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ORIGINAL ARTICLE

# The Evaluation of Geomorphosites with regards to Geoheritage: Case Study of the Novohradské Mountains, Czechia

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**Abstract**
Czechia, due to its location in Central Europe and long geomorphological development, has seen the development of a varied relief, and therefore the creation of different types of geomorphological landscapes. Recently, considerable attention has been paid to the research and evaluation of geomorphological landscapes. The concept of geodiversity and geomorphosites is mainly used for evaluation. So far, less attention has been paid to the Czech-Austrian border area, where the valuable relief of the Novohradské Mountains with a number of important geomorphosites is located. The main goal of this contribution is therefore the presentation of selected rare geomorphosites in the southern part of the Novohradské Mountains (Mt. Kamenec, Mt. Myslivna and Mt. Jelení) and their evaluation using the concept of geomorphosites. The basic methodological step was the detailed geomorphological mapping and geomorphological inventory of the area of interest, followed by the identification and selection of the studied localities—geomorphosites. The selected localities were then evaluated according to the existing methodology for evaluating geomorphosites, which is used in the Czech Republic with regard to a possible mutual comparison of the evaluated geomorphosites. The evaluated geomorphosites were compared with the previously evaluated sites in the northeastern part of the area of interest in the past research. We can state that all sites have a high scientific value with respect to their conservation value, the occurrence of specific forms of weathering on the granites, and palaeogeographic importance, with only the Jelení Mt. having lower total values due to the remoteness and poor accessibility of the locality. The acquired knowledge can be used for geoeducational and geotouristic activities in the study area. Another possibility for using this local geoheritage is the option of guided walks from local geotourism organizations.

**Keywords** Abiotic nature · Geodiversity · Geotourism · Geoeducation · Geoheritage

## Introduction

Geoheritage values are the basic indicators by which we evaluate geomorphosites using geomorphological heritage whereas a broader definition of geomorphosites not only emphasises their intrinsic significance but also the symbolic value they assume or have assumed. Panizza (2001) and Panizza and Piacente (2008) defined geomorphosites as "landforms with particular and significant geomorphological attributes, which qualify them as a component of a territory's cultural heritage (in a broad sense)". According to these authors, the attributes that may confer value to a geomorphosite are scenic, scientific, socioeconomic, and cultural. This broader definition, which considers all values as interrelated and interdependent within a holistic conception, is suitable in the popularisation context (geotourism, education, promotion, geoparks). They can be single geomorphological objects or wider landscapes and may

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be modified, damaged, and even destroyed by the impacts of human activities (Reynard and Panizza 2005).

The importance of geomorphological heritage in the landscape and its significance is discussed, for example, in the publications of Reynard et al. (2009a, b), Migoń (2014), Kirchner et al. (2017). Geomorphological heritage is based on the significance of a site for a particular area, but also on the knowledge and popularity of the site and other values (e.g. historical, economic, aesthetic, or ecological aspects). We focus on selected components of the regional/local geomorphological heritage, both singular landscape shapes and their complexes in our assessment (Reynard and Panizza 2005). This local or regional geoheritage is very important for local development (on the level of communities, higher administrative units (districts), and in some cases particular regions or counties).

The first evaluation using the concept of geomorphosites for the whole territory of the Czech Republic was carried out by Demek et al. 2011. Evaluation based on the concept of geomorphosites has also been used for the assessment of landforms on both a regional and a local scale (e.g. Rypl et al. 2019). The surveys mentioned above have brought forth much new knowledge about the high geodiversity of the landscape (especially its abiotic parts), and offer valuable information for the legal protection of geological and geomorphological heritage (Kubalíková 2016).

An important overview of geomorphologically valuable relief forms, geomorphological landscapes and the legal protection of geomorphological heritage is currently provided by monographic publications dedicated to individual states, including those of Europe (e.g. Fort and André, 2014; Lehotský and Boltižiar 2022; Migoń Jancewicz 2024; Embleton-Hamann 2022), and specifically Czechia (Pánek and Hradecký 2016).

Currently, there are many geomorphologically valuable areas in Czechia which are not legally protected, so it is important to evaluate these areas and propose options for further use and protection. These regions include the territory of the Novohradské Mountains on the Czech-Austrian border. The Novohradské Mountains are built mainly from the Variscan granite rocks of the Bohemian massif. The specific shapes found in our country demonstrate the development of the relief in the Cenozoic (weathering and development of the Paleogene planation surface, the influence on it of neotectonics, and its remodeling by cryogenic processes in the Pleistocene—Demek 2004).

Previously, researchers such as Demek 1964 or Demek et al. 1964 have focused on the geomorphological research of granite areas especially on the character of weathering. Typical granite castle koppies (tors) and inselbergs, including the structural-tectonic character of granites, were characterized by e.g. Votýpka (1979), in the border areas with Germany, or by Kubíček and Migon (1992) and Štepančíková and Štemberk (2016) on the Czech-Polish border. From the granitoid massifs of the Sudetes border area, it is possible to mention, for example, publications by Migoń (1996) and Michniewicz et al. (2020), that deal with inselbergs and ruwares as well as weathering microforms.

In the border area with Austria (the Waldviertel Region – Lower Austria), which adjoins the Novohradské Mountains, there are also widespread specific forms on granites that have the value of regional heritage, especially tors and microforms of weathering (in more detail e.g. Chábera and Huber 1999; Huber 1999; Migoń et al. 2018, 2022). The possibilities of using these specific locations were discussed in the work of Michniewicz et al. (2015) with regard to geotourism.

The main goal of the article is to evaluate selected geomorphological sites in the Novohradské Mountains (Czechia) using the concept and methodical approach of geomorphosites according to Kubalíková (2012). Knowledge about the values of sites will contribute to the recognition of the geomorphological heritage (e.g. Reynard et al. 2016; Reynard and Brilha 2018) of the study area at the regional level.

