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Assessing the geotourism potential of abandoned quarries with multitemporal data (České Středohoří Mts., Czechia)

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Abstract: Quarrying represents a major human impact on the landscape. The positive effects of quarrying have also been appreciated over the last several decades and concern the role of quarries as sites with the potential for geoscientific education and geotourism. In this paper we present a procedure for establishing a multitemporal database of abandoned quarries and their multicriterial assessment in order to determine sites suitable for geotourism purposes. The case of the České středohoří Protected Landscape Area in Northern Czechia is used, as an example of conflicting interest between nature conservation and intense quarrying. Using the combination of old maps and current orthophotomaps, we identified 80 (mid-19th Century), 57 (mid-20th Century) and 38 (2007) quarries. 104 of them were further evaluated according to criteria of scientific and educational value and 'potential use' value (visibility, accessibility and extent). This process enabled to determine sites with the highest suitability for geotourism purposes. Finally, we discuss management context for these sites, and possible threats to the sites caused by increased geotourism.

Key words: quarry, old maps, aerial photos, geoconservation, geotourism, geomorphosites

Highlights for public administration, management and planning:
- Abandoned quarries may represent important sites for geotourism and promotion of geoheritage.
- Multitemporal database of abandoned quarries combined with multicriterial assessment of their scientific-educational vales and accessibility enable to determine suitable sites for geotourism.

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1. Introduction

1.1 Environmental impacts of quarrying

Quarrying represents a major human impact on the landscape. The effects of quarrying can be both direct and indirect. A number of these effects become apparent in the short term, while others can display a high level of persistence in a landscape (Fig. 1). Regardless of the variability of these effects, they are generally considered to be environmental threats (e.g., Milgrom 2008).

Over the last several decades, much attention has been devoted to the reclamation and restoration of abandoned quarries, and these studies have contributed to a more complex appreciation of quarries as new types of ecosystems and sites worthy of environmental protection (Davis, 1983; Novak & Konvička 2006; Novák & Prach 2003) and the revegetation of quarries (Ursic et al. 1997). Others focused on the abiotic environment of quarries and have primarily dealt with anthropogenic modifications to the landforms for stability purposes and for restoration strategies (Schor & Gray 2007; Dávid 2008). Several authors (Gunn et al. 1992; Walton & Allington 1994; Yundt & Lowe 2002) emphasised the necessity of an understanding to landforms and geomorphologic processes in quarries when designing a landform replication strategy to increase the geomorphic and ecological diversity of abandoned quarries,

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

and others focused directly on the positive geomorphologic effects of quarrying at various territorial levels (Bradshaw 2000; Raška et al. 2011). As Chuman (2007) noted, the evolution of valuable biotic communities inhabiting these landforms has led to the conservation of many of the abandoned quarries in Central Europe.

1.2 Quarries as objects for geotourism

The significant, positive effects of quarrying that have been appreciated over the last several decades concern the role of quarries as geological and geomorphological heritage (geoheritage) sites with the potential for geoscientific education (e.g., Petersen 2002) and geotourism (e.g., Newsome & Dowling 2006; Pralong 2005; López-García et al. 2011; Baczyńska et al. 2017; Stefano & Paolo 2017). Abandoned quarries perceived as geological and geomorphologic heritage sites enable a society to study old quarry sites and their technical infrastructure as historical objects to understand both the variability in approaches and techniques for quarrying over time and quarrying's specific impacts on the Earth's surface. In this sense, these sites represent the so-called original offer, which is anything that attracts tourists to a place (Reynard 2008). The derived offer, in turn, denotes the infrastructure needed for the realisation of geotourism.

The significance of individual geomorphologic sites for geoscientific education and geotourism has recently been based primarily on the concept of geomorphosites (Reynard & Coratza 2007), which are sites with a scenic/aesthetic, scientific, cultural/historical and/or a social/economic value, due to human perception of geological, geomorphological, historical and social factors (e.g., Panizza 2001; Reynard et al. 2007). Geomorphosites express the geomorphologic diversity (geomorphodiversity) of the area, and when based on rigorous assessment processes, they can be applied for different issues, including the conservation management of the geological heritage in natural protected areas (Serrano & Gonzáles-Trueba 2005). In this respect, geomorphosite inventories and assessments are closely related to the principles of geoconservation audits, which serve as the basic stage of geoconservation investigating the identification of conservation priorities (Burek & Prosser 2008) and an inventory of regionally important geological and geomorphological sites (Higgit 2001).

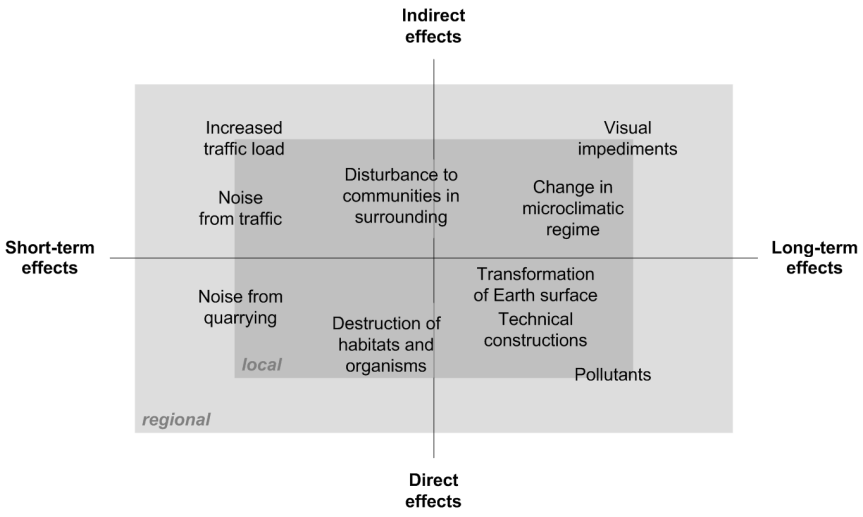

Fig. 1 – Schematic overview of the major environmental effects of quarrying

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

In the Czech Republic, an assessment of geomorphodiversity has been made for the entire area (Demek et al. 2011). The first studies in individual regions date to as early as the 1980s (Kirchner 1982) and inventoried geomorphological sites for conservation purposes; however, since that time, relatively scant attention has been paid to the evaluation of geomorphologic sites. Among the latest studies, the assessment of geomorphosites in some parts of the country is worth mentioning because it presents a comparison of different sets of criteria for geomorphosite assessments (Kubalíková 2009, 2011; Kubalíková et al. 2016). Within the geomorphodiversity concept, however, the quarries represent a specific type of landform because they are strictly spatially limited and are predominantly related to the intrinsic geomorphodiversity of the study region (cf. Panizza 2009). Moreover, as anthropogenic objects, quarries have a much shorter 'life-length' than natural objects. Therefore, the evaluation of quarries as potential geomorphosites must employ historical approaches using old maps, aerial images and other documentary data, which is something that has not been undertaken to date. Studying quarries as geoheritage is even more specific, in fact, because quarries have traditionally been viewed as degradation features in a landscape not worth close attention. Until now, there have only been a limited number of studies dealing directly with quarries in the Czech Republic.

