Salt Mine, Poland; Lewarde Mining History Centre, France; Grand-Hornu Mine, Belgium). In Romania, the most developed underground tourism is the tourism in the salt mines (salinas) (Salina Turda in Cluj County; Salina Praid in Harghita County, Salina Slănic in Prahova County, Salina Ocnele Mari in Vâlcea County, etc.), annually visited by hundreds of thousands of Romanians and foreign tourists. Less developed (but still with a large number of participants) is the tourism in caves, mostly of them included in protected areas (e.g., Bear’s Cave, Meziad Cave, and Scărișoara Cave in Apuseni Natural Park). Underground tourism within an ore deposit mine is possible only in one place, at Roșia Montană (Alba County), in a site that is described in this study.

While, in many countries of Europe, geotourism has been developing for more than two decades, it is just emerging in Romania. It can be said that a step in this direction was taken with the establishment (in 2004) of the “Hațeg Country Dinosaurus Geopark” (“Hațeg Geopark”), the only Romanian geopark included in the European Geoparks Network (EGN) and UNESCO Global Geoparks (UGGp) [34]. It is situated approximately 35 km southwest of our study area.

Known worldwide for their ore deposits and mineralogical diversity and having a high geological complexity, the Metaliferi Mountains have been studied for more than 250 years and still present a high scientific interest (e.g., References [35–48]).

Mining for gold in the area of the Metaliferi Mountains dates back to Roman and even pre-Roman times. There are historical and archaeological data that sustained the existence of mining activity long before the conquest of Dacia by Roman armies in AD 106 (during the rule of Trajan, the Roman emperor from A.D. 98 to 117) (e.g., References [31,32,38,49–52]). Late in the 19th century and early in the 20th century, the exploitation of gold and other precious metals in this region was highly intensified. It seems that the name of the Golden Quadrilateral (Patrulaterul Aurifer in Romanian) started to be used at the beginning of

the 20th century to emphasize the richness in the ore deposits of these mountains. At that time, the region was one of the main centers of mining and extraction of gold in Europe. The Golden Quadrilateral delimited the area containing the ore deposits, the corners of the quadrilateral represented by the following localities: Săcărâmb (in the south), Zlatna (in the east), Baia de Arieș (in the northeast), and Caraci (in the northwest) [39,40,49] This area is shown in Figure 1a,b (the area delimited by the orange full line).

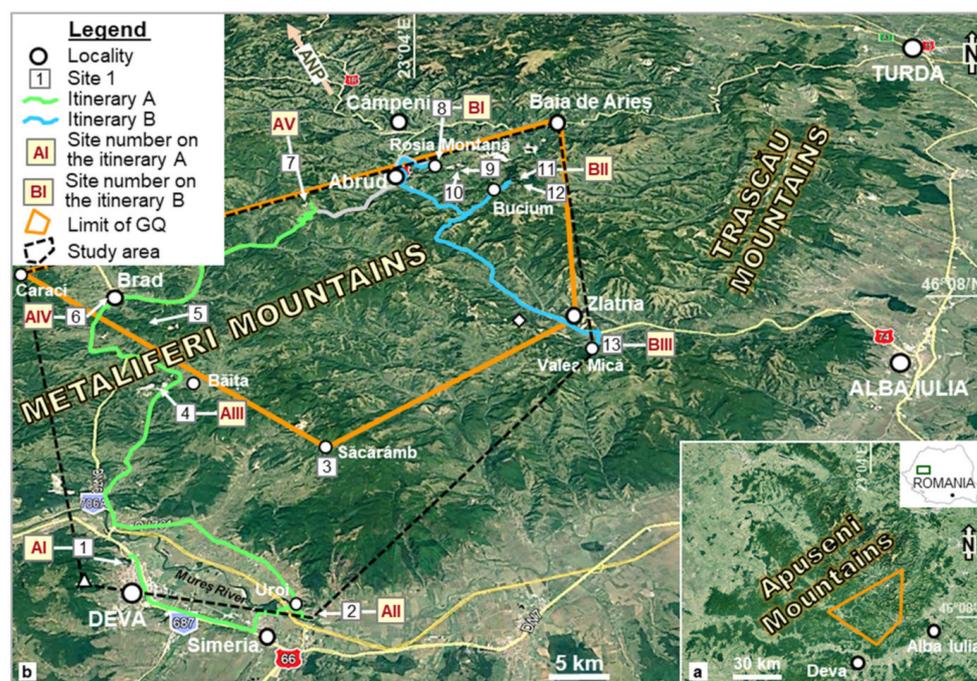


Figure 1. Two Google Earth images (© 2021 Google, Landsat/Copernicus): (a) Image of the Apuseni Mountains, indicating the limit of the Golden Quadrilateral (GQ). (b) Image showing the limit of the GQ in the Metaliferi Mountains, the study area, the location of the sites of geological and mining heritage interest (white squares), and the two proposed itineraries (itinerary A in green; itinerary B in blue). Site names: 1. Citadel Hill (Deva, HD). 2. Măgura Uroiului (Uroi; Simeria; HD). 3. Săcărâmb Village (Certejul de Sus, HD). 4. Limestones from Măgura Hill (Băița, HD). 5. “Roman Stairs” mine gallery (Ruda-Brad; HD). 6. Gold Museum (Brad, HD). 7. Vulcan Mountain (Buceș, HD). 8. Gold Mining Museum (Roșia Montană, AB). 9. Piatra Corbului (Roșia Montană, AB). 10. Piatra Despicață (Roșia Montană, AB). 11. Detunata Goală (Bucium; AB). 12. Detunata Flocoasă (Bucium; AB). 13. Limestones from Valea Mică (Valea Mică; AB). A white triangle indicates the location of the Deva ore deposit. A white rhomb indicates the location of the Fața Băii ore deposit. Abbreviations: AB—Alba County; ANP—Apuseni Natural Park; HD—Hunedoara County.

In the last two centuries, mining was one of the main sources of revenue for many people living in the region of the Metaliferi Mountains. However, in the 1990s began the decline of mining activities, which almost ceased in the 2000s.

The main purposes of this work are: (i) to highlight the important geological and mining heritage of the Golden Quadrilateral through inventory and a description of the characteristics and particularities of the sites, (ii) to present the first quantitative assessment of the geosites of the Golden Quadrilateral as a geotourism destination, and (iii) to promote geotourism in the Metaliferi Mountains as a potential source of sustainable development at the local and regional levels.

2. Study Area

The Metaliferi Mountains are part of the South Apuseni Mountains. In the north, the Crișul Alb River and the Arieș River delimit the Metaliferi Mountains from the North Apuseni Mountains. The Mureș River constitutes their southern and southeastern limits.

To the east, beyond the Ampoi Valley (the eastern limit of the Metaliferi Mountains), there are the Trascău Mountains. West of the Metaliferi Mountains, there are the Zarand Mountains. The regional geomorphology is characterized by hilly to mountainous reliefs. The elevation ranges from about 180–200 m above sea level (a.s.l.) (the Mureş Riverbed between Deva and Simeria) to 1348 m a.s.l. (in Vâlcoi Peak), and, further to the northeast, to 1437 m a.s.l. (in Poieniței Peak).

The Golden Quadrilateral, as it was initially imagined, is entirely enclosed in the Metaliferi Mountains area (Figure 1a,b). However, in this study, the extended meaning of the Golden Quadrilateral will be used, meaning a larger area resulting from the discovery of new ore deposits, including beyond the primary boundaries of the Golden Quadrilateral (\cong study area in Figure 1b). For instance, it is the case of the Deva porphyry Cu-Au deposit located immediately south of the Metaliferi Mountains (near the city of Deva) and related to the same Neogene magmatism as the ore deposits of the Golden Quadrilateral.

From a geological point of view, the Apuseni Mountains consist in Alpine tectonic units made predominantly of Pre-Mesozoic crystalline rocks overlain by Permian-Mesozoic sedimentary covers or of Jurassic ophiolites and calc-alkaline volcanic rocks and their associated sediments [45,53,54]. Late Cretaceous magmatites and Cenozoic igneous and sedimentary rocks are also well-developed.

Long-term, the Neogene magmatism of the South Apuseni Mountains has been interpreted as subduction-related magmatism [40,55]. During the last three decades, complex geological studies have shown that Neogene volcanism is post-collisional, generated in a transtensional regime [46,47,56]. In the South Apuseni Mountains, the magmatic activity started around 15 Ma with explosive activity (widespread volcano-sedimentary sequences), followed by intense volcano-intrusive activity (complex volcanic/subvolcanic structures) between 14.7 and 7.4 Ma [47,57]. To note, a volcanic episode related to the activity on the South Transylvanian Fault System took place in the Quaternary; it is represented by the occurrence of Măgura Uroiului Hill (see Section 4.1.1).

The Metaliferi Mountains are known worldwide as the richest metallogenic region of Romania and hosts for numerous Au-Ag-(Te) or Pb-Zn-Cu-(Au, Ag) epithermal and porphyry Cu-(Au-Mo) deposits [38,39,43,44,48,58]. These deposits are related to Neogene magmatism. The main metallogenic events took place in the Middle to Late Miocene. The ore deposits are distributed in four metallogenic fields: Brad-Săcărâmb, Zlatna-Stănița, Roșia Montană-Bucium, and Baia de Arieș.

Mining artifacts discovered in the area of the Apuseni Mountains suggest that the first mining works date back to Late Neolithic when gold was exploited at the surface (mainly alluvial gold) [31,32,38,49,52]. During the Roman Dacia (from 106 to 271–275 A.D.), in the Medieval period and, also, in the 18–20th centuries, the Metaliferi Mountains were one of the most important gold mining regions of Europe. The exploration and exploitation of precious metals boomed in the 18th and 19th centuries and continued to be important in the 20th century [59]. Eighty years ago, Ghițulescu and Socolescu [38] noted that, during that time, starting with the Roman period, the total quantity of extracted gold from the Metaliferi Mountains was about one thousand tonnes and that the mountains “still contain important quantity of gold”. To emphasize how important and developed mining was in this region, notes that, on the “Geological and mining map of the Metaliferi Mountains and surrounding areas”, scale 1:75,000 [38,60], 441 mine adits are localized, and a list of their name is presented. After World War II, the Metaliferi Mountains continue to be the main golden exploitation center of the country. Traces of old mining works can still be seen in many places in the Metaliferi Mountains. Mining almost stopped in the 1990s–2000s, mainly due to: (i) the lack of economic efficiency, (ii) mine exhaustion, and (iii) waiting for: new exploration works and results and new technologies for metal extraction.

3. Materials and Methods

The materials used for this paper include: (i) published literature related to the topic of this work and the study area; (ii) geological maps at different scales as Geological map

of Romania scale 1:1,000,000 [61], geological maps of Romania, scale: 1:50,000 [62–67]; (iii) Map of mineral resources of Romania, scale 1:1,000,000 (with representative areas and explanatory notes) [68]; (iv) topographic maps. The scientific literature review of relevant articles provided an essential part of information needed for presentation of the characteristics of the geological and mining heritage sites.

