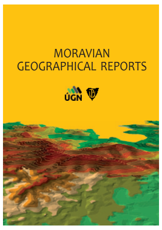

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Geoheritage values and threats related to sandstone crags of the Chřiby ridge (Moravian Carpathians, Czech Republic)

Lucie Kubalíková [a*], Karel Kirchner [b], Piotr Migoń [c]

Abstract

Rock landforms provide non-invasive, easy insights into the distant geological past, and they reflect landform evolution and processes shaping the earth surface in the past and present. Moreover, rock landforms, especially crags and tors, have a high geoheritage relevance. The territory of the Czech Republic shows many diverse examples of crags and tors, especially in sandstone areas. However, while the Bohemian Cretaceous areas have been examined in detail, the sandstone crags in Moravian Flysch Carpathians have been given only limited attention. The paper is focused on the sandstone crags in the Chřiby Mountains being explored from two main perspectives: identification of the crags as geoheritage elements and their assessment in terms of threats and degradation risk. The application of semi-quantitative assessment methods (degradation risk evaluation and Risk Assessment Matrix) enabled the ranking of the sites according to the degree of possible deterioration and helped to identify particular threats, which can be considered important when planning and managing the area's natural resources. The recognition of geoheritage values of sandstone crags, along with identifying and evaluating risks and threats, may serve as a basis for effective management and further research.

Keywords: Sandstone crags, geoheritage, Chřiby, degradation risk, threats to geodiversity

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1. Introduction

Rock landforms, understood as topographic elements built of exposed solid rock (Migoń et al., 2017; Migoń, 2022), occur in a large variety of sizes, shapes, and origins. Depending on bedrock properties and climatic conditions favouring (or not) the development of thick soils and vegetation spread, rock landforms may be abundant, even dominant, or rare within a given area. Thus, they may exist in extensive clusters (e.g., rock cities) or as continuous outcrops many kilometres long (e.g., rock escarpments), whereas elsewhere they occur in isolation, separated by tracts of regolith-covered terrain. In the latter cases, rock landforms generated particular curiosity as natural features difficult to explain and hence, were often associated with myths and legends (Vitaliano, 1968; Piccardi & Masse, 2007; Kirchner & Kubalíková, 2015; Khoshraftar & Torabi Farsani, 2019; Telecka, 2024). With the advent of modern tourism, rock landforms began to be appreciated for their scenic values (Gordon, 2012; Reynard & Giusti, 2018) and became popular tourist destinations as 'wonders of nature'.

The realisation of their geoheritage values is of more recent date, and so is the awareness that they also face various threats and require conservation efforts, as other components of nature do (Gray, 2013; García-Ortiz et al., 2014; Crofts et al., 2020; Selmi et al., 2022; Kubalíková, 2024). The core scientific values of rock landforms are twofold. First, they provide non-invasive (as opposed to quarries), easy insights into the distant geological past, into the times when a given rock complex came into being. The larger the rock landform, the more insightful this view could be, as one can examine the continuity and variability of sedimentary structures, lithological changes, or the pattern of tectonic structures. Therefore, rock landforms are highly valued by geologists, especially in areas where outcrops are rare. Second, rock landforms are the subject of geomorphological studies. Being an outcome of differential denudation and erosion, they inform us about geological controls in landform evolution and processes shaping the earth surface in the past and present. Examined in the context of the geomorphological setting and cover deposits in the vicinity, they become vital sources of information about mechanisms and pathways of landform development (Linton, 1955; Cunningham, 1965; Thomas, 1965; Gerrard, 1988; André, 2004; Michniewicz, 2019). Most recently, cosmogenic exposure dating performed on rock landforms helps constrain lowering the timing of surface lowering (Phillips et al., 2006; Raab et al., 2021, 2024; Máčka et al., 2023). Therefore, rock landforms, especially crags and tors, are increasingly presented within the geoheritage framework (Washington & Wray, 2011; Kubalíková & Kirchner, 2016; Rypl et al., 2019; Duszyński & Migoń, 2022).

Among the most scenic rock landforms are those built of sandstone (Mainguet, 1972; Härtel et al., 2007; Young et al., 2009; Adamovič et al., 2006, 2010; Twidale, 2010) and the territory of the Czech Republic shows many and diverse examples. Some are of international significance, for instance, the rock cities in

[a] Department of Geology and Soil Science, Faculty of Forestry and Wood Technology, Mendel University in Brno, Czech Republic (*corresponding author: L. Kubalíková, e-mail: *lucie.kubalikova@ugn.cas.cz*)

[b] Department of Environmental Geography, Institute of Geonics of the Czech Academy of Sciences, Brno, Czech Republic

[c] Institute of Geography and Regional Development, University of Wrocław, Wrocław, Poland

northern Bohemia, which are the core value of the Bohemian Paradise UNESCO Global Geopark (Adamovič et al., 2006; Mertlík & Adamovič, 2016). This paper focuses on the isolated ridge of Chřiby in the Flysch Carpathians, which stands out in terms of the number and diversity of sandstone rock landforms, referred to as crags. Crags are understood as natural, rugged outcrops of bedrock protruding from ridge tops and regolith-covered slopes, which emerged due to selective weathering and mass wasting. Moreover, most of these landforms are easily accessible, located not far from public roads and along waymarked hiking trails or next to these. This easy access is a significant factor for geoconservation, contributing to the growing human impact associated with multiple uses. Crags in Chřiby also have various cultural associations, so their value is not limited to the scientific one, but the added cultural value becomes important and is explored separately in a geomythological context (Kubalíková et al., 2025).

This paper examines sandstone crags in the Chřiby ridge from two main perspectives. First, we aim to present a selection of the most representative crags from a scientific point of view, mainly emphasising their geomorphological diversity. Thus, we identify the crags as geoheritage/geodiversity elements. Second, the crags are assessed in terms of threats and degradation risk, which will be done semi-quantitatively. This paper is a region-specific study that fills a gap in regional knowledge but is also of broader relevance for at least two reasons. First, crags are not endemic to the Chřiby area but are a repetitive theme for the entire Flysch Carpathians (Alexandrowicz, 1978, 2008; Kubalíková & Kirchner, 2016; Welc & Miśkiewicz, 2020; Bayrak & Heneralova, 2024). Therefore, this study provides a reference for an area that is hardly accounted for and will inform any future range-wide reviews focused on rock landforms. Second, crags are popular places to visit wherever they occur and hence, their use generates various conservation challenges, especially if the crags are, for some reason, particularly vulnerable to human impact (Migoń, 2022). Thus, our approach through the lens of degradation risk assessment may be inspirational for similar studies elsewhere.

2. Theoretical Background

Given their scientific but also scenic values, selected sandstone crags may be considered an important part of the geoheritage of a given area. The concept of geoheritage is based on the definition of natural heritage, which was presented already in 1972 (UNESCO, 1972), and later, the concept of geoheritage was developed by Dixon (1996) and Sharples (2002). Currently, geoheritage is respected as a full-value part of natural heritage and is examined from different points of view (Reynard & Brilha, 2018; Kubalíková et al., 2023 and references herein). Although on an international level, it is not so strongly represented as biodiversity values, considerable efforts to raise its status have been recently undertaken, e.g., within special commissions of the International Union for Conservation of Nature (IUCN) or the International Union of Geological Sciences (IUGS) and as other initiatives (ProGEO, Global Geoparks Network, working groups within the International Association of Geomorphologists (IAG)).

Sandstone crags, as an important part of geoheritage, may be considered geosites, defined as portions of the geosphere that present particular importance for the comprehension of Earth history (Reynard, 2004). Thus, geosites are associated with value, which is primarily scientific (Brilha, 2016). However, these scientific values are of different kinds. In some studies, the focus is on sedimentary structures exposed in crags, with little consideration of processes that have led to the emergence of the crag so that they become essentially sites of geological interest. In this study, we primarily analyse the crags as landform elements, and hence, the specific term 'geomorphosite' may be used to emphasise the focus on crags' geomorphology. It was also argued that the values of geological and geomorphological objects may reside in their cultural/historical, aesthetic and/or social/economic attributes, being related to the diversity of human perception or exploitation (Panizza, 2001; Bussard & Reynard, 2022).