This article follows on from research on the north-eastern part of the Novohradské Mountains (Rypl et al. 2019) and subsequently tries to compare both pieces of research (see Discussion and conclusion).

## Study Area

The studied area is the southern part of the geomorphological unit of the Novohradské Mountains (Fig. 1). The unit of the Novohradské Mountains belongs to the Hercynian orogenic belt (Demek and Mackovčin 2014) in Czechia and is situated at the boundary between Czechia and Austria. The core of the mountains is represented by the Pohořská Mountains with the highest peak of Kamenec (1 072, 1 m a.s.l.). The mountains are limited by up to 300 m high fault scarps on the western and northern side. Remnants of an etchplain are preserved in the central part of the mountains. The rivers Lužnice, Malše, and Stropnice spring in the Mountains.

From the geological point of view, the area of the Novohradské Mountains is situated within the southern part of the Moldanubian Pluton, which represents the southern part of the Bohemian Massif formed during the Variscan orogeny. The most common bedrock types of this area include late Variscan igneous/magmatic rocks such as Weinsberg-type granite and Mrákotín-type granite. The geological structure is completed by Moldanubian cordieritic gneiss (Staník 1991; Heřmánek and Matějka 1998). Their deep valleys dissected the landscape. Granite rock landforms that developed in the tropical climate of the early Cenozoic and in the periglacial conditions of cold periods of the

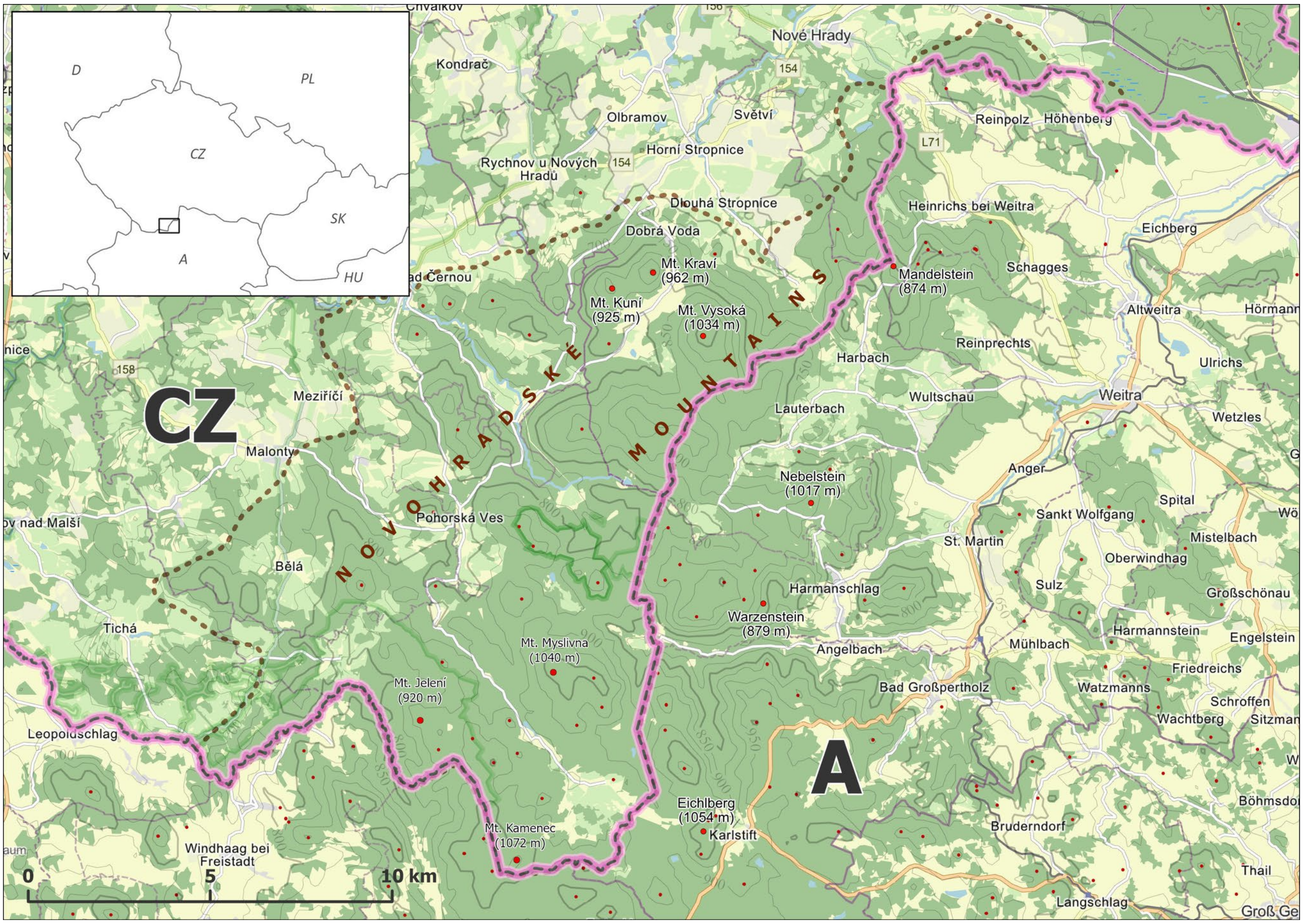


**Fig. 1** Location of the Novohradské Mountains

Pleistocene, such as castle koppies, tors, frost-riven cliffs, corestones, or blockfields, are common in this landscape (e.g. Rypl et al. 2014, 2017; Rypl and Kirchner 2017 etc.). Among the structural landforms, there are bornhards and ruwares with forms of cavernous weathering (Vítek 1995).

The wider part of this unit known as the Gratzen Mountains is located in Austria. The Gratzen Mountains are part of the Granite and Gneiss Plateau (Weber and Duyster 1990).

