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Development of two Bohemian Forest glacial cirques based on their structural-geological conditions and morphology

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Abstract
In the Bohemian Forest, moraines were dated demonstrating glaciation in the Late Glacial. Evidence of older glaciations, which authors of numerous studies assume to have occurred, is lacking. We suggest that the allometric development of the size and shape of glacial cirques may prove the occurrence of older glaciations. We conducted detailed field research at two glacial cirques. These cirques were classified as a slope cirque and a schrundline cirque according to their shape, with different degrees of development. Structural-geological conditions are essential for the shape and development of cirques. Considering the allometric development of cirques, the investigated cirques must have developed over a period of at least 300 ka and, thus, during more than one glacial cycle.

Key words: Bohemian Forest, cirque development, morphostructural analysis

INTRODUCTION

Over the last twenty years, detailed geomorphological research with absolute dating of moraines (REUTHER 2007, MENTLÍK et al. 2010, REUTHER et al. 2011, MENTLÍK et al. 2013) has been carried out in the formerly glaciated areas of the Bohemian Forest. The results provide evidence of glacial activity in the Late Glacial, but do not provide data that would indicate older glaciations. Thus, for the Pleistocene glaciation of the Bohemian Forest, the fundamental question of glacier activity during older cold periods (which has been documented in other Hercynian mountain ranges of Central Europe e.g. the Black Forest, FIEBIG et al. 2004) remains unresolved. In the Bohemian Forest region, this question is particularly relevant because, especially in the works of German authors (e.g. HAUNER 1980, HAUNER et al. 2019), older glaciations are not only assumed but are reported to be well beyond the extent of glaciation linked only to glacial cirques. In formerly glaciated areas, not only accumulation forms such as moraines, but also erosional forms – especially cirques – provide information on landscape development (BROOK et al. 2006, BARR & SPAGNOLO 2015).

Previous research in the Bohemian Forest shows that structural-geological conditions and deflation plateaus from which snow was transported to the cirques were influential for the formation and development of cirques (MENTLÍK 2006, STEFFANOVÁ & MENTLÍK 2007, Mentlík et al. 2010, Mentlík 2016). Therefore, the geological conditions of the cirques were evaluated as a factor influencing the length of time over which the cirques developed.

In the context of other studies pointing to the allometric nature of cirques (Gordon 1977, Evans & Cox 1995, Brook et al. 2006, Evans 2006, Barr & Spagnolo 2015), the aim of this paper is to infer how long (how many glacial cycles or cold Pleistocene periods) the development of the two Bohemian Forest cirques may have lasted. Sub-objectives of the present study are to verify the relationship between the morphology of these cirques and the geological structure and between the size and position of the deflation plateau and the cirques development. The size and position of the plateaus may have influenced to the rate of cirques development. Therefore, the paper summarises the local structural-geological conditions that have been identified in the Bohemian Forest as essential for the formation and development of cirques, especially at the sites of Prášilské Lake and Laka Lake (Mentlík 2006), see Fig. 1. These findings are supplemented by new results from research carried out at cirques on the German side of the Bohemian Forest – Kleiner Rachelbach cirque and Großer Schwarzbach cirque (Fig. 1).