However, despite their apparent values and existing and established legal protection, there is still a range of possible threats (both natural and anthropogenic) that may affect these valuable sites. In the last years, the topics of vulnerability and resilience of geoheritage have been discussed in numerous papers from different points of view – climatic change, urban pressure, and tourist and recreational use (Prosser et al., 2006; Ruban, 2010; García-Ortiz et al., 2014; Fuertes-Gutiérez et al., 2016; Wignall et al., 2018; Vereb et al., 2020; Crofts et al., 2020; Németh et al., 2021; Selmi et al., 2022; Kubalíková & Balková, 2023). The overview of the methods is presented by Vandelli et al. (2024). Crofts et al. (2020) presented 11 types of threats associated with 1) Urbanisation and construction, 2) Mining and mineral extraction, 3) Changes in land use and management, 4) Coastal protection and river management and engineering, 5) Offshore activities, 6) Recreation and geotourism, 7) Climate change, 8) Sea-level rise, 9) Restoration of pits and quarries, 10) Stabilisation of rock faces, 11) Irresponsible fossil and mineral collecting and rock coring. Further types of threats include the lack of state or regional financial support for management, vandalism, vegetation overgrowth, social pressure regarding the use of the sites, confusion in protection measures, or indifference to geoheritage (Górska-Zabielska et al., 2020; Kubalíková et al., 2021; Selmi et al., 2022; Kubalíková & Balková, 2023; Kubalíková, 2024).

Within the concepts of geosites/geomorphosites, the assessment of vulnerability, risks and threats is usually included in the general assessment methods that have been continuously developed during last decades (for a recent overview, see Mucivuna et al., 2019). Generally, there are two main ways how to assess the threats and risks at a site:

1. Degradation risk assessment, which is based on the set of criteria used for geosite/geomorphosite assessment (Brilha, 2016; Reynard et al., 2016) – this method has been developed and applied, among others, for geosites in Malta (Selmi et al., 2022), Brazil (Rabelo et al., 2023), Romania (Papp, 2023), and Czech Republic (Kubalíková & Balková, 2023);
2. application of Risk Assessment Matrix (or concepts of probability and impact), where every threat is considered (Brooks, 2013; Gordon et al., 2022; Kubalíková & Balková, 2023; Kubalíková, 2024). The effective evaluation, classification and prioritisation of risks, threats and conflicts of interest followed by the design of adequate management proposals (e.g., monitoring, strengthening legal protection or community participation) can contribute to the balance of all needs and demands at a site or within an area (Gordon et al., 2021, 2022; Selmi et al., 2022; Kubalíková et al., 2022; Ruban et al., 2022; Papp, 2023; Kubalíková, 2024).

Up to now, only a limited number of studies have explored the geoheritage values of sandstone rock landforms in the Czech Flysch Carpathians and associated geoconservation issues. The scientific significance of selected crags may be inferred from geomorphological studies emphasising periglacial inheritance (Czudek et al., 1961; Kirchner et al., 1996; Křížek, 2001; Bubík et al., 2004; Stráník et al., 2021) and genetic relationships with landsliding and deep-seated slope gravitational deformations, including the formation of non-karstic caves (Kirchner, 2004; Lenart et al., 2014; Lenart, 2015; Břežný et al., 2021). Adamovič et al. (2010) included a few sandstone crags, including examples from the Chřiby area, in their site-by-site presentation of sandstone landforms in the Czech Republic. Further examples from this region can be found in geomorphological regionalisation by Demek and Mackovčin (2015) and in regional inventories of protected areas and geological sites at the Zlín district level (Mackovčin & Sedláček, 2002; Mackovčin, 2007; Hrabec et al., 2017; Šnajdara et al., 2021). Numerous crags and other rock landforms were also presented within regional popular science literature (Baščan et al., 2003a, 2003b, 2003c, 2004, 2005; Žižlavský et al., 2019, 2020; Žižlavský, 2021).

Studies focused explicitly on geoheritage issues are even fewer. Kubalíková and Kirchner (2016) examined a few representative geomorphosites in the Vizovická vrchovina Highland, including crags and tors, and argued for their suitability for geotourism, although threats related to excessive use, particularly by climbers, have also been noted. Pánek and Lenart (2016) presented several geomorphological sites in Beskydy Mountains and mentioned their geocultural value and tourist aspects of the area. Studies from the adjacent Polish Flysch Carpathians are also relevant to the subject. The first papers arguing for the scientific value of crags and the need of their legal protection date back to the 1930s (Klimaszewski, 1932; Świdziński, 1932), whereas comprehensive, detailed presentations including geological and geomorphological characteristics were offered by Alexandrowicz (1970, 1978, 1987, 1989), Alexandrowicz and Pawlikowski (1982), Alexandrowicz et al. (2014). In the last two decades a series of papers explored sandstone crags in the context of their attractiveness for geotourism (e.g., Alexandrowicz, 2008; Welc & Miśkiewicz, 2019, 2020).

3. Methods

The first procedural step is the identification of crag sites, which could be considered most representative of the area and would have the most evident geoheritage value. Among the factors and properties taken into account were dimensions, shape, relief complexity, topographic setting and related distinctiveness in the landscape, and the presence of weathering features. Cultural associations were considered of secondary importance. An underlying assumption was that crag localities that are more extensive (longer and/or higher), more complex and distinctive are more valuable from the geoheritage standpoint than minor outcrops lacking any special features. Based on the literature review and fieldwork, 10 crag localities have been selected for more detailed analysis. They have been described qualitatively in terms of the properties listed above and then assessed regarding the degradation risk.

In the assessment of threats and risks at a particular crag locality, a set of criteria proposed by Brilha (2016), Selmi et al. (2022) and Kubalíková and Balková (2023) is used (Tab. 1). However, some criteria have been modified to better account for the local conditions, whereas others have been excluded (e.g., density of population, because the value is practically the same for all the sites). Based on Selmi et al. (2022), the degree of risk degradation was established on a numerical scale (Tab. 2).

The degradation risk assessment was accompanied by a Risk assessment matrix where the most relevant threats were evaluated. The Risk assessment matrix is a simple tool for risk evaluation originally used in project planning, but very useful in nature conservation studies as well (Brooks, 2013; Kubalíková, 2024). For every identified threat, a probability and impact are determined on a scale of 1 to 5 (for a detailed explication see Kubalíková & Balková, 2023). The multiplication then shows the total risk: minor, moderate, major, and severe (Fig. 1). Based on this complex assessment, proposals for further management are discussed.

4. Study area

The study area, Chřiby Mountains, is situated in south-eastern Moravia (south-eastern part of the Czech Republic) between the municipalities of Koryčany, Staré Město and Otrokovice (Fig. 2). The Chřiby Mts. correspond to an eponymous geomorphological unit which is oriented from southwest to northeast. They are about 35 km long, up to 10 km wide, and cover an area of about 335 km^2. The highest peak, Brdo, reaches 587 m a. s. l. Etymologically, the toponym 'Chřiby' may refer to the Slavic word that means 'hills'; however, this is just one of several hypotheses.