## Methodological Approach

Geomorphological heritage may be considered as the set of landforms worthy of being protected and transmitted to future generations (Reynard et al. 2009a, b). Geomorphological heritage is thus presented as part of geoheritage, itself a "component of natural heritage" (Reynard et al. 2009a, b). In accordance with the further development of knowledge (see in more detail Coratza and Hobléa 2018), geomorphological heritage includes not only geomorphological objects sensu stricto but also cultural components with a heritage value that is partly determined by the geomorphological context in which they are inserted.

Accordingly, our methodological approach includes: (1) the identification and selection of significant geomorphosites; (2) detailed description; (3) an assessment of the scientific and additional values, potential for use, and threats and vulnerability; and (4) synthesis.

The identification and selection of the significant geomorphosites (Mt. Kamenec, Mt. Myslivna, and Mt. Jelení) were based on detailed geomorphological mapping and detailed geomorphological description in the study area (e.g. Rypl et al. 2014; 2016; 2020; Rypl and Kirchner 2017). The resulting short and simplified descriptions are presented in the Results section and illustrated in Fig. 2.

An assessment of the scientific and additional values, potential for use, and threats and vulnerability was carried out based on the methodology of Kubalíková 2012 (see below). This is a geomorphosites assessment methodology that is applied to the territory of Czechia.

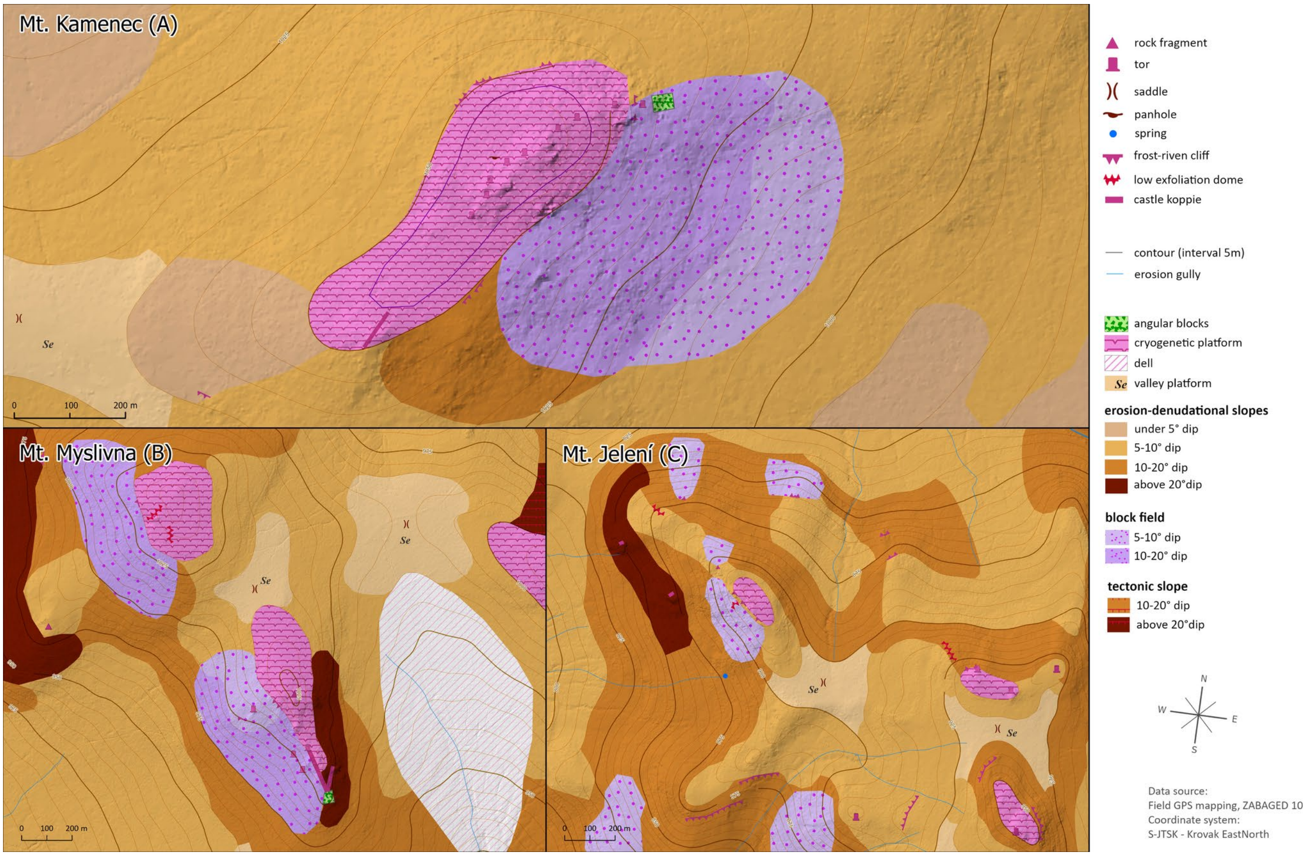


**Fig. 2** **A** Geomorphological map of Mt. Kamenec source: Rypl et al. 2014. **B** Geomorphological map of Mt. Myslivna source: Rypl et al. 2016. **C** Geomorphological map of Mt. Jelení source: (photos Rypl)

As part of the numerical evaluation, the values 0, 0.5, and 1 are most commonly ascribed to individual phenomena. The value 0 is applied when the phenomenon is not represented. On the other hand, the value 1 is added when the phenomenon is very representative. Kubalíková (2012) compared geomorphosites evaluation methodologies from various European workplaces and proposed a methodology that is most suitable for the Czech environment or the environment of Central Europe. The methodology of Kubalíková (2012) was primarily intended for the needs of the protection of abiotic nature. In addition, the obtained materials can be used as a basis for geodidactic and geotouristic evaluation.