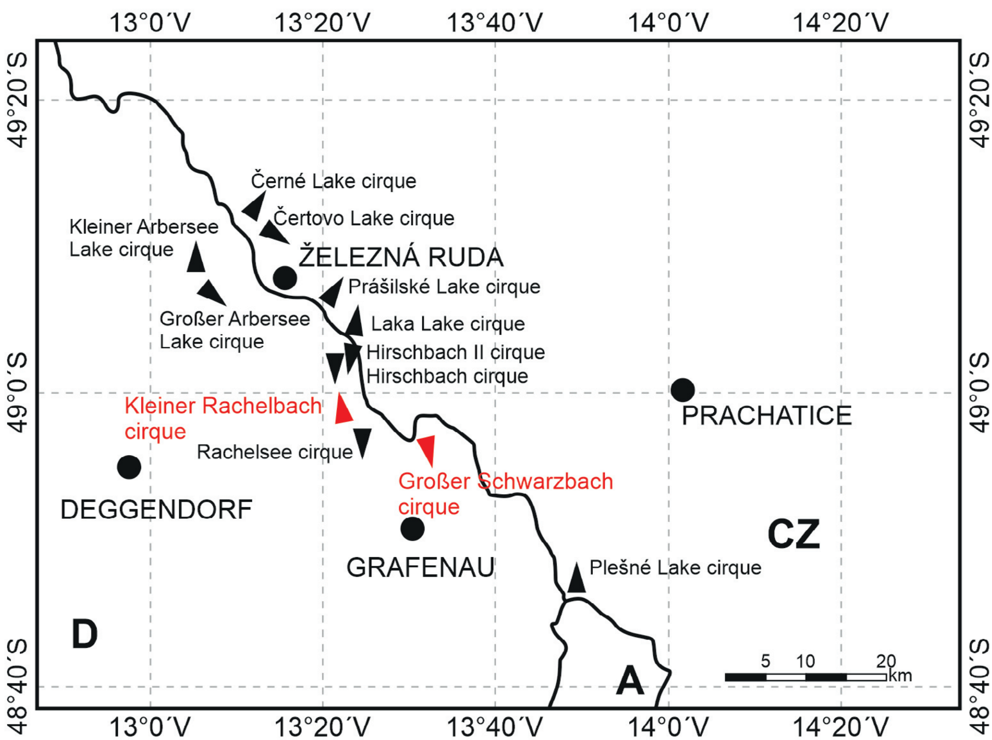

Fig. 1. Location of cirques (black arrows) in the Bohemian Forest mentioned in Křížek et al. (2012) and two areas of interest (red arrows). The orientation of the arrow indicates the orientation of the cirques.

State of Research

On the main Bohemian Forest ridge, which runs NW–SE, there are numerous valleys based on old tectonic lines, which are oriented N–S (MENTLÍK 2016). Glacial cirques formed on the Czech and German sides of the Bohemian Forest and glaciers were active during the cold periods of the Pleistocene (REUTHER 2007, KŘÍŽEK et al. 2012, MENTLÍK et al. 2013, VOČADLOVÁ et al. 2015, HAUNER et al. 2019) in these valleys.

Glacial cirques carry information about the glaciation and about the climate that accompanied it (HUGHES et al. 2007, MÎNDRESCU et al. 2010, BARR & SPAGNOLO 2015, BARR et al. 2019). As with other geomorphological forms, different degrees of cirque development can be observed (Fig. 2, e.g. from grade 1 representing a marginal cirque to grade 5 representing a classic cirque; EVANS & COX 1995), which may indicate a different time period over which the cirque was glacially formed (BROOK et al. 2006, EVANS 2006, BARR & SPAGNOLO 2015). The degree of development is determined by the morphological characteristics. Larger and deeper cirques are generally more developed and probably formed over a longer period of time. Moreover, it is assumed that the cirques develop allometrically (GORDON 1977, EVANS & COX 1995, BROOK et al. 2006, EVANS 2006, BARR & SPAGNOLO 2015). According to this concept, the morphological characteristics of cirques change at

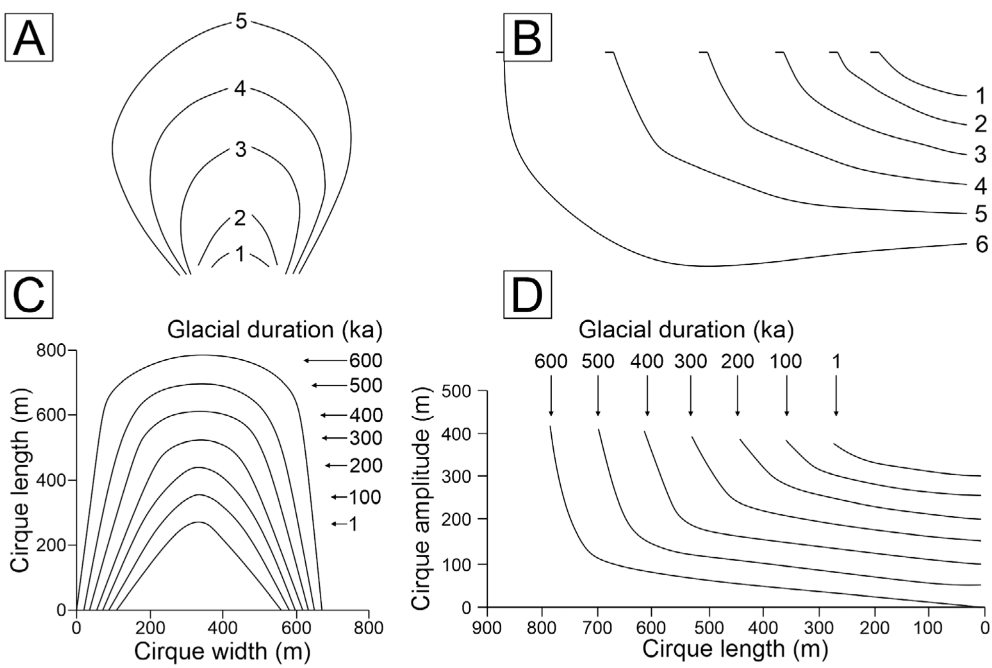

Fig. 2. Generalised representation of allometric cirque development in planform (A) and longitudinal profile (B) with planform development (C) and longitudinal profile development (D) of an idealised cirque in the Ben Ohau Range, New Zealand (after BROOK et al. 2006). Panel A and B after GORDON 1977. The L/W ratios for particular grades of development in panel A are: gr. 1 = 0.40; gr. 2 = 0.71; gr. 3 = 1.00; gr. 4 = 1.07; gr. 5 = 1.10.

