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When Individual Geosites Matter Less—Challenges to Communicate Landscape Evolution of a Complex Morphostructure (Orlické–Bystrzyckie Mountains Block, Czechia/Poland, Central Europe)

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Abstract: This paper explores problems associated with explanation of geoheritage at the landscape scale and argues that focus on individual geosites that show rock outcrops or small-scale landforms may not be sufficient to tell the story. The area of Orlické–Bystrzyckie Mountains Block in Central Europe lacks spectacular landforms or large rock outcrops, and yet has a most interesting geological history that involved Mesozoic planation, Cretaceous marine transgression and the origin of sedimentary cover, Cenozoic differential uplift and the origin of tectonic topography, resultant fluvial incision and Quaternary periglaciation. Individual geosites documented in the area fail to show this complexity and give an incomplete picture. Therefore, viewpoint geosites, allowing for in situ interpretation of regional landscapes, have a role to play and they collectively illustrate the effects of the main stages of geological and geomorphological evolution. In addition, the potential of simple visualization technologies is investigated, as these 3D visualizations may enhance ground views, putting things into even broader perspective.

Keywords: geoheritage; geotourism; geosites; geo-interpretation; Sudetes

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1. Introduction

Geosites, defined as localities of particular significance for comprehension of Earth history [1,2] and recognized by scientists mainly on the basis on their expert knowledge, are powerful tools to both protect geoheritage and to develop geotourism. The former results from the solid scientific basis provided by experts working in specific fields of geosciences, who reveal the importance of the sites which otherwise may escape attention, especially if the geosite lacks visual attractiveness. At the same time, well-researched sites of geoscientific interest are most suitable for the development of interpretation, which is at the core of properly defined geotourism [3–5].

However, focus on geosites in geotourism has potential weaknesses and limitations, especially in areas where environmental characteristics (relief, vegetation) and land use effectively hide much of geological and geomorphological history and record from sight. Thus, geosites are very promising for systematic explanation and interpretation of various themes within geoheritage, but being thematically and physically disconnected they may fail to show the 'big picture', that is, how a particular area evolved in terms of both its rock record over geological time and its geomorphology. This comment particularly applies to non-expert geotourists [3,6], who are less able to integrate separate local stories into one, region-wide 'journey' throughout geological history.

There are ways to overcome these limitations, although they will not necessarily work in each setting. Individual geosites may be combined into a thematic itinerary, real—based on interpretation panels [7,8]—or virtual [9–14], designed as a hiking trail or car route [15–17]. Designing such itineraries may be feasible at the local scale and in high geodiversity areas, where geographically adjacent sites can collectively tell a story. However, in large-scale landscapes relying on individual classical geosites it may not be enough and it is so for several reasons. First, these geosites may be so dispersed over an area of interest that finding a connection between them becomes challenging, especially for non-specialists. Second, the key pieces of the story may be told by landforms, which are much bigger than classical geosites and, therefore, viewpoint geosites capable of interpreting physical landscapes [18] have a particular role to play. However, even the viewpoint geosites are not easy to set and interpret, especially in forested or otherwise vegetated areas, where the relationships of landforms to geological structure are obscured. Moreover, in landscapes without high relief, they may easily get overlooked. In another conceptual approach, a large area—a 5 km long gorge—is considered a singular geosite ('big and complex geosite' [19]) and it is argued that such designation will help tourism management at the site and facilitate interpretation.

This paper addresses this problem, present at the interface of geoheritage protection and awareness and geotourism, on the example of the Orlické–Bystrzyckie Mountains Block in Central Europe, at the Czech/Polish borderland. It lacks individual spectacular geosites and in this respect, is overshadowed by adjacent areas [20–22]. However, it represents a complex morphostructure whose geomorphic evolution can be traced back to the Cretaceous and involved marine transgression over a weathered land, large-scale tilting, origin of mountain fronts and other fault-generated escarpments, stripping of cover deposits, deep fluvial incision and Quaternary periglacial 'ornamentation'. We will discuss if and how this exciting story can be told using existing concepts in geo-interpretation and available tools.

2. Study Area

2.1. Location and General Topography

The Orlické–Bystrzyckie Mountains Block (OBMB) is part of the large elevation of the Sudetes in Central Europe, which form the north-eastern peripheral zone of the Bohemian Massif, being also its highest part (1603 m a.s.l.). Topographically, the Sudetes are highly complex, comprising high-altitude (>1000 m a.s.l.) massifs, uplands, and intramontane basins of different size and shape. This complicated morphological pattern is interpreted as a response of a geologically very heterogeneous area to crustal stresses and loads transmitted from the emerging Alps and the Carpathians, principally during the Neogene and Quaternary [23].

The OBMB is located in the central part of the Sudetes, elongated in NNW–SSE direction. It is c. 60 km long and 25–10 km wide, tapering to the south (Figure 1). Its axial part is the main ridge of the Orlické Mountains, with elevations above 1000 m a.s.l. in the northern part (Vrchmezí, 1084 m; Velká Deštna, 1115 m) and close to 1000 m a.s.l. in the central (Anenský vrch, 992 m) and southern part (Suchý vrch, 995 m). This ridge separates two morphologically different parts of OBMB. The western side may be compared with a large ramp that connects the lowlands west of OBMB with the main ridge. Elevations gradually rise from 350–400 m a.s.l. at the foothills, resulting in the mean gradient of c. 3°, although closer to the main ridge slopes become steeper. The ramp is dissected by numerous river valleys, with the depth of incision from 50 to more than 150 m and valley sides locally as steep as 45°. Large tracts of planar relief occur on the interfluves and the upper slope breaks are often very sharp. The ramp is less evident on the southernmost part of OBMB, but overall asymmetry of the main ridge occurs there as well. In the east, by contrast, the main ridge is limited by a clear escarpment of NNW–SSE trend (inner mountain front), along which altitudes drop by 250–350 m in the north and more than 400 m in the south. This escarpment is less evident in the central sector, where the Divoká Orlica river cuts through the main ridge flowing south-westward. The part of OBMB east of this escarpment consists of isolated massifs (Jagodna, 985 m; Czerniec, 891 m) in the south and extreme north (Wolarz, 852 m), and two westward-inclined blocks in the north-east. For the latter, long planar slopes of WSW aspect and much steeper opposite slopes are characteristic. A deeply incised branched drainage network of Bystrzyca Łomnicka river is a characteristic feature, whereas in the north, the S–N trending valley of Bystrzyca Dusznicka is up to 250 m deep. By contrast to the diffuse western boundary of OBMB, the eastern boundary is topographically most distinctive and formed by a mountain front which is locally more than 400 m high and separates OBMB from the intramontane graben of Nysa Kłodzka river (Upper Nysa Graben).