Table 1 shows the results of partial evaluation criteria for individual sites in the area of interest. In the following subchapters, point evaluations of individual criteria and their justifications are presented. The obtained results of the assessment of individual geomorphological localities can be compared with assessments already carried out in other areas of the Czech Republic (e.g. Kubalíková and Kirchner 2016; Bajer et al. 2016), but, of course, a certain degree of evaluator subjectivity cannot be excluded.

## Results

Based on a development scheme of the Czech territory, the Paleogene planation surface developed via weathering, and a weathered mantle (mostly kaolinitic, often more than 100 m thick) was created (Czudek and Demek 1970). Owing to neotectonic movements, the territory was uplifted, weathering mantles were removed, the basal surface was exposed, and a younger planation surface of the etchplain type developed (Czudek and Demek 1970; Demek 1975). The geomorphic evolution of the studied area was accomplished in two stages. On the exposed basal surface of the weathered mantle some resistant rocks stood out as isolated rock formations and tor groups – castle koppies. According to Demek et al. (2006), the territory of what is now the Czech Republic was located not far from the frontal part of a continental ice sheet in the Pleistocene, where the climate was cold and cryogenic processes took place. These geomorphological processes formed cryoplanation terraces with frost-riven cliffs, tors, castle koppies, and blockfields (Demek et al. 2006). These

**Table 1** Overview of the assessment criteria (Kubalíková 2012) and results of the numerical assessment of the selected sites of Mt. Kamenec, Mt. Myslivna, and Mt. Jelení

| 1. SCIENTIFIC VALUES | max. pt | Mt. Kamenec | Mt. Myslivna | Mt. Jelení |
|---|---|---|---|---|
| a. Representativeness | 1 | 0.5 | 0.5 | 0.5 |
| b. Conservation (current state of the site, condition) | 1 | 1 | 0.75 | 0.75 |
| c. Exemplarity, educational value | 1 | 1 | 1 | 0.5 |
| d. Rarity (number of similar sites in the study area) | 1 | 0.5 | 0.5 | 0.5 |
| e. Presence and diversity of meso- and microforms | 1 | 1 | 1 | 0.5 |
| f. Presence of further geological and pedological features | 1 | 0.5 | 0.5 | 0.5 |
| g. Geological significance (understanding of geological evolution) | 1 | 1 | 1 | 1 |
| h. Palaeographic significance (possibility of landscape or climate reconstruction etc.) | 1 | 0.5 | 0.5 | 0.5 |
| i. Popularity of the site from the point of view of Earth sciences, scientific publications | 1 | 0.5 | 0.5 | 0.5 |
| j. Level of legal protection due to geomorphological reasons | 1 | 0.5 | 0.5 | 0.5 |
| Total Scientific value | **10** | **7.0** | **6.75** | **5.75** |
| 2. ADDITIONAL VALUES | max. pt | Mt. Kamenec | Mt. Myslivna | Mt. Jelení |
| a. Aesthetic value | | | | |
| Number of colours; 1 colour (0 pt.) \| 2–3 colours (0.25 pt.) more than 3 colours (0.5 pt.) | 0.5 | 0.25 | 0.25 | 0.25 |
| Structure, number of clearly differentiable components | 0.5 | 0.25 | 0.25 | 0.25 |
| General aesthetic value | 1 | 1 | 0.5 | 0.5 |
| b. Ecological value | | | | |
| The impact of geomorphological features on biota | 1 | 0.5 | 1 | 1 |
| The presence of significant preserved species of plants and animals | 0.5 | 0.5 | 0.5 | 0.5 |
| The level of legal protection due to ecological reasons | 0.5 | 0.5 | 0.5 | 0.5 |
| c. Cultural value | | | | |
| Historical and archaeological significance | 1 | 0.5 | 0 | 0 |
| Religious and symbolic significance | 1 | 0 | 0 | 0 |
| Literature and artistic significance | 1 | 0 | 0 | 0 |
| d. Popularity of the site from the point of view of ecological, aesthetic, and cultural value | 1 | 0.5 | 0.5 | 0.5 |
| Total Additional values | **8** | **4** | **3.5** | **3.5** |
| 3. POTENTIAL FOR USE | max. pt | Mt. Kamenec | Mt. Myslivna | Mt. Jelení |
| a. Recognisability | 1 | 0.5 | 0.5 | 0.5 |
| b. Accessibility (on foot, by car, by public transport) | 1 | 0 | 0 | 0 |
| c. Infrastructure | 1 | 0.5 | 1 | 0.5 |
| d. Actual use of geoscientific values of the site, approximate number of visitors per year | 1 | 0.5 | 0.5 | 0.5 |
| e. Actual use of additional values of the site | 1 | 0.5 | 0.5 | 0.5 |
| f. Propagation and existence of commercial products presenting the site | 1 | 0.5 | 0.5 | 0 |
| g. Limits to use, ease of access, entrance, approach, possibility of guided tours | 1 | 1 | 1 | 0.5 |
| h. Number of possibilities for use of the site (geoeducation, geotourism, sport, culture etc.) | 1 | 1 | 1 | 0.5 |
| Total potential for use | **8** | **4.5** | **5** | **3** |
| 4. THREATS AND VULNERABILITY | max. pt | Mt. Kamenec | Mt. Myslivna | Mt. Jelení |
| a. Existence of natural threats leading to the devaluation of the site | 1.5 | 1.5 | 1.5 | 1.5 |
| b. Existence of anthropogenic threats leading to the devaluation of the site | 1.5 | 1 | 1 | 1 |
| c. Existence of legal protection of the site d. (any kind of legal protection) | 1 | 0.5 | 0.5 | 0.5 |
| Total threats and vulnerability | **4** | **3.0** | **3.0** | **3.0** |
| Total value | **30** | **18.5** | **18.25** | **15.25** |

landforms also developed in the Novohradské Mountains. They stand next to the Bohemian Forest (Šumava Mountains), a mountain range covered by an alpine glacier in the late Pleistocene (Votýpka 1979; Mentlík 2006). Tors and castle koppies were formed via the same process (Migoń 2006). In our approach, we distinguish the morphology of tors and castle koppies, in comparison to the English-language literature, where these forms are equated (e.g., Ehlen 2006) or not distinguished (Hugget 2011). We consider tors to be isolated rocks that rise significantly above the surrounding surface. The rocks are less extensive in area and their height exceeds their size. A castle koppie is a larger rock formation, often elongated in shape, limited by vertical surfaces. Its area is greater than its height (more detailed Czudek 2005; Demek and Mackovčin 2014, Smolová and Vítek 2007; Rubín et al. 1986).