different rates during their development (EVANS & COX 1995, BROOK et al. 2006, EVANS 2006). The length of a cirque changes more rapidly than its width (BROOK et al. 2006, EVANS 2006, BARR & SPAGNOLO 2015), so more developed cirques tend to be more elongated (L/W index > 1); see Fig. 2.

By fitting the morphological characteristics of the cirque into the assumed allometric series (Fig. 2), it is possible to estimate how many glacial cycles it took for the cirque to develop (EVANS & COX 1995, BARR & SPAGNOLO 2015). BARR & SPAGNOLO (2015) compare the allometric series of cirque development (Figs. 1A–1B) with the development of cirques in New Zealand (Figs. 1C and 1D). They then infer the duration of cirque development based on the length, width, and height of the cirques and their allometric variation (BARR & SPAGNOLO 2015). When using this approach, it must also be considered that cirques do not appear to develop uniformly over time. It has been found (BARR et al. 2019) that cirques develop most rapidly at the beginning of their development and then their development slows down (because according to BARR et al. (2019) a "least resistance" shape is formed, because trapped subglacial sediment protects the bedrock from erosion).

MENTLÍK (2006) presents a possible classification of cirques (Fig. 3A) into three main morphological types for the Bohemian Forest (division based on HAYNES 1968). The first type is the slope cirque (Fig. 3), connected with the western flanks of the valley (exposed to the east), morphologically rather round, characterised by less remodelling and a shorter expected development time. The second type is the L cirque and the third type is the schrundline cirque (Fig. 3). The second and third types are associated with valley closures, are rather elongated and are characterised by greater remodelling than slope cirques and therefore have a longer expected development time (MENTLÍK 2006). This raises the question of whether the different morphological types of cirques and hence the predicted rate of development may be related to structural-geological conditions. This would mean that cirques could develop over a similar period of time, but their shape or degree of development would be more influenced by the structural-geological conditions.

The influence of the bedrock structure on the development of cirques has been demonstrated several times (RAAB 1999, MENTLÍK 2006, HUGHES et al. 2007, BENN & EVANS 2010). In the Bohemian Forest, this influence has been described by VOTÝPKA (1979, 1997) for the Plešné Lake cirque. He showed that the specific arrangement of the joint systems of the granite determined the formation and shape of the cirque (VOTÝPKA 1979, 1997), which is strongly elongated and well developed (KŘÍŽEK et al. 2012). Evidence for the influence of the rock structure on the origin and development of glaciation was also investigated in the Bohemian Forest by MENTLÍK (2006), who presented the results of his investigations into the relationship between the geological structure and the cirque morphology from two sites. In the Prášilské Lake cirque (slope cirque, Fig. 3B), the boundary between granite and crystalline schists was crucial, because each rock type shows a different fracture system (MENTLÍK 2006, MENTLÍK et al. 2010). In the Laka Lake cirque (schrundline cirque, Fig. 3C) the direction of foliation of the crystalline schists was reported to determine the course of the cirque wall and is identical here with the valley closure (MENTLÍK 2006). VOČADLOVÁ (2011) presents the results of geomorphological and geological research at the Černé Lake cirque, on the basis of which the Černé Lake cirque can also be classified as a schrundline cirque.

In the case of the Bohemian Forest cirques, the schrundline and L cirques seem to be almost indistinguishable, especially in relation to the observed geological conditions, i.e. the determination of the cirque wall by the foliation of the crystalline schists. Therefore, we decided to use only two groups for classification. Table 1 divides the Bohemian Forest cirques presented in KŘÍŽEK et al. (2012) into slope and schrundline cirques and lists the basic morphological characteristics of each cirque. Based on Table 1, it is clear that we find significantly fewer slope cirques in the Bohemian Forest.