Regarding the methods used for this contribution, it is to note both the fieldwork realized strictly for the purposes of the study, and the fieldwork undertaken by author during the research for different topics (e.g., geological mapping; petrological, geochemical, metallogenic, and environmental studies) [69–71]. Field trip missions organized for preparations of several geological excursions in the South Apuseni Mountains and the excursions themselves represented an opportunity both to accumulate field data and to notice the interest of specialists and students in geosciences for this region (e.g., Reference [72]). In the area of each geosite included in this study, field observations, descriptions and measurements were performed. Besides the observations related to the geological and geomorphological characteristics of the geosites, during the fieldwork, for each geosite, were collected data regarding accessibility, vulnerability, integrity, use limitations, safety, observation conditions, scenery, associations with other values, proximity of recreational areas, deterioration of geological elements, etc. The paper author took all the photographs used in this work. Supplementary data were obtained by macroscopic and microscopic study of rock fragments collected during the field missions. Their mineralogical and petrographic characteristics were determined by optical microscopy; the obtained results have been integrated within the description of geosites (Section 4.1.1). As for the methodologies used in this study, it is to mention: the inventory and characterization of the sites of interest; the evaluation of geological and mining heritage of the sites; the proposal of two geoitineraries and description of the included sites; the qualitative assessment of the sites included in the two geoitineraries as potential sites for scientific, educational, and geotourism/recreational uses; the assessment of their degradation risk. The evaluation of the sites is based on field work and literature review; for designation category and year of designation of geosites, data furnished by National Agency for Natural Protected Areas (ANANP) [29,30]. The online databases of the National Heritage Institute [31] and the National Archaeological Registry [32] were also used in this study; data provided by National Institute of Statistics were used too. For the sites included in the two proposed geoitineraries a description, emphasizing their particularities, is presented.

As it was mentioned in Section 1 (Introduction), for the inventory and quantitative assessment of the geosites, different methodologies have been proposed (e.g., References [8–11,22,23]). Due to the fact that Brillha methods [10,11] are applicable both to geological heritage and the geodiversity sites, they are used in this study. Besides, at the beginning of this research, for the first studied geosites (field observations and information), I used criteria and indicators according with these methods. Later, during the fieldwork for the rest of geosites, I continued to use the same criteria and indicators in order to have a uniform set of data.

The quantitative assessment of the geosites consists in the numerical evaluation of the sites' capacity to support scientific, educational, and geotourism/recreational uses and in quantitative assessment of the sites' degradation risk [10,11]. These evaluations are based on specific criteria; each criterion is characterized by three or four indicators quantified by a numerical parameter (a value accorded of the selected indicator). Each criterion has been assigned a weight (%). The final score for a criterion is obtained by multiplying the value of selected indicator with correspondent weight of the criterion. The sum of the final values of specific criteria gives the final score of potential uses and degradation risk of a site. Thus, quantitative assessment of the geosites' capacity to support educational use is based on twelve criteria. Quantitative assessment of the geosites' capacity to support geotourism/recreational use is based on thirteen criteria. To note that the first ten criteria of the two potential uses are the same, namely: vulnerability, accessibility, use limitations, safety, logistics, density of population, association with other values, scenery, uniqueness, and observation conditions. The two other criteria of potential educational

use are didactic potential and geological diversity. The three other criteria for potential geotourism/recreational use are: interpretative potential, economic level, and proximity of recreational areas. Each criterion is ranked with 1, 2, 3, or 4 points (according to the value of the selected indicator); each criterion has been assigned a weight (%). For more details, see Section 4.2. During this work, a particular attention was paid to the evaluation of the sites for geotourism, and educational use. In this regard, some other criteria were taken on consideration as well [8,9,13,15,73].

4. Results

4.1. Inventory of Geological and Mining Heritage of the Study Area

The natural protected areas of national relevance of Romania are divided into five categories: scientific reserves, national parks, nature reserves, natural monuments, and natural parks [29]. Based on detailed field investigations and the literature review, an inventory of the geological and mining heritage sites located in the studied area has been realized. The obtained results are summarized in Table 1. In this table, for each site, the following elements are presented: site number, site location (locality and GPS coordinates), main features, a short description, and potential values. The location of each site is shown in Figure 1b. The inventory contains nine geosites of national relevance as follows: five nature reserves and four natural monuments. For these sites, the designation category and year of designation are also indicated (Table 1).

Table 1. Inventory and characteristics of the geological and mining heritage sites in the Golden Quadrilateral (Metaliferi Mountains).

Site No	Site Name	Locality /County *	GPS Coordinates	Main Features	Short Description	Value **	Designation	Year
1	Dealul Cetății Deva (Citadel Hill)	Deva /HD	45°53'21" N 22°53'48" E	Landscape, magmatism, petrology, panoramic view	A Miocene subvolcanic body of andesites and a 13th century fortress built at the upper part of it; Medieval architectural ensemble, archaeological site	S, E, T, A/H, C	Nature Reserve	1954
2	Măgura Uroiului	Uroi; Simeria; Rapoltu Mare/HD	45°51'39" N 23°02'39" E	Type locality (mineralogy locality), petrology, volcanic landform	Quaternary volcanic dome of alkaline rocks (trachyandesites); type locality for two minerals; archaeological site	S, E, T, A/H	Nature Reserve	1988
3	Săcărâmb Village	Certejul de Sus/HD	45°58'25" N 23°02'12" E	Type locality, mineralogy, ore deposit, mining heritage	Old mining locality (nearly 250 years of continuous mining activity); Neogene Au-Ag-Te epithermal deposit; type locality for eight minerals	S, E, M, C, H, T	-	-
4	Limestones from Măgura Hill	Băita /HD	46°01'48" N 22°52'34" E	Stratigraphy, sedimentary processes, speleology	Late Jurassic sedimentary rocks (Tithonian reef limestones on Oxfordian–Kimmeridgian calcareous breccia); dolines and caves; cave habitations (archaeological site)	S, E, A/H, T	Nature Reserve	1988

Table 1. Cont.

Site No	Site Name	Locality /County *	GPS Coordinates	Main Features	Short Description	Value **	Designation	Year
5	“Roman Stairs” Mine Gallery	Ruda-Brad; Brad /HD	46°05'36" N 22°50'37" E	Mining heritage, history of mining	Mining heritage from Roman period in Dacia (2nd to 3rd centuries A.D.); mining industrial heritage, archaeological site	S, E, M, A/H, C	-	-
6	Gold Museum	Brad /HD	46°07'44" N 22°47'28" E	Mineralogy, metallogeny, ore deposits, history of mining	Collections: exceptional specimens of minerals and rocks (most of them from gold mines of Romania); hundreds of native gold and gold-bearing samples; mining tools; mining-related documents	S, E, M, A/H, C, T	-	-
7	Vulcan Mountain	Buceş /HD	46°14'18" N 22°57'44" E	Geomorphology, stratigraphy, tectonics, paleontology	Kimmeridgian–Berriasian massive limestones on Hauterivian–Lower Aptian flysch deposits; gravitational nappe, fossils, dolines, talus deposit (see Section 4.1.1)	S, E, T	Nature Reserve	1978
8	Gold Mining Museum	Roşia Montană Village /AB	46°18'15" N 23°06'52" E	Mining and mining industrial heritage, archaeological/historical heritage	In Roşia Montană (ancient Alburnus Maior), mining activities are known since Antiquity. Museum consists in: an underground part (Roman galleries) and an open air part (equipment for mining and ore processing, archaeological vestiges)	S, E, M, A/H, C, T	-	-
9	Piatra Corbului	Roşia Montană com-mune /AB	46°17'50" N 23°08'01" E	Endogenous and exogenous processes	Named the Raven’s Rock (in Romanian) due to the fact that its form resembles a crow’s head, the magmatic rocks occur in the area of the Roşia Montană ore deposit	S, E, T	Natural Monument	1999
10	Piatra Despicață	Roşia Montană com-mune /AB	46°17'51" N 23°07'40" E	A huge exotic block of magmatic rocks	A legend says that a giant carrying the block over the Apuseni Mts., dropped it right there, where it is now	S, T, C	Natural Monument	1999
11	Detunata Goală	Bucium /AB	46°16'38" N 23°10'53" E	Scenic volcanic landform, history of geology	Neogene basaltic andesites occurring as spectacular columns that dominate the landscape of the area; first declared natural monument of geological interest in Romania	S, E, T, C	Natural Monument	1938

Table 1. Cont.

Site No	Site Name	Locality /County *	GPS Coordinates	Main Features	Short Description	Value **	Designation	Year
12	Detunata Flocoasă	Bucium /AB	46°16'01" N 23°12'05" E	Volcanic processes, mineralogy, petrology	The same main features as site no. 11, but this one is more covered by vegetation	S, E, T, C	Natural Monument	1968
13	Limestones from Valea Mică	Valea Mică; Zlatna /AB	46°04'47" N 23°16'38" E	Tectonics, stratigraphy, sedimentary klippes (olistoliths)	Imposing white block (steep cliffs) of Mesozoic sedimentary rocks detached from a carbonate platform; cave	S, E, T, C	Nature Reserve	1994

* County: AB—Alba; HD—Hunedoara. ** Potential values [10,11]: S—scientific; E—educational; T—tourism; M—mining heritage; A/H—archaeological/historical; C—cultural.

In addition to the geosites from Table 1, in the Metaliferi Mountains, there are a few more natural protected areas (sites of geological and/or geomorphological significance). They are not included in this work, because they are located in the south–southeast part of the Metaliferi Mountains, outside of the considered limit of the Golden Quadrilateral.

The aspects regarding the biodiversity of the natural area are not discussed in this paper. Besides the nine geosites from Table 1, in this inventory, I also introduced:

- (i) The village of Săcărâmb (former Nagyág) (site no. 3 in Table 1 and Figure 1b), due to its importance for mining history not only of the Apuseni Mountains but, also, of Europe. Săcărâmb is an epithermal Au-Ag-tellurides ore deposit, world-famous for its richness in precious minerals and, especially, for the very high contents in gold and tellurides. The ore deposit was discovered in 1740s [38,44,49], and since then, the Săcărâmb mines have been in production for over 250 years. The mining activity ceased in 2006. Săcărâmb is the type locality for eight minerals (see below). Figure S1a shows the location of the Săcărâmb Village in an area with volcanic structures of Neogene age. An image taken in this village is presented in Figure S1b, in which, in the foreground, a dry stone fence made of andesites (the main volcanic rock occurring in this area) can be seen. This construction technique, used in some of villages in the Apuseni Mountains, gives a special charm to the villages and should be preserved;
- (ii) The “Roman Stairs” Mine Gallery (site no. 5 in Table 1 and Figure 1b), an important mining heritage from Roman period in Dacia (2nd to 3rd centuries A.D.). At that time, Brad area was a very famous mining center for gold in Europe ([38] (pp. 394–396); [49] (pp. 106–109)). The adit of the Roman mine (Figure S2) is located on the left slope of Ruda Valley (a right tributary of the Luncoiul Stream), upstream of the village of Ruda-Brad. The mine was dug by hand (mainly with hammers and chisels) using the stairs method for the exploitation of the deeper part of the ore deposit. The “Roman Stairs” mine gallery is on the list of Historical Monuments of Romania (archaeological site) [31]. According to the Annex 3 of the Law no. 5/2000 [28], it is also a cultural heritage (historic monument of exceptional value), category: industrial architecture (from Roman times);
- (iii) The Gold Museum in Brad Town, Hunedoara County (site no. 6 in Table 1), which is considered an important ex situ geodiversity site [74] containing mineral specimens, mining tools and documentation that have heritage value;
- (iv) The Gold Mining Museum in Roșia Montană, Alba County (site no. 8 in Table 1), a site of both mining and industrial architecture heritage, and historical and archaeological heritage.