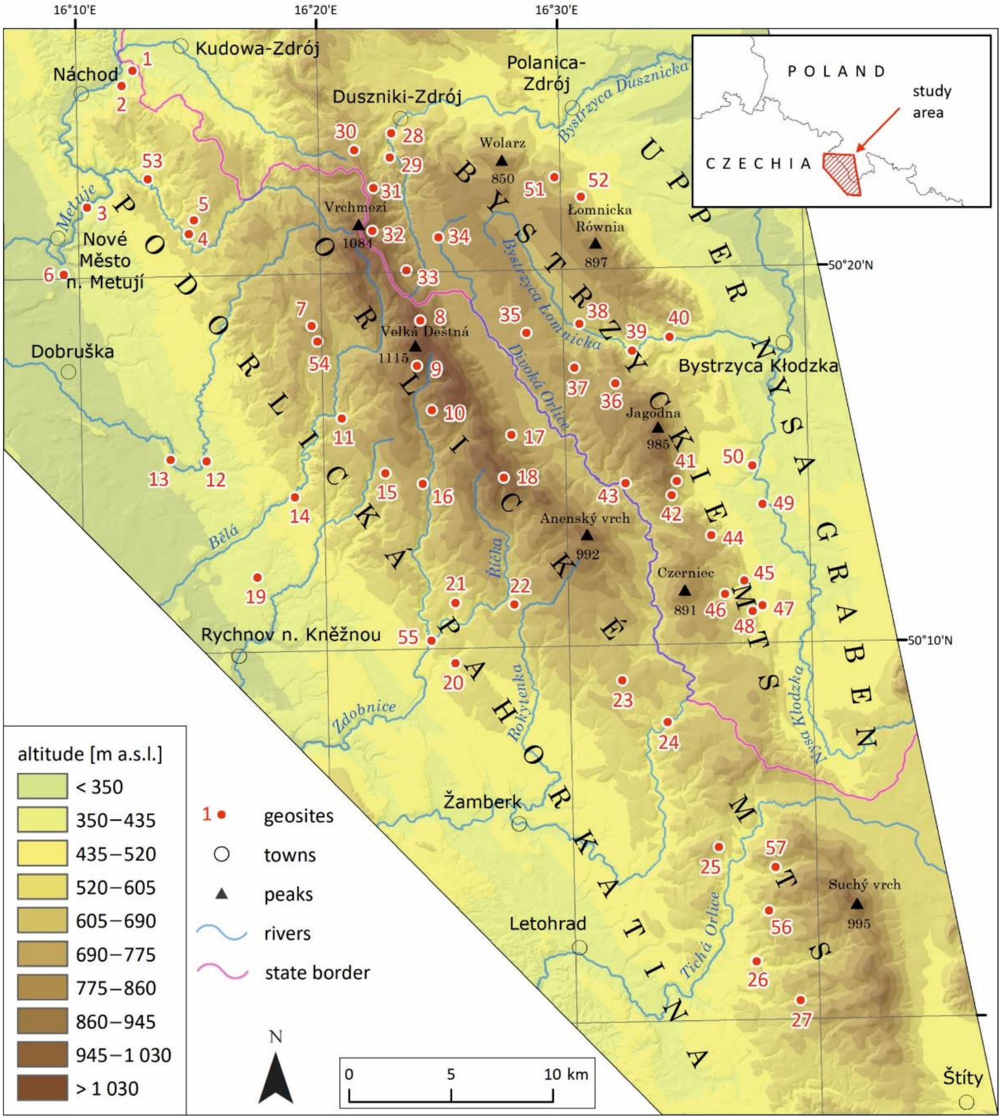

Figure 1. Hypsometry of the Orlické–Bystrzyckie Mountains Block and location of geosites (names of geosites no. 1 to 50 in Tables 1 and 2. Remaining geosites: 51—Kamienna Góra, 52—Toczek, 53—Olešenka valley, 54—Špíčák, 55—Plačtivá skála, 56—Černovický potok, 57—Těchoninský potok.

2.2. Geology

Geologically, the OBMB comprises two structural units: Precambrian/Early Palaeozoic basement and sedimentary cover. The basement includes various medium- and low-grade metamorphic series, ultimately consolidated during the Variscan orogeny, intruded by Carboniferous granites in the north-western part of the region. Gneisses dominate the basement, especially in the central, most elevated, part of the OBMB, whereas other basement rocks include mica schists, greenschists, phyllites, meta-trachytes, amphibolites, serpentinites, gabbro, and other rocks (Figure 2). They are divided into the Nové Město folded belt in the west and the Orlica–Śnieżnik Dome in the east, separated by the Olešnice–Uhřinov thrust fault. Pre-Variscan and Variscan history of the OBMB is still insufficiently known and opinions diverge [24–26], but these uncertainties have little bearing on the post-Variscan evolution, which is addressed in this paper.

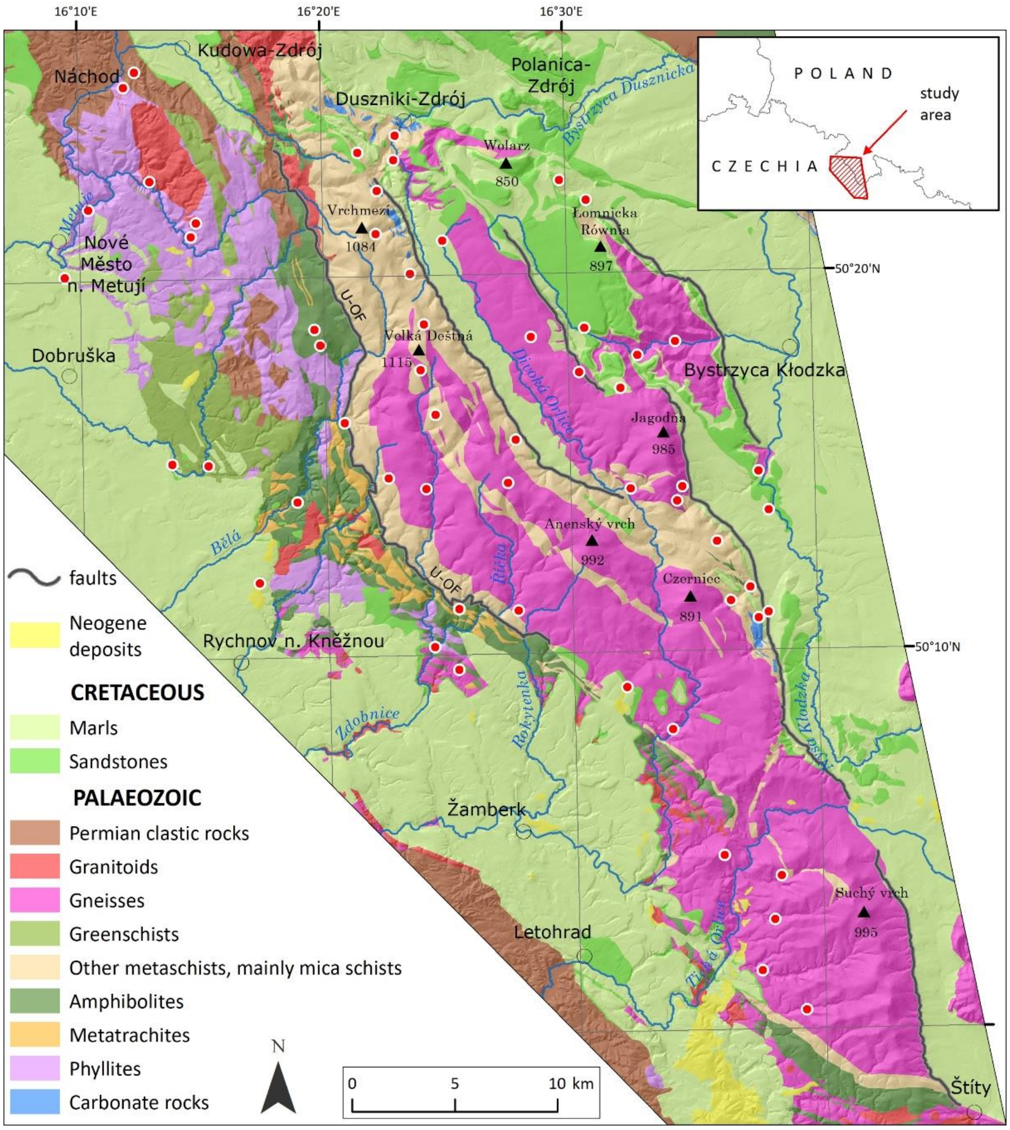

Figure 2. Geology of the Orlické–Bystrzyckie Mountains Block and location of geosites (see Figure 1 for specific geosite numbers). U-OF—Olešnice–Uhřinov Fault.