In addition to the preglacial relief and geological structure, the formation and development of the Bohemian Forest glaciers and thus the cirques themselves was influenced by the deflation (ridge or summit) plateaus above the cirques (STEFFANOVÁ & MENTLÍK 2007, MENTLÍK et al. 2010, MENTLÍK 2016). This link has already been described by JENÍK (1961) in the Giant Mountains (Krkonoše Mts.) and other mountain ranges as an anemo-orographic system. The importance of deflation plateaus in the Giant Mountains was also described in

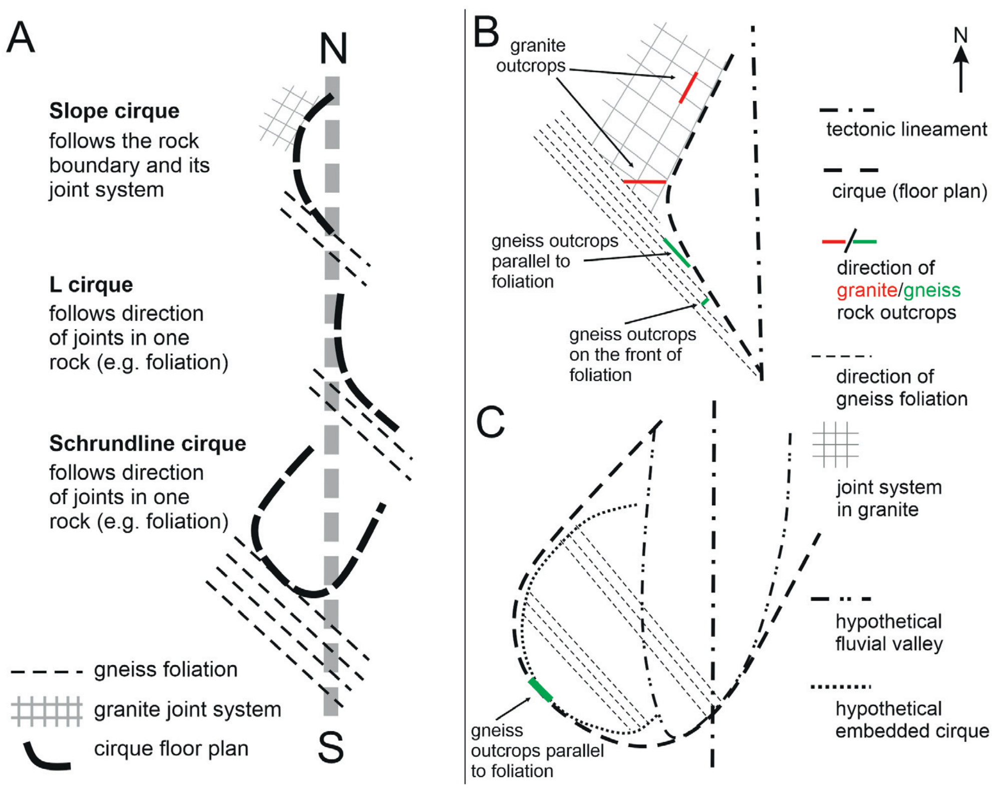

Fig. 3. A) Classification of cirques in Bohemian Forest according to their morphology. B) Morphostructural predisposition of a slope cirque using the example of Prášilské Lake. C) Morphostructural predisposition of a schrundline cirque using the example of the Laka Lake cirque. Adapted from MENTLÍK 2006.

Table 1. Classification of cirques studied by KŘÍŽEK et al. (2012) into the proposed typology of the Bohemian Forest cirques with their basic morphological characteristics. Unless otherwise stated (1) STEFFANOVÁ & MENTLÍK 2007 and 2) this study), data according to KŘÍŽEK et al. (2012). Italics indicate cirques for which we know the structural-geological conditions. Bold highlighting indicates cirques for which structural-geological conditions will be verified. The area of the deflation plateau is not available for every cirque (marked as missing data).

Cirque type	Cirque name	L/W	A – Cirque area (ha)	Area of deflation plateau (ha)
Slope	*Prášilské Lake cirque*	*1.06*[1]	*36.9*[1]	17.0[1]
	Großer Schwarzbach cirque	**0.94**[2]	**36.8**[2]	54.0[2]
	Hirschbach II cirque	1.10	16.2	missing data
Average for the slope type		1.03	30.0	
Schrundline	*Laka Lake cirque*	*1.34*	*68.9*	95.5[1]
	Černé Lake cirque	*1.25*	*86.3*	49.6[1]
	Čertovo Lake cirque	0.82	71.4	33.7[1]
	Plešné Lake cirque	1.33	53.6	27.8[1]
	Kleiner Arbersee cirque	1.65	148.1	missing data
	Großer Arbersee cirque	0.83	154.5	47.6[1]
	Rachelsee cirque (Altersee + Rachelsee)	0.87[1]	66.9[1]	66.9[1]
	Kleiner Rachelbach cirque	**1.29**[2]	**53.2**[2]	9.0[2]
	Hirschbach cirque	1.07	11.1	missing data
Average for the schrundline type		1.16	79.33	

more recent studies (MIGOŃ 1999, PILOUS 2012). Snow transported from a westward deflation plateau allowed the formation of glaciers even below the regional snowline (MENTLÍK et al. 2010). The westward position of the deflation plateaus is based on the prevailing westerly winds which are assumed to have existed at temperate latitudes in the cold Pleistocene periods (ISARIN et al. 1997, FLORINETH & SCHLÜCHTER 2000). However, it is not clear whether the sizes of the deflation plateaus influenced the morphology of the cirques. To evaluate the relationship between the size of the deflation plateaus and the degree of cirque development, the sizes of the plateaus (based on STEFFANOVÁ & MENTLÍK 2007 and presented research) for each cirque are listed in Table 1.