More data about each of the two museums are presented in Section 4.1.1.

As it is shown in Table 1, each site present at least three of the six values (scientific, educational, tourism, mining heritage, archaeological and/or historical, and cultural) taken into account in order to evaluate them.

It is important to point out that the Metaliferi Mountains is a region where new minerals have been discovered. In order to illustrate the relevance of the studied area for

the history of mineralogy, Table 2 shows the list of minerals discovered for the first time in the world, in the area of Golden Quadrilateral. For this table I used data from the list of minerals presented by International Mineralogical Association (IMA) [75] and also data from literature (for type localities) [44,76–82]. Location of each type locality is indicated in Figure 1b.

Table 2. Minerals discovered, for the first time in the world, in the area of Golden Quadrilateral. Data according to IMA (International Mineralogical Association) list of minerals [75] and literature.

Mineral	Chemical Formula	Year *	Type Locality	County **
pseudobrookite	$(\text{Fe}^{3+}_2\text{Ti})\text{O}_5$	1878 (1988 r.d.) ***	Uroi	HD
magnesio-fluoro-hastingsite	$\text{NaCa}_2(\text{Mg}_4\text{Fe}^{3+})(\text{Si}_6\text{Al}_2)\text{O}_{22}\text{F}_2$	2005 (2012 r.d.)	Uroi	HD
alabandite	MnS	1832	Săcărâmb	HD
nagyágite	$[\text{Pb}_3(\text{Pb,Sb})_3\text{S}_6](\text{Au,Te})_3$	1845	Săcărâmb	HD
petzite	Ag_3AuTe_2	1845	Săcărâmb	HD
krennerite	Au_3AgTe_8	1877	Săcărâmb	HD
muthmannite	AuAgTe_2	1911	Săcărâmb	HD
stützite	$\text{Ag}_{5-x}\text{Te}_3$ ($x = 0.24 - 0.36$)	1951 (1964 r.d.)	Săcărâmb	HD
krautite	$\text{Mn}(\text{AsO}_3\text{OH})\cdot\text{H}_2\text{O}$	1974	Săcărâmb	HD
museumite	$[\text{Pb}_2(\text{Pb,Sb})_2\text{S}_8][(\text{Te,Au})_2]$	2003	Săcărâmb	HD
alburnite	$\text{Ag}_8\text{GeTe}_2\text{S}_4$	2012	Roşia Montană	AB
sylvanite	AgAuTe_4	1835	Baia de Arieş	AB
tellurium	Te	1802	Faţa Băii	AB
tellurite	TeO_2	1845	Faţa Băii	AB

Notes: * Year of original description for minerals discovered before the establishment of IMA in 1958; year in which the mineral was approved by IMA for minerals discovered after 1958. ** County: AB—Alba, HD—Hunedoara; *** (1988 r.d.)—redefined in 1988. For location of the type localities, see Figure 1b.

Therefore, from a scientific point of view, localities as Uroi, Săcărâmb, Roşia Montană (Table 1), are highly significant on an international scale, each of them been type locality for one or more of minerals listed in Table 2. It is to notice that eight of the fourteen minerals from Table 2 were discovered in the 19th century, fact that shows both the importance and the degree of development of mining (including the associated research work), at that time in this part of Europe. Spectacular specimens of minerals coming from the Golden Quadrilateral are exhibited in museums around the world.

In order to emphasize the characteristics and particularities of geological and mining sites in the study area and also to consider them in a possible sequence of visiting, here below two geotourism itineraries are proposed.

4.1.1. Two Proposed Itineraries

The two itineraries connect a series of sites of geological and mining interest; each site is briefly described. The itineraries are shown in Figure 1b as itinerary A (green line) and itinerary B (blue line). It is to note that these are two suggestions: the tourists may choose to follow only one of it or they could combine the visit of sites of these itineraries with other sites of interest. The participants at the two itineraries will see beautiful landscapes, volcanic and subvolcanic rocks, spectacular columns of basaltic andesites, olistoliths, reef limestones, rare minerals, etc. They will also visit two museums, the Gold Museum (in town of Brad, Hunedoara County) and the Gold Mining Museum (in Roşia Montană Village, Alba County), and a medieval fortress in Deva City (Hunedoara County). For

diverse reasons, some of the sites shown in Table 1 are not included in these itineraries: it takes too much time to reach the site (Săcărâmb Village, Piatra Corbului, Piatra Despiciată); the site is not yet open to visitors (“Roman Stairs” Mine Gallery; the municipality of Brad Town plans to open it); the site (Detunata Goală, included in one of the itineraries) is less easy to access as is another site (Detunata Flocoasă) with which it has common features.

With the aim of facilitating the preparation of an excursion to visit the sites included in the itineraries, I realized schematic presentations showing the two itineraries (Figure 2a) represented as in Figure 1b, and the distances between sites in correlation with time (time spent on place and travel time) (Figure 2b). The values for time are approximate values that depend on the visitor (or group of visitors) intention for time spent on place, the necessary time to attend a site, etc. The walk distance is the walk distance from travel vehicle (parking place) to the site; it does not include the walk distance within or around the site and neither the walk distance to return to the vehicle. Similarly, the walk time is just the time need to reach the site of interest.

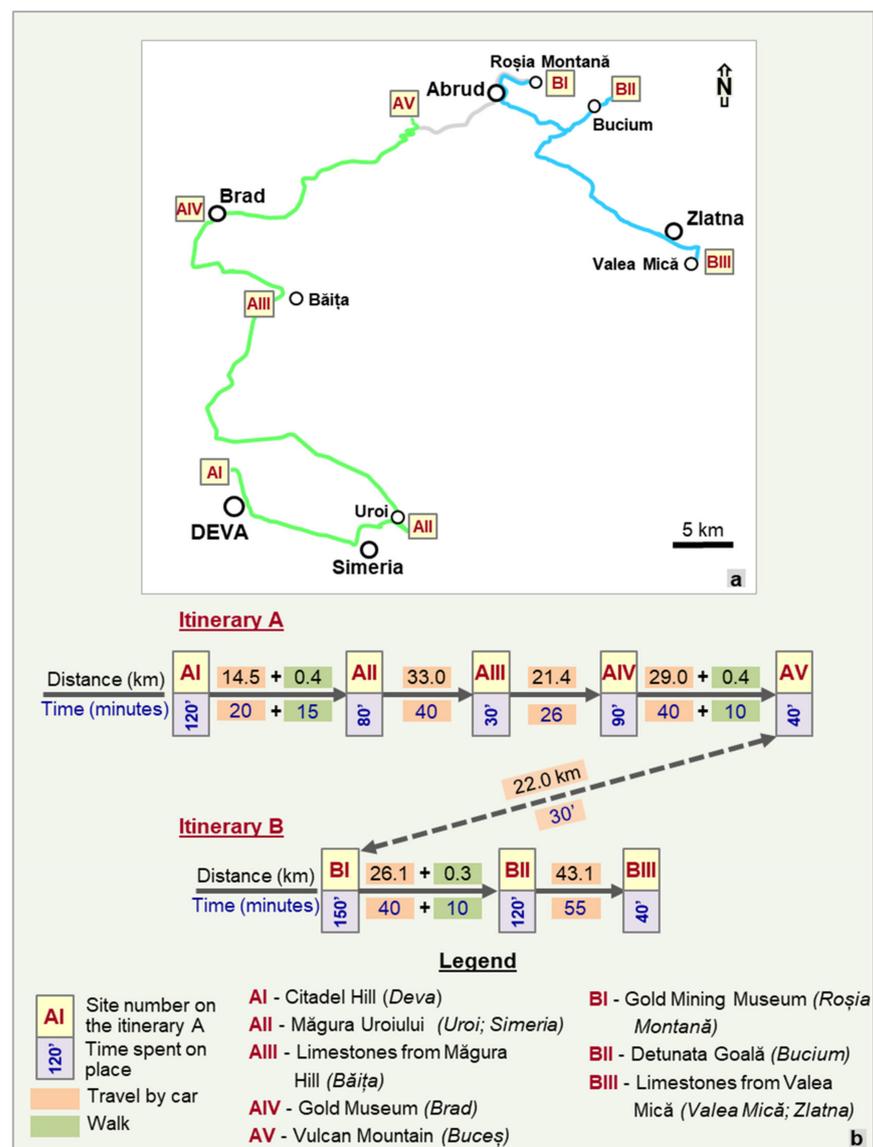


Figure 2. Schematic representations of the two proposed itineraries showing: (a) the two itineraries drawn as in Figure 1b (itinerary A in green; itinerary B in blue) and (b) the distances between sites in correlation with time (spent on place, traveled by car, walk time). For the location of the sites, see also Figure 1b and Table 1.

In this work, the schema from Figure 2b was used mainly in the quantitative assessment of the sites and, therefore, including in the assessment of the geological and mining heritage of Golden Quadrilateral as potential tourism destination.

- First Itinerary (Itinerary A—Day 1)

First proposed itinerary contains five of the sites of Table 1, noted here (and on the Figures 1b and 2) from AI to AV, as follows: AI. Citadel Hill (Deva); AII. Măgura Uroiului (Uroi, Simeria); AIII. Limestones from Măgura Hill (Băița); AIV. Gold Museum (Brad); AV. Vulcan Mountain (Buceș). Therefore, the itinerary includes four geosites and a museum. The length of the itinerary is about 100 km; all the sites are easy to access.

AI. Citadel Hill

Location: Deva City; Hunedoara County

Citadel Hill is a remarkable landform in this area (Figure 3a–c) whose altitude is of 369.6 m above sea level (a.s.l). At the bottom of the hill, the altitude is of around 200 m a.s.l. The hill is a subvolcanic body consisting of andesites. The rock has a porphyritic texture (Figure 3d). Phenocrysts are represented by plagioclase, hornblende and biotite occurring in a micro-cryptocrystalline groundmass [72]. Intrusive breccias occur at the contact between the andesitic body and the Upper Cretaceous sedimentary rocks (sandstones, conglomerates, etc.). According to the radiometric age data (K-Ar method) obtained on these andesites (11.85 ± 0.48 Ma), [47], their age is Miocene.