The post-orogenic sedimentary cover includes Permian and, mainly, Cretaceous rocks (Figure 2). The former are present in the north-western part of the area and comprise conglomerates and arkosic sandstones [27]. A few patches of Permian clastic rocks have also been recognized further south. The spatial extent of Cretaceous sedimentary rocks, represented by shallow marine sandstones and marls, is much larger. They occur as a continuous cover in the north-eastern part of the OBMB block, becoming less widespread towards the south and eventually disappearing. In the north-central part of the area they form a narrow belt trending NNW–SSE, coincident with an intramontane trough of the Divoká Orlice river. Minor isolated patches of Cretaceous rocks occur in the central-south part of the area. However, Cretaceous sedimentary rocks are widespread both to the east and west of OBMB (Figure 2), which, given their sedimentary environment, indicates the former existence of the Cretaceous cover in the entire OBMB and its subsequent stripping from the most elevated part [24].

2.3. Origin of the Orlické–Bystrzyckie Mountains Block Morphostructure—Patterns and Timeline

The history that resulted in the present-day appearance of OBMB can be traced back to the Cretaceous. Its outline, presented below, is based on both existing, although rather patchy literature [28–34], and our own, mostly not yet published data [35,36], and considers wider regional context of OBMB. It is important to note that whereas the general pattern of landscape evolution can be deciphered reasonably well, establishing the timeline of this evolution is far more challenging and only a few pinning points to constrain it are available.

Remnants of deeply weathered basement rocks (laterites) on the western ramp of OBMB [28] indicate that the landscape at the end of Early Cretaceous was one of low relief, with saprolitic covers of variable thickness. This characteristic actually applies to most of the Bohemian Massif at that time [37,38]. Marine transgression over OBMB commenced in the early Late Cretaceous (Cenomanian) and progressed from west to east. This event is documented by transgressive surfaces that separate basement rocks and the Cretaceous cover, exposed in several places along the western foothills of OBMB. Not long after the onset of transgression, the whole basement of OBMB was submerged and then covered by sediments. Historical outcrops in the Polish part of the block, not available anymore, showed evidence of bedrock cliffs and islets modelled by shoreline processes [39]. It is not known when the sea withdrew, re-exposing the landsurfaces underlain by Cretaceous sediments. It was likely causally related to the inversion tectonics at the Cretaceous/Palaeogene boundary, which manifested in the origin, or re-activation of large thrust faults elsewhere in the Sudetes [40]. However, the magnitude of early Cenozoic uplift of OBMB is not known and the existing thermochronological data have limited potential to constrain it [41]. Likewise, it is not known for how long the continuous Cretaceous sedimentary cover persisted over OBMB.

Sometime during the Cenozoic, most likely in the Neogene given the regional context, uplift of OBMB commenced and relief differentiation started. Uplift was accomplished by several superimposed mechanisms. The entire block was arched-up, akin to a large anticline [42,43], but numerous faults originated or were rejuvenated, causing topographic offsets. They were mainly broadly parallel to the NNW–SSE axis of OBMB, but W–E trending faults were also active. These faults are easy to identify within the part of OBMB, where Cretaceous cover is partly preserved, but are more difficult to be identified in basement areas. The most important ones are the eastern boundary faults, arranged en echelon and separating OBMB from the Upper Nysa Kłodzka graben [30,31,44]. However, no clear morphology of fault-generated escarpments occurs on the western side of OBMB and it is, therefore, hypothesized that late Cenozoic uplift assumed a form of gentle updoming in the western part, resulting in the origin of an inclined ramp, and block-faulting in the east, with consecutive blocks descending to the Upper Nysa Graben. These different styles of tectonics-controlled relief differentiation account for the large-scale asymmetry of OBMB, including the origin of an intramontane half-graben of Divoká Orlice. Uplift increased erosion and deep fluvial incisions into the ramp may be causally linked with this phase of landscape development. Likewise, headward erosion of rivers draining the eastern (Bystrzyca Łomnicka drainage basin) and northern part of OBMB (Bystrzyca Dusznicka drainage basin) appears associated with this regional uplift. The water gap of the Tichá Orlice river may owe its origin to antecedence at that time [45], as likely does the water gap of the Metuje river (Peklo) in the northwest. The greatest enigma is the history of the Divoká Orlice river, which flows towards SSE within the intramontane trough and then cuts through the axial ridge of OBMB forming the Zemská brána gorge, turning southwest, then south and finally, west. This contorted course suggests some major drainage pattern changes and indeed, the former flow to SSE beyond the Zemská brána gorge was hypothesized, but evidence is missing [46]. It was also observed that several rivers draining the part of OBMB west of the main ridge flow to the south in their headwater reaches (Zdobnice, Řička, Rokytenka), leading to speculations about their former continuation in this direction and ultimate drainage to the Danube basin. However, Prosová [29] argued that relict Neogene fluvial sediments in the western part of the ramp indicate the general drainage to the west and Labe drainage system.

The Quaternary has brought further changes to the geomorphic landscape of OBMB, but did not alter the big picture. Remodelling of slopes and water-divide surfaces occurred under cold-climate environmental conditions, although the altitude was not high enough to allow local glaciers to form. Therefore, the evidence of periglaciation includes mainly frost-shattered regolith, including blockfields (now mainly vegetated), angular rock outcrops, screes within deeply incised valleys, and widespread solifluction mantles. Landslides occurred in several places, mainly in the eastern part [47,48], although the area in general is not landslide-prone. Separating Quaternary and earlier fluvial downcutting within the deeply incised valleys does not appear possible at present.

3. Materials and Methods

This study is primarily an outcome of our original research carried out in the Orlické–Bystrzyckie Mountains Block, aimed at deciphering the pattern of Cenozoic tectonic displacements and geomorphic response. It mainly involved work with digital data, including high-resolution digital elevation models, to get a good overview of regional topography and to quantify its various characteristics. The transboundary location of the study area imposed the necessity of integrating two different models. The first one was a DEM available from the Polish Centre of Geodetic and Cartographic Documentation—a raster dataset of 1 m resolution and mean elevation error 0.05–0.15 m [49]. The second one is Digitální model reliéfu České republiky 5. generace (DMR 5G), characterized by a mean error of 0.18–0.30 m [50]. Both DEMs were re-projected to a specified coordinate system (UTM 33 N) and resampled into lower resolution, in order to return topographic features relevant to the regional scale of analysis, without inference form anthropic modifications. Background materials to analyse geology–landform relationships included Detailed Geological Map of the Sudetes (1:25,000) [51] and a geological map of the Czech Republic (1:50,000) available as a digital source on the Czech Geological Survey website [52]. After necessary generalization and unifications of legends, 12 lithological units were finally distinguished through manual vectorization. ArcGIS 10.2 software was used for all GIS analyses, preparation of maps and 3D visualizations.

Desk work was supplemented by field work, during which a few tens of geosites on both sides of the state border were visited and evaluated in terms of their potential to contribute to an overarching story of long-term landform evolution. For the Czech part, the popular-science publication by Vítek [53] proved a particularly useful source. While travelling across the area, particular attention was paid to localities offering good panoramic views, as these may significantly contribute to the understanding of regional landform pattern. In addition to our own field expertise, we considered geosites contained in two sources relevant to the area. For the Czech part, the Orlické Mountains, the database of geologically significant localities maintained by the Czech Geological Survey [54] was used. It includes 27 specific localities. "Geostrada Sudecka" [55] was a project carried out in cooperation of Polish and Czech Geological Surveys, aimed at making a car route across the Sudetes which would connect geologically important localities. One section of the route crosses the Polish part of the area, the Bystrzyckie Mountains, where 23 geosites were identified along it or in the nearest vicinity. Geosites from both groups were classified according to the dominant theme, to see whether they provide a complete picture of geomorphological evolution of the region.