4.1 Geology

The area is formed by Upper Cretaceous to Oligocene flysch sediments (sandstones, claystones and siltstones) belonging to the Magura Flysch and the subordinate Rača Unit, Soláň Formation (Czech Geological Survey, 2024a). Within this formation, several facies and members can be distinguished, with the Lukov Beds and Ráztoky Beds being the most relevant for the study area. The Lukov Beds (Upper Palaeocene), which are from 200 to 800 m thick, represent the so-called 'wild flysch' deposited from dense turbidity currents in the upper parts of submarine deltaic cones. They are characterised by the predominance of coarse arkosic sandstones, which are very resistant, forming distinctive narrow ridges and elevations with crags (e.g., Budačina, Komínky, Kozel). The Ráztoky Beds (up to 1,200 m thick) are of Upper Cretaceous (Campanian–Maastrichtian) to Palaeocene age and are represented by moderately rhythmic flysch with claystone interbeds and sandstones. These sedimentary rocks are less resistant and usually form the slopes. The valleys and depressions are usually excavated in less resistant Paleogene claystones and filled with Quaternary hillslope sediments.

4.2 Geomorphology

The Chřiby Mts. (Fig. 3) belong to the geomorphological region of the Central Moravian Carpathians and the geomorphological subprovince of the Outer Western Carpathians. They are characterised by rugged relief arising from erosional response to intensive neotectonic uplift, the occurrence of relatively narrow and structurally controlled ridges, deep valleys, and bear evidence of intensive periglacial processes which occurred during the Pleistocene (Demek & Mackovčin, 2015). Numerous rock outcrops are affected by weathering, producing abundant honeycombs, tafoni, ledges, fissure caves and other micro- and mesoforms, making the area very valuable from the geoheritage point of view. Due to the regional geomorphological and hydrogeological situation, the area is susceptible to landsliding and other slope processes (Czech Geological Survey, 2024b; Krejčí et al., 2023).

4.3 Historical and cultural aspects related to geodiversity

The area has been settled since prehistoric times, as confirmed by archaeological evidence from the Upper Palaeolithic (Aurignacian culture findings in the northeastern part of the study area, approx. 20,000–40,000 BP). An important settlement phase is also represented by the Eneolithic period (Bronze Age), approx. 3,000 BP, proved by findings of the Lusatian Culture, e.g., fortifications on the Brdo Hill (Baščan et al., 2003a; Hrubý, 1961).

In the 6th century, Slavs came to this area, as evidenced by a considerable number of archaeological findings. In the 9th century, the Great Moravia Empire influenced this area considerably as the settlement of Staré Město, one of its important centres, was situated nearby. Numerous archaeological structures of Slavic tumuli (e.g., Tabarky) or fortresses, e.g., St. Kliment (Baščan et al., 2005; Hrubý, 1961), come from this period.

In the Middle Ages, several castles were founded on distinctive terrain elevations, some among natural outcrops and crags, e.g., Střílky, Cimburk, Buchlov. Also, in the 12th century, a Cistercian monastery was founded in Velehrad, a site that, in oral tradition, is connected with the centre of Great Moravia. In the 14th century, the Augustinian monastery and provostry on St. Kliment Hill were established, but later, they were destroyed during the Hussite

Criterion	Description	Scoring
Integrity	Related to the present status and conditions of the geosite or geodiversity site. The better the conditions are, the lower the risks that can occur.	0 – excellent conditions; 0.25 – good conditions; 0.5 – medium, average conditions; 0.75 – bad conditions, but with a possibility to recover; 1 – bad conditions; site is damaged
Accessibility /availability of parking	Possibility of how to reach the site. The closer the parking, the higher risk can occur due to more frequent visits. The scoring and distances may be adjusted according to local conditions (e.g., proximity of cities, character of surrounding landscape).	0 – parking place situated at a distance more than 5 km from a site; 0.25 – 2–5 km; 0.5 – 1–2 km; 0.75 – 0.2–1 km; 1 – parking place situated at a distance less than 200 m from the site
Accessibility/availability of public transport	Possibility of how to reach the site. The closer the stop of public transport, the higher risk can occur due to more frequent visits. The scoring and distances may be adjusted according to local conditions (e.g., proximity of cities, character of surrounding landscape).	0 – bus/train stop situated at a distance more than 5 km from a site; 0.25 – 2–5 km; 0.5 – 1–2 km; 0.75 – 0.2–1 km; 1 – bus/train stop situated at a distance of less than 200 m from the site
Presence of accompanying tourist infrastructure	Position of the site near the well-marked and easily accessible paths, overall attractiveness of the site's surroundings.	0 – the site is situated near marked paths, not accompanied by tourist infrastructure; 0.5 – the site is well accessible, some basic infrastructures are in proximity (e.g., shelters, educational paths); 1 – the site is well accessible and situated near other sites of interest (e.g., cultural assets, shelters, refreshments…)
Management on site	Existence of strategic document that deals with site management (care plans, set of recommendations…). If any documents exist, it can be assumed that they can prevent the site from deterioration.	0 – existing care plan where geodiversity is a subject of protection and taken into account within site management; 0.5 – existing care plan, but only focused on species and ecosystem; geodiversity is not a subject of protection, but it is treated as a part of the ecosystem; 1 – recommendations for management, but on a very general level, e.g., Set of recommendations for a Special Area of Conservation (EVL) or no recommendation (not in our study area)
Legal protection	Legislative tools applied to a site. The stronger legislative protection, the lower the risk that can occur. In this method, the criterion is adapted to reflect the Czech environmental legislation (Act No. 114/1992 Coll.) but may be adjusted to local conditions.	0 – Category National Natural Monument/Reserve (or site declared as protected on a national level); 0.25 – Category Natural Monument/Reserve (or site declared as protected on a regional level); 0.5 – Category Important Landscape Element or Special Area of Conservation (or site declared as protected on municipal level); 0.75 – Included in the database or list of geological localities of a National Geological Survey, ongoing monitoring of the site, but no legal protection; 1 – No legal protection, not in the database or list of geological localities
Proximity to areas/activities with the potential to cause degradation	The lower the distance, the higher the risk can occur (e.g., proximity to roads, cities, municipalities, big camping places, recreational areas, factories and other possible disturbing activities).	0 – Site located less than 1 km from a potential degrading area/activity; 0.5 – Site located within 0.5–1 km distance from a potential degrading area/activity; 1 – Site located less than 0.5 km from a potential degrading area/activity
Current use of the site	A number of different uses (hiking, climbing, mineral and rock collecting, etc.). The higher the number of various site uses, the higher risk can occur.	0 – 1 possible activity; 0.5 – 2 different activities; 1 – 3 and more different activities
Visitation (public influx)	Number of visitors. The higher the number of visitors, the higher the risk that can occur. Based on expert estimation as it is not possible to count the visitors exactly.	0 – low number of visitors; 0.5 – medium number of visitors; 1 – high number of visitors, causing problems
Use limitations	Limits of the use related to the possibility of access and safety. The easier the access to the site (no need for permissions, no obstacles), the higher the risk to a site that can occur. It also refers to the presence of fences or other types of physical protection of the site.	0 – The use is restricted due to difficult terrain, safety issues or the necessity to obtain the permission; 0.5 – The site can be used after overcoming limitations (legal, permissions, safety, etc.); 1 – The site has no limitations to be used by wide public, no obstacles, no fences or physical barriers

Tab. 1: Degradation risk assessment
Source: Authors' conceptualisation based on García-Ortiz et al. (2014); Brilha (2016); Selmi et al. (2022); Kubalíková and Balková (2023)

Total Score on Degradation Risk	Risk Level
0.00–2.25	low
2.50–4.75	medium
5.00–7.75	high
8.00–10.00	very high

Tab. 2: Classification of the degradation risk level of geosites
Source: Authors' conceptualisation adjusted from Selmi et al. (2022)