Investigated sites

Geomorphological mapping (DUFFEK et al. 2023) and the related analyses of the geological structure was carried out at two sites of interest (see Fig. 4). One was in the Kleiner Rachelbach (according to HAUNER et al. 2019) north-facing valley closure with the schrundline type glacial cirque and the other in the Großer Schwarzbach (according to HAUNER et al. 2019) south-facing valley with the slope type glacial cirque, which developed on the eastern slope of the valley.

Characteristics of the investigated sites

Both study sites are located in the Bavarian Forest National Park. Access to these sites and the research itself was permitted by the Bavarian Forest National Park Authority, which also provided us with digital map data (a digital elevation model and a geological map). According to the 1 : 25 000 geological map (LFU 2021), the sites are mainly made up of gneisses. A granite lens is shown on the geological map in the Kleiner Rachelbach cirque (Fig. 4A).

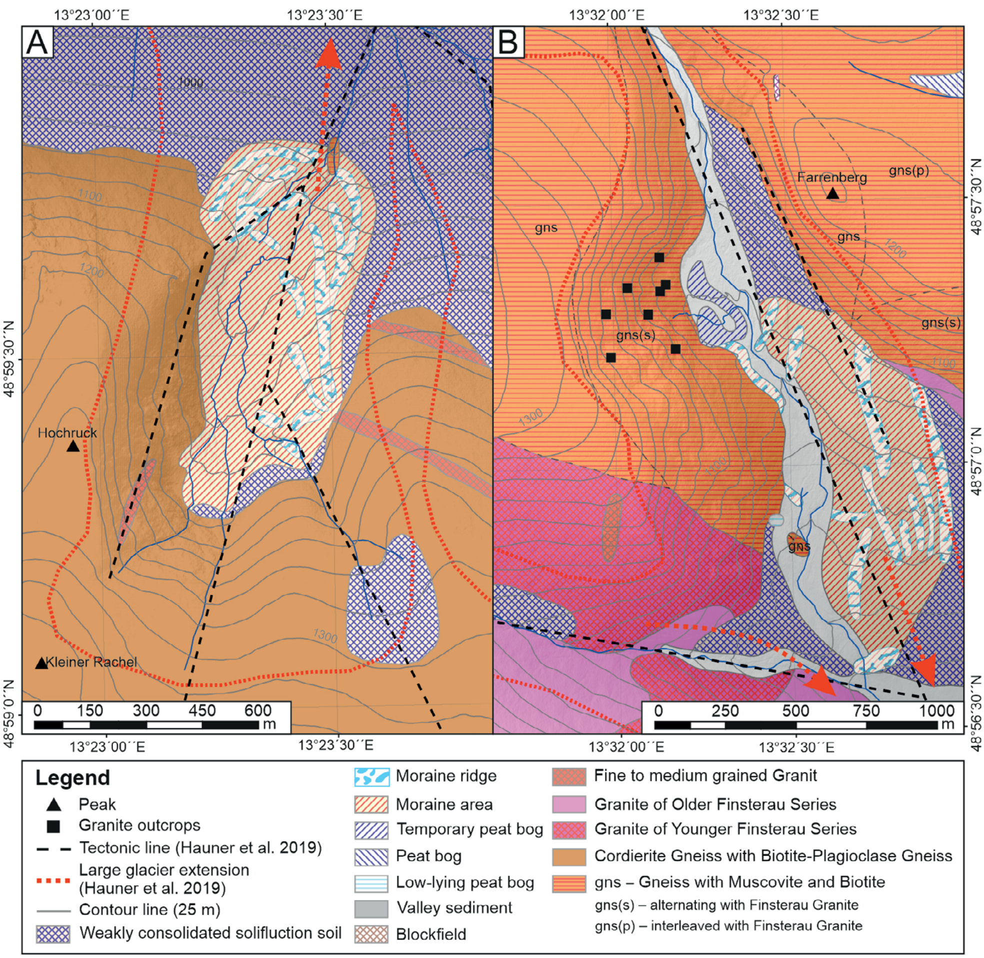

Fig. 4. Geological maps of the investigated sites. A) Kleiner Rachelbach site, B) Großer Schwarzbach site. Background data provided by the Bavarian Forest National Park Authority. The red dotted arrows in both panels show the flow direction of hypothetical large glaciers.