Table 1. List of geosites in the Czech part of the Orlické–Bystrzyckie Mountains Block, included into the database of the Czech Geological Survey [54].

Number of Geosite (See Figures 1 and 2)	Specific Name (If Applicable) or Name of Nearest Settlement (in Brackets)	Content	Type of Geosite—Main Theme	Remarks
1	(Běloves)	Conglomerate crags	Geology–lithology	Protected site
2	(Běloves)	Abandoned rhyolite quarry	Geology–lithology	-
3	Peklo	River gorge	Geomorphology	Protected area
4	(Nový Hrádek)	Abandoned granodiorite quarry	Geology–lithology	-
5	(Nový Hrádek)	Abandoned phyllite quarry	Geology–lithology	-
6	(Nové Město nad Metuji)	Natural outcrops of Cretaceous sediments over basement	Geology–lithology	-
7	Špičák	Abandoned gabbrodiorite quarry	Geology–lithology	-
8	Jelení lazeň	Peat bog	Geomorphology	Protected area
9	Marušin kámen	Gneissic crag	Geomorphology	-
10	Sfinga	Schist crag	Geomorphology	Protected site
11	(Mnichová)	Amphibolite outcrops in road cut	Geology–lithology	-
12	(Masty)	Working amphibolite quarry	Geology–lithology	Not accessible without permission
13	(Bílý Ujezd)	Natural outcrops of Cretaceous sediments over basement	Geology–lithology	-
14	Růženina Hut′	Abandoned amphibolite quarry	Geology–lithology	-
15	(Kačerov)	Mica schist crag	Geomorphology	-
16	(Zdobnička)	Abandoned gneiss quarry with lamprophyre dykes	Geology–lithology	-
17	Na Dolech	Ancient mining works	Mining history	-
18	U Kunštatské kaple	Peat bog	Geomorphology	Protected area
19	(Lukavice)	Man-made outcrops of weathered rocks (laterite)	Geology–lithology	Inaccessible underground galleries
20	(Pěčin)	Abandoned gabbrodiorite quarry	Geology–lithology	-
21	(Nebeská Rybna)	Trachyte outcrops in road cut	Geology–lithology	-

Table 1. *Cont.*

Number of Geosite (See Figures 1 and 2)	Specific Name (If Applicable) or Name of Nearest Settlement (in Brackets)	Content	Type of Geosite—Main Theme	Remarks
22	Myší díra	Natural outcrops of serpentinite	Geology–lithology	-
23	(Bartošovice v Orlických horach)	Abandoned sand pit in Cretaceous sediments	Geology–lithology	-
24	Zemská brána	River gorge	Geomorphology	Protected area
25	Studenské skály	Gneissic crags	Geomorphology	-
26	Udolí Orličky	Natural gneiss outcrops	Geology–lithology	-
27	Čenkovička	Natural gneiss outcrops	Geology–lithology	Protected area

Table 2. List of geosites in the Polish part of the Orlické–Bystrzyckie Mountains Block, included into Geostrada Sudecka project [55].

Number of Geosite (See Figures 1 and 2)	Specific Name (If Applicable) or Name of Nearest Settlement (in Brackets)	Content	Type of Geosite—Main Theme	Remarks
28	Duszniki-Zdrój	Mineral springs in spa park	Hydrogeology	-
29	(Duszniki-Zdrój)	Mylonite outcrop	Geology–lithology	-
30	Kozia Hala	Abandoned marble quarry	Geology–lithology	-
31	(Zieleniec)	Abandoned dolomite quarry	Geology–lithology	-
32	Złota Sztolnia	Ancient mining works	Mining history	Not accessible
33	(Zieleniec)	Mica schist outcrop	Geology–lithology	-
34	Torfowisko pod Zieleńcem	Peat bog	Geomorphology	Limited accessibility—nature reserve
35	Siwa Skała	Gneissic crag	Geomorphology	-
36	(Spalona)	Abandoned gneiss quarry	Geology–lithology	-
37	Szary Kamień	Gneissic crag	Geomorphology	-
38	(Młoty)	Sandstone blockfields	Geomorphology	-
39	(Młoty)	Gneiss outcrop in disused gallery for power station	Geology–lithology	Not accessible
40	(Wójtowice)	Gneiss outcrop	Geology–lithology	-
41	(Poręba)	Gneiss outcrops in road cut	Geology–lithology	-
42	(Poręba)	Mica schist outcrop in road cut	Geology–lithology	-
43	(Rudawa)	Gneiss outcrop in road cut	Geology–lithology	-
44	Jedlnik	Viewing point	Geomorphology	-
45	Szczerba	Castle ruins—amphibolite as building stone	Geology–lithology	-
46	Solna Jama	Karstic cave	Geomorphology	-
47	Różanka	Sandstone sculptures next to church	Use of rock resources	-
48	(Różanka)	Abandoned marl and sandstone quarry	Geology–lithology	-
49	(Długopole-Zdrój)	Working sandstone quarry	Geology–lithology	Not accessible without permission
50	Długopole-Zdrój	Mineral springs in spa park	Hydrogeology	-

4. Geosites

The database of the Czech Geological Survey contains descriptions of 27 sites of geological interest in OBMB (Table 1). The majority are outcrops of different basement rocks that build the block, whereas several others are classified as geomorphological localities, although crags are both landforms and rock outcrops. Two localities (no. 3 and 24) are not classic geosites, but larger areas—a few kilometres long fluvial gorges, with numerous rock outcrops and hillslope and fluvial geomorphic features. Apart from lithological and geomorphological sites, one mining heritage locality was included.

Geosites on the Polish side identified in [55] are more diverse in terms of the main theme and include, beside rock outcrops and landforms, localities exploring hydrogeological theme, mining heritage and the use of stone resources (Table 2). Within geomorphosites, a karst locality (Solna Jama cave) is included and the mining heritage site actually combines underground works with a natural cave passage. However, it is not accessible for safety reasons and only the closed entrance can be seen. A geosite deserving interest is the roadside panoramic viewpoint below Mt. Jedlnik (Table 2; no. 44), which allows the visitors to see the graben of Nysa Kłodzka river and the Śnieżnik Massif further to the east, with the elevation difference of nearly 1000 m. However, the site is less suitable to appreciate general relief of OBMB itself.

Table 3 shows brief summary of geosites included in both sources and Figure 3 shows selected examples. Classic geological localities, that is rock outcrops, both natural and artificial (road cuts, quarries), dominate, accounting for nearly two-thirds of the sites. Among them, three are important for post-Variscan history of the area, showing products of pre-Cretaceous tropical weathering (Table 1; no. 19) and the evidence of Cretaceous marine transgression over the basement (Table 1; no. 6,13). However, the first one is practically inaccessible. Geomorphosites constitute nearly one-third of the total, but they do not represent a thematically diverse population. Six of them are gneissic/schist crags, three are peat bogs and two are river gorges, although the latter are not classic geosites (singular localities), but larger areas along the rivers (linear geosites according to Ruban [56]). Except two river gorges, none of these geosites can be used to build the story of Cenozoic emergence of the mountain block. Instead, they mainly illustrate the pre-Variscan geological history and Late Quaternary shaping of fine details of morphology (crags, blockfields, peat bogs), with a huge temporal gap in between.

Table 3. Summary of geosites in the study area, classified by the principal theme.