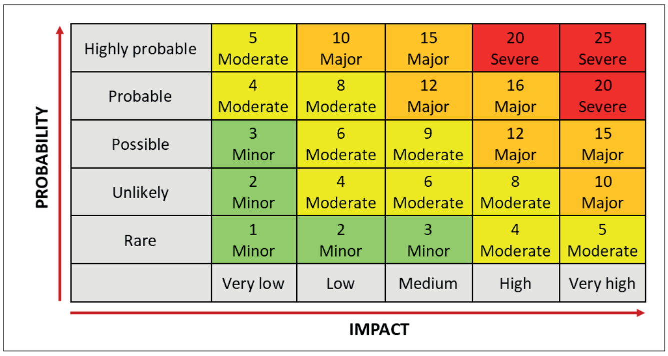

Fig. 1: Risk assessment matrix
Source: Adapted from Leveson (2011)

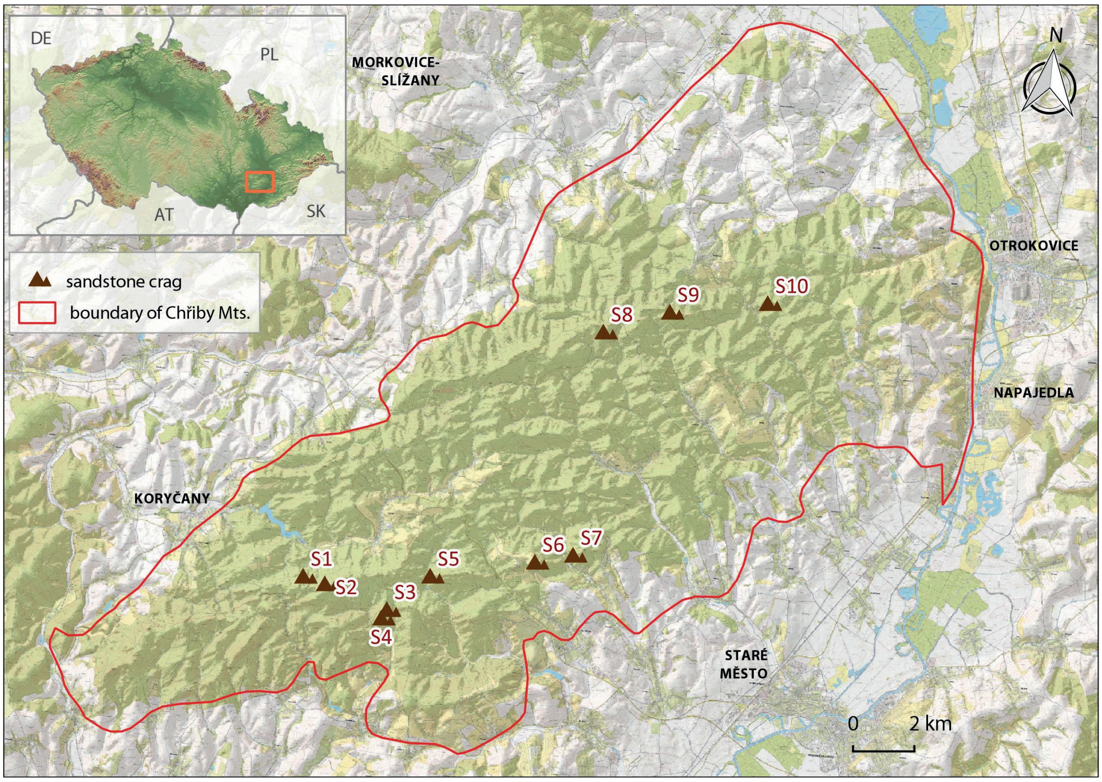

Fig. 2: Chřiby Mts. and their position within the Czech Republic. Sandstone crags: S1 Kozel, S2 Kazatelna, S3 Osvětimanské skály, S4 Trpasličí město, S5 Zbořené zámky, S6 Barborka, S7 Břestecká skála, S8 Jeřabčina, S9 Komínky, S10 Budačina
Source: Basic topographic map of the Czech Republic 1:10,000, Czech Office for Surveying, Mapping and Cadastre

Fig. 3: The panoramic view of the southern part of the Chřiby Mountains, including the main landscape dominants (landmarks) of the study area. From left to right: Holý kopec (548 m a. s. l.), Buchlov (509 m a. s. l., with a castle on the top), Barborka (510 m a. s. l., also called Modla) and Komínek Hill (456 m a. s. l.)
Photo: L. Kubalíková

Wars. All these geocultural sites are closely related to the myths and legends and represent an important part of local identity (Psotová, 2015; Daníčková & Bajer, 2019; Baščan et al., 2003a, 2003b, 2003c, 2004, 2005).

Regarding the use of natural resources, sandstone has long been extracted in the study area, as testified by numerous remnants of old quarries (e.g., Vraní lom near Koryčany, an abandoned sandstone quarry in Stupava). The local stone was used primarily to build the above-mentioned castles and fortifications. In the northern part of the area, several small limestone quarries near the village of Cetechovice used to operate. The material extracted was widely used as a decorative stone ('Cetechovice marble') on sacral monuments in the towns of Uherské Hradiště, Křtiny and Brno (Mrázek, 1993; Rybařík, 1994).

4.4 Nature conservation, current use of the area, risks and threats to geodiversity

The Chřiby Mts. are protected as a Nature Park (since 1991, according to the Act No. 114/1992 Coll.) and as a Special Area of Conservation (according to the Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora). There is a considerable number of small-scale protected sites – 6 Nature Reserves and 23 Nature Monuments. The scientific importance of Chřiby is not limited to geomorphological values. However, the area is also significant for biological reasons, and some protected species have their northernmost extent here, e.g., *Cordulegaster heros* (Holuša & Holušová, 2022). Despite its natural values, the area is not protected in any higher category (National Nature Reserve/Monument), and there is no large-scale area of special territorial protection (Nature Conservation Agency, 2024). Currently, the area is used mainly for tourism and recreation, thanks to easy access from regional centres around the cities of Brno and Zlín. Tourist infrastructure is good thanks to the dense network of tourist trails and numerous accommodation facilities (Bajer et al., 2018). The crags are often used for climbing (Association for climbing of the Czech Republic, 2024; Kohn & Bajer, 2015).

5. Results

5.1 Description of the crags and their geoheritage value

Based on the detailed fieldwork and comparison with literature and other resources (Adamovič et al., 2010; Czech Geological Survey, 2024c; Nature Conservation Agency, 2024), 10 crags have been described and documented (Figs. 4, 5, 6). The results of the identification and description of representative sandstone crags, emphasising their geoheritage and geocultural values, are presented below.

S1 Kozel

Kozel ('Goat') is a solitary sandstone rock tower rising from a moderately inclined upper slope (Fig. 4A). It is shaped as a narrow rock wall, up to 22 m in height, 18 m long, but only 6 m wide. The ground plan reflects the presence of two joint sets perpendicular to each other, whereas slightly inclined bedding planes are exposed in rock faces, facilitating selective weathering (Fig. 6A). Rows of arcades and cavernous features are ubiquitous, whereas a large recess is present along a more porous conglomeratic layer, approximately halfway up the height of the crag. In the vicinity of Kozel, numerous low outcrops (up to 2–2.5 m in height) and detached boulders are present, some hosting small weathering pits and tubes.

Kozel has been a traditional climbing and tourist destination since the 19th century. Thanks to its shape, the crag is associated with several legends. It is said to be a petrified devil who wanted to thwart the construction of a chapel planned by a local hermit.

The area near the crag is cleared of trees, so the crag itself is clearly visible. A marked trail runs next to it and the rock is currently heavily used by climbers. It is listed as a Nature Monument, but on-site interpretation is currently missing.

S2 Kazatelna

Kazatelna ('Pulpit') is a lone tower-like sandstone outcrop rising from the upper slope, close to the flattened crest (Fig. 4B). It is distinctively asymmetric, only 2.5 m on the upslope side, but 8–9 m in height on the downslope one. Vertical rock surfaces are irregular as an effect of selective weathering, but well-developed cavernous features are missing. The crag was anthropogenically modified: steps were cut in the rock to reach the top surface, and an iron cross was erected on the top. Next to Kazatelna, a similar but much lower asymmetric sandstone outcrop (2.5 m in height) is present.