In the results, selected geomorphosites are briefly characterized and the evaluation of geomorphosites is also provided.

## Localities

### Mt. Kamenec (1 072 m a.s.l.)

Mt. Kamenec is situated 0.5 km from Ulrichov 3.5 km southwest of the village of Pohoří na Šumavě on the Austrian border and it is the highest peak on the Czech side of the Novohradské Mountains. The cadastral area of Mt. Kamenec is the village of Pohoří na Šumavě (Rypl et al. 2014). Mt. Kamenec represents a bornhardt (Vítek 1995). The summit of Mt. Kamenec is formed by a cryoplanation platform elongated in the NE-SW direction, where the cryogenic relief of the southern part of the study area is best developed. Demek et al. (2006) describes two peaks of Mt. Kamenec – the north-eastern one with an altitude of 1072 m and the south-western one with an altitude of 1058 m. However, both peaks are only 150 m apart, with no saddle or any distinctive depression dividing them and their altitude difference is given purely by a height variance of rock mezoforms located on the platform. Slopes surrounding the summit flat are of erosion-denudational character with an inclination of 5–10°. At the south-western end, the ridge transforms into the short erosion-denudational slope of 2–5° incline, which changes along the state border to a slope of 0–2° incline (Rypl et al. 2014).

The cryoplanation platform is developed in two altitude levels copying the direction of the peak ridge. In its upper level, the platform is 150 m long and 70 m wide and contains a group of 7 tors. The tors are 15 m high, with smaller tors of 5 m width and length clearly distinguishable from the larger ones with width and length ranging between 10 to 30 m. GPS measurement has confirmed that the tors are aligned in a row and are separated by frost-riven cliffs 2 to 10 m wide. We therefore postulated that formerly a single large castle koppie existed in this place prior to being remodeled to its present shape (Rypl et al. 2014).

The cryoplanation platform at lower altitude surrounds the upper platform. Its total length is approximately 300 m and width up to 80 m. The north-western and the opposite south-eastern rim of the cryoplanation platform is demarcated by frost-riven cliffs. The north-western rim contains 2 cliffs each 8 m long and 4 m high (respectively 20 m × 8 m). Another cliff of 13 m length and 5 m height is located along the northern edge of the cryoplanation platform. The frost-riven cliff in the north of the southeastern rim has dimensions of 18 m × 5 m and beneath it there is a partially developed short block stream. Two rock forms are also located on the described cryoplanation platforms. The castle koppie is situated at the south-western end of the platform, its length is 60 m, width 15 m, and height 15 m at maximum. Within this koppie, a fissure-type rock gate, 3 m high and 2 m wide at most has developed, formed by the release and movement of individual blocks of rock. By contrast, the tor occurs at the north-eastern end of the platform and reaches a height of 10 m. Due to alignment of this tor and the aforementioned castle koppie with tors on the cryoplanation platform, it is presumed that these two landforms were also part of a single massive unit. This massive unit underwent progressive erosion during the colder periods of the Pleistocene and gained its present appearance (Rypl et al. 2014).

Landforms located on the slopes of the northern part of the summit are also remarkable. On the eastern slope, approximately 10 altitude metres below the north-eastern end of the cryoplanation platform, rest two frost-riven cliffs, 20 m × 8 m and 10 m × 5 m, respectively. A tor has developed on a slope roughly 20 m below the larger cliff. Its maximum size is 6 m and a talus pile (28 m × 17 m) runs out from it. Further down the slope beneath these landforms a blockfield extends which is overgrown with forest. Away from these forms of relief, towards the southeastern to southern slope, another frost-riven cliff, 10 m long and 5 m high, is located. Within a distance of 80 m a high tor has developed on a slope, underneath which a frost-riven cliff (8 m × 4 m) has formed. To the SW from the cryoplanation platform, there are several smaller frost-riven cliffs 5–15 m in length and 3–5 m in width. Close to an erosion-denudational slope with an inclination of 0–2° a frost-riven cliff 6 m × 3 m in size has developed (Rypl et al. 2014).

Distribution of the landforms at Mt. Kamenec is illustrated in Fig. 2A.

### Mt. Myslivna (1 040 m a.s.l.)

Mt. Myslivna is the second highest peak of the Czech part of the Novohradské Mountains. It is situated 3.5 km to the northwest of Pohoří na Šumavě, within the cadastral area of the settlement of the same name (Rypl et al. 2016). Mt. Myslivna represents a bornhardt (Vítek 1995). The summit part of Mt. Myslivna forms a watershed ridge approximately 1 km long, elongated in the NNW-SSE to NW–SE direction. Erosion-denudational slopes with an inclination of 10—20° prevail in the surroundings of the peak. The eastern part of the ridge is adjoined by an erosion-denudational slope with 2–5° inclination, which at an altitude of 990 m changes its inclination to 0–2°. In the northern upper part of the watershed ridge (1040 m) with an upland cryoplanation platform, a frost-riven cliff of 5 m height and 10 m length has developed on the western edge. The front of the cliff is oriented to the west and beneath it, a blockfield has developed (with dimensions 460 m x 160 m). In the uppermost part two ruwares have developed in a N-S and NE-SW direction. The N-S dome is 15 m long and 5 m high, the second dome bears more pronounced signs of cryogenic erosion, mainly on the NW side, which is more distinctive and higher compared to the opposite side. This dome is 30 m long and up to 6 m high (Rypl et al. 2016) (Figs 3 and 4).