Principal Theme	Number of Geosites			
	Czechia	Poland	Total	
			Absolute	Percentage
Geology—lithology	18	13	31	62
Geomorphology	8	6	14	28
Mining history	1	1	2	4
Hydrogeology	-	2	2	4
Use of geological resources	-	1	1	2
Total	27	23	50	100

The geosites examined above do not exhaust the list of potential geosites in the region and some important gaps remain. For example, no natural outcrops of Cretaceous sandstones, present in the north-eastern part of OBMB [57], are included into either of the lists. Some of these, as on Mt. Kamienna Góra (Figure 1, no. 51), are quite impressive and include rock cliffs more than 10 m high, fallen rock pillars, extensive block and boulder fields (Figure 4). Another missing topic are landslides, which are infrequent but nevertheless occur, including the largest landslide complex in the Polish Sudetes, at Mt. Toczek (Figure 1, no. 52) [47,58]. The valley of Černovický potok in the massif of Suchý vrch (Figure 1, no. 56) contains a fine example of a small waterfall—a rather unique feature in

OBMB. The representation of bedrock crags can be expanded, to account for their different settings. For example, impressive mid-slope crags with associated blockfields occur in the lower, deeply incised reach of the Olešenka valley in the NW part of OBMB (Figure 1, no. 53) [59], whereas Plačtivá skála in the Zdobnice valley (Figure 1, no. 55) is a good example of phyllite crag that rises straight from the channel to the height of some 15 m. Periglacial blockfields can be examined in different places in the basement area, including Mt. Špičák (Figure 1, no. 54).

Figure 3. Selected geosites in the Orlické–Bystrzyckie Mountains Block, included in the respective inventories on the Czech [54] and Polish [55] side of the area. (**A**) Rock outcrop to show transgressive Cretaceous marine deposits lying unconformably on the Palaeozoic basement (site no. 6; Table 1); (**B**) abandoned gabbrodiotite quarry (site no. 7; Table 1); (**C**) gneissic crags (site no. 25; Table 1); (**D**) bedrock channel in fluvial gorge (site no. 24; Table 1); (**E**) peat bog (site no. 34; Table 2); (**F**) ruins of a castle built from local stone material (site no. 45; Table 2).

Figure 4. Selected potential geosites in the Orlické–Bystrzyckie Mountains Block, not included in any existing databases or inventories. (**A**) Huge residual sandstone blocks, Mt. Kamienna Góra (Poland); (**B**) head scarp and associated trenches form parts of landslide morphology at Mt. Toczek (Poland); (**C**) waterfalls in the Černovický potok valley (Czechia); (**D**) Plačtivá skála in the Zdobnice valley (Czechia); (**E**) slope blockfield in the Olešenka valley (Czechia); (**F**) rock cliffs in the Těchoninský potok valley (Czechia). Locations indicated on Figure 1.

5. Large-Scale Landforms—How to Show, Explain and Integrate into a Story?

5.1. The Role of Viewpoint Geosites

Viewpoint geosites were defined as 'a specific locality which allows for unobstructed observation of the surrounding landscape and comprehension of Earth history recorded in rocks, structures and landforms visible from this locality' [18]. Hence, their primary role is to offer a view, which also becomes a context for more focused classic geosites. Consequently, viewpoint geosites include both well-exposed localities in open terrains, as well as different man-made structures, which facilitate good panoramic views, e.g., viewing towers. Obviously, any panoramic view has to be explained and interpreted in terms of geological and/or landform evolution history, if contribution to geo-interpretation is to be made.

Table 4 includes a selection of possible viewpoint geosites within OBMB, whereas Figure 5 shows their location and the width of panoramic views, corresponding to images included in Figure 6. The respective views, after introducing necessary annotations, can help to better understand the gross geomorphological landscape of OBMB and fill the gap emergent from the sole focus on classic geosites. The viewpoint geosites presented here are complementary in the sense that no single locality can show all the key landscape features of the region, which directly emerges from the distinct asymmetry of the block. In other words, this is because geomorphologically the eastern side is very different from the western side. Thus, while viewpoint geosites are important and may be developed for geotourism and geo-interpretation purposes, other ways of conveying the message should be also explored, generally falling into the field of digital visualization [60]. These innovative means would also help to overcome problems faced by people with mobility problems, who may not be able to visit classic geosites and viewpoint geosites. In the study area, some geosites presented in Section 4 and some viewpoint geosites are roadside locations and these can be relatively easily visited, but others require longer hikes to reach, including over steep terrain.

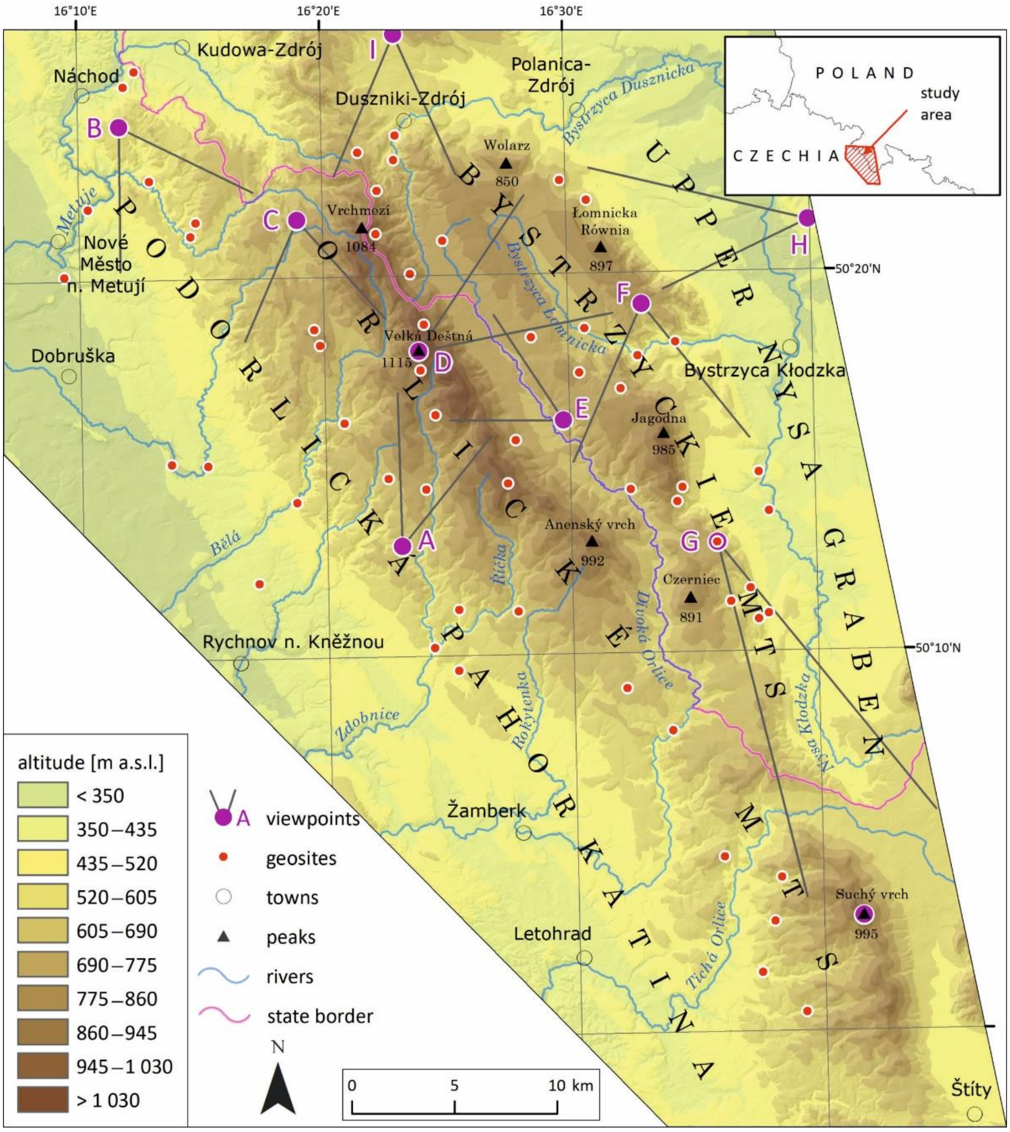

Figure 5. Location of panoramic viewpoints in the Orlické–Bystrzyckie Mountains Block. Letter codes consistent with Table 4 and Figure 6.