Fig. 4: General view of sandstone crags: A – Kozel, B – Kazatelna, C – Osvětimanské skály, D – Trpasličí město, E – Zbořené zámky
Photos: L. Kubalíková (A, E) and P. Migoń (B, C, D)

Fig. 5: General view of sandstone crags: A – Barborka, B – Břestecká skála, C – Jeřabčina, D – Komínky, E – Budačina
Photos: P. Migoń

Geocultural connections are represented by popular histories about the Byzantine Christian theologians and missionaries Cyril and Methodius (known as Apostles to the Slavs) who preached here and converted pagans to Christianity. According to other, more recent popular histories, Jan Amos Komenský (Comenius), a famous Moravian philosopher and pedagogue, stopped here to preach and then went into exile, never to return. The crag is located next to a popular hiking trail and is listed as a nature monument.

S3 Osvětimanské skály

A small rock city, consisting of seven larger sandstone outcrops, numerous smaller ones, and detached boulders, in places piled one upon another, crowns the top of a low elevation (Fig. 4C). It is approximately 40 × 40 m, with the height up to 10 m. The ground plan of the rock city shows adjustment to two main joint directions, N–S and W–E, whereas the shapes of the outcrops in detail reflect selective weathering along moderately inclined (approximately 40°) bedding planes. Arcades, honeycombs and small tafoni, up to 0.5 m across, are common. A remnant boulder on top of one of the outcrops seems to be turning into a balanced rock due to enhanced weathering at the base. A space between the eastern and western outcrops is partially filled with large sandstone boulders, apparently products of in situ disintegration rather than fall from the adjacent outcrops.

Osvětimanské skály are also called 'Devil's rocks' thanks to the existence of numerous legends related to the site that should have served as a gateway to the hell from where the devils came out and punished bad people. Several decades ago, a small tramp settlement was founded here. The site is used by climbers and described in climber literature. The Osvětimanské skály rock city is located away from marked hiking trails and, hence, is not well known and less visited. However, access is easy along forest paths, and the crags are visible from quite a distance, thanks to the open forest. No special protection is enforced, and no interpretative facilities exist.

S4 Trpasličí město

The locality, whose name translates as 'Dwarfs town', consists of two crags on top of a low, flattened elevation, some 40 m from each other (Fig. 4D). The one in the northwest resembles a cube and is 2.5 m in height, with a few minor outcrops and boulders in the immediate vicinity. The southeastern one is asymmetric, only 2 m in height towards the hilltop, but up to 8 m in height towards the slope. Its upper surface is nearly flat and approximately 7 m across. A distinctive feature of both crags is the extreme development of cavernous features along horizontal bedding planes. The hollows of different shapes (hemispherical, oval, horizontal slots) coalesce and penetrate deeply into the outcrops, locally piercing them through (Fig. 6B). In the SE crag, the length of a horizontal slot through the entire rock is up to 7 m. In the distance of 150 m to the south, at the slope break, two more crags are located, known as Dvě hlavy ('Two heads'). From the downslope side, they are up to 7 m high. A feature of interest is the basal recess due to enhanced weathering of a conglomeratic inlier.

No marked trail goes to the crags, although the site is easily accessible along unmarked forest paths. No special protection is enforced, and no interpretative facilities exist.

S5 Zbořené zámky

The asymmetrical rocky ridge called Zbořené zámky ('Demolished (or collapsed) castles'), also known as Cvičitelská skála ('Exercise/Trainer Rock'), is a continuation of one of the main ridges in Chřiby – Holý Kopec (Fig. 4E). The top part reaches 375 m a. s. l. The southern face of the rocky ridge is formed by an inclined plate, about 8 m high, whereas the northern face is a nearly vertical cliff with basal overhangs, approximately 20 m high. The length of the crag is approximately 25 m. The rock ridge continues on the opposite slope, and it is possible that the Dlouhá řeka Brook cut through the originally compact (integral) ridge. The alternation of sandstone and conglomerate beds is reflected in variable resistance to weathering, the conglomerates being more prone to cavernous weathering. It is particularly effective along the bedding planes, which are well visible on the northern face of the ridge.

Thanks to its massiveness, visual similarity to a building (also called 'Stone chalet') or castle ruins, and traces of quarrying leaving the partially worked blocks of rock behind, the site is connected with several legends. According to popular histories, since the Great Moravian period, there used to be a space where people could spend the night and later, the site served as a shelter for bandits. The sandstone was exploited until the beginnings of the 20th century. On the nearby Holý kopec Hill, there used to be a large Slavic settlement, whose ditches and mounds are visible until now.

The site is a part of the Maršava Nature Monument. Although there is a marked cyclo-path in the Dlouhá řeka Valley, the site is not easily accessible for ordinary tourists. It is mainly used by climbers who come by a narrow path leading to the steep slope. Many climbing routes have been designated; there are also traces of fireplaces.

S6 Barborka

The name refers to a large group of sandstone outcrops (Fig. 5A) within the steep southern slope of Barborka Hill (510 m), extending over an area of 250 × 70 m. It consists of ten individual crags, mainly in the shape of asymmetric towers rising from the slope and subvertical rock slabs. The height of individual outcrops reaches 20 m on the downslope side but only a few metres on the upslope side. The south-facing rock surfaces are inclined rather than vertical, adjusted to the steep dip of sandstone strata to the south. Cavernous weathering is ubiquitous along bedding planes, whereas conglomeratic inliers are locally preferentially weathered into slots and tunnels. Basal overhangs and narrow slots due to gravitational displacements are further features of interest.

On the top of the hill, the baroque St. Barbora Chapel, dating back to the 17th century, is situated. It served as a family tomb and pilgrimage site. However, traces of human settlements are much older. Archaeological research confirmed the Eneolithic age of ceramics. Later, a Halstatt Age (Lower Iron Age) settlement was located here, with mounds and ditches still visible. From the Late La Tène Age (European Iron Age culture), there is evidence of a settlement, which, according to folk tradition, was a sacred site and a cult place. There were intentions to build a monastery here during the Late Middle Ages, but the idea was abandoned. Some crags are modified by quarrying (stone was used for building St. Barbora Chapel).