The southern part of the watershed ridge, where the second summit of Mt. Myslivna, with an altitude of 1025 m has developed, is richer in rock landforms. The uppermost part is formed by an upland cryoplanation platform with a relic of a tor (Fig. 5). Dimensions of the platform are 450 m × 100 m and of the tor 8 m × 5 m and up to 2 m height. Approximately 30 m westerly from the relic of the tor, in an erosion-denudational slope with 10–20° inclination, a frost-riven cliff (12 m × 5 m) has developed. A blockfield 470 m long and 180 m wide spreads below this cliff. In the rock pile, cca 60 m below the described frost-riven cliff, there is a 10 m high tor on a slope, accompanied by a high frost-riven cliff that is 15 m long and 8 m high (Rypl et al. 2016).

The most interesting rock landforms at this site are located at the southern tip of the upland cryoplanation platform. These include two castle koppies. The longer of the castle koppies has orientation almost corresponding with orientation of the peak ridge, i.e. NNW-SSE The second castle koppie (Fig. 6) is then oriented in a NNE-SSW direction. The southern tips of both castle koppies are joined, therefore

**Fig. 3** Castle koppie on the top of Mt. Kamenec (photos Rypl)

**Fig. 4** Tor on the top of Mt. Kamenec (Rypl et al. 2014)

**Fig. 5** Castle koppie on the southern top plate of Mt. Myslivna (photos Rypl)

it is presumed that in the past they formed one massive complex. The uppermost sections of the castle koppies probably represent the original topographic surface, which is also supported by the fact that the peak of the northern tip of the longer castle koppie is approximately in the same altitude as the above-mentioned relic of the tor on the cryoplanation platform. The castle koppie oriented in the NNE-SSW direction is 60 m long, approximately 30 m wide, and up to 15 m high. The southeastern wall of this koppie transverses into a steeper part of the erosion-denudational slope with a 10–20° inclination. The rock ridge elongated in the direction of the peak ridge is around 150 m long, 20 m wide, and 15 m high. Erosion is more pronounced in its upper northern section, where several tors are formed. One of the tors lies within the line of the koppie, forming its northern edge, and its shape is close to a rock tower, with its height significantly exceeding its length and width. Two other tors exhibiting similar character have formed in close proximity to the western side of the castle koppie (Rypl et al. 2016) (Figs 7 and 8).

Distribution of the landforms at Mt. Myslivna is illustrated in Fig. 2B.

### Mt. Jelení (947 m a.s.l)

The most interesting landforms at the location of Mt. Jelení are found in two places (Ulrichov, Mrzenáč).

## Ulrichov

Ulrichov is situated 2,5 km south of the village of Leopoldov and 0,5 km north of Mt. Jelení. The cadastral area of Ulrichov is the village of Dolní Příbrání. Since January 1, 2015, Ulrichov has been part of the Natural Monument of Horní Malše, where the main object of protection is the forest-like growth of flowering and acidophilic beeches, together with the occurrence of frost landforms. The nameless peak of 958 m a. s. l. is separated from Mt. Jelení by

**Fig. 6** The relic of the tor on the southern top plate of Mt. Myslivna (Rypl et al. 2016)

a saddle platform and formed by a cryoplanation platform. The cryoplanation platform is approx. 150 m and wide approx. 57 m. There are two tors on it. The more easterly located tor is smaller with a height of approx. 6 m. The tor located further west is higher with a height of approx. 15 m. In these places, the cryoplanation platform ends with the frost-riven cliff with dimensions of 25 m × 5 m. There is still a ruware on the northwest slope. The ruware reaches a length of 15 m and a maximum height of 2 m and extends in a NW—SE direction. The other tor is located in the eastern part of the peak with a height of about 10 m. There are erosion-denudational slopes around the peak inclined 10–20° (on the north side) and 5–10° (on the south side).

## Mrzenáč

Mrzenáč is situated 0.5 km from Ulrichov and represents the northwestern edge of Mt. Jelení. The top of Mrzenáč is formed by a cryoplanation platform that stretches in a NW—SE direction and has a length of approx. 145 m and a width of approx 60 m. The most dominant landforms are the group of frost-riven cliffs on the southwest side of the cryoplanation platform with dimensions of approx. 12 m × 10 m. There is a vast blockfield (100 × 50 m) on the erosion-denudational slope inclined 10–20°. A ruware (approx. 20 × 2) is the last most interesting landform in the location.

Distribution of the landforms at Mt. Jelení is illustrated in Fig. 2C.

### Scientific Values

All three individual localities attained 0.5 points, (middle representativeness – mainly for the scientific community) regarding *criterion 1a, Representativeness*. The sites are included in the database of geologically important localities kept by the Czech Geological Survey. For *criterion 1b, Conservation*, Mt. Myslivna and Mt. Jelení both attained 0.75 points. The conservation of the sites was influenced mainly by their location within the Czech Republic and

**Fig. 7** The cryoplanation platform on the top of Mrzenáč (photos Rypl)

long-standing human disinterest. The location of the sites near the Czech-Austrian border was the reason for the limited human activity during the time of the so-called 'Iron Curtain', before the year 1989. In the past, the main human activities in this area were wood processing and glass making. Another reason for the long-standing lack of human interest is also the vicinity of the more attractive touristic area, the Šumava Mountains. The best preserved landforms are located on Mt. Kamenec, which thus attained 1.0 points for criterion 1b.

Mt. Kamenec and Mt. Myslivna attained 1.0 points for criterion 1c because the landforms there have a clear genesis and have direct use in geodidactics or geotourism. Individual components and processes are visible and illustrative, but the explanation of an educator (a teacher or any other specialist being able to describe and explain exemplarily individual components and processes) is necessary on Mt. Jelení, which thus attained 0.5 points for criterion 1c.