In the Großer Schwarzbach cirque (Fig. 4B), the prevailing gneiss alternates with granite. The main tectonic lines are defined in both localities (after HAUNER et al. 2019), which have a predominantly NNE–SSW direction in the Kleiner Rachelbach locality and NNW–SSE in the Großer Schwarzbach locality (Fig. 4).

Remnants of glacial erosional and accumulation landforms with different extents can be observed at both sites (Fig. 4). The occurrence of infilled lakes of unknown depth lying at the bottom of the cirques is assumed, suggesting that they have been overdeepened (PFAFFL 1997, PFAFFL 2010, HAUNER et al. 2019, VONDRÁK et al. 2019). The moraine ridges with clear connections to the cirque (Fig. 4) are estimated to date to the end of the last glacial period (HAUNER et al. 2019). Extensive glaciation well beyond the defined glacial cirques (Fig. 4) is assumed by German authors (ERGENZINGER 1967, HAUNER 1980, HAUNER et al. 2019) at both sites, within which glacial tongues up to 6 km long are proposed. The age of this glaciation is estimated to date to the penultimate glacial period (HAUNER et al. 2019).

METHODOLOGY

Morphological analysis of the glacial cirques

Morphological characteristics were previously determined for both sites by KŘÍŽEK et al. (2012). A LIDAR digital elevation model was not available for this research and the conclusions were not verified by detailed field mapping. Therefore, using field research and the data presented (DUFFEK et al. 2023), the basic morphological characteristics (length (L), width (W), height (H) L/W index, area (A) of both cirques were recalculated (Table 1) after FEDERICI & SPAGNOLO (2004), BARR & SPAGNOLO (2015), CHANDLER et al. (2018). The areas of the deflation plateau were calculated for both sites (Table 1) as well. The deflation plateaus were defined, as at the other sites in the Bohemian Forest (after STEFFANOVÁ & MENTLÍK 2007), as the higher plateau lying west of the cirque with a slope of 0–12°.

Morphostructural analysis

Three types of joint systems are assumed to be important for geomorphological forms (AHNERT 1996, JAROŠ & VACHTL 1992):

1) in intrusive rocks (especially granites) contraction joints formed during cooling of magma – SQL joint systems as defined for granites by CLOOS (1925);
2) in crystalline schists, compression joints formed by lightening according to the predispositions of the rock – mostly metamorphic foliation;
3) and also tectonic joints on crystalline schists, the formation of which is associated with tectonically determined movements of the Earth's crust.

MENTLÍK (2006) used the following procedure in the Prášilské Lake cirque to determine the influence of the morphological structure on the origin and development of the cirque:

1) the main morphostructural lines prevailing in the area were identified – morpho lineaments were defined (MINÁR et al. 2011), which included direct rock boundaries, direct parts of watercourses, predominant fault directions – lines of significant length were included.
2) Fault directions were analysed:
   a) for intrusive rocks;
   b) for crystalline schists.

ad a) For intrusive rocks, the directions of all joints were measured to determine the directions of the SQ joint systems formed during cooling and thus contraction of the intrusive body.

ad b) For crystalline schists, a distinction was made between potentially tectonic joints (with inclinations of 75° to 90°) and compressive joints, where their formation was assumed to be related to the lightening of the rock (in the cas of crystalline schists, the opening of joints in a direction consistent with the metamorphic foliation).

3) the directions of the rock outcrops were measured (directions perpendicular to their fall line). It is assumed that rock outcrops preferentially form on joints or other faults by complete separation of one part of the rock mass. Therefore, the directions of rock outcrops should correspond to some of the morphostructural directions mentioned above on both granites and crystalline schists.

Our research followed the above methodology at both study sites. The main tectonic directions presented in HAUNER et al. (2019) were analysed and taken as the main directions of the morpho lineaments. Furthermore, the directions of the available rock outcrops and joint systems were analysed. For joints, the inclination and direction were measured with a geological compass. In order to distinguish tectonic joints (according to AHNERT (1996) and JAROŠ & VACHTL (1992) joints associated with pressure tectonics) the joints with slopes greater than 75° were measured and evaluated separately (as in MENTLÍK 2006).

RESULTS

Kleiner Rachelbach cirque

The Kleiner Rachelbach cirque was formed in a valley closure in an approximately N–S direction. The orientation of the cirque axis is NNE. The cirque has a significant length over width ratio (L/W = 1.63) (Fig. 5) and corresponds to the schrundline cirque type (Fig. 3). The cirque is linked to a higher deflation plateau, which is relatively small by Bohemian Forest standards (only 9 ha, see Table 1), and is ridge-like in character.