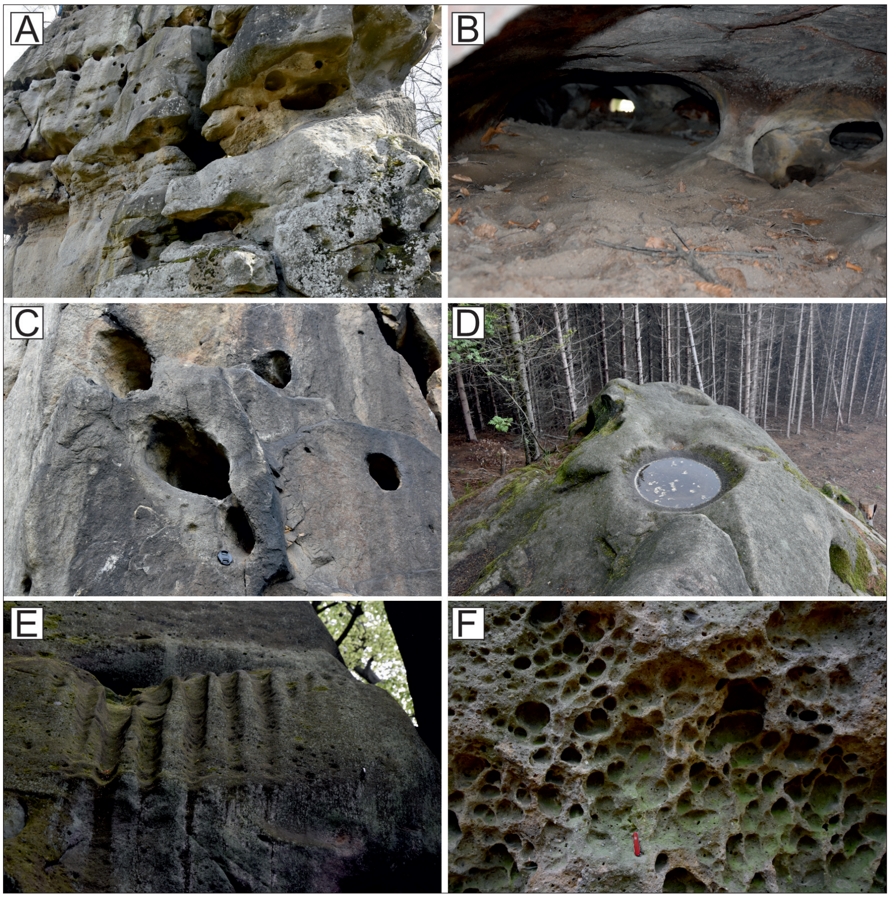

Fig. 6: Diversity of weathering features on crag surfaces in Chřiby. A – selective weathering along bedding planes (Kozel), B – tube through an entire crag (Trpasličí město), C – tafoni, probably after complete dissolution of carbonate concretions (Břestecká skála), D – weathering pit (Jeřabčina), E - karren (Komínky), F – honeycombs (Budačina)
Photos: P. Migoń

Despite its proximity to important historical sites and a marked trail nearby, the locality is not easily accessible for ordinary tourists. This is because of the very steep slope, the absence of clearly marked paths, and dense forest. Crags are visible neither from the trail nor from the viewing point next to the hilltop chapel. However, it is known among climbers, and many climbing routes have been designated. The entire slope is under protection as a Nature Monument.

S7 Břestecká skála

Břestecká skála is a complex outcrop, partly natural and partly of anthropic origin, located on the sloping ridge (Fig. 5B). The upper part is natural and consists of a series of inclined rock walls, towers and spurs, as well as minor steps and low angular outcrops within a less inclined section of the slope. The shapes of outcrops reflect a steep dip (50° and more) of sandstone beds to the south, whereas ubiquitous cavernous weathering develops along inclined bedding planes. Some caverns are remarkably smooth and regular, genetically linked with the dissolution of carbonate concretions (Fig. 6C). Thin (~1 m) conglomeratic beds are apparently less resistant than sandstone and have been weathered to narrow clefts and abri. In the lower part, natural outcrops have been undercut by now abandoned quarries, and it is difficult to identify the boundary between natural and anthropic features. The height of natural outcrops is up to 10 m, whereas the cumulative height of quarry walls is even higher.

In the surroundings, the traces of Neolithic settlement have been found. There are some old quarries and an old scout log cabin in the nearby valley. The top of the crag is easily accessible along a marked trail, but the most interesting parts below are more difficult to reach (no signage, unstable sloping surfaces). Likewise, no waymarked route goes to the old quarries. The locality is used by climbers, and a number of routes have been designated. The entire slope, from the highest crags to the valley floor, is protected as a nature monument. No educational facilities are available; only brief information about the site exists near the road (together with the Nature Monument sign).

S8 Jeřabčina

Jeřabčina skála is a cluster of sandstone outcrops on the top of an elevation within the main ridge of Chřiby (Fig. 5C). The highest one is an asymmetric, massive tower, rising by only 2 m on the upslope side, but approximately 12 m in height on the downslope side. A large overhang is present at the base. Next to it, on the ridge, are two fins approximately 3 m high, with ubiquitous cavernous weathering. More to the east is a rounded outcrop sloping steeply to the south, with several weathering pits on the upper surface, some periodically filled with rainwater (Fig. 6D), and shallow tafoni on the subvertical walls. Further outcrops and loose boulders occur in between the main crags.

The name 'Jeřabčina' refers to the local word for rowanberry tree (Sorbus). Nearby, a traditional tourist chalet, 'Na Bunči', is situated. A marked trail provides access to the crags. The locality is not under special protection and lacks interpretative facilities.

S9 Komínky

The crag crowns an elevation (521 m a. s. l.) in the main ridge of Chřiby. It is a discontinuous rock wall, up to 5 m in height in the central, highest section (Fig. 5D). Because of the steep (~ 50°) dip of sandstone beds to the south, the wall is asymmetric, with overhangs on the northern side. The central section was subject to anthropic modification: a series of rock-cut steps facilitates access to the narrow crest of the crag. To the north of the summit wall, a sandstone cliff that is approximately 15 m long up to 10 m in height exists, rounded in the upper part and undercut by a recess at the base. A feature of special interest is a group of parallel karren, up to 1 m long (Fig. 6E) – generally a rare phenomenon among sandstone outcrops in Chřiby. Further crags are present approximately 200 m to the west of the main elevation, shaped as inclined walls, fins and boulder piles.

Archaeological research confirmed the Halstatt Age of ceramic pieces. According to popular histories, the hill served as a 'fire mountain' where the guards (patrols) would set fires here in case of danger, and the smoke would warn others in the surroundings. Since the 19th century, it has been a favourite tourist destination, offering great views of the surrounding landscape. Steps have been carved into the rock and there used to be railings. When the railings were inserted into the rock, there was much smoke, which gave birth to the mystification of the volcanic origin of Komínky (the word can be translated as 'Little chimneys') and the reactivation of a dormant volcano. This popular history is used very often to promote the site. Komínky also served as a border stone (a visible carving H:K) delimiting the Kvasice estate, with further border stones situated on the continuation of the ridge. There is also a memory plaque of scout Emanuel Rupert, who tragically died here in 1998.

A marked trail provides access to the crags, which are also used for climbing and bouldering. The locality is protected as a Nature Monument, and interpretative panels are erected at the crossings of marked trails nearby.

S10 Budačina

The name refers to a group of crags which mostly form a discontinuous cliff line a few metres high along the upper slope break (Fig. 5E). However, two isolated rock landforms exist in front of the steep slope, named Velká skála ('Big Rock') and Malá skála ('Little Rock'). The former is particularly impressive, being more than 20 m long and 12 m high, with subvertical rock surfaces all around the perimeter. Its shape reflects geological structure, namely a steep (> 60°) dip of sandstone and conglomerate beds to the south. Variable thickness of beds and preferential weathering along bedding planes produced inclined rock slabs and a jagged outline of the crag, with a distinctive crest in the top part. Another effect of bedding-controlled weathering is a fissure cave that extends approximately 7 m into the crag; it is 1 m wide and 2 m high. Several other widened fissures also developed along subvertical bedding planes and joints. Evidence of cavernous weathering is abundant, mostly as small honeycombs existing in clusters (Fig. 6F). The coalescence of honeycombs gives rise to larger hollows within the rock walls, but deep tafoni are apparently absent.

The site is connected with several legends about famous bandits Ondráš and Juráš, who had their shelter here and kept stolen goods in the fissure cave. There is also a commemorating plaque of Antonín Rozsypal, a founder of Forest settlement for young campers in the nearby valley (Kudlovická dolina).

The crag is easily accessible from a local road nearby (less than 1 km) and located next to a waymarked hiking trail. It is used by rock climbers. Next to the crag an interpretive panel was erected, but information about geology and geomorphology is very limited. The site is protected as a Nature Monument, which extends over a larger section of the slope, covering 8.2 ha in total.

The detailed geomorphological analysis of selected crags allows for the following summary of their geoheritage values (Tab. 3).

5.2 Degradation risk assessment

The detailed description and analysis of the specific sites served as a basis for assessing threats and risks. The results of the degradation risk assessment are presented in Table 4.

According to the risk level classification (Tab. 2), most sites (7 sites) fall within the medium risk category, including one nearly at the boundary with low risk. Two sites scored above 5 (S1 Kozel, S8 Jeřabčina), meaning high risk. Only one site falls in the category of low risk.