1.3 Aims of the study

The aim of this paper is to present a complete process for planning the territorial network of abandoned quarries in the protected landscape area (PLA) of the České Středohoří Mts. (Northern Czech Republic, Central Europe) for the purposes of geoheritage conservation and geotourism. The underlying goal of the study is to test a multitemporal approach for the inventory of abandoned quarries and their assessment as potential geomorphosites (in this paper understood as geotourism sites); however, this study does not focus on derived offers of geomorphosites and their promotion. The individual steps that are presented within this case study include a method for constructing a retrospective inventory of abandoned quarries, a modification of the methodological approach for geomorphosite assessments to evaluate quarries and a final evaluation of geoconservation and geotourism significance for selected geomorphosites supplemented with management considerations.

2. Rationale for regional study

2.1 Study area

The České Středohoří Mts. comprise a 60-km long, SW–NE trending neovolcanic range located in the Northern Czech Republic (Fig. 2). This range's volcanism belongs to four different formations with activity between approximately 36–13 Ma (Cajz et al. 1999). The spatially prevailing products of volcanism are basalts, phonolites, trachytes and volcanoclastics. During and after its volcanic evolution, the area was subject to intense tectonic movements (Cajz & Valečka 2010). In the Quaternary period, the geomorphological character of the area was diversified due to the erosive strength of the Labe River (largest river in the Czech Republic in terms of average annual discharge) and its tributaries. The tectonic movements, together with erosion, resulted in the presence of many individual elevations surrounded by gentle slopes. These unique geologic, geomorphologic and ecological conditions (Raška & Cajz 2016) were the foundations of the PLA (1063.17 km²) in the mountain range in 1976. Nevertheless, the area was affected by different human activities acting as environmental stressors during the 20th century, among which quarrying played a significant role (Balej et al. 2008; Balej & Anděl 2011). The elevations of solid neovolcanic rocks represent suitable localities for quarrying of stone and have been intensively exploited since the 19th century. Among all 25 PLAs in the Czech Republic, quarrying in the České Středohoří Mts. (Fig. 3) is responsible for more than 50 % of building-stone production. This level of quarrying requires a new approach to quarry planning and re-evaluation of the effects of abandoned quarries on the landscape.

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

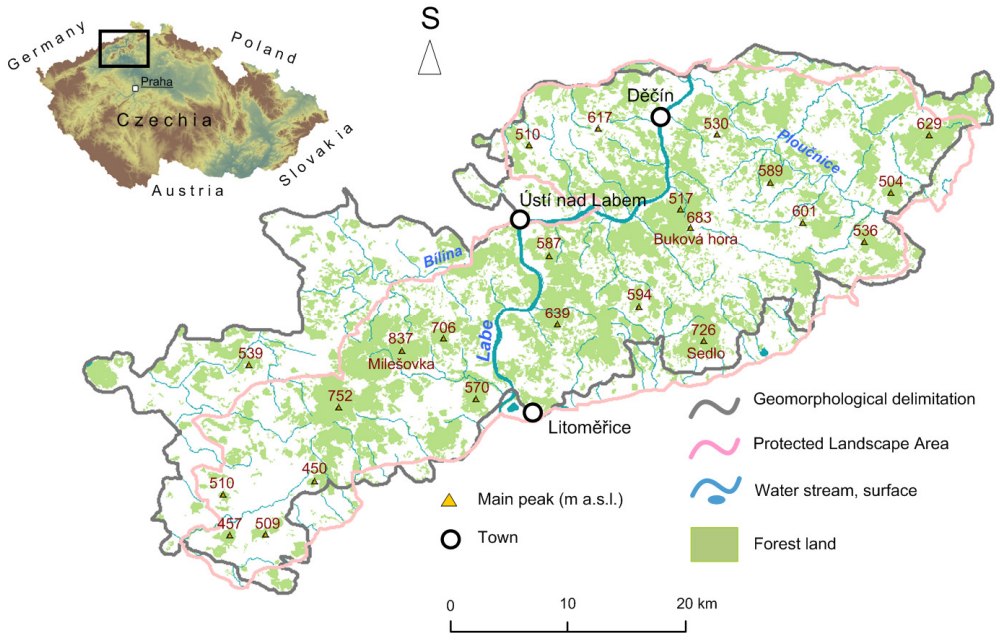

Fig. 2 – Overview map of the study area – the České středohoří Mts. Protected Landscape Area