Table 4. Selection of viewpoints which allow to see and interpret the gross relief of the Orlické–Bystrzyckie Mountains Block. Letter codes correspond with Figure 5.

Letter Code	Locality	Type of Viewpoint	Brief Description of View	
			Foreground	Background
Western Part				
A	Liberk	Open terrain	Shallow trough valleys within undulating surface of the ramp	Main ridge of the Orlické–Bystrzyckie Mountains Block (OBMB)—the most uplifted part
B	Dobrošov	Viewing tower	Deeply incised valleys into an area of secondary uplift within the ramp	Inclined ramp surface with residual hills; main ridge of OBMB in the far left
C	Polom	Open terrain	Transition from the ramp surface to the main ridge—evidence of increasing uplift	Rock-controlled hills (monadnocks) rising above the ramp
Axial Part				
D	Velká Deštná	Viewing tower	Tilted half-horst (fault-generated escarpment not visible) and intramontane trough of Divoká Orlice	More distant tilted half-horst, with structure-controlled planar surfaces facing the viewer
E	Mostowice	Open terrain	Intramontane trough of Divoká Orlice, with Cretaceous sediments preserved	Fault-generated escarpment delimiting the main ridge of OBMB from the east
Not coded	Suchý vrch	Viewing tower	Axial part of the main ridge (southernmost part)	Asymmetric uplift of Suchý vrch block, fault-generated escarpment in the east (left), westward tilt
Eastern Part				
F	Huta	Open terrain	Fluvially dissected surfaces in densely faulted terrain	Asymmetric uplift of Mt. Jagodna block, fault-generated escarpment in the east (left), westward tilt
G	Jedlnik	Open terrain	Uplifted surfaces above the eastern mountain front	Intramontane Štity Graben (middle) and Suchý vrch horst (right)
H	Mielnik *	Open terrain	Intramontane Upper Nysa Graben	Fault-generated eastern escarpment of OBMB
Northern Part				
I	Skały Puchacza *	Open terrain	Northern foreland of OBMB (intramontane basin of Duszniki)	Westward inclined half-horst, incised by Bystrzyca Dusznicka river, with structure-controlled planar surfaces (left), and fault-generated eastern slope of the main ridge.

* Viewpoint geosites located outside OBMB.

Figure 6. *Cont*.

Figure 6. Panoramic viewpoints in the Orlické–Bystrzyckie Mountains Block, allowing the visitors to follow gross relief features attested to the long-term landform evolution of the area. Localities: (**A**) Liberk; (**B**) Dobrošov; (**C**) Polom; (**D**) Velká Deštná; (**E**) Mostowice; (**F**) Huta; (**G**) Jedlnik; (**H**) Mielnik; (**I**) Skały Puchacza. Location of viewpoints on Figure 5.

5.2. Opportunities from Remote Sources

Among remote sources made available recently, Google Earth Pro 7.3$^{\text{TM}}$ (GE) is particularly useful, being freely accessible and easy to work with, at least at the elementary level [61,62]. It allows the user to produce a customized three-dimensional view of the Earth's surface, in which the height, width, and orientation of the image can be controlled. Collated images on the GE website [63] are derived from satellite imagery and, hence, relief is shown alongside land cover, which may enhance the image and facilitate interpretation of landforms or, conversely, blur the relief through introduction of unnecessary land cover and land use details. Examination of GE images for the study area provides examples of both kinds (Figure 7). Figure 7A,B show rather detrimental effect of land cover, whereas on Figure 7C,D forested areas highlight key geomorphological features.

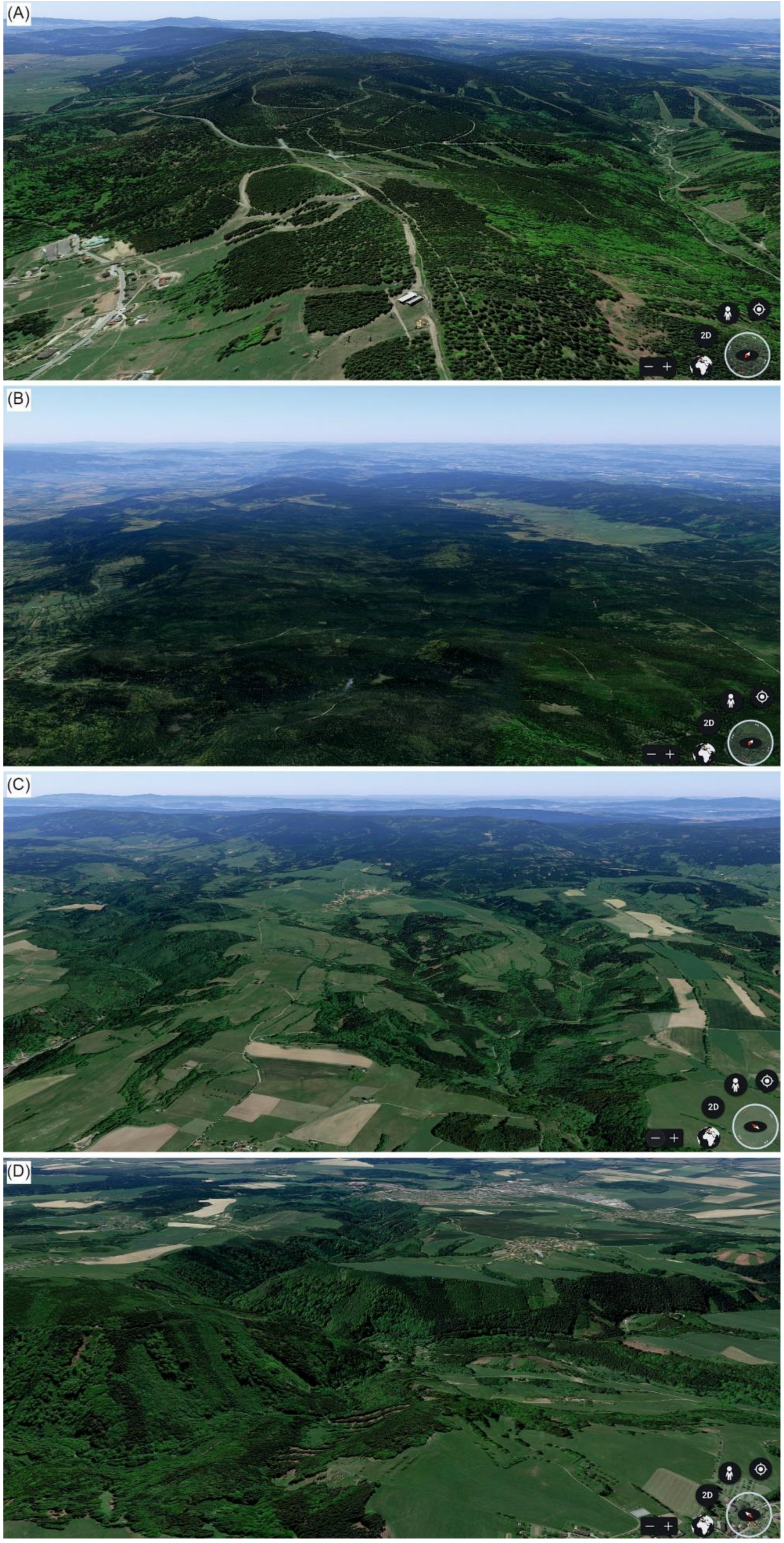

Figure 7. Selected relief features of the Orlické–Bystrzyckie Mountains Block illustrated by Google Earth Pro$^{\mathrm{TM}}$ images: (**A**) main ridge of the Orlické Mts.—view from the north; (**B**) downfaulted steps of the Bystrzyckie Mts.—view from the north; (**C**) dissected ramp on the western side of the Orlické Mts.—view from the south-west; (**D**) Peklo gorge in the NW part of the Orlické Mts.