Crag	Key geoheritage values
Kozel	The highest crag in the area; distinctive shape; good visibility; evidence of rock-controlled selective weathering
Kazatelna	Unusual shape; connection with local history
Osvětimanské skály	A good example of a rock city, unique in the area
Trpasličí město	Unique weathering features (cavernous weathering, long horizontal slots)
Zbořené zámky	Complex shape; clear example of bedding control on weathering patterns
Barborka	Large complex of rock slabs, towers and spurs; evidence of gravitational displacements
Břestecká skála	Distinctive setting on a spur; unusual cavernous weathering; selective weathering of conglomerate beds
Jeřabčina	Distinctive cluster of large outcrops; alveolar weathering and weathering pits
Komínky	Ridge-top crest (rare in the area); the occurrence of karren and basal recesses; connection with local cultural history
Budačina	Large dimensions of the main crag; distinctive shape related to rock structure (steep dip of sandstone beds); fissure cave; ubiquitous cavernous weathering

Tab. 3: Key geoheritage values of sandstone crags in the Chřiby area
Source: Authors' elaboration

Criterion/site	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Integrity	0.5	0.5	0.25	0.25	0	0	0.5	0.5	0.5	0.25
Accessibility/availability of parking	0.75	0.5	0.75	0.75	0.25	0.75	0.75	0.75	0.75	0.5
Accessibility/availability of public transport	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0	0.25	0.25
Presence of accompanying tourist infrastructure	1	1	0	0	0	1	1	1	0.5	0.5
Management on site	0	0	1	1	0	0	0	1	0	0
Legal protection	0.25	0.25	0.5	0.5	0.25	0.25	0.25	0.5	0.25	0.25
Proximity to areas/activities with the potential to cause degradation	0	0	0	0	0	0.5	0	0.5	0	0
Current use of the site	1	0	1	0.5	0	0	0.5	0.5	0.5	1
Visitation (public influx)	1	1	0	0	0	0	0.5	1	1	0.5
Use limitations	1	1	1	1	0	0	0.5	1	0.5	1
Total degradation risk	**5.75**	**4.5**	**4.75**	**4.25**	**0.75**	**2.75**	**4.5**	**6.75**	**4.25**	**4.25**

Tab. 4: Degradation risk assessment for geomorphological sites
Source: Authors' elaboration

The values of total degradation risk differ depending on various aspects. Generally, the sites that are unsafe to visit (no good access path, location within steep unstable slopes) have acquired relatively low scores, so they can be considered facing less risk than sites that are well accessible and safe. The latter, situated near tourist facilities (such as chalets), marked on tourist maps and close to the tourist paths (or on tourist paths), with available parking places nearby and good access by public transport, are more endangered. In some cases, despite existing legal protection, the sites have reached relatively high scores (e.g., S1 Kozel or S2 Kazatelna and S7 Břestecká skála).

Zbořené zámky (S5) is the least endangered site, especially due to its limited accessibility and lower safety. The site is not widely known and, moreover, it is situated in a Nature Monument which should ensure protection and suitable management. Perhaps unexpectedly, the S6 site of Barborka also emerged as being at rather a low risk (the second lowest score). The locality is a well-known and often visited site due to its proximity to Buchlov Castle, easy access to the hilltop, and the presence of a cultural monument. It is also located close to the public road with parking. However, in the assessment exercise, only the south-facing slope with crags was examined, not the adjacent hilltop. The slope, in turn, is not developed for tourism, so crags are not visible and poorly accessible. Safety issues additionally discourage ordinary tourists from exploring the steep slope. The site is used only by climbers and is not recommended for ordinary tourists.

Generally, the most endangered site is S8 Jeřabčina, which is very well accessible and safe to visit but has no legal protection and management plan. Also, the site S1 Kozel has reached quite a high score, especially due to its good accessibility, intensive use, and high visitation. Also, it is one of the best-known sites within the Chřiby Mts., in the proximity of Cimburk castle ruins.

5.3 Risk assessment matrix

The degradation risk assessment is accompanied by evaluating particular threats using the Risk Assessment Matrix. Based on fieldwork, several threats have been identified (Fig. 7) and assessed (Tab. 5).

Table 5 shows the main threats identified for all the sites and their assessment. It can be noted that the intensity of the threat varies depending on the site. Generally, after elaborating the simple average of all the results for particular threats, it appears that the most important threats are represented by Recreation and tourism (18) and Climbing and consequent damage of the crags (15.7). Other threats, such as Natural geomorphological processes (15), Lack of finances (14.7), Vegetation overgrowth (14.5) and Changes in land use (14), can also be considered important. Regarding the 'Emphasising the living nature', it proved to be moderate, reaching an average value of 7.9.

The values of risk intensity for particular sites are presented as an average value of all the particular threats for a single site. According to this method, the most threatened sites are S8 Jeřabčina (15.9) and S1 Kozel (15.4), which corresponds to the final ranking and values of Degradation risk in Table 4. These most endangered sites are followed by S6 Barborka (14.4) and then, with the same value (14.3), S3 Osvětimanské skály, S4 Trpasličí město, and S10 Budačina. S9 Komínky (14) and S2 Kazatelna (13.4) are the less endangered sites. According to this evaluation, the least threatened site is S5 Zbořené zámky, which corresponds with the ranking in Table 4 (Degradation risk assessment).

6. Discussion

Based on the results, particular management proposals can be discussed. Given the character and focus of the methodological approaches, these proposals can be focused in two directions:

1. On particular sites – following the results of Degradation risk assessment and also Risk Assessment Matrix, the S1 Kozel and S8 Jeřabčina should gain the priority attention as they have reached the highest score, so they are considered the most important;

Sites	Threats	Changes in land use (including agriculture, forestry, new cottages, expanding recreational areas, …)	Recreation, tourism (visitors' pressure, – overtourism, littering, vandalism, breaking the rules)	Climbing and consequent damage of the crags	Lack of finances for maintaining the sites and their Earth Sciences phenomena	Emphasising the living nature	Vegetation overgrowth	Natural geomorphological processes (slope processes, erosion, accumulation of debris)	Average risk on specific site
S1 Kozel	prob	3	5	5	3	1	2	3	
	imp	5	5	5	5	3	5	5	
	total	**15**	**25**	**25**	**15**	**3**	**10**	**15**	**15.4**
S2 Kazatelna	prob	1	5	4	3	1	2	3	
	imp	5	5	5	5	4	5	5	
	total	**5**	**25**	**20**	**15**	**4**	**10**	**15**	**13.4**
S3 Osvětimanské s.	prob	3	3	4	5	3	3	3	
	imp	5	5	4	3	3	5	5	
	total	**15**	**15**	**16**	**15**	**9**	**15**	**15**	**14.3**
S4 Trpasličí m.	prob	3	3	4	5	3	3	3	
	imp	5	5	4	3	3	5	5	
	total	**15**	**15**	**16**	**15**	**9**	**15**	**15**	**14.3**
S5 Zbořené z.	prob	1	1	3	3	3	4	3	
	imp	5	5	4	5	3	5	5	
	total	**5**	**5**	**12**	**15**	**9**	**20**	**15**	**11.6**
S6 Barborka	prob	4	3	3	3	3	3	3	
	imp	5	5	4	5	3	5	5	
	total	**20**	**15**	**12**	**15**	**9**	**15**	**15**	**14.4**
S7 Břestecká s.	prob	3	4	4	3	3	3	3	
	imp	5	5	4	5	3	5	5	
	total	**15**	**20**	**16**	**15**	**9**	**15**	**15**	**15.0**
S8 Jeřabčina	prob	4	5	3	5	3	3	3	
	imp	5	5	4	3	3	5	5	
	total	**20**	**25**	**12**	**15**	**9**	**15**	**15**	**15.9**
S9 Komínky	prob	3	4	3	3	3	3	3	
	imp	5	5	4	4	3	5	5	
	total	**15**	**20**	**12**	**12**	**9**	**15**	**15**	**14.0**
S10 Budačina	prob	3	3	4	3	3	3	3	
	imp	5	5	4	5	3	5	5	
	total	**15**	**15**	**16**	**15**	**9**	**15**	**15**	**14.3**
Intensity of particular threats		**14**	**18**	**15.7**	**14.7**	**7.9**	**14.5**	**15**	

Tab. 5: Risk Assessment Matrix for the particular sites (prob = probability, imp = impact)
Source: Authors' elaboration

2. On particular threats – following the results of Risk Assessment Matrix, abundant tourist and recreation use of the sites and climbing are the threats that should be addressed with priority when designing the management proposals for a wider area.