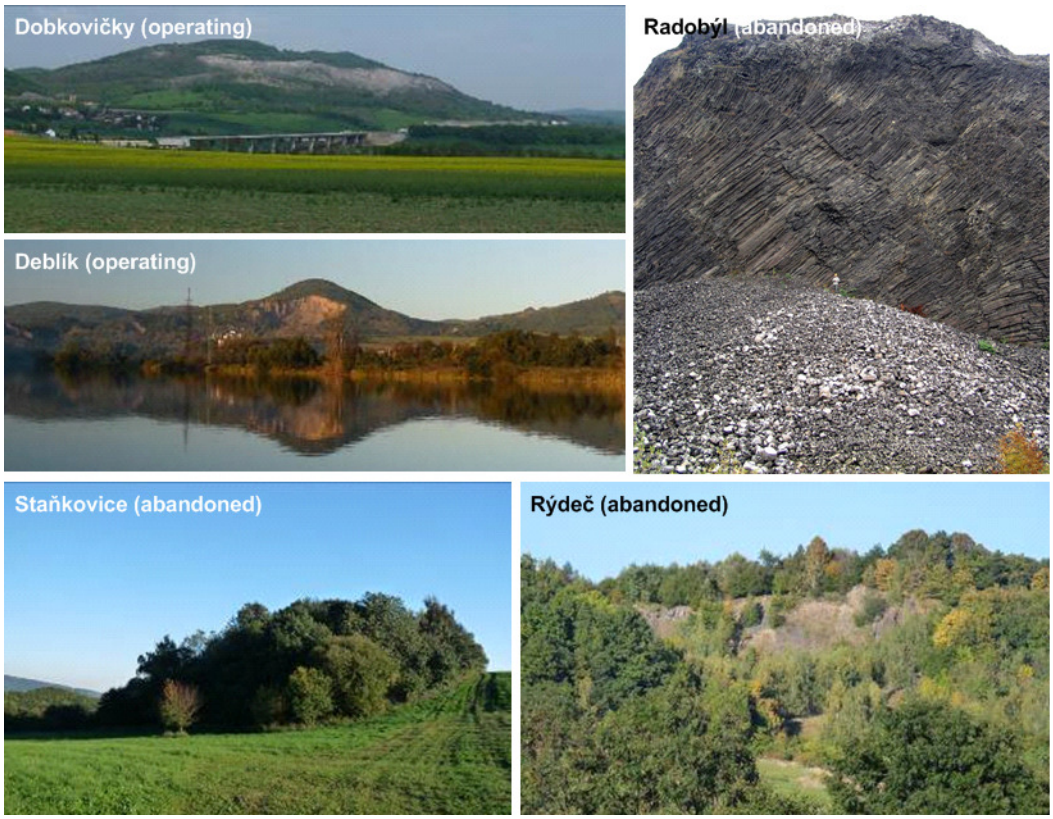

Fig. 3 – Examples of the operating and abandoned quarries in the study area

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

2.2 Perception of abandoned quarries

The presented research is part of a long-running project to study the landscape-ecological effects of abandoned quarries. The research was performed in the protected landscape area, which is the second highest level of landscape conservation in the Czech Republic. The specific legislative conditions related to landscape management in PLAs requires new approaches for the evaluation of operating quarries and their management after abandonment. Within the project framework, special attention has been given to the regional perception of quarrying. At the beginning of the project in 2010, we performed a sociologic inquiry among the mayors of municipalities that are fully or partially located within the PLA of the České Středohoří Mts.

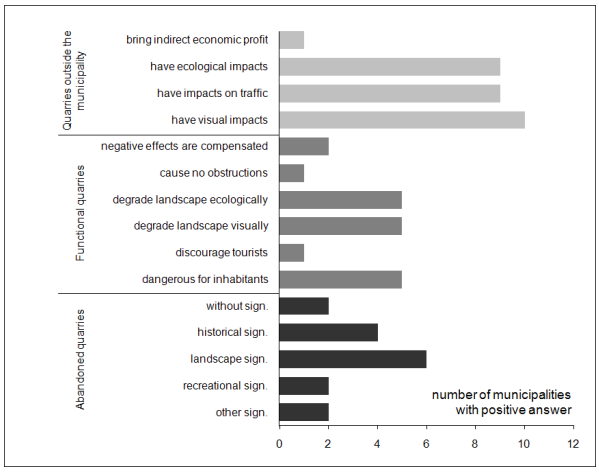

Fig. 4 Results of the sociological inquiry among mayors of municipalities within the study site (number of inquired municipalities = 116; number of returned questionnaires = 43; performed during May–August 2010; sign. – significance)

This set consisted of 116 municipalities from which 43 questionnaires were returned with answers concerning the perception of effects from functioning and abandoned quarries and opinions concerning possible new quarries in the area. We should note that quarries were not located in all of these municipalities; however, the questionnaire was distributed to all of them because we wanted also to examine the perception of quarries outside the municipal boundary.

The results of the inquiry are shown in Fig. 4. Despite the relatively small number of returned questionnaires, the inquiry indicated that there were discrepancies between the perception of operating and abandoned quarries. Operating quarries were generally considered to have negative effects. In contrast, historical and landscape values were ascribed to abandoned quarries in several cases. Despite such perception of abandoned quarries, there is a limited number of abandoned quarries that are managed as historical sites or as valuable landscape and recreational localities.

3. Methods

3.1 Multitemporal inventory of abandoned quarries

The multitemporal approach for constructing a database requires the combination of different data sources produced in individual time periods. First, we set the time horizons for the inventory. These time horizons reflected the results of a preliminary search for available data sources and corresponded with horizons that have typically been used in land-use and landscape features development studies in the Czech Republic (Bičík et al. 2001; Skaloš et al. 2011; Raška et al. 2017). These time horizons were as follows: (1) mid-19th century, (2) mid-20th century and (3) present day. The data sources that were used for the multitemporal inventory are listed in Table 1 and Fig. 5. For each source, we identified all quarries being visible. If a quarry appeared in more than one period, all periods were recorded. The old maps and aerial photos were orthorectified and georeferenced to create a new vectorised digital database of quarries.

The basic dataset included information regarding the presence of a quarry in individual time periods and the spatial extent of the quarries and was further supplemented with other variables (see section 3.2). We used the database of Czech Geological Survey (Pokorný & Peterková 2016) and geological and geoscience maps of the study area (Cajz 1996 ed.) as supplementary sources for the geomorphosite assessment because they

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

represent the only modern existing summary of geologically important sites in the area.

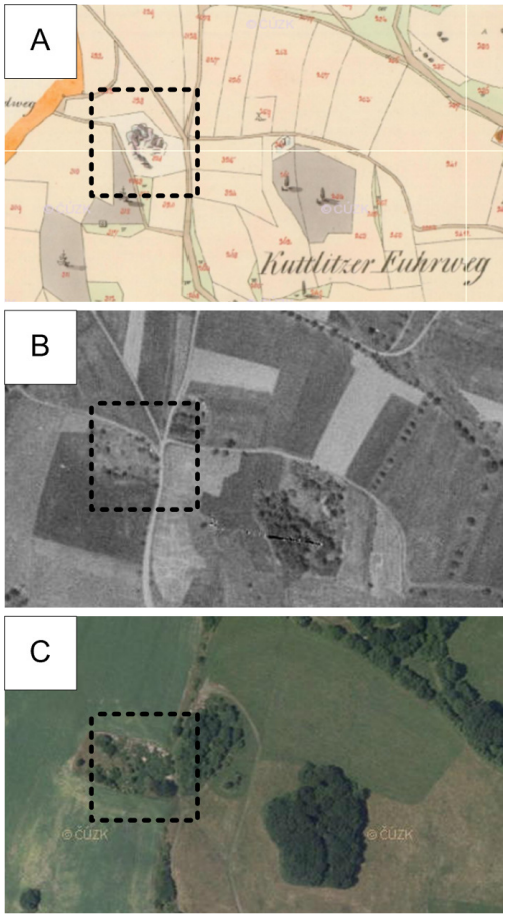

Fig. 5 Example of the Soběnice abandoned quarry in Soběnice village (S part of the study area) in three map sources (A – 1843, B – 1953, C – 2007)

3.2 Geomorphosite assessments

Recent literature offers a wide-ranging spectrum of methods for geomorphosite assessments. For the purposes of this study, however, we have to modify the standard approaches for the following reasons.