All three sites considered in this study show considerable diversity of landforms. Each locality is assigned 0.5 points due to the number of localities in the study area, according to Kubalíková (2012). Mt. Kamenec and Mt. Myslivna achieved a value of 1.0 points for *criterion 1e, Presence and diversity of meso- and microforms*. There are representative mesoforms (e.g. castle koppies, tors, frost-riven cliffs), as well as microforms of the relief (e.g. weather pits, rock ledges). Mt. Jelení attained 0.5 points for criterion 1e because the mesoforms and microforms present there are not as representative.

The three sites were assessed identically according to *criterion 1f,'Presence of further geological and pedological features*. Mt. Kamenec, Mt. Myslivna, and Mt. Jelení attained only 0.5 points for this criterion. The situation is similar for the non-geomorphological and abiotic aspects of these sites in that they can all be protected and marked with 1.0 points after Kubalíková (2012). The localities attained 1.0 points (existing geological significance) from the point of view of *criterion 1 g,'Geological significance*'. In all three localities, there is a large number of granite cryogenic landforms, which are evidence of the development of the landscape in the Pleistocene. Due to the coexistence of different landforms, it is possible to use the locality for local palaeographic reconstruction of the landscape. For this reason, each locality was assigned 0.5 points within *criterion* 1 h according to Kubalíková (2012).

Localities were evaluated according to the number of publications in the scientific Web of Science and Scopus scientific databases, and they attained 0.5 points for *criterion 1i, Popularity of the site from the point of view of Earth sciences and scientific publications* because there are several studies about localities that are registered in the WoS and Scopus database. All three of the localities are included in the database of geologically important localities kept by the Czech Geological Survey. Hence, they all attained 0.5 points for *criterion 1j*.

**Fig. 8** The tor on the eastern top plate of Ulrichov (photos Rypl)

### Additional Values

In terms of the type and relative predominance of colours, green tints are characteristic for this area due to the typical spruce monoculture spread in this area with only a small impact of the anthropogenic factor (buildings, fields, water areas, infrastructure etc.). The value of 0.25 points was chosen (2 to 3 colours) for all three localities for this reason regarding *criterion 2a,'Aesthetic values*'. Of course, the colouring changes during the year. The number of clearly differentiable components was evaluated at 0.25 points for all localities. There are individual components such as forests and meadows etc. Mt. Myslivna and Mt. Jelení both attained a medium score of 0.5 points for general aesthetic value. Mt. Kamenec attained a high score of 1.0 points because of its abundant frost-weathering landforms.

Mt. Myslivna and Mt. Jelení attained 1.0 points for the impact of geomorphological features on biota within *criterion 2b, Ecological value* since both localities have been declared as Natural Monuments to preserve beech forest. Mt. Kamenec attained 0.5 points within the same criterion. The study area represents a part of the Novohradské Mountains, an area with a great number of protected species of animals and plants. Localities attained 0.5 points for the criterion assessing the existence of protected species for this reason. The study area was assessed as a locality with existing legal protection in the case of the criterion assessing the legal protection for ecological reasons. Hence, the chosen assessment was 0.5 points.

*Criterion 2c,'Cultural values*'The assessment of this criterion was based on field research and a survey of the available literary sources. The survey aimed to explore mentions in the literature and assess the artistic significance of the study area. No reference to'*Historical and archaeological significance*'was found in connection to either Mt. Myslivna or Mt. Jelení and thus the sites attained 0.0 points each. The remains of a castle and an inn have been found near the top of Mt. Kamenec and thus the site attained 0.5 points. No reference to''religious or symbolic significance or to literary or artistic significance''was found in connection to any of the three locations and thus the sites attained 0.0 points.

The locality is not absolutely unknown, but on the other hand, it is not very popular on an international or even national level. For this reason, the medium evaluation of 0.5 points was chosen for *criterion 2 d, Popularity of the locality*, i.e. popular on the regional level, taking into account the fact that the localities are located near the border with Austria.

## Potential for Use

The localities attained 0.5 points (individual sites are recognisable) regarding *criterion 3a,'Recognition*', but for the observation of individual geomorphological components, it is necessary to walk through the localities directly. *Criterion 3b*, describes the'*Accessibility of the site*'. The assessment of this criterion was based on the fact that all three localities are located more than 1,000 m from the nearest car park. For this reason, for criterion 3b, they each attained 0.0 points. Regarding *criterion 3c,'Infrastructure*, Mt. Myslivna attained 1.0 points because a cottage located right at its peak is available for rent from the state enterprise Forests of the Czech Republic. Mt. Kamenec and Mt. Jelení attained 0.5 points for this criterion because the nearest infrastructure is more distant than 5,000 m.

All three localities attained a value of 0.5 (partially used) for *criteria 3 d and 3e, The actual use of the geoscientific and additional values of the site*. Mt. Kamenec and Mt. Myslivna attained 0.5 points for criterion 3f, *The existence of commercial products presenting the site and propaganda*. The area is shown in tourist guides of the Novohradské Mountains. The tourist information offices in the neighbouring towns, especially in Nové Hrady, offer leaflets aimed at the promotion of hiking routes and bike routes. This area is shown on various websites. Mt. Jelení attained 0.0 points for this criterion because this area is not shown on commercial products presenting the Novohradské Mountains.

Mt. Kamenec and Mt. Myslivna attained 1.0 points for *criterion 3 g* because the localities are easily accessible on foot or by car. Mt. Jelení attained 0.5 points because access is less convenient. Similarly, Mt. Kamenec and Mt. Myslivna attained 1.0 for *criterion 3 h, The possibilities of use* because there are a lot of possibilities for use in this area – there are hiking trails and some geocaching locations. Mt. Jelení attained 0.5 points because the possibilities for use are less significant.