Regarding the most endangered sites, in the case of S1 Kozel, legal protection has already been established. Thus, other measures should be applied to avoid future degradation or damage of the Earth Sciences phenomena. Environmental education focused on geoheritage values and the development of geoeducational products that inform about Earth Sciences values of the sites prove to be effective tools (Pijet-Migoń & Migoń, 2019; Bussard & Reynard, 2022; Rodrigues et al., 2023). Also, the education of local residents can be useful (Muzambiq et al., 2021). Lowering the number of visitors by their re-distribution in a wider area could also reduce degradation risk. However, visitors usually tend to visit the 'top' sites within a certain area (S1 Kozel is one of the best-known sites) and rarely miss them (Drápela, 2023), so this proposal may not be so effective. In the case of S8 Jeřabčina, which has no legal protection, it is possible to include the site in the Database of Geological Sites (Czech Geological Survey, 2024c), which would ensure at least regular monitoring. Later, this record can serve as a basis for establishing legal protection, which can contribute to lowering the degradation risk. Although, in some cases, the establishment of legal protection may result in a higher frequency of visits, more often, the attractiveness of a site for visitors is conditioned by other factors, such as visual attractiveness of the locality, access, visit safety, or information availability (Štrba et al., 2020).

The other sites evaluated as less endangered using the Degradation risk methodology should be at least regularly monitored. Generally, this is ensured for legally protected sites, as an existing care plan is updated every 10 years (Nature Conservation Agency, 2024). However, regular monitoring should have a shorter interval as changes can occur rapidly. One of the possibilities of monitoring more frequently is to include particular sites in the local communities' activities or projects, which proved

Fig. 7: Threats on selected sandstone crags: A – heavy use of the crags by climbers (Kozel), B – significant trail erosion (Komínky), C – various examples of rock defacing from bouldering (traces of magnesium) and making fires (Komínky), D – vegetation overgrowth (Břestecká skála), E – graffiti making (Komínky), F – making fires and camping (Jeřabčina)
Photos: P. Migoń (A, B, C, D) and L. Kubalíková (E, F)

to be an effective tool to raise awareness about geoheritage values or care about the sites (Prosser, 2019). These include such activities as 'Watch over a rock' (Vegas et al., 2018) or participatory mapping of geoheritage (Drápela, 2019; Bollati et al., 2023).

Regarding point 2 (particular threats), the most important issues in the study area are recreation and tourism, followed by climbing and consequent damage to the crags. In both cases, environmental education may help to reduce these threats. Another possibility is to employ 'nature guards', which is quite usual in National Parks and Protected Landscape Areas (González & Martin, 2007). In the case of Chřiby, however, there is no roofing large-scale protected area administration, so the pool of nature guards is complicated to set up or invite to the particular sites.

There is a possibility of enhancing legal protection (from Nature Monuments to National Nature Monuments) or establishing new protected sites. However, as legal instruments of geoconservation are top-down initiatives resulting from political decisions, the local communities may be reluctant to accept that and may consider it useless; thus, it is appropriate to involve local communities in the decision process (Nunes et al., 2022). Moreover, proper legal conservation or protection does not assure that the site will not face any threats and risks (Crofts et al., 2020; Nunes et al., 2022; Kubalíková & Balková, 2023; Kubalíková, 2024). A bottom-up approach to geoheritage care and protection can also be considered. These initiatives can result in a complex involvement of various stakeholders from the area and the creation of a Geodiversity Action Plan, which may contribute to more effective management of geoheritage (Burek, 2012; Ferrero et al., 2012; Dunlop et al., 2018; Kubalíková et al., 2022). The positive effects of community-led conservation and care activities are already proven (Tavares et al., 2015; Gravis et al., 2020; Bollati et al., 2023).

Regarding climbing, which has been identified as one of the main threats, there is a significant difference between particular sites. For example, S1 Kozel is intensively used, and traces of magnesium and other negative consequences can be found on-site (e.g., littering or even vandalism). In contrast, other sites (e.g., S5 Zbořené zámky and S6 Barborka), which are also intensively used and well-known among the climbers' community, are less damaged and endangered. It is probably related to the accessibility of the sites and the individual behaviour of the climbers. Closer communication between the nature conservation authorities and the Association for Climbing of the Czech Republic is desirable in order to minimise the negative influence and can contribute to a better understanding and more respectable use of the sites for climbing and bouldering. Moreover, according to Bollati et al. (2014, 2024), sport climbing is a powerful tool for disseminating complex scientific information (e.g., conditions for rock formation, types of deformation, surface modelling and geological time) and consequent appreciation of geoheritage values.

The topic of natural geomorphological processes and their influence on geo-phenomena may be viewed in two ways. First, if the natural processes damage the Earth Sciences phenomena under protection, they should be somehow treated, e.g., in the case of heavy erosion and intensive slope processes which may damage profile of sediments or important stratigraphic boundaries. This is usually reflected in care plans; however, in some cases, there is an emphasis on living nature management, and abiotic features are considered 'in good conditions' (Nature Conservation Agency, 2024). Second and more often, these natural processes are taken as an inseparable part of a particular site (Smith, 2005; Prosser et al., 2006), and such sites should be treated in a complex way as dynamic geomorphosites (Kubalíková, 2024). In the case of specific sites in the study area, most probably there is a very limited possibility to avoid processes such as occasional rock fall, but it is possible to reduce the intensity of other slope processes, such as soil creep or overland flow, e.g., by regulating the number of visitors or by redirecting their movement. This, however, would require some investment into supporting infrastructure and higher financial demands.

7. Conclusions

This research was focused on two main points: recognition of sandstone heritage in a less explored terrain of the Chřiby Mountains and evaluation of risks and threats to particular sites (sandstone crags). Based on the literature and map review and using results of detailed fieldwork, 10 sandstone crags have been described and qualitatively evaluated regarding their geoheritage values. The diversity of sandstone geoheritage within selected sites is high, especially when considering mesoforms and microforms (e.g., abundant occurrence of tafoni, honeycombs, or perforations). Based on their geoheritage values, some sites may be proposed for a higher degree of legislative protection, or at least they can be included in the Database of geological localities, ensuring regular monitoring. Nevertheless, further research is needed, focusing, e.g., on micro- and mesoforms inventories, the intensity of natural geomorphological processes, and the genesis of the sandstone crags.

The evaluation of degradation risk and the use of a risk assessment matrix enabled us to rank the sites according to the degree of possible deterioration and helped to identify particular threats, which should be considered as important when planning and managing natural resources of the area. The most important threat is represented by recreation and tourism (and related camping, making fires or littering and vandalism), followed by climbing (and consequent damage of the crags) and natural geomorphological processes. Several management proposals have been discussed, but the application of particular measures to specific sites or practical dealing with particular threats is a subject of further efforts, communication with relevant authorities, and community involvement. Nevertheless, recognising the geoheritage values of sandstone crags and identifying and evaluating possible risks and threats may be considered an important step towards effective management and further research.

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