(i) First, in contrast to other studies, we only assess one repeating type of geomorphologic object, i.e., quarries. Therefore, we had to set the criteria to represent the unique characteristics of the assessed sites and enable us to differentiate the varying significances of these sites.

(ii) Second, the quarries are anthropogenic features, and as such, they display specific features that were included in the set of criteria to explain the potential of abandoned quarries for geoconservation as heritage objects and for geotourism purposes (e.g., visibility of the rockwall or regional visibility based on viewshed analyses). Alternatively, certain criteria that are typically used in geomorphosite assessment were excluded (e.g., palaeogeographical value).

These modifications also imply a minor change to our understanding of the criteria that are recurrently used in geomorphosite assessments (see Grandgirard 1999; Reynard et al. 2007) because some of the 'synthetic' and 'rarity' values can only be adequately used in relation to the extrinsic values of geomorphosites (Panizza 2009). These extrinsic criteria are relative because the assessed object (landform) attains a value based on a comparison with other sites outside the region.

Moreover, some of the synthetic values concerning the criteria of integrity have been excluded from the assessment and used as ex post evaluation criteria. In particular, these evaluation criteria consisted of threats and management measures. This approach emerges from the fact that the entire study region is subject to landscape conservation. Therefore, both threats and management measures should be evaluated and recommended (in case of management measures) at the regional level and should not represent criteria for the assessment of diversity of potential geomorphosites/ geotourism sites. The recent state of management measures in the study area is summarized in the section 4.2.2 and the relevance of ex-post evaluation of these management measures in relation to the process of geomorphosite assessment is discussed in the section 5. An overview of the final set of criteria is shown in Table 2 and includes a comparative reference to the methodological approach presented by Reynard et al. (2007). The data for each criterion have been compiled into a digital database.

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

Table 1 – Data sources used for multitemporal inventory of quarries

Period	Source title	Specification	Source
1. (1823–1843)	maps of Stable Cadastre	old maps 1:2880	Czech Institute of Geodesy and Cadastre
(1876–1878)	maps of 3rd Military Survey	old maps 1:75000	Faculty of Environment UJEP
2. (1952–1954)	aerial orthogonal images	black and white aerial photos	Military Geographical and Hydrometeorological Administration - VGHMÚř
3. (2007)	aerial orthogonal images	colour aerial photos	GEODIS, a.s. company

Table 2 – Criteria for the assessment of quarries as potential geomorphosites

Criteria for geomorphosite assessment in this study			Reference to relative criteria in Reynard et al. (2007)
Scientific and educational value			
criteria	value range	specification	
rock type	1–5	representativeness of rock type for the regional geologic history	3 Scientific value
rock face	0–10	visibility of rockwall (rock face)	3 Scientific value
(micro-)geodiversity	1–6	number of visible landforms	3 Scientific value
geoscientific significance	1–5	illustration of geologic, geomorphological, ecological processes and phenomena	3 Scientific value
history	1–10	the first period in which the site was identified according to inventory	4c Cultural value
ecology	0–4	recent land use / land cover of the site assessed from aerial photos	4a Ecological value
'Potential use' value			
criteria	value range	specification	
extent	1–5	extent according to multitemporal GIS inventory	1 General data
regional visibility	0 or 5	recent visibility of quarry (based on viewshed* and aerial images analyses)	4b Aesthetic value (partly)
accessibility	1–5	distance to the nearest tourist trail	none
Total value range	**6–55**		

*Note: *the viewshed analyses has been performed in ESRI Arc GIS 10.3 using a multitemporal database of quarries and Digital Terrain Model based on elevation data 1:10000. The visibility of a rock-face within the PLA České středohoří Mts. was assessed.*

4. Results

4.1 Multitemporal database of abandoned quarries

The overall results of the multitemporal inventory of quarries are summarised in Table 3. Using the old maps and aerial photos, we identified 80 quarry sites for the first horizon, 57 for the second one and 38 for the present-day horizon. In some cases, the sites overlay or extend the older quarry that was inventoried for the previous period(s). If we assess only the locations of the quarries regardless if a temporal succession exists, the database includes 136 sites. The typical trend in quarrying over the monitored period showed a decreasing number of quarries and increasing average size, as shown in Table 3.

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

Of these quarries, around ten are still in operation currently. The geomorphosite assessment was based on a modified database, which emerged from the multitemporal database according to the following criteria:

• sites where the historical quarry was overlain by another operating quarry have been excluded from the database because our aim was to only assess the abandoned quarries;

• sites with multiple records in the database (i.e., sites with a temporal succession of quarries) were considered as single localities and were ascribed a size and other variables from the latest detectable period.

The final number of abandoned quarries that were assessed as potential geomorphosites/ geotourism sites was 74 for the first horizon, 24 for the second one and 6 for the present-day horizon.

Table 3 – Number of quarries in the multitemporal inventory and used in the geomorphosite assessment

	1823–1843	1952–1954	2007
number of quarries from the multitemporal inventory	80	57	38
- average size of the quarry (m^2)	*2999*	*18134*	*58752*
- total size (km^2)	*0.2*	*1.0*	*2.2*
- from this group, the number of quarries still in operation	0	1	13
number of quarries included in the geomorphosites database	74	42	26
- from this group, the number of quarries identified in the previous periods	0	18	20
number of quarries assessed as potential geomorphosites	74	24	6

Note: sum numbers of quarries for the three periods is higher than the total number of quarries (136) due to succession of quarries, i.e. existence of a specific quarries in more periods.