More than 200 joints were analysed in the Kleiner Rachelbach cirque, which is mainly composed of gneiss. Granites were not recorded during the detailed field survey, which contradicts the information on the geological map (see Fig. 4A). Compression joints based on the foliation of metamorphites have one predominant direction WNW–ESE (Fig. 5). The same direction was found for the tectonic joints, but also a direction perpendicular to it (NNE–SSW). Both of these joint directions determine the formation of rock outcrops with a predominant direction of NNE–SSW.

The rock outcrops in the cirque wall are strongly linked to the rock foliation. Outcrops that are perpendicular to the direction of the foliation (NNE–SSW, analogous to the faces of layers in sedimentary rocks) and then outcrops with directions that correspond directly to the foliation (WNW–ESE) predominate. Moreover, the NNE–SSW direction corresponds to the main tectonic lineaments (and thus the predominant directions of tectonic faults) presented in (HAUNER et al. 2019), which seem to have been crucial for the formation of the entire valley.

Großer Schwarzbach cirque

The Großer Schwarzbach cirque is not linked to the valley closure, but it was formed on an east-facing slope (Fig. 6) and the orientation of its main axis is SE. The shape of the cirque is circular, with a slight predominance of width over length (L/W = 0.87). The cirque is linked to a higher deflation plateau of 54 ha, which has a summit character – the flat top of the Steinfleckberg Mountain.

Almost 200 joints were analysed in the Großer Schwarzbach locality, which is mainly composed of gneiss alternating with granites. The alternating granites here do not form continuous geological bodies (Fig. 4B) and their occurrence is not tied to one particular part of the cirque. The joint system of the crystalline schists (about 160 fractures were analysed) and the joint system of the granite (only 30 fractures were found) were evaluated separately. Fracture directions on the granites were analysed only to allow comparison with the directions of the granitic rock outcrops (n = 10).

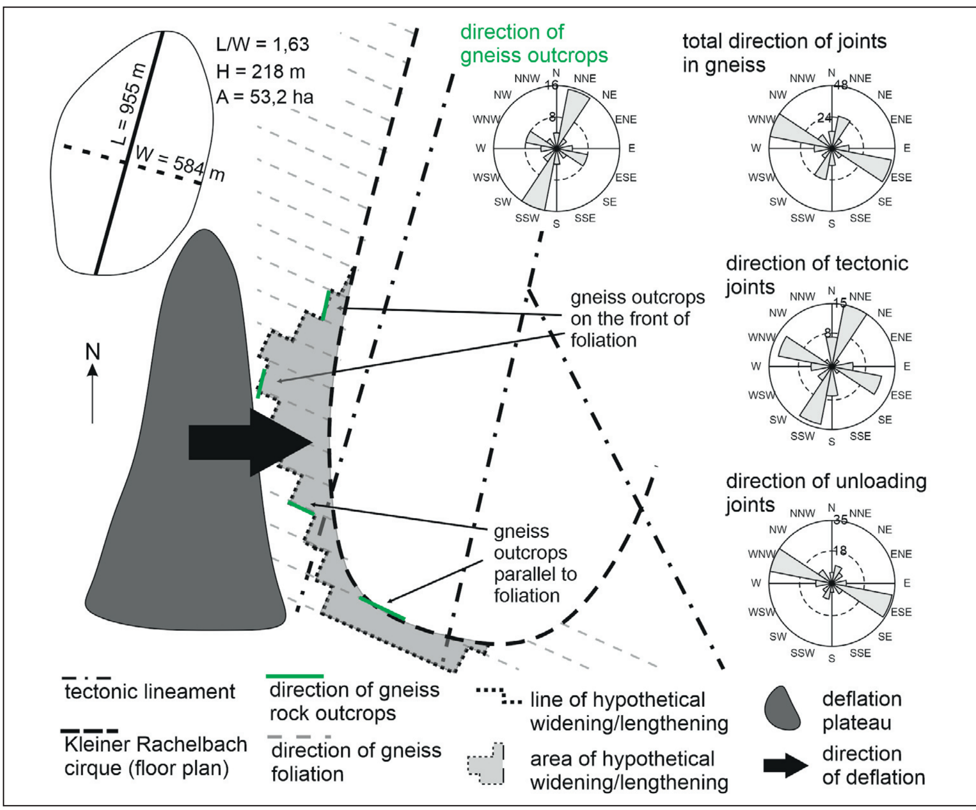

Fig. 5. Representation of the morphological characteristics and structural-geological conditions at Kleiner Rachelbach cirque with the ridge plateau from which the snow was deflated into the cirque. The position and area of the deflation plateau is only schematic.