Figure 7A shows the main ridge of the Orlické Mountains, which is the axis of the entire morphostructure. It descends towards the intramontane half-graben of Divoká Orlice river on the left via a fault-generated escarpment, whereas the general slope to the right is lower, signifying asymmetric uplift and large-scale tilting. However, ski-resort facilities in the foreground and middle right capture attention and mask topographic differences. The half-graben is also visible on Figure 7B (right), along with two back-tilted steps to the left, terminating in another fault-generated escarpment in the far left of the image. However, nearly continuous forest cover in the foreground effectively hides topography, whose vertical range is less than 500 m in total. By contrast, forest areas emphasize deeply incised fluvial valleys dissecting the western ramp (Figure 7C). Despite rather modest depth of incision (100–150 m), the valley sides are sufficiently steep to prevent any agricultural use, which in turn occupies low-relief interfluves. Thus, the image shows juxtaposition of two contrasting landforms very clearly: extensive, planar, or gently rolling interfluves (compare with ground view on Figure 6A) and deeply incised valleys, whose co-existence is crucial to understand neotectonic history of OBMB. Figure 7D presents a similar case, zoomed in to show the Peklo gorge of the Metuje river and its tributary of Olešenka river (foreground). The effects of large-scale tilting and the presence of the ramp are particularly well seen behind the confluence of two V-shaped valleys (middle of the image), where the inclined planar relief is structure-controlled, adjusted to tilted Cretaceous strata.

Digital elevation models can be also used to build three-dimensional views, although visualization options available to ordinary users of governmental websites [50,64] are limited. Moreover, bare models, without an interpretation layer, are certainly not sufficient to increase understanding of the complex stories hidden behind the sceneries. However, if customized views can be prepared and then annotated, such visualizations may become very useful and complement large-scale perspectives obtained from other sources. Figure 8 shows relief models that capture the entire morphology of OBMB from three different directions, whereas annotations highlight the key features of large-scale geomorphology, such as major morphostructures, fault-generated escarpments, selected rivers and most significant fluvial gorges. Although the models are complementary, even an individual one conveys the message (we also tested a view from NE, but this proved rather disappointing). Annotated visualizations of this kind, supplemented by more extensive textual commentary, can be used as interpretation tools on information panels, providing graphical regional context to the explanation of specific sites of interest, or on dedicated websites. The advantage is that they show regional relief, impossible to present using other available tools. These models can be further enriched by overlying geological (lithological information), although the result of map overlay may not be entirely satisfactory if both relief and lithology are very complex.

Visualizations of DEMs may be also used for more restricted areas, to highlight specific geomorphic features, especially if these are hardly seen due to vegetation cover. One application field is to enhance experience from viewing points and provide additional perspective, inaccessible from the ground level. Figure 9 shows an attempt to overcome visibility restrictions from two viewing points presented in Section 5.1 (localities B—Dobrošov and G—Jedlnik) and includes panoramic views of relief from a certain height above the ground. Comparison with Figure 6B,G demonstrates the added value of such 3D visualizations in that both wider geomorphic context becomes more evident, as well as various landforms, otherwise obstructed (hidden) by those located closer to the observer, can be seen. More generally, important features located further from an observer can be highlighted using this means. For example, a view from Dobrošov (Figure 6B) does not reveal the asymmetric shape of the entire OBMB morphostructure, having the main ridge on the skyline, and the true extent of the ramp, but both can be appreciated on a model (Figure 9B).

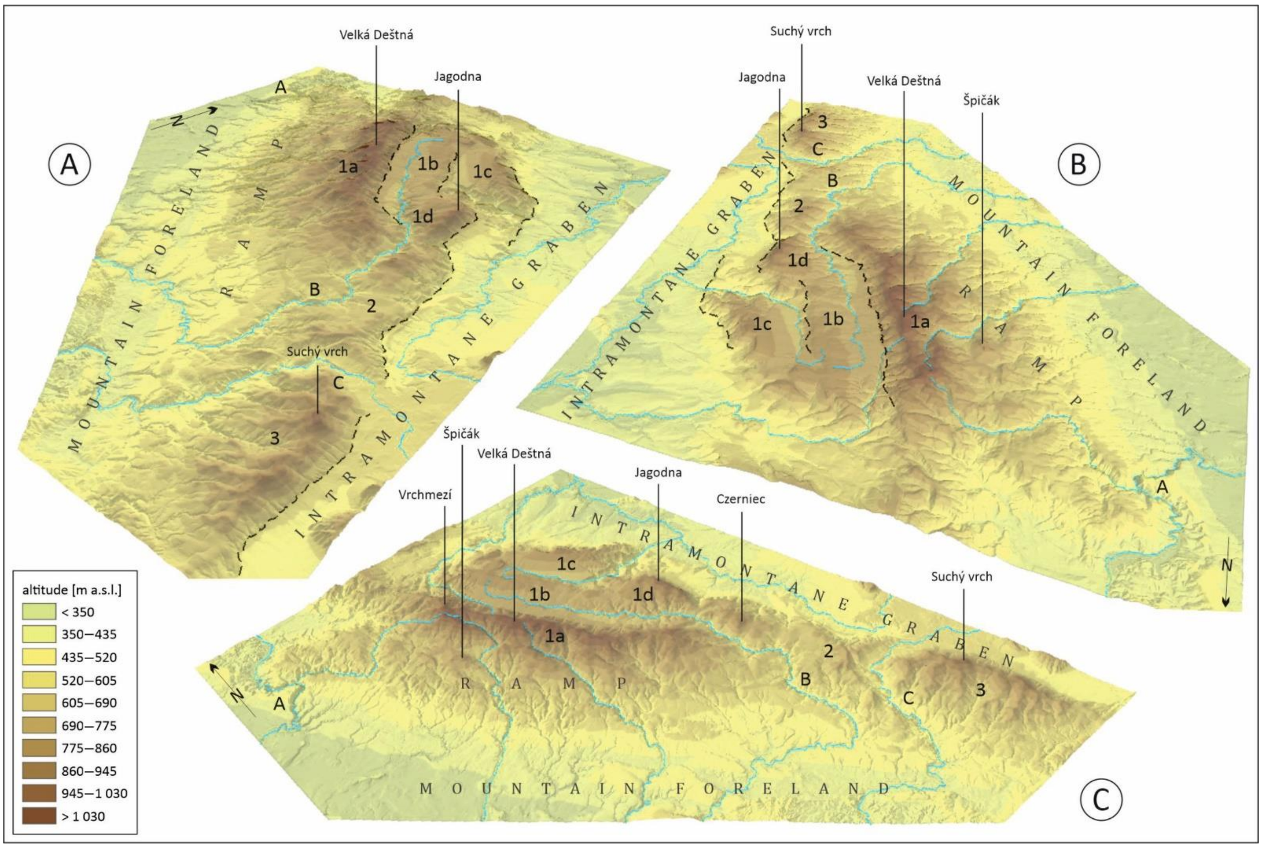

Figure 8. Large-scale topography of the Orlické–Bystrzyckie Mountains Block on 3D visualizations: (**A**) view from SSE; (**B**) view from NNW; (**C**) view from SW. Explanations: 1–3—three main geomorphic units of OBMB: 1—the most elevated northern part, with the main ridge of the Orlické Mts. (1a) and downfaulted steps of the Bystrzyckie Mts. (1b to 1d), 2—least elevated central part, 3—Suchý vrch massif; fluvial gorges: 1—Peklo, 2—Zemská brána (Divoká Orlice water gap), 3—Tichá Orlice water gap; broken lines—footslopes of fault-generated escarpments.