The records for all 104 quarries (Supplement 1) assessed as potential geomorphosites were completed with the variables listed in Table 2 using geological maps, tourism maps, aerial images, field surveys and other documentary (archival) sources. Selected characteristics of the inventoried quarries indicated certain regularities in the spatial distribution and the temporal evolution of the quarries over the study period. Fig. 6 shows a relatively small number of large quarries (>5001 m2) in the area, which were predominantly remnants from the historical periods. The most represented types of rock were neovolcanites, which was self-evident from the regional geologic history of the area. However, there were also several quarries of sedimentary rocks exposed during the tectonic uplift, quarries of crystalline rocks from the Palaeozoic basement and Tertiary methamorphites. The persistence of quarries in a landscape can be accurately assessed by the presence of a compact rockwall (rock face), which is typically preserved in neo-volcanite quarries.

The post-quarrying development of quarry sites is indicated by the prevailing land use and cover (LUC) categories present. We determined seven categories of LUC based on traditional simplified classifications (CORINE, Bičík et al. 2001) along with a specific category for conservation reflecting the goals of our study. The results illustrated in Fig. 7 indicate the dependence of LUC on the size of the quarry, which also denotes the dependence of post-quarrying development on the size of the quarries.

The number of quarries that were recently forested or covered by shrubs gradually decreased with an increase in their size. Most of the forested quarries were small sites from historical periods. These quarries have tremendous potential as objects of geological heritage, but this potential is partially decreased if they are completely covered because of forest

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

vegetation succession, which influences both the accessibility of the sites and their visual representativeness of the landscape. The ecological significance of these sites was variable. Most of the forested quarries were located on foots of steep slopes and were known only in local communities; therefore, they are not subject to intense environmental management but rather to spontaneous succession. On the other hand, some sites were covered by a mosaic of forest and shrub patches combined with grasslands and represented alternative ecosystems for disturbed natural habitats. Some of these types of sites were included in the NATURA 2000 programme and were subject to environmental management and conservation. Similar to the forested quarries, there was an obvious prevalence of agricultural LUC categories (meadows, pastures, grasslands and arable lands) in the small quarries. In contrast, larger quarries tended to persist as bare land areas or were built up with technical constructions.

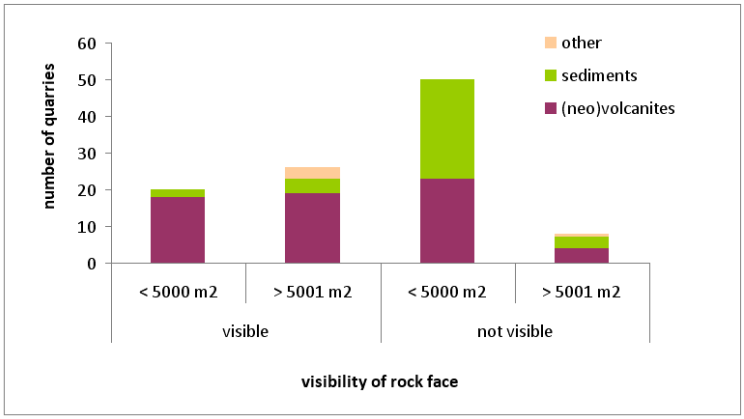

Fig. 6 – Number of quarries with visible rock faces according to the rock type and quarry extent

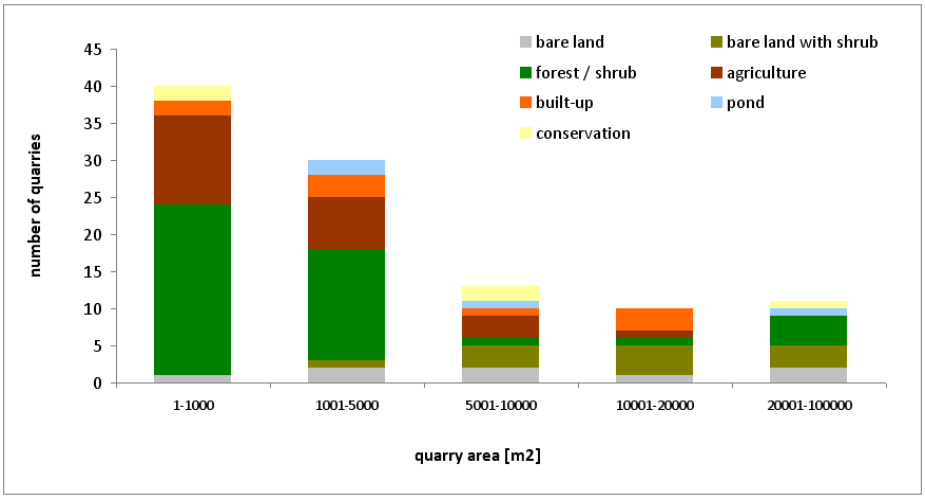

Fig. 7 – Number of quarries according to recent land use and cover (LUC)

4.2 Quarries as geomorphosites

4.2.1 Results of the geomorphosite assessment

Using the set of criteria to assess the scientific and educational value of the quarries and their value for potential exploitation in geotourism ('potential use' value), we examined all 104 abandoned quarries. While the hypothetical values of the assessment ranged from 6 to 55 (Table 2), the resulting values ranged from 18 to

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

44 with an average value of 28.33. The basic descriptive statistics of the dataset are summarised in Table 4. Within the assessment approach, the scientific and educational value (SEV) was ascribed a higher significance than the 'potential use' value (PUV). The relative significance of these values ranged from 4−40 for the SEV and 2−15 for the PUV, which results in a ratio of 72.1 % and 27.9 %, respectively, for median values within the range. Significant deviations from this ratio (more than 10 %) occurred in 28 % of cases. Approximately two thirds of these cases were in favour of the relative significance of the PUV. The sites represented by these deviations were predominantly larger quarries that were abandoned in recent decades and located around cities and near roads. These sites had good accessibility and, in some cases, good scientific value; however, they typically did not display the representative diversity of landforms, and the vegetation succession was in the early stages, or the quarry floor was built up with technical constructions. On the other hand, one third of the deviation was characteristic of small abandoned quarries in peripheral locations. These sites were often not indicated in any tourist or geoscientific map, but they had an average scientific and educational value.

The overall distribution of values among the assessed quarries approximated a normal distribution (Fig. 8) with a slightly higher number of quarries below the average geomorphosite value (Table 5).