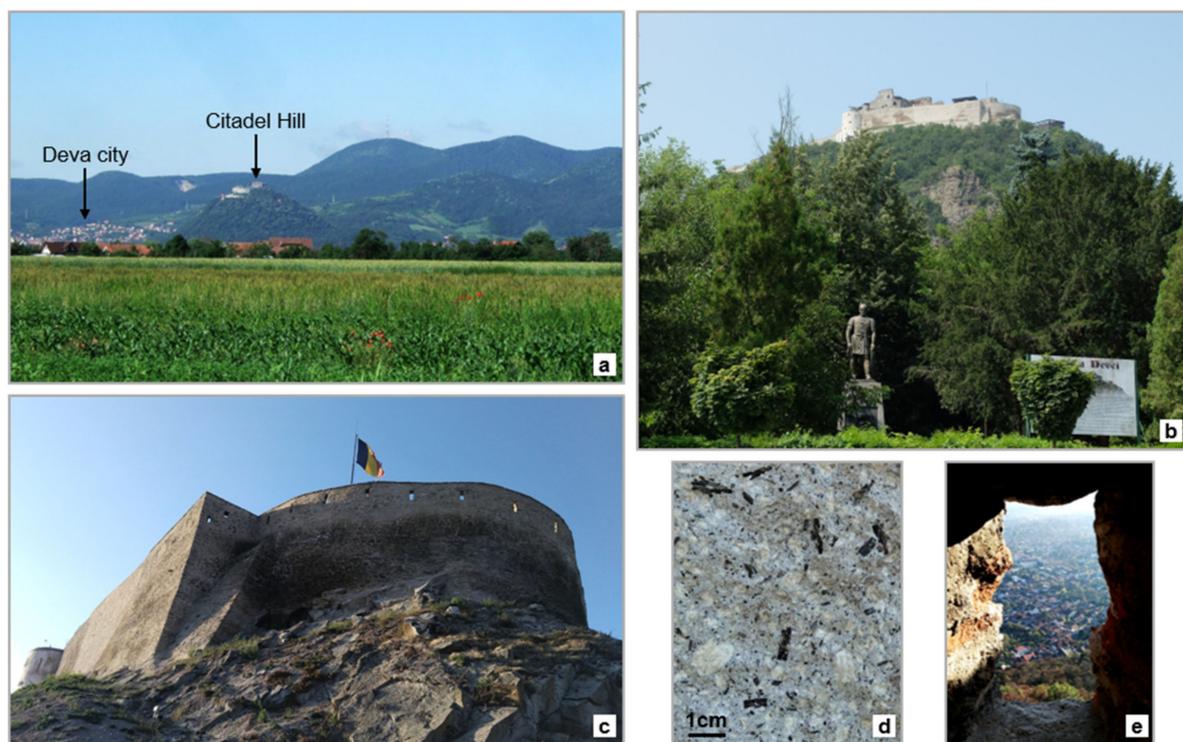


Figure 3. Citadel Hill (Deva City; Hunedoara County). (a) Panoramic view looking south-west, showing the Citadel Hill and its location in the area of Deva City. (b) Image of the Neogene subvolcanic body with the Deva Fortress at the upper part of it. View taken from the historical part of the city. In the foreground, at the bottom of the hill, a sculpture of Decebalus, the last king of Dacia (from A.D. 87 to 106). (c) The Medieval fortress built on andesites. (d) A close-up view of the andesites from Figure 3c, showing their porphyritic texture due to the presence of phenocrysts of plagioclase (light grey crystals) and amphibole (rare, biotite) (black crystals) in a micro-cryptocrystalline groundmass (grey). (e) Deva City seen through an embrasure in the wall of the fortress (view to the west).

At the upper part of the hill, there is a fortress (Deva Fortress) (Figure 3a–c,e) built in the 13th century (first documented in 1269, under the name of *Castrum Deva*). The

architectural ensemble is a historical heritage of national interest [28,31,32]. To note that an archaeological site (prehistoric settlements), located on the southern slope of the hill, is also on the list of historical monuments of national interest. At the foot of the hill, the tourists can visit the Museum of Dacian and Roman Civilisation housed in a castle (Bethlen Castle or Magna Curia) built in 17th century, a historical monument of national interest too [31,32].

Outcrops of andesites can be observed both on the slopes of the hill and inside the fortress; the fortress walls also contain blocks of andesites. Xenoliths of sedimentary and metamorphic rocks can be seen in the andesites occurring both on the side of the road that go up to the fortress, and inside the fortress.

Tourists can reach the fortress not only by walking; a cable car can be taken up to the fortress too. Once reached the upper part of the hill, beautiful panoramic views open up to them: the Mureş River and the southern end of the Metaliferi Mountains (Figure S3, the city of Deva (Figure 3e), the shape of the Măgura Uroiului hill, etc.

AII. Măgura Uroiului

Location: Uroi Village, Simeria Town; Rapoltu Mare commune; Hunedoara County

Situated not far to the southeastern end of the Brad-Săcărâmb metallogenic district, at a straight-line distance of 12 km from the above-mentioned village of Săcărâmb, Măgura Uroiului is a nature reserve (Table 1). It is a reddish hill that can be seen from far away (Figure 4a). From the level of the county road (see green line, at the lower part of the hill, in Figure 1b) where the altitude is of around 200 m a.s.l., up to the top of the hill (altitude 388.6 m a.s.l.) there is an altitude difference of about 188 m. A trail facilitates the access to the top of the hill from where the tourists can enjoy the great all-around view of the area.



Figure 4. Two images of the Măgura Uroiului geosite (Uroi Village, Simeria Town; Rapoltu Mare commune; Hunedoara County) taken after a spring rain. (a) Eastward view of the Măgura Uroiului volcanic dome consisting in alkaline rocks (quartz trachyandesites). Age of rocks: Pleistocene [57]. (b) Măgura Uroiului Hill, view from the south. In the foreground, a block of quartz trachyandesite (approximately 3 m in width/1.5 m in height).

Măgura Uroiului is a volcanic dome consisting in alkaline rocks (quartz trachyandesites) resulting from lava flows and some pyroclastic explosions [83]. The quartz trachyandesites were dated at 1.6 ± 0.10 Ma (K-Ar method) [57]; therefore, their age is Quaternary (Pleistocene). The quartz trachyandesites contain micro-phenocrysts of plagioclase, pyroxene, amphibole, biotite, quartz and hematite, in a microcrystalline groundmass with the same composition. Apatite, zircon, ilmenite and pseudobrookite are the main accessory minerals. Xenoliths of magmatic, metamorphic and sedimentary rocks are also present [84]. As a result of post-volcanic processes, the lavas were intensely oxidated resulting two main facies of different colors: one greyish and another reddish. Figure 4b shows these reddish lavas (with hematite), occurring on the steep slope of the hill, and, in the foreground, a block of them.

The first research on the rocks of Măgura Uroiului Hill has been made more than a century and a half ago (in 1863), by von Hauer and Stache [35] who identified them as

being trachyandesites. Fifteen years later, the mineralogical study of Koch [77] led to the discovery of a new mineral—the pseudobrookite $[\text{Fe}_2\text{O}_3]$, Uroi becoming the type locality for this mineral. At the beginning of 21st century, Uroi also became the type locality for the mineral magnesio-fluoro-hastingsite $(\text{NaCa}_2(\text{Mg}_4\text{Fe}^{3+})(\text{Si}_6\text{Al}_2)\text{O}_{22}\text{F}_2)$, a mineral discovered by Bojar and Walter [81]. It was approved by IMA in 2005 and redefined in 2012 (Table 2).

Therefore, Măgura Uroiului is a geosite containing an important mineralogical and petrological heritage. It is still of interest for specialists in geosciences (e.g., mineralogy, petrology, volcanology, tectonics, geomorphology).

It is noteworthy that the steep wall visible on the southern slope of the hill (Figure 4b) is the result of a stone quarry dating back to the Roman period, now on the list of historical monuments of Romania. Moreover, Măgura Uroiului is on this list as an archaeological site of national relevance, consisting of: (a) settlements from Neolithic, Early Bronze Age, and Hallstatt period; (b) Roman stone quarry [31,85].

AIII. Limestones from Măgura Hill

Location: Băița commune; Hunedoara County

This geosite is located at the confluence of the Căianul Stream (right tributary of the Mureș River), with its right tributary, Ormindea Brook. Figure 5 presents two photos taken in the zone of limestones from Măgura Hill geosite. Figure 5a shows Măgura Hill consisting in Late Jurassic sedimentary rocks. Almost entire hill contains Tithonian reef limestones; only at the bottom of the hill, within the confluence zone, occur red calcareous breccias of Oxfordian–Kimmeridgian age [54]. The same succession of sedimentary rocks was found in the hill situated just across the road from Măgura Hill (Figure 5b).

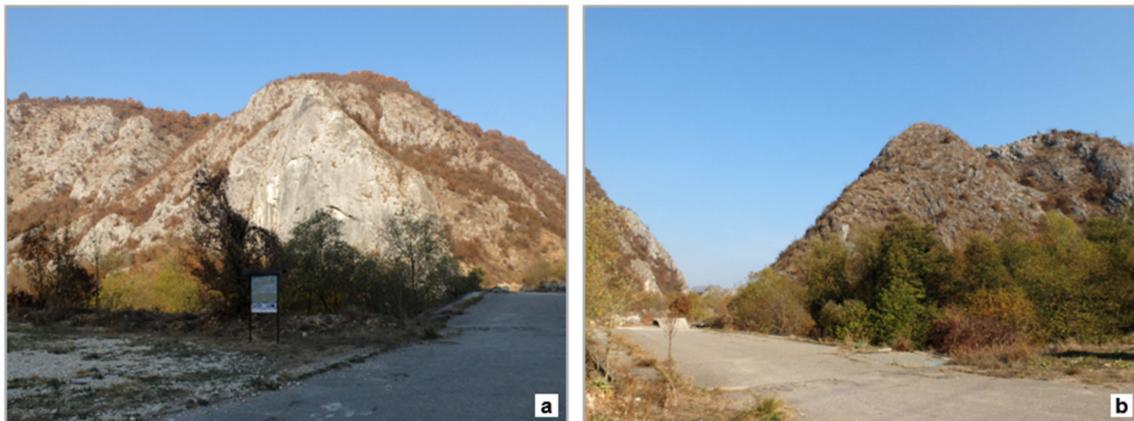


Figure 5. Photographs taken in the zone of the limestones from the Măgura Hill geosite (Băița commune, Hunedoara County). (a) Măgura Hill consisting in Late Jurassic sedimentary rocks: mainly Tithonian reef limestones with some calcareous breccia, of Oxfordian–Kimmeridgian age, at the bottom of the hillslope [62]. (b) A smaller hill containing the same succession of Late Jurassic rocks, occurring right across the road from the hill from Figure 5a.

Karst landforms, as dolines and caves, developed in these hills, including in the Măgura Băița Hill (altitude 662.3 m a.s.l.) situated in the same area, on the left side of the Căianul Stream. Cave habitations (dating from Bronze Age, Hallstatt, and Medieval period) were found in Măgura Hill. They constitute an archaeological site that is on the list of historical heritage of local interest [31,32].