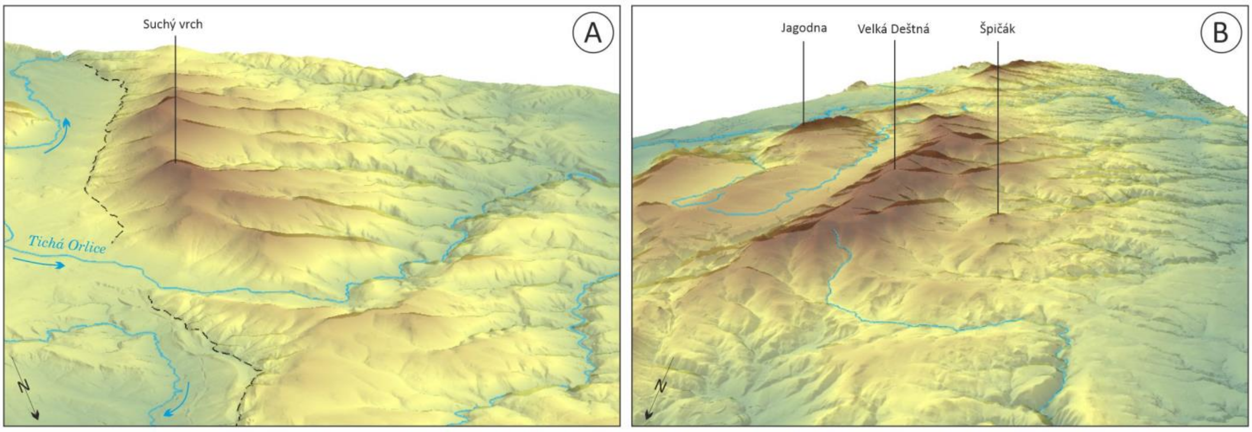

Figure 9. Two representative 3D visualizations, meant to enhance views available from the ground level. Image (**A**) corresponds to the ground view from Mt. Jedlnik (Figure 6G) and shows the entire Suchý vrch massif, highlighting its asymmetry, as well as the water gap of Tichá Orlice river, not visible from the viewing point. Image (**B**) corresponds to the view from Dobrošov (Figure 6B) and allows to see the downfaulted blocks located beyond the main ridge of the Orlické hory and the large extent of the ramp.

Another potential resource to appreciate and examine the large-scale geomorphology of OBMB is the commercially available relief map of the area, enriched in topographic details and tourist-oriented information [65]. At a rather coarse scale of 1:75,000, it lacks various topographic details but due to necessary generalization it shows the main features of morphology fairly well (Figure 10). Hypsometric color scale (however, not explained in the key, so basic map reading abilities are required) helps to visualize altitude relationships. The map appropriately conveys the key messages about relief differences between the northern, central, and southern part of the area, the narrowing of OBMB to the south, asymmetry of the southernmost sector, the presence of intramontane trough in the north and sharp versus gradual boundaries of OBMB in the east and west, respectively. However, map availability may be a problem and its use in the physical form (75 × 100 cm) in outdoor interpretation is rather problematic.

Figure 10. Three-dimensional relief map of the Orlické–Bystrzyckie Mountains Block, commercially available. Original scale is 1:75,000.

The latter problem may be partially overcome using customized three-dimensional relief models, which can be built using available elevation data and then printed [66]. These models can then be annotated and used as teaching tools in outdoor education, both formal and informal, providing the necessary context for explanation of classic geosites. However, we were unable to evaluate this approach in the specific context of OBMB. If approximately the same printing setup is adopted as by Hasiuk et al. [66], the model comparable to the relief map shown in Figure 10 (original scale 1:75,000) would consist of about 50 tiles measuring 10 × 10 cm, which would clearly constrain its outdoor use. Reducing the scale to 1:200,000 would result in a more practical number of six tiles, but many details of relief could be lost from the models.

5.3. The Contributing Role of Classic Geosites

Although unable to tell a big story, classic geo(morpho)sites still have a role to play. For visitors, they provide a balance between commented views, hence, rather static and not necessarily much engaging experience, and opportunities for closer, more active interactions with geoheritage, including physical exercises while hiking to the sites. However, their real contribution is that they provide insights into finer details of larger landforms and which the local controls are. In the particular context of OBMB the following themes may be explored at geosites: (a) modelling of faulted escarpments by landslides, particularly evident at Mt. Toczek, where the landslide terrain is conveniently crossed by forest road and hiking trails; (b) crags and vegetated blockfields on mountain-tops and ridges show the role of Pleistocene frost-related processes in shaping water-divide surfaces; (c) rock cliffs, taluses, and scree on steep slopes of deeply incised valleys inform how hillslope processes follow fluvial incision, helping to understand the concept of relief rejuvenation; (d) details of fluvial bedrock erosion can be examined at bedrock channels, waterfalls, and potholes. Moreover, they help to understand linkages between regional uplift and stream behaviour. Ideally, at each such site, if interpretation is provided, a cause-and-effect link to the large-scale processes should preferably be made.

However, an important point is that these links seem to be unidirectional. Resolving gross relief features such as planation surfaces, fault-generated escarpments and deep valleys into medium-size and minor landforms is conceptually easier, whereas systematic examination of small-scale geomorphosites does not readily lead to the appreciation and understanding of the 'big story', in which endogenous processes play the major part.

6. Conclusions

To decipher the history of landscape evolution is among the main tasks of geomorphology. One may also argue that telling such stories, 'hidden behind the scenery', is an effective way to capture visitors' interest, increase their engagement and understanding. However, the larger and more complex an area is, and the more multifaceted its geomorphological evolution, the more difficult such stories are to tell. Problems are exacerbated if land cover and land use obscure landforms and geological structures. We addressed this issue on the example of Orlické–Bystrzyckie Mountains Block in Central Europe, whose landscape evolution spans at least the entire Cenozoic (geological evolution being much longer than that) and involves various subaerial processes, both endo- and exogenous. More than fifty potential geosites, most of them fitting the 'classic' understanding of the term, have been identified previously and more can be added to fill thematic gaps. However, even collectively, they fail to illustrate the complete story and, therefore, the long-term, large-scale landscape evolution of OBMB cannot be recreated from the geosites alone. Viewpoint geosites may help, providing opportunities for interpretation of broader-scale landform patterns, but they are still insufficient to build the big picture. These limitations can be overcome using modern technologies, digital resources, and 3D visualizations, which can be customized to show gross geomorphological features, unobstructed by either smaller-scale landforms or land cover. Although not explored in this paper, digital elevation models can be further used to build animations to show landscape evolution through time, with a caveat in mind that going backward in time, specific landform configurations would become increasingly hypothetical.

These three means, i.e., specific ('classic') geosites, viewpoint geosites, and digital technologies, if used jointly, may be building blocks of an interpretation package that can be explored both indoor and outdoor. The third component in particular would help to include people with various disabilities as another target group for geoeducation. Such a package is capable to offer an integrated story, where small pieces (individual landforms presented at 'classic' geosites) fit into a wider spatial picture and the relevant timescale. Although the flow of the paper was from singular geosites, through viewpoint geosites, to large-scale views based on modern technologies, the geoeducation and teaching practice should probably follow a reverse trajectory, starting from a broad perspective and then zoom in on specific geosites, illustrating components of the big story. The package, to be effective, should include easy jumps from a small-scale to a large-scale story, so that the context is never lost. For example, if a series of outdoor information panels to erect at geosites, including viewing geosites, is considered, each one should have a separate section with a 3D visualization for the entire area and a brief outline of the long-term and large-scale story. In each case, however, geomorphological interpretation adjusted to the potential user should be provided, as neither panoramic views from viewpoint geosites nor 3D visualizations, including printed terrain models, are self-speaking.

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