Table 4 – Statistical characteristic of the geomorphosite values for the identified quarries

	min	max	average	standard deviation
Scientific and educational value	14	32	20.80	4.88
'Potential use' value	3	15	7.52	3.20
Total value	18	44	28.33	6.46

Table 5 – Number of quarries with below-average and above-average geomorphosite values

		n	f [%]
Number of sites	total	104	100
	below average	58	56
	above average	46	44

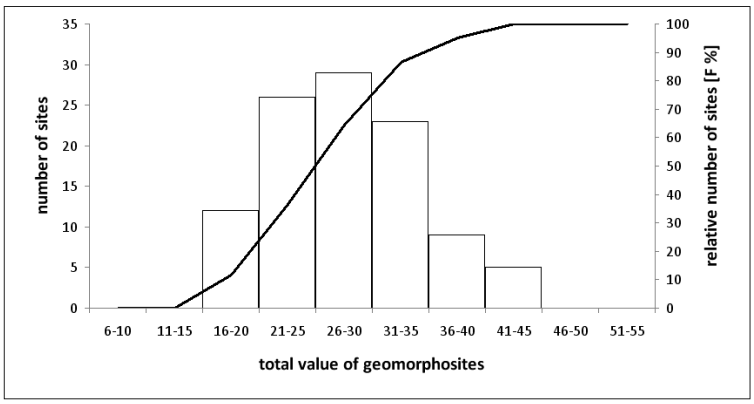

Fig. 8 – Results of quarry assessments as potential geomorphosites

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

Sites with the ten highest values included four localities, which have been established as natural reserves, due to the newly established natural conditions following the abandonment of the quarry. This fact partly certifies the adequacy of the defined methodological approach and the set of criteria in this study. All of these quarries were located in neovolcanites, and they had a preserved rockwall showing the rock structure. The talus cones were built by clasts of different shapes and sizes, and their openwork structure displayed specific microclimatic circulation regimes (cf. Raška et al. 2011). Other landforms present included quarry floors, cavities, anthropogenic relics of quarrying, landslides, and ponds. The vegetation succession was in the later stages and is typical of a mosaic of forests, shrubs and grasslands. Another natural reserve, Hnojnice, which is located in the southern margin of the area, was among the first 15 values. The reason for these slightly lower values emerges from the geological character of the site, which is an explosive maar with a low diversity of landforms. The geoscientific significance of the site is enormous (e.g., Valenta et al. 2010), but its accessibility and visibility from surrounding locations are low.

Besides the sites that have recently been protected as natural reserves and represent a geotourism destination, we identified several other sites that should be included in the regional network of geomorphosites for geoconservation and geotourism. These sites can be grouped into the following specific clusters:

(i) suburban, partially visited sites: represent historical quarries with good accessibility and landform diversity; they are already visited by locals, but not for their geoscientific significance;

(ii) rural/peripheral, partially visited sites: small peripheral quarries, partly forested, but some of them also including ponds and are already used for recreation by locals;

(iii) partially visited sites in the Labe River valley: located in the transportation corridor of the valley, they have good accessibility; they are historical sites with high landform diversity and visual representativeness;

(iv) rural/peripheral, not-visited sites: usually smaller quarries located around villages, they are known to locals but without geotourism infrastructure or promotion;

(v) newly abandoned sites: abandoned in the last years and displaying high landform diversity and good accessibility.

4.2.2 Threats and management measures for geomorphosites – basic considerations

Basic guidelines for the management of abandoned quarries should reflect the general landscape management principles in PLAs according to the national Nature and Landscape Conservation Act (No. 114 valid since 1992 with amendments) and Mining Act (No. 44 valid since 1988 with amendments). According to the first act, it is forbidden to modify the preserved natural environment in contradiction to the conditions for nature conservation, and it is forbidden to extract raw materials and humolites in the first protection zone of the PLAs. Additionally, the Mining Act enables the protection of exclusive deposits of raw materials to avoid all of the potential limits of their extraction. Besides the legislative norms and processes, which solve the possible contradictions between the individual legislative acts and individual interest groups, there are several threats and management tools that apply to abandoned quarries.

The major threats and management measures for abandoned quarries with respect to geomorphosite management are twofold. First, management must protect the sites against the accelerated succession of invasive species and against the modification of the surface morphology of the quarries. Second, threats arise from increased frequency of tourists at locations assessed as geomorphosites. For this purpose, legislative protection should be accompanied by carrying capacity studies (e.g., Mexa & Coccossis 2004). The concrete measures listed in the management plan for the PLA České Středohoří Mts. for the years 2000–2009 includes the following summarised issues for the management of geologic objects. The management of localities

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

that are not protected within the small-scale natural reserves should focus on the following:

(a) protection against further extraction of stone;

(b) protection against wild dumps;

(c) reduction of vegetation cover;

(d) protection against destruction of regolith and of talus cones;

(e) installation of informational tables at selected localities.

This summary of measures lists the important issues but lacks a conceptual approach for the management of abandoned quarries and concrete processes. Moreover, this summary lacks the fundamental premise necessary to follow these measures, which is a database of the abandoned quarries. In this respect, the database developed here and the creation of a regional network of geomorphosites (abandoned quarries) may help the following issues:

(a) providing a foundation for new, small-scale natural reserves with intensified legislative conservation measures;

(b) identifying significant trends in vegetation succession in relation to local environmental conditions and to the age of the abandoned quarries (enables adequate techniques for vegetation management);

(c) promoting the sites as indirect tools to limit the potential destruction of these sites by further extraction of stone and by wild dumps – this activity is based on the presumption that most of the affected sites are not known and not included in regional inventories; therefore, they cannot be periodically checked by inspectors from the PLA authority;

(d) fulfilling the integrity of the desired regional network of geomorphosites that will represent the geological and geomorphological specifics of the region, changes in quarrying techniques and post-quarrying development of quarries (both biotic and abiotic successions).

In this context we argue that evaluation of threats and management measures should represent a ex-post step when assessing a single type of landform in an area under landscape conservation with the following rationale:

(i) First, the protection rules emerging from the national Nature and Landscape Conservation Act covers the entire area. Only certain localities are subject to intensified protection because they are small-scale natural reserves within the protected landscape area. For this purpose, the category of natural reserve might be included in the land cover and land use parameter (ecological value) and could potentially increase the significance of the abandoned quarries protected as natural reserves.