AIV. Gold Museum

Location: Brad Town; Hunedoara County

Situated in the middle of the town of Brad and offering parking spaces right in front of it, this museum is easy to access. The history of the museum collections goes back to the end of the 19th century. It seems that approximately (about) 125 years ago, an Austrian engineer working in the Brad area started to collect samples of exceptional specimens of minerals and rocks, mainly from the Brad area but also from other areas of the Metaliferi

Mountains. It is considered that the museum was founded in 1912 [44,52]. Nowadays, the museum collections contain more than 2000 pieces; hundreds of them are of native gold or gold-bearing samples. The vast majority of samples are from the Golden Quadrilateral and other areas of Romania (e.g., from the Oaş–Gutâi Mountains, Northern Romania). There are also samples from Europe and other continents. The collections contain many rare samples of native gold and gold mineralizations with astonishing crystallographic forms. Three examples of native gold exposed in museum are presented in Figure 6a–c. The Gold Museum detains a collection of minerals (mainly tellurides) including minerals discovered for the first time in the world on the present territory of Romania (e.g., sylvanite, nagyágite, krennerite). I consider the collections of minerals and mineralized rocks of this museum an *ex situ* geodiversity site [74]. Among the samples of this museum, some have a heritage value (mineralogical heritage). Objects like tools used in mining, old documents, also owned by this museum, may be considered as part of this *ex situ* heritage too.



Figure 6. Examples of gold and gold-bearing samples in the Gold Museum (Brad Town, Hunedoara County). (a) Fine crystals of gold associated with sphalerite on quartz. (b) Lamellar gold. (c) An elongated wire of gold grown on quartz. The white line represents 1 cm.

AV. Vulcan Mountain

Location: Buceș commune; Hunedoara County

This site is located on the limit of Hunedoara County with Alba County. Vulcan Mountain is a geomorphological landmark that, in a sunny day, can be seen as far as from the Deva Fortress. Vulcan Mountain (vulcan meaning volcano in Romanian), does not consist of volcanic rocks as it could be imagined. Maybe the fact that this impressive landform (Figure 7a,b) has an altitude of 1257.4 m a.s.l., higher than the altitude of the real volcanic structures occurring to the south (in the Brad–Stănița zone), could be the reason why people named it volcano. In fact, the mountain is made of Mesozoic sedimentary rocks, with the particularity that older rocks (massive limestones of Kimmeridgian–Berriasian age) occur at the top of the mountain and the younger ones (flysch deposits of Hauterivian–Lower Aptian age and even Maastrichtian age, at its northeast limit) at the lower part (Figure 7b). It has been long debated if these massive limestones represent an olistolith or not. Taking into account the stratigraphic and tectonic data, and bearing in mind the large volume of the Kimmeridgian–Berriasian limestones, Bordea and Constantinescu [63] and Bordea [86] considered them as representing a rest of a gravitational nappe. To note the presence of fossils (ammonites, belemnites, etc.) within blocks of red limestones (Oxfordian in age) found at the base of the massive limestones, on the northern slope of the mountain [87]. Talus deposits can be seen at the lower part of the cliff faces (Figure 7b); dolines were formed on the top of the mountain.

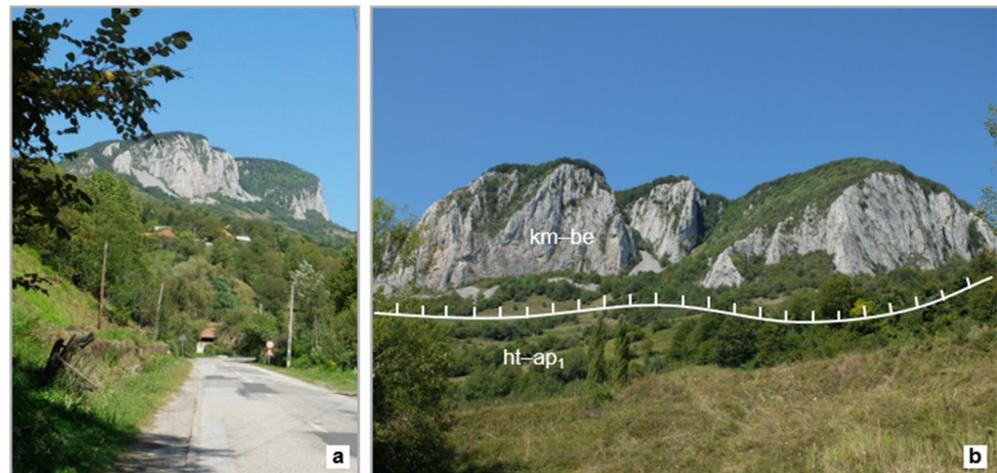


Figure 7. Vulcan Mountain geosite (Buceș commune, Hunedoara County). (a) Vulcan Mountain view from Buceș-Vulcan Village looking north–northeast. (b) Photo of Vulcan Mountain, seen from the southeast, showing the age of rocks and the overthrust between the Kimmeridgian–Berriasian (km–be) massive limestones and the Hauterivian–Lower Aptian (ht–ap₁) flysch deposits. Geological data according to [63].

For those who want to spend more time in this area, there is a large circuit trail of low difficulty, partially around the steep walls of the mountain but mostly outside of the nature reserve limit, which takes at least four hours to be completed. Another circuit trail starts from the Buceș-Vulcan Pass (altitude 745 m a.s.l.) and arrived on the top of Vulcan Mountain; this one is of moderate to high difficulty and is not recommended to beginners. From this geosite, the tourists can continue the itinerary in the Abrud direction (grey line on Figure 1b). Depending on their touristic schedule, they could spend the night in one of the guesthouses or farmhouses that exist in the area of localities Abrud, Cămpeni, Roșia Montană, Bucium. The distance between the site AV and the first site (BI) of the second itinerary is of 22 km, a distance covered in about 30 min (Figure 2b).

- Second Itinerary (Itinerary B—Day 2)

Second proposed itinerary includes three heritage sites, noted from BI to BIII, namely: BI. Gold Mining Museum (Roșia Montană); BII. Detunata Goală (Bucium); BIII. Limestones from Valea Mică (Valea Mică; Zlatna) (Figure 1b). The itinerary connects a museum (a mining and industrial architecture heritage but also a historical and archaeological heritage site) with two geoheritage sites (Table 1). This itinerary includes only three sites because it takes a considerable time to visit the first two sites (Figure 2b). The itinerary develops for about 70 km (between BI and BIII). If the distance between the site BIII and the city of Alba Iulia (see below) is taken into consideration, then this itinerary developed for about 100 km.

BI. Gold Mining Museum

Location: Roșia Montană Village; Alba County

The village of Roșia Montană (*Alburnus Maior* in Roman times) is situated on the Roșia Valley, at 5 km east from the national road that connects localities like Turda (to the east) with Brad (to the west) passing by towns like Baia de Arieș, Cămpeni and Abrud (Figure 1b).

With a well-documented starting point of mining activity during the Roman Dacia period (2nd to 3rd centuries A.D.), Roșia Montană is known worldwide as a high-grade gold-silver deposit of epithermal type. This deposit still contains considerable quantities of precious metals. In 2012, Roșia Montană became the type locality for the mineral alburnite ($\text{Ag}_8\text{GeTe}_2\text{S}_4$) (Table 2) [75,82].

Commonly known as Mining Museum, but with the official name of Gold Mining Museum (according to [88]), it is located in the center of the Roșia Montană Village in a zone with old houses, which, themselves, are part of the national historical heritage [28,31,32]. It is noteworthy to point out that the “Cătălina Monulești” mining gallery from the protected zone of the historic center of the village is a national historical heritage (Roman, Medieval and Modern periods) [31].

The museum was open in 1981, and consists of two main parts: one in the open air and other underground. The open air part is in the courtyard of the mining company that founded it, presently called the National Company of Copper, Gold and Iron “Minvest”–S.A. Deva. The museum is administered by this company. In the courtyard, the museum exposes archaeological vestiges (e.g., tombstones with inscriptions from Roman times) (on the left in Figure 8a), and equipment for mining and ore processing (e.g., a wooden stamp mill used to crush the gold-bearing-rocks) (in the background in Figure 8a).



Figure 8. Gold Mining Museum (Roșia Momtană Village, Alba County). (a) Open air part of the museum in which the visitors can see archaeological vestiges (the lapidarium, on the left in Figure 8a) and equipment for mining and ore processing. (b) An image taken in the underground part of museum: a Roman gallery. (c) Photograph of a block of hydrothermal breccia, typical for Roșia Montană ore deposit, placed in front of the Roman gallery entrance. (d) Traces of mining works from Roman times in Fortress Hill of Roșia Montană (image after an old photo exposed in an exhibition room of the museum).

From the open air museum, the visitors can go down in the underground part of the museum. Once passed the mine entrance, by descending a number of 157 stairs, they reach the level of visitable galleries (~400 m of galleries). There, they can see galleries from the Roman period, with their specific trapezoidal cross-section, and observe the rocks in which the galleries were dug (Figure 8b). They also will learn about the mining procedure and technics at that time (e.g., the galleries were performed with chisels and hammers; the miners followed the gold and silver mineralization, so the galleries turned and twisted to follow the highly mineralized zones). To note that a block of mineralized hydrothermal breccia (Figure 8c), representative for breccia found in Roșia Montană ore deposit, can be seen in the museum courtyard, been exposed near the mine entrance. Figure 8d shows an image in which traces of mining works from Roman times can be observed within Cetate Hill, located on the territory of the Roșia Montană commune, not very far away from the historic center of Roșia Montană Village. Therefore, the Gold Mining Museum visit offers to participants the opportunity to experience not only an underground mine visit but also to go back in time and see Roman underground mining works.

BII. Detunata Goală

Location: Bucium Village; Alba County

Detunata Goală is a scenic volcanic landform of Neogene volcanic rocks occurring in an area with sedimentary rocks of Late Cretaceous age [65]. Declared protected area more than eighty years ago, Detunata Goală (Figure 9a–c) was the first natural monument of geological interest in Romania [24]. Nowadays, it is a nature reserve of geological and botanical interest.