## Threats and Vulnerability

Localities attained 1.5 points in the case of *criterion 4a*, according to Kubalíková (2012), when there are no natural threats leading to the deterioration of the locality. All three localities are almost invulnerable from this point of view.

*Criterion 4b, Existence of anthropogenic threats leading to the devaluation of the site*, is significant today. There are visible signs of human activity at each locality which slightly affect the non-geomorphological aspect of localities. For this reason, each locality is assigned 1.0 point within this criterion.

For *criterion 4c,'Already existing legal protection of the site*', all three localities attained 0.5 points. The study area is a part of the Natural Park of the Novohradské Mountains, and all three localities have been declared geomorphologically significant localities by the Czech Geological Survey.

Further, the Myslivna Natural Monument on the slopes of Mt. Myslivna and the Ulrichov Natural Monument on the slopes of Mt. Jelení have been declared. But it is not possible to assign a higher value for this criterion in this case because this area has not been declared a national park.

## Discussion and Conclusion

The specific mountainous relief on the Variscan granitoid rocks of the Bohemian Massif occurs especially in the border area with Austria and Germany (see Pánek and Hradecky 2016, within Europe see Migon 2016 for more details). However, the evaluation of localities using the geomorphosites methodology concept (according to Kubalíková 2012) has so far only been used for the specific granite landforms in the Novohradské Mountains, and therefore it is difficult to compare it with other areas built by granite landforms with bornhardt-type hills (Vítek 1995). In the following text, we present the basic findings that contribute to the knowledge of the geoheritage of individual sites in the studied area—local geoheritage.

We tried to at least compare the obtained results with the results of research that was carried out in the past in the northeastern part of the Novohradské Mountains (Rypl et al. 2019). We compare sites—Mt. Vysoká, Mt. Kraví, and Mt. Kuní—with geomorphosites of the southern part of the Novohradské Mountains (Mt. Kamenec, Mt. Myslivna, and Mt. Jelení) (Table 2.).

The results of Rypl et al. 2019 and the results of the analysis (Rypl et al. 2020) show five localities in the Novohradské Mountains with a high representation and great importance of periglacial landforms, namely on Mt. Myslivna, Mt. Kamenec, Mt. Kuní, Mt. Kraví, and Mt. Vysoká. In this study, only Mt. Myslivna a Mt. Kamenec along with Mt. Jelení were evaluated and compared with the evaluation results of Mt. Vysoká, Mt. Kraví, and Mt. Kuní in the publication of Rypl et al. (2019). Total values for the five locations mentioned above do not differ much. Evaluation for Mt. Jelení is roughly three points lower. It can be explained by the lower representation of periglacial landforms and the poorer accessibility of the territory. The results of such analysis can be useful for decision-makers when assessing geoheritage, designating protected areas, or managing geodiversity resources (Argyriou et al. 2016; Dunlop et al. 2018). Defining the areas of high geomorphological diversity is also crucial for planning and developing sustainable forms of tourism (respectively geotourism) as these areas are considered aesthetically attractive for visitors and possess considerable educational potential (Goudie 2002; Dowling and Newsome 2018).

All geomorphosites have a relatively high scientific value (especially thanks to high conservation value, the presence of meso- and micro-forms, and palaeogeographic importance), which represents a good basis for geoeducational and geotouristic purposes (Rypl et al. 2021). Elements of STEM education may also be developed within geoeducation. Another way to present this important local/regional heritage to the public (not only to tourists from abroad or other parts of the Czech Republic, but also to local/regional weekend visitors) is to offer guided walks (there is a high potential to connect the geoscience component of the area with hydrological and cultural components) (Rypl et al. 2019). The guided walks would be organised by e.g. the tourist office of Nové Hrady with the cooperation of enthusiasts, scientists, and local people who know the area very well (both its nature and history), e.g. local primary and secondary school teachers. Gamification (e.g. storytelling, geocaching, questing etc.) can also make the area attractive for education and tourism development.

From a trans-regional point of view, the knowledge obtained about geomorphosites may be used in the research of granite relief forms within Central Europe (e.g. Migoń 2006), especially in the neighbouring Austria, where the Bohemian Massif extends geologically (Waldviertel region, e.g. Chábera and Huber 1999; Huber 1999; Michniewicz et al. (2015), Migoń et al. 2018; Migoń et al. 2022). There is the possibility to develop a proposal for a geotourist trail (with gamification elements) in this attractive border area in cooperation with Austrian geomorphologists.

Unfortunately, it is not yet possible to compare this study and the study by Rypl et al. (2019) with adjacent areas in Austria. For the time being, no detailed geomorphological mapping and geomorphological inventory have been carried out on the Austrian side to serve as a basis for the needs of the

**Table 2** The results of numerical assessment of Mt. Vysoká, Mt. Kraví, Mt. Kuní, Mt. Kamenec, Mt. Myslivna, and Mt. Jelení

| Localities | Scientific value | Additional value | Potential for the use | Threats and vulnerability | Total value |
|---|---|---|---|---|---|
| Mount Vysoká | **6.25** | **4.75** | **5.50** | **2.00** | **18.50** |
| Mount Kraví | **6.25** | **4.25** | **5.50** | **3.00** | **19.00** |
| Mount Kuní | **6.25** | **4.25** | **5.50** | **3.00** | **19.00** |
| Mount Kamenec | **7.00** | **4.00** | **4.50** | **3.00** | **18.50** |
| Mount Myslivna | **6.75** | **3.50** | **5.00** | **3.00** | **18.25** |
| Mount Jelení | **5.75** | **3.50** | **3.00** | **3.00** | **15.25** |

geomorphological assessment. For the purpose of the study by Rypl et al. (2021), only terrain reconnaissance was carried out on the Austrian side of the Novohradské Mountains (Mandelstein, Nebelstein, Warzenstein, Eichlberg peaks) without further detailed geomorphological investigations.

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## Declarations

**Conflicts of interest** No potential conflict of interest was reported by the authors.



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