(ii) Second, the threats and management measures do not represent the implicit geomorphologic significance of abandoned quarries. All of the quarries are, in fact, the result of anthropogenic disturbances to the environment. According to the resilience, age and previous management of these sites, they are in a certain phase of succession to the natural (semi-natural) environment. Therefore, the speed, efficiency and results of this succession do not only reflect the geomorphologic (i.e., natural) character of these sites but also the concurrent modifications of the management policies central to the highly dynamic human domain. Thus, the evaluation of threats and management measures relating to abandoned quarries should represent the last step of geomorphosite assessments. Based on this information, this paper presents a set of geomorphosites supplemented with recommendations for management measures to increase sustainable geotourism in the protected landscape area and provides a new opportunity for the future exploitation of abandoned quarries, while reflecting the conservation approaches and opinions of regional authorities acquired from the sociological survey.

5. Discussion and Conclusions

This paper presented a multitemporal process to inventory abandoned quarries in the České Středohoří Mts. and to assess their potential as geomorphosites for geoconservation and geotourism. The combination of various historical documents and cartographic sources was an important approach required for completion of

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

the geodatabase. Using a combination of old maps and aerial images from different periods, we obtained complex information about the spatial distribution, temporal development and character (i.e., geographical context, LUC of surrounding area) of the quarries. The validation of the database is possible by using the Archive of the Czech Geological Survey (Geofond), which includes data about all the abandoned, undermined, operating and reserved mining and quarrying sites. Alternatively, we encountered several methodological problems, which have also been referenced by other authors using old cartographic sources. These problems include the variability in scales and coordinate systems used in georeferencing (e.g., Skaloš et al. 2011) and differences in cartographic expression. Nevertheless, the use of a combination of multitemporal data sources proved to be a valid approach for constructing an inventory of abandoned quarries for geomorphosite assessment. Using this approach, we created a database of 104 abandoned quarries from the three monitored periods beginning in the mid-19th century. The use of historical documentary sources was also crucial for the assessment of historical values and of land cover succession stages in the geomorphosite assessment.

In the second step, we assessed the abandoned quarries as potential geomorphosites according to the methodological approach emerging from that of Reynard et al. (2007). The specific demands for this assessment necessitate modifications of the standard assessment procedure. This method is in contrast to assessments focused on geomorphosites of different types in complex geomorphological terrains. The assessment of a single type of landform (quarries) calls for criteria that will differentiate the significance within the assessed dataset. Therefore, quarry-related features, such as the rockwall (rock face), which illustrate geological and mineralogical specifics of the sites, enable us to study the post-quarrying surface dynamics of the site (cf. Raška et al. 2011). Furthermore, the exact evaluation has been performed for a diversity of individual landforms. The landforms are not only related to the history of quarrying but also implicitly indicate the diversity of habitats and are a significant measure of the ecological diversity in the abandoned quarries (Davis 1982 ed.; Novák & Prach 2003). When the set of abandoned quarries was selected as valuable geomorphosites, we finally considered the implications for geoconservation and their exploitation for geoscientific tourism to define the major threats and management measures for abandoned quarries.

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GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

Supplement 1

Multitemtporal database of abandoned quarries and their assessment as potential geomorphosites/geotourism sites (ordered according to total value)

	Basic information				Scientific and Educational Value (SEV)						Potential Use' Value (PUV)				
Location	Stable cadastre	III. Military Survey	1950s	2007	RT	RF	GD	GS	HI	EC	EX	VI	AC	total	
Valkerice1	ne	yes	yes	yes		5	5	5	3	10	3	5	5	3	44
Radobyl	ne	no	yes	yes		5	5	5	5	5	4	5	5	5	44
Valkerice	ano	yes	yes	yes		5	5	5	3	10	3	3	5	3	42
Valkerice2	ne	yes	yes	yes		5	5	5	3	10	3	3	5	3	42
Valkerice3	ne	yes	yes	yes		5	5	5	3	10	3	3	5	3	42
Vrkoc	ano	yes	no	no		5	5	3	5	10	4	3	0	5	40
Vetruse	ne	yes	yes	yes		5	5	3	2	10	2	3	5	4	39
Panska skala	ne	no	yes	yes		5	5	3	4	5	4	3	5	5	39
Dubí hora	ne	no	yes	yes		5	5	3	5	5	4	1	5	5	38
Strekov	ne	yes	yes	yes		5	5	3	2	10	0	3	5	4	37
Kozí vrch	ne	no	yes	yes		5	5	3	3	5	2	5	5	4	37
Rydec	ne	no	yes	yes		5	5	4	3	5	3	3	5	4	37
Zdar	ne	yes	yes	no		5	5	3	2	10	3	5	0	3	36
Kozlí	ano	no	yes	no		5	5	3	3	10	3	3	0	4	36
Nebocady	ne	yes	no	no		5	5	3	2	10	3	3	0	4	35
Trmice	ne	yes	no	no		5	5	3	3	10	2	3	0	4	35
Velke Brezno	ne	yes	no	no		5	5	3	2	10	3	3	0	4	35
Dolni_Tynec	ano	no	no	no		5	5	3	2	10	3	3	0	4	35
Chudoslavice	ano	no	no	no		5	5	3	2	10	3	3	0	4	35
Hnojnice	ne	no	yes	yes		5	5	3	5	5	4	1	5	2	35
Kamyk	ne	no	yes	yes		5	5	3	2	5	2	3	5	5	35
Porta Bohemica	ne	no	yes	yes		3	5	3	4	5	2	3	5	5	35
Nova Ves	ne	yes	yes	no		5	5	3	2	10	2	3	0	4	34
Zitenice	ne	no	yes	yes		5	5	3	2	5	2	3	5	4	34