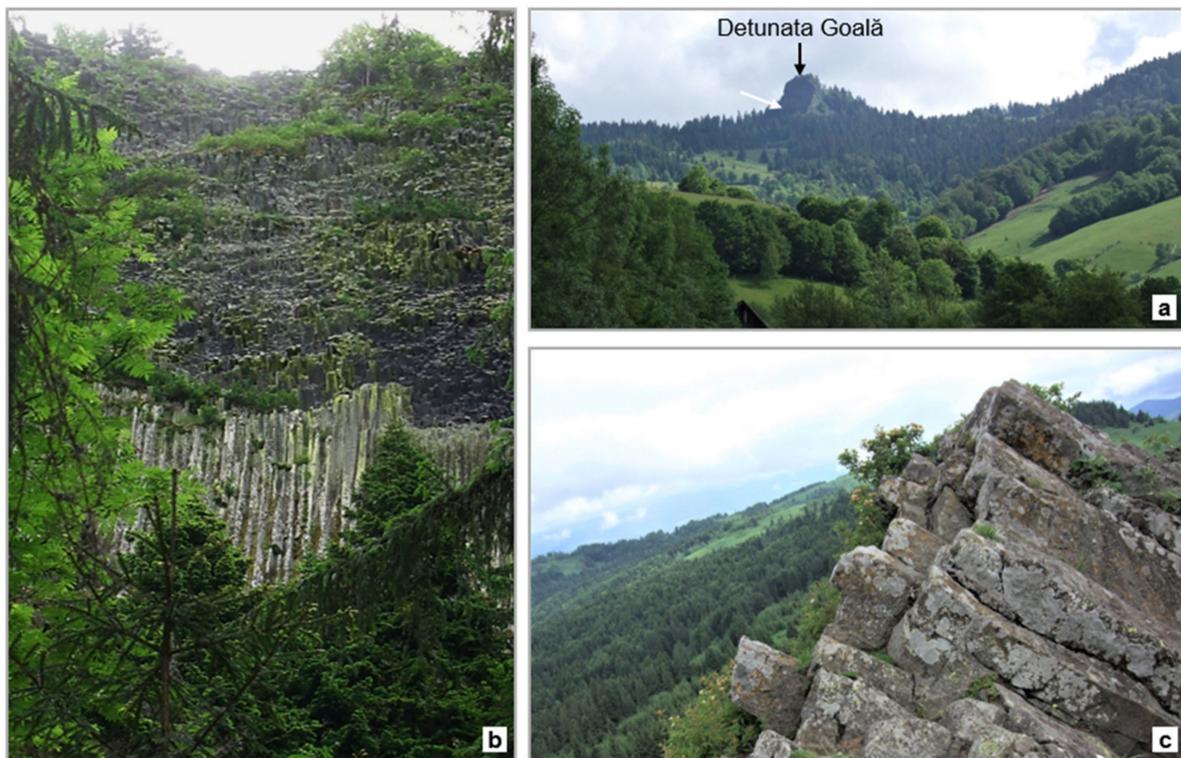


Figure 9. Detunata Goală (Bucium Village; Alba County), the first Romanian natural monument of geologic interest (established in 1938). (a) Panoramic view of the area of Detunata Goală looking northeast. (b) Spectacular columns of Late Miocene basaltic andesites. The white arrow on Figure 9a points the place from which this photo was taken. (c) Column of basaltic andesites occurring at the top of the volcanic structure (northward view). The black arrow on Figure 9a indicates the top of the site and the location of rocks from this image.

The spectacular columns of volcanic rocks (Figure 9b,c) have attracted the attention of specialists since the 19th century (e.g., References [35,89]). In 1900, Schafarzik, in his “Report on the excursion organized by the Hungarian Geological Society from 2–7 July 1899 to the Transylvanian Ore Mountains” [90] noted that the participants to the excursion, in their way to visit the golden mines in the Metaliferi Mountains, took a detour to see Detunata Goală, which he described using personal observations and data from Loczy [90,91].

Known for long time as the basalts of Detunata (or Detunatele, the plural form, meaning the Thunderstruck Rocks in Romanian), in fact they are basaltic andesites consisting mainly in phenocrysts and microlites of olivine, pyroxene and plagioclase feldspar in a vitreous groundmass; chlorite and carbonates precipitated in vesicles or occur as secondary minerals [40,92]. To note that the basaltic andesites contain sedimentary xenoliths and quartz xenocrysts [93,94]. It has been assumed that these rocks are either Late Neogene [38–40] or Late Neogene–Quaternary [65] or even Quaternary in age [92]. In 1995, the basaltic andesites were dated (K-Ar method) at 7.4 ± 0.3 Ma (Late Miocene) [47,57].

The columnar-jointed lavas rise from an altitude of around 1060 to 1080 m a.s.l., at their limit with the Maastrichtian sedimentary rocks (on the southwestern slope), up to 1158 m a.s.l. at the top of Detunata Goală Peak (Figure 9a,c). The columns are almost

vertical at the lower part of the volcanic structure and inclined up to fanning-upward at its upper part. The dominant column shape is four- to five-sided.

Geosites Detunata Goală and Detunata Flocoasă (sites no. 11 and 12 in Table 1) offer to visitors the possibility to see volcanic rocks as huge columnar jointed lavas. There are no other occurrences like these ones in the area of the Metaliferi Mountains. To note that a well-marked walking trail, which has as starting point the village of Roşia Montană, arrived at Detunata Goală.

From geosite BIII, the itinerary returns to the national road Abrud–Alba Iulia (DN74) and continue in the direction of Alba Iulia City.

BIII. Limestones from Valea Mică

Location: Valea Mică Village; Zlatna Town; Alba County

Valea Mică is a village administratively belonging to the town of Zlatna; it is located at approximately 6 km southeast from this town. Zlatna, known as Ampelum in Roman times, have a long history related to mining and ore metallurgy in the Metaliferi Mountains [38,49].

In the village, near the church, on both sides of the road and both slopes of the Valea Mică Brook (a right tributary of the Ampoi River) respectively, occur imposing white blocks of rocks (Figure 10) that can be seen from far away. These steep cliffs consist in limestone breccia containing elements of Late Jurassic (Tithonian) and Early Cretaceous limestones. According to Bleahu and Dimian [95] and Mantea et al. [96], the isolated blocks, detached from a carbonate platform, are sedimentary klippe (olistoliths) occurring within Cretaceous (Albian—Cenomanian) wildflysch deposits. The highest block has a height of 20 m; the other one, who is across the road of it, is around 12 m height. There are few caves in the highest one. It is said that long time ago, these caves were inhabited by hermits. To note that in the background of Figure 10, the Trascău Mountains can be observed; the white cliff (pointed by the arrow) is the Pietra Bulbuci natural monument (of geological and geomorphological interest).

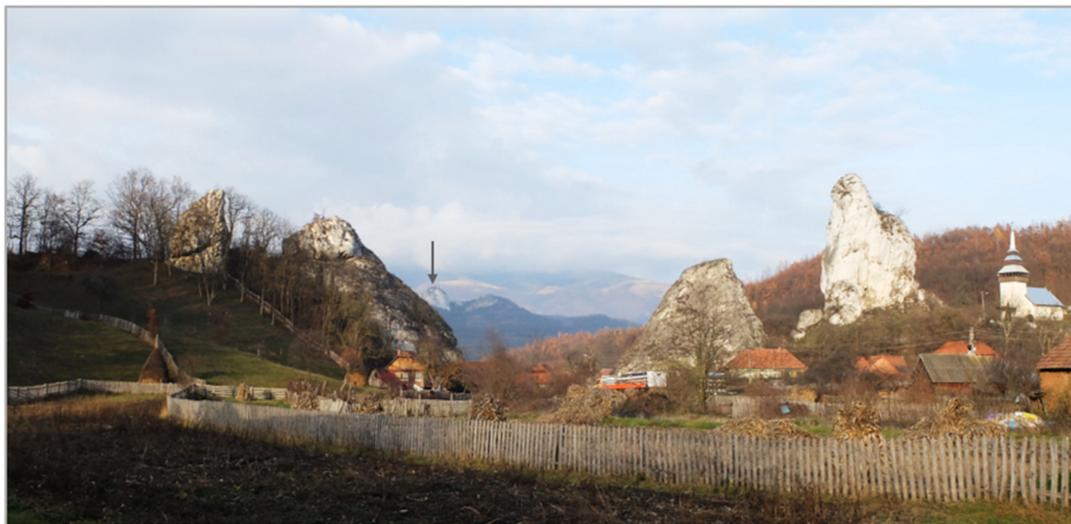


Figure 10. Panoramic view of the geosite limestones from Valea Mică (Valea Mică Village; Zlatna Town; Alba County). View to the north–northeast, taken from the village. The protected area contains the steep cliffs of limestone breccia occurring on both sides of Valea Mică. In the background, the Trascău Mountains can be seen; the black arrow indicates the geosite Pietra Bulbuci.

From Valea Mică Village, the tourists could continue their itinerary and, after 32 km, reach the city of Alba Iulia (Figure 1b), the seat of Alba County. Known as Apulum during the Roman Dacia province, among the main objectives to be visited there are the ruins of the Roman Fort of the XIII Legion Gemina and the Principia Museum, the Alba Carolina Citadel, and the National Museum of the Union.

Summarizing, the characteristics and particularities of the thirteen sites included in this study, indicate that the research area contains a remarkable geological and mining heritage. Moreover, the existence of both in situ and ex situ heritage sites in the area of the Golden Quadrilateral offers to visitors the opportunity to learn about geological and geomorphological processes and phenomena, geodiversity and geoheritage, geoconservation, type localities, nature reserves and monuments, mining history and mining heritage, archaeological/historical and cultural heritage, etc. They will have the opportunity to admire geosites with high aesthetic value (e.g., Citadel Hill, Figure 3a; Măgura Uroiului, Figure 4a; Vulcan Mountain, Figure 7a,b; Detunata Goală, Figure 9a,b; limestones from Valea Mică, Figure 10); volcanic landforms; spectacular columns of basaltic andesites; steep cliffs of sedimentary rocks; sedimentary klippen; exceptional species of minerals; Roman mine galleries; archaeological vestiges, etc.

4.2. Quantitative Assessment of the Sites Included in the Proposed Itineraries

For the purposes of this study, the quantitative assessment refers only to the sites included in the two proposed itineraries. The quantitative assessment of the geosites was performed using Brilha method [10,11].

Considering the main aim of this work, I will start with the quantitative assessment of the geosites as potential sites for educational and geotourism/recreational uses. As it was mentioned in Section 3, quantitative assessment of the geosites' capacity to support educational use is based on twelve criteria; quantitative assessment of the geosites' capacity to support geotourism/recreational use is based on thirteen criteria. Taking into account the information acquired during this study (by field observations, discussion with local people, literature review, etc.), by applying this method to the geosites of the two proposed itineraries, I obtained the values presented in Table 3.

Table 3. Quantitative assessment of the geosites of the two proposed itineraries as potential sites for educational and geotourism/recreational uses (Brilha method [10,11]).

Criteria	Itinerary A						Itinerary B					
	AI		AII		AIII		AV		BII		BIII	
	Edu	Geot	Edu	Geot	Edu	Geot	Edu	Geot	Edu	Geot	Edu	Geot
	Criterion Score = Indicator Value × Criterion Weight											
Vulnerability	40	40	40	40	20	20	40	40	40	40	20	20
Accessibility	40	40	30	30	30	30	30	30	30	30	40	40
Use limitations	20	20	20	20	15	15	20	20	20	20	20	20
Safety	40	40	30	30	30	30	30	30	20	20	30	30
Logistics	20	20	20	20	20	20	15	15	20	20	15	15
Density of population	20	20	15	15	5	5	5	5	5	5	5	5
Association with other values	20	20	20	20	20	20	5	5	15	15	15	15
Scenery	20	60	20	60	5	15	15	45	15	45	5	15
Uniqueness	5	10	20	40	5	10	5	10	10	20	5	10
Observation conditions	40	20	40	20	40	20	40	20	40	20	40	20
Didactic potential	80		60		60		60		60		60	
Geological diversity	30		40		40		30		30		30	
Interpretative potential		30		20		30		30		30		30
Economic level		15		10		5		5		5		10
Proximity of recreational areas		20		20		5		0		10		10
Final Score	375	355	355	345	290	225	295	255	305	280	285	240

Note: for site locations, see Figures 1b and 2a. Abbreviations: AI—Citadel Hill; AII—Măgura Uroiului; AIII—Limestones from Măgura Hill; AV—Vulcan Mountain; BII—Detunata Goală; BIII—Limestones from Valea Mică; Edu—educational use; Geot—geotourism/recreational use.

The presentation on the same table of the quantitative assessment of the geosites as potential sites both for educational, and for geotourism/recreational uses, offers an easy comparison of the two types of potential use. Moreover, I appreciate that an important part of the visitors could be the teachers with their students. Therefore, I also chose to present in the same figure (Figure 11) the values of the final score for both educational and geotourism/recreational use. The four intervals of potential use are also drawn in this figure, as follows: low (final score ≤ 100), moderate ($100 < \text{final score} \leq 200$), high ($200 < \text{final score} \leq 300$), and very high ($300 < \text{final score} \leq 400$).

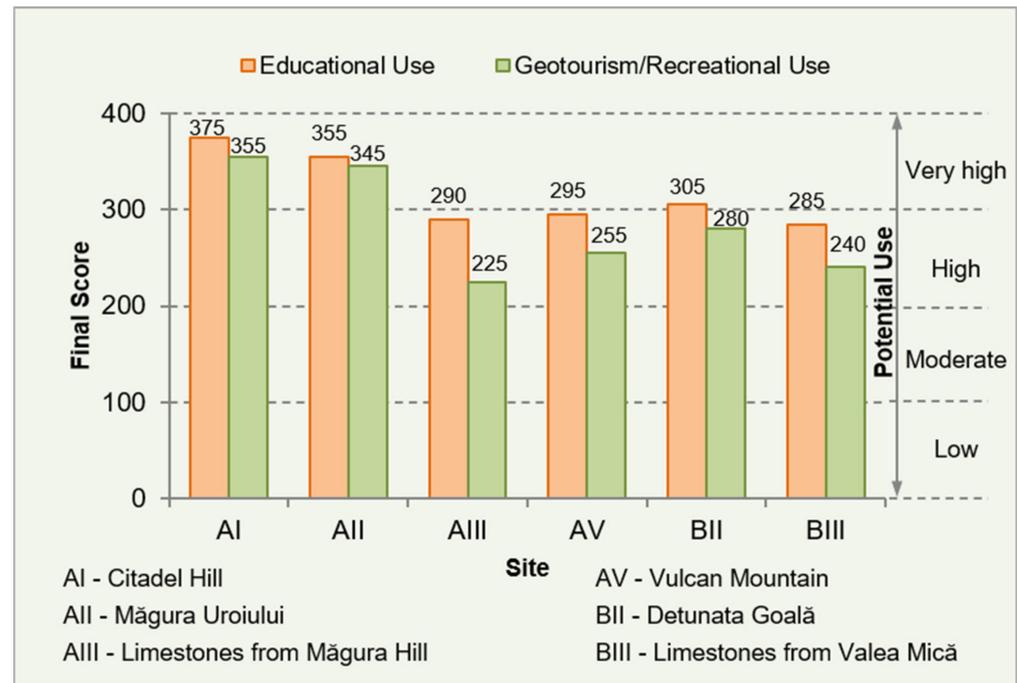


Figure 11. Graphical representation of the geosites' capacities to support educational and geotourism/recreational uses. The values for final score (see Table 3) were obtained by applying the Brilha method [10,11]. The four intervals of the potential uses (low, moderate, high, and very high) are also shown in this figure.

As is shown in Table 3 and Figure 11, for all the geosites, the values for final scores are higher than 200 (high to very high potential use). The highest final scores, both for educational use and the geotourism/recreational use, were obtained for the geosites Citadel Hill and Măgura Uroiului. Therefore, all the geosites included in the two proposed itineraries fulfil the criteria to be considered sites that can be used for geo-education and geotourism.

The next step consists of the quantitative assessment of the sites' capacities to support scientific uses (assessment of their scientific value), which operate with seven criteria: representativeness, key locality, scientific knowledge, integrity, geological diversity (variety of geological elements), rarity, and use limitations. Each criterion is ranked with 1, 2, or 4 points (according to the value of selected indicator); each criterion has been assigned a weight (e.g., 30% for representativeness, 20% for key locality). Following the above enumerated procedure, the final value (weighted score) of each criterion has been obtained. The calculated final scores of the capacity of these geosites to support scientific use are graphically represented in Figure 12. The intervals of potential use (the same intervals as in Figure 11) are also shown in this figure.

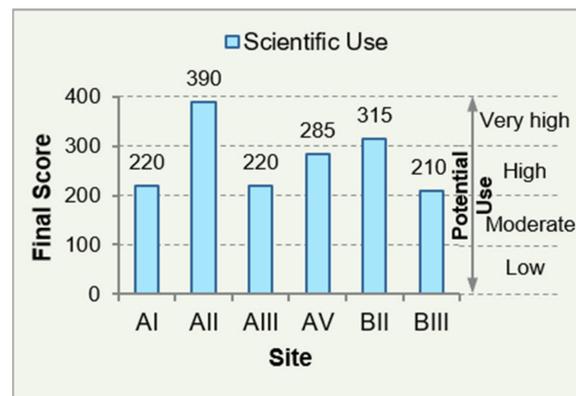


Figure 12. Bar graph showing the geosites' capacities to support scientific use (scientific value). The four intervals of the potential use (low, moderate, high, and very high) are also indicated in this figure. For site names, see Figure 11.

There is no doubt that the protected areas included in our study are scientifically important (mineral type localities, rare rocks, volcanism, stratigraphy and tectonics, geomorphology, etc.) (Section 4.1). The geosites present values for final score placed either in the interval of high potential use (Limestone from Valea Mică, Citadel Hill, Limestone form Măgura Hill, and Vulcan Mountain), or in the interval of very high potential use (Detunata Goală and Măgura Uroiului). The highest final score was obtained for the Măgura Uroiului geosite. Due to the fact that the geosites could offer multiple levels of information, they can be interesting to both the specialists and the general public.

Regarding the quantitative assessment of degradation risk, five criteria are utilized: deterioration of geological elements, proximity to areas/activities with potential to cause degradation, legal protection, accessibility, and density of the population. The degradation risk is classified as low (final score ≤ 200), moderate ($200 < \text{final score} \leq 300$), and high ($300 < \text{final score} \leq 400$). The calculated final score for degradation risk of each geosite is presented in Figure 13.

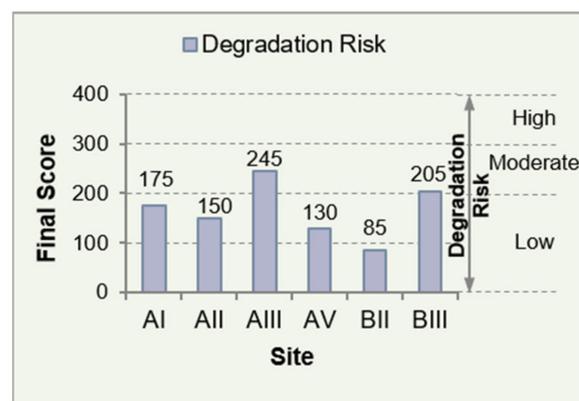


Figure 13. Bar graph showing the degradation risk for the geosites included in the two proposed itineraries. The degradation risk intervals (low, moderate, and high) are also represented in this figure. For site names, see Figure 11.

As it can be seen in this figure, the final score values range from 85 (site BII—Detunata Goală) to 245 (site AIII—Limestones from Măgura Hill). The three intervals (low, moderate and high) of degradation risk are also drawn in Figure 13. It is observable that, excepting the sites AIII and BIII, all the other sites placed in the interval of low degradation risk. The degradation risk of site BIII (Limestones from Valea Mică) is slightly above the limit between low and moderate risk. The site AIII placed at the lower part of the interval of moderate degradation risk. Nowadays, the geosite AIII (Limestones from Măgura

Hill) is threat due to the rock exploitation in this zone. I took in consideration this major vulnerability in the evaluation of the site. As for Măgura Uroiului Hill, it was in danger to be, at least partially, erased by quarrying and that starting with the Roman period (see Section 4.1.1). Fortunately, nowadays, Măgura Uroiului Hill is both on the list of natural protected areas, and of national historical monuments.

In conclusion, the results obtained by the quantitative assessment of the geosites as potential sites for scientific, educational, and geotourism/recreational uses (Figures 11 and 12) are sustained by the quantitative assessment of the degradation risk (Figure 13), which shows that the sites in consideration are at low to moderate risk. The major risk came from the anthropic activities not related to the scientific, educational, or touristic use.

The two museums included in the proposed itineraries (Figure 2a,b)—the Gold Museum (site AIV, located in Brad Town) and the Gold Mining Museum (site BI, located in Roșia Montană Village)—were not introduced in the above assessments because the Brilha method do not apply to them [11]. However, taking into consideration that, in the Metaliferi Mountains, many ore deposits are mined out, almost all the mines are closed, the sampled places are no longer accessible or do not exist anymore, etc., the Gold Museum is a very important ex situ geodiversity site [74] that contains elements of geological, and mining heritage value. As regards the Gold Mining Museum, it is a very good example of the mining heritage viewed as interface between geoheritage (georesource) and cultural heritage. Moreover, Roșia Montană is a locality with great archaeological, historical, geological, mining and cultural values. It could be seen as a symbol of the mining and industrial heritage not only in Romania but also in Europe. If the potential use of the geosites for education and geotourism is taken into account, the two museums fit perfectly in the proposed itineraries.

5. Discussion

The methods and methodologies used in this study allowed: (i) to emphasize the significant geological and mining heritage of Golden Quadrilateral (Metaliferi Mountains); (ii) to provide an inventory of this heritage; (iii) to present a quantitative assessment of the geosites included in the two proposed itineraries, as potential sites for scientific, educational and geotourism/recreational uses.

In this paper is propose a tourism centered on the geodiversity and geoheritage of the research area, to which is added an important mining and mining-related industrial heritage. As it shows in Table 1, the geosites discussed in this study are nature protected areas of national relevance [29,30]. The table contains five nature reserves (Citadel Hill, Măgura Uroiului, Limestones from Măgura Hill, Vulcan Mountain, and Limestones from Valea Mică) and four natural monuments (Piatra Corbului, Piatra Despicață, Detunata Goală, and Detunata Flocoasă) (Figure 1b). All these geosites are protected by Law no. 5/2000 [28], with later modifications and completions. The inventory presented in Table 1 also includes the follow sites: Săcărâmb Village, “Roman Stairs” Mine Gallery, Gold Museum and the Gold Mining Museum. Săcărâmb Village is an old mining locality (over 250 years of mining history), type locality for eight minerals (Table 2). The Au-Ag-Te ore deposit discovered here (in 1740s) is world famous for the mineralogical diversity, the richness in precious minerals and the high contents in gold and tellurides. Regarding the “Roman Stairs” Mine Gallery (in Ruda-Brad Village, Brad Town), it is on the list of National Historical Monuments (archaeological site) [31]. According to the Annex 3 of [28], it is also a cultural heritage (historic monument of exceptional value), category: industrial architecture. To note that among the minerals of the Gold Museum (in Brad Town), some have heritage value. As for the Gold Mining Museum (in Roșia Montană Village), the visitable Roman mining works, are part of a larger National Historical Heritage (Roman, Medieval and Modern periods) [28,31]. Regarding Roșia Montană, it is important to note a very recent information: on 27 July 2021, Roșia Montană Mining Landscape was inscribed on the List of UNESCO World Heritage and also on the List of World Heritage in Danger (whc.unesco.org/en/news/2319; accessed on 28 July 2021).