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

Techlovice	ano	yes	no	no	5	5	3	2	10	3	1	0	4	33
Dubice	ano	no	no	no	5	5	3	2	10	3	1	0	4	33
Hlupice	ano	no	no	no	5	5	3	2	10	3	1	0	4	33
Mnichovsky_Tynec	ano	no	yes	yes	5	0	2	2	10	2	3	5	4	33
Trmice	ne	no	no	yes	5	5	3	3	1	2	5	5	4	33
Dolní Zálezly	ne	no	yes	no	1	5	2	2	5	3	5	5	4	32
Chraberce	ne	no	no	yes	5	5	3	2	1	2	5	5	4	32
Libochovany1	ne	no	no	yes	5	5	3	2	1	2	5	5	4	32
Libochovany2	ne	no	no	yes	5	5	3	2	1	2	5	5	4	32
Strekov1	ne	no	yes	yes	5	5	3	2	5	0	3	5	4	32
Svadov	ne	no	yes	yes	5	0	3	2	5	3	5	5	4	32
Libochovany3	ne	no	yes	no	5	5	3	2	5	2	5	0	4	31
Strekov2	ne	no	yes	yes	1	5	2	3	5	3	3	5	4	31
Dolni_Tynec	ne	no	yes	no	5	5	3	2	5	3	3	0	4	30
Korozluky	ne	no	yes	no	5	5	2	4	5	3	3	0	3	30
Rtyne nad Bilinou1	ne	no	no	yes	5	5	3	2	1	2	3	5	4	30
Vchynice3	ano	yes	no	no	5	0	2	2	10	3	3	0	4	29
Boletice	ne	yes	no	no	5	0	2	2	10	3	3	0	4	29
Lysa1	ano	no	no	no	5	0	2	2	10	3	3	0	4	29
Mlade	ano	no	no	no	1	5	2	2	10	3	3	0	3	29
Rtyne nad Bilinou2	ne	no	yes	no	5	5	3	2	5	2	3	0	4	29
Skrsin	ne	no	yes	no	3	5	2	2	5	3	5	0	4	29
Rana	ano	no	no	no	5	0	2	3	10	1	3	0	4	28
Sobenice2	ano	no	no	no	5	0	2	2	10	3	3	0	3	28
Dobkovice	ne	no	no	yes	5	5	3	2	1	0	3	5	4	28
Merboltice	ne	no	yes	yes	3	5	2	3	5	1	1	5	3	28
Podmokly	ano	yes	no	no	1	5	2	2	10	0	3	0	4	27
Dolni Kamenice	ne	yes	yes	no	5	0	2	2	10	3	3	0	2	27
Volfartice	ne	yes	no	no	5	0	2	2	10	3	1	0	4	27
Habrovany	ano	no	no	no	5	0	2	2	10	3	1	0	4	27
Hlinena	ano	no	no	no	5	0	2	2	10	3	1	0	4	27
Lysa2	ano	no	no	no	5	0	2	2	10	3	1	0	4	27

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

Mala Velen	ano	no	no	no	5	0	2	2	10	3	1	0	4	27
Repnice	ano	no	yes	no	5	0	2	2	10	3	1	0	4	27
Retoun	ano	no	yes	no	5	0	2	2	10	3	1	0	4	27
Sebuzin	ano	no	no	no	5	0	2	2	10	3	1	0	4	27
Tlucen	ano	no	no	no	5	0	2	2	10	3	1	0	4	27
Touchoriny	ano	no	no	no	5	0	2	2	10	3	1	0	4	27
Trebusin	ano	no	no	no	5	0	2	2	10	3	1	0	4	27
Repcice u Rydece	ne	no	yes	no	5	5	2	3	5	3	1	0	3	27
Babetin	ano	no	no	no	5	0	2	2	10	3	1	0	3	26
Lukov	ano	no	yes	no	5	0	2	2	10	3	1	0	3	26
Zubrnice	ano	no	no	no	5	0	2	2	10	1	1	0	4	25
Litomerice	ano	yes	no	no	1	0	1	2	10	2	3	0	5	24
Chotimer	ne	yes	no	no	1	0	1	2	10	3	3	0	4	24
Trebivlice4	ano	no	no	no	1	0	1	2	10	3	3	0	4	24
Trebivlice5	ano	no	no	no	1	0	1	2	10	3	3	0	4	24
Lenesice	ano	no	yes	no	1	0	1	3	10	1	3	0	4	23
Mukarov1	ano	no	yes	no	5	0	2	2	10	1	1	0	2	23
Mukarov2	ano	no	yes	no	5	0	2	2	10	1	1	0	2	23
Nackovice	ano	no	no	no	5	0	2	2	10	1	1	0	2	23
Pohorany	ano	no	no	no	1	0	1	2	10	3	1	0	5	23
Sobenice3	ano	no	no	no	1	0	1	2	10	3	3	0	3	23
Zandov	ne	no	yes	no	5	0	2	2	5	2	3	0	4	23
Maskovice	ano	yes	no	no	1	0	1	2	10	1	3	0	4	22
Velke Zernoseky	ano	yes	no	no	1	0	1	2	10	1	3	0	4	22
Vchynice1	ano	yes	no	no	1	0	1	2	10	1	3	0	4	22
					1	0	1	2	10	3	1	0	4	22
Dolni_Vysoke	ano	no	no	no										
Jablonec	ano	no	yes	no	1	0	1	2	10	1	3	0	4	22
Stankovice	ano	no	no	no	1	0	1	2	10	3	1	0	4	22
Trebivlice1	ano	no	no	no	1	0	1	2	10	1	3	0	4	22
Obrice	ne	no	yes	no	5	0	2	2	5	2	3	0	3	22
Podmokly	ne	no	yes	no	1	5	2	2	5	0	3	0	4	22

GeoScape 11(2) - 2017: 93–111 doi: 10.1515/geosc-2017-0008 Available online at www.degruyter.com

Lhotka2	ano	yes	no	no	1	0	1	2	10	0	3	0	4	21
Vchynice2	ano	yes	no	no	1	0	1	2	10	0	3	0	4	21
Bily_Kostelec	ano	no	no	no	1	0	1	2	10	3	1	0	3	21
Horni Police	ano	no	no	no	1	0	1	2	10	1	3	0	3	21
Horni_Nezly	ano	no	no	no	1	0	1	2	10	3	1	0	3	21
Lhotka1	ano	yes	no	no	1	0	1	2	10	1	1	0	4	20
Brezno	ne	yes	no	no	1	0	1	2	10	1	1	0	4	20
Brusov	ano	no	no	no	1	0	1	2	10	3	1	0	2	20
Medvedice	ano	no	no	no	1	0	1	2	10	1	1	0	4	20
Mirejovice	ano	no	no	no	1	0	1	2	10	1	1	0	4	20
Pokratice	ano	no	no	no	1	0	1	2	10	1	1	0	4	20
Trebivlice2	ano	no	no	no	1	0	1	2	10	1	1	0	4	20
Trebivlice3	ano	no	no	no	1	0	1	2	10	1	1	0	4	20
Korozluky	ne	no	yes	no	3	0	1	4	5	1	3	0	3	20
Decin	ano	no	no	no	1	0	1	2	10	0	1	0	4	19
Sobenice1	ano	no	no	no	1	0	1	2	10	1	1	0	3	19
Rane	ano	no	no	no	1	0	1	2	10	0	1	0	3	18

Note: RT – rock type, RF – rock face, GD – geodiversity, GS – geoscientific significance, HI – history, EC – ecology, EX – extent, VI – visibility, AC – accessibility.