The two geotourism itineraries described in this study (Section 4.1.1) connect a series of sites of geological and mining interest (Figures 1b and 2a). The first itinerary (itinerary A) includes four geosites (Citadel Hill, Măgura Uroiului, Limestones from Măgura Hill, and Vulcan Mountain) and a museum (Gold Museum). The second itinerary (itinerary B) includes two geosites (Detunata Goală and Limestones from Valea Mică) and a museum (Gold Mining Museum). This combination between sites of geological interest with visiting of two museums, including an underground mine visit (Roman galleries), can be attractive for the general public [14,16].

The quantitative assessments of the geosites as potential sites for educational and geotourism/recreational uses indicate that each of the eight geosites can be used for geo-education and geotourism (Table 3 and Figure 11). As for the quantitative assessment of the geosites' capacities to support their scientific use (quantitative assessment of scientific value), the obtained results show that the geosites present either high potential or very high potential use (Figure 12). The quantitative assessment of the degradation risk placed these geosites at low to moderate risk (Figure 13). The anthropic activities not related to scientific, educational or touristic use, represent the main risk of their degradation. Therefore, the sites present a high potential not only for scientific studies but also for enhancement of public understanding of science. The two museums can have an important contribution both to the geo-education of visitors and in promoting sustainable development of the region [14,97].

The sites are easy to access. They can be reached either directly by car or by car and a short walk distance (Figure 2b). The roads are in acceptable condition, and they are going to be improved. Moreover, modernization of the county road DJ107 (in progress) will facilitate a connection between the highway, which go on the eastern border of the Apuseni Mountains, and the town of Abrud, passing through Bucium Village, the nearest village to the geosites Detunata Goală and Detunata Flocoasă (sites no. 11 and 12 in Table 1). Thus, this road offers a fast access to the Metaliferi Mountains and, further to the north, to the Apuseni Natural Park. Likewise, the highway that passes near the Deva City (Figure S1), provides a fast access of both national and foreign tourists to this part of the Metaliferi Mountains and, thus to the sites of first geotourism itinerary. Abrud—Câmpeni—Roșia Montană—Bucium area (Figure 1b) can be taken in consideration by tourists for spending one or more nights in the guesthouses or farmhouses that exist there. Accommodation in guesthouses is also available in and around the towns of Brad and Simeria. The cities of Deva (start point of the itinerary A) and Alba Iulia (end point of the itinerary B) offer many accommodation places in hotels, villas and guesthouses. At each site, observations conditions are good. To note that at each of geosites there is a panel (e.g., Figure 5a) containing general information about the protected area. Interpretation of geosites needs to be improved (in order to be interesting to the general public) and therefore, an informative panel should be installed at each geosite. A panel containing data about the geoitineraries should be placed at least at the first site of each of two itineraries.

It is worth noting that in the Apuseni Mountains and the surrounding zones there are places that are highly visited (hundreds of thousands of tourists annually) by both national and foreign tourists: the Apuseni Natural Park (located in the North Apuseni Mountains), the Turda Salt Mine—a huge salt mine located in the area of Turda City (Ancient Potaissa) [72], Alba Iulia City, the Deva City, etc. (Figure 1b).

Concerning the sites discussed in this paper, the Citadel Hill (Deva City, Hunedoara County) and the Gold Museum (Brad Town, Hunedoara County) are the most visited. Located at the upper part of Citadel Hill, the Deva Fortress (Figure 3b,c) is highly visited (visitors from Romania as well as from Europe and other continents): the average annual visits during the interval 2016–2019 was about 200,000. As for the Gold Museum, the number of visits per year during the same interval varies between 18,000 and 20,000. Therefore, the city of Deva and the town of Brad could have a significant contribution to the promotion of the geological and mining heritage of the Metaliferi Mountains, including in promotion of the geotourism itineraries. For instance, in the city of Deva, the Centre

of Tourism Information and Promotion could have this role. In the town of Brad, the Gold Museum, mostly visited by school groups, could make this contribution; it also could become a center for the promotion of nature-protected areas. Likewise, in Roșia Montană Village, the Gold Mining Museum could participate in the promotion of mining, archeological, historical, and cultural heritage; a visitor center could be established here too. The author assumes that the National Geology Museum (located in Bucharest), a museum belonging to the Geological Institute of Romania, could also contribute to raising awareness among visitors about the geological and mining heritage of the Golden Quadrilateral, and promoting it as a geotourism destination (realization of an itinerary brochure, a thematic exposition, contribute to the interpretation of geosites, etc.).

This study could have a role in promoting the geodiversity, and the geological and mining heritage of the research area [98,99]. It can be said that, since the first half of the last century, the Metaliferi Mountains have represented a highly appreciated region of interest for student field trips (in different domains of Geosciences such as Geomorphology, Mineralogy, Metallogeny, Stratigraphy, Sedimentology, etc.). The study might be of use to students during the field activities. Moreover, as the analyze of characteristics of geosites included in the proposed itineraries indicated, the geosites presents a high didactic potential (Table 3), containing geological elements that are taught in school and university [10]. By offering multiple levels of information, the sites can be interesting to both general public and specialists. The results presented in this paper could be useful to the local and regional authorities in tourism development and promotion and, also, to schoolteachers, the protected area managers and rangers, museum curators and guides, etc. in their collaborative work to organize educational and touristic activities.

In the Metaliferi Mountains, mining has been one of the main sources of income for the population living around the mines. Started with 1990s mining declined up to almost ceased. According to Nita et al. [100], “post-mining areas may become an interesting component of tourist spaces if appropriately developed”. Moreover, López-García et al. [101] discuss abandoned mine sites and geoheritage (a perspective from the Mazarrón and Cartagena–La Unión Mining Districts, SE Spain) in terms of scientific, educational, and environmental value. The authors consider that if a mine site have enough educational and scientific value, it should be granted protection at the level of a geoheritage site. Regarding the mining sites included in the present paper (Săcărâmb, Ruda-Brad, Roșia Montană), it is to note that they are highly important not only for history of mining and geology but also from archaeological and cultural point of view (Tables 1 and 2). Geotourism in the Metaliferi Mountains region could create opportunities for sustainable development of the local communities. Geotourism-related activities could become a source of income for the local residents mainly by: (a) creating employment opportunities, (b) hosting tourists in guesthouses and farmer houses, (c) selling artisanal handicrafts (e.g., traditional cloths, products made of woolen, wood, straw), artisanal dairy products, etc. The development of the geotourism requires support from the regional and local authorities, protected area managers and the population [16,101,102]. According to Ibănescu et al. [103], who studied the impact of tourism in sustainable development of rural areas in Romania, there is a positive relation between tourism activities and the level of sustainable development. Their results “confirm the role of tourism in supporting the socio-development of rural areas in Romania”. Adamov et al. [104], in their study on the sustainability of agritourism in three Romanian mountain rural regions, showed that this form of rural tourism could be one of the solutions for increase the income of rural population in a sustainable way. Taking in consideration the results presented in our paper, geotourism can also be a way of sustainable development of rural communities.

By presenting an inventory of the geological and mining heritage sites in the research area, and the qualitative assessment of the geosites included in the two proposed itineraries, this work is a step in the process of development of geotourism in Golden Quadrilateral. According to [105–108], such itineraries are meant to spread knowledge about geological history and heritage of the visited territories, and to promote geodiversity conservation.

Although the data presented in this study lead us to see the Golden Quadrilateral (a part of it) as an area having the required characteristics for a possible future geological and mining park (or a geomining park), for now, it is important to focus on the protection, conservation, and management of these valuable sites. Despite over two millennia of mining (with discontinuities) in the Metaliferi Mountains, the region still presents metallogenic interest. Besides, the Romanian Carpathians still have a significant metallogenic potential [109]. It is imperative that specialists from different domains find the most appropriate strategies both for a sustainable mining, and to preserve the geodiversity and the biodiversity of the concern territories.

6. Conclusions

This work is a preliminary study of the geological and mining heritage in the Golden Quadrilateral (Metaliferi Mountains). It presents, for the first time, an evaluation of the geological and mining heritage sites of the research area as possible tourism destinations. The Golden Quadrilateral constitutes a remarkable example of an area having significant geological and mining heritage. The sites discussed here are important for their values (scientific, educational, geotourism, mining heritage, archaeological, historical, and cultural). Moreover, the existence of both in situ and ex situ heritage sites in the area of the Golden Quadrilateral offers to visitors the opportunity to admire and learn about nature reserves and monuments, geodiversity and geoheritage, geoconservation, mining history and mining heritage, geological and geomorphological processes and phenomena, etc.

Mining and mining-related activities had been a major source of revenues for many localities (especially the rural ones) of the Metaliferi Mountains. This work shows that the geological and mining heritage sites of the Golden Quadrilateral are suitable for tourism. As our results indicate, geotourism could be part of the development strategy of the rural areas in this region. Therefore, not only the ore deposits represented and, to a certain extent, still represent one of the main riches of the Metaliferi Mountains, the geological and mining heritage of this region could also be seen as a valuable resource.

Future research needs to extend the study to the entire area of the Metaliferi Mountains and even beyond of it, on the scale of the Apuseni Mountains, while always paying attention to the impact of geotourism on the protected areas and how geotourism could be useful to the local people in view of the sustainable development of the rural areas. Interdisciplinary research combining geodiversity and biodiversity data, on the one hand, with archaeological, historical, and cultural data, on the other hand, could provide a comprehensive image of the natural and cultural heritage of the studied area.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/su131810114/s1>: Figure S1: Săcărâmb Village (Certejul de Sus commune; Hunedoara County): an old mining locality (nearly 250 years of continuous mining), world-famous for the epithermal gold-silver-telluride ore deposit related to Neogene magmatic activity; type locality for eight minerals. (a) Panoramic view of the southeast end of the Brad—Săcărâmb Neogene volcanic area, showing the location of Săcărâmb Village. (b) Image taken in Săcărâmb Village. In the foreground, an old dry stone fence made of blocks of andesites. Figure S2. “Roman Stairs” mine gallery (Ruda-Brad Village; Brad Town, Hunedoara County). It is a historical monument of national interest (archaeological site and mining industrial architecture from Roman times—2nd to 3rd centuries A.D.) [28,31]. The photograph shows the mine entrance. Figure S3: Panoramic view (to the northeast) of the Metaliferi Mountains, showing typical volcanic landforms. In the foreground, the A1 highway runs almost parallel to the Mureş River (the river is not visible on image because of vegetation). Image taken from the upper part of the Citadel Hill (Deva City, Hunedoara County).

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