The diversity of the rock structure and the crossing of the different joint systems can be seen in the cirque (Fig. 6). The directions of the measured joints on the granites (N–S and E–W) form a typical SQ joint system and correspond to the directions of the granitic rock outcrops (N–S and E–W). The prevailing gneiss is characterised by a distinct joint pattern that is conditioned by foliation. The directions of the compression joints are NW–SE and NNW–SSE. The same predominant directions (NW–SE and NNW–SSE) can be observed for the tectonic joints, complemented by directions perpendicular to these (ENE–WSW).

The predominant direction of the rock outcrops is perpendicular to the main direction of the gneiss foliation, which corresponds to the main dominant direction of the fractures on the crystalline schists. As with the previous site, these are rock outcrops on the faces of layers and, less commonly rock outcrops with directions (NNW–SSE) occurring in the foliation direction (Fig. 6).

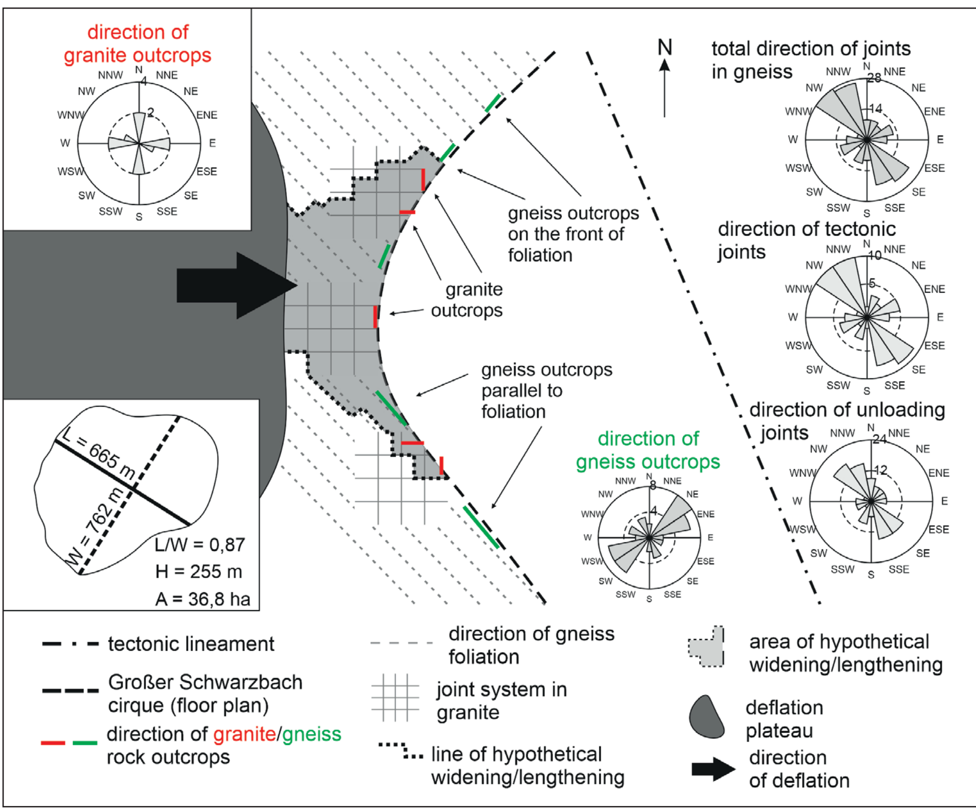

Fig. 6. Representation of the morphological characteristics and structural-geological conditions in the Großer Schwarzbach locality with the summit plateau from which the snow deflated into the cirque. The position and area of the deflation plateau and the position of the granites rock outcrops are only schematic.

Discussion

Comparison and discussion of the relationship between the structural-geological conditions and the morphology of the two cirques and their relation to the Bohemian Forest context

The results show that the two researched localities differ in their structural-geological characteristics. At the Großer Schwarzbach site, a higher diversity of rock structure and thus crossing of different joint systems and a higher frequency of joints can be observed in the slope cirque. A similar analogy can be found in the Prášilské Lake cirque (Mentlík 2006, Mentlík et al. 2010), which also has a low L/W index (L/W index = 1 according to Mentlík 2006). In contrast, at the Kleiner Rachelbach locality in the schrundline cirque we do not find similar geological features and the cirque is oriented perpendicular to the main direction of the joints. A similar analogy can be found at the Laka Lake or Černé Lake sites (Mentlík 2006, Vočadlová 2011). Both of these cirques are oriented perpendicular to the main direction of the gneiss foliation (Mentlík 2006, Vočadlová 2011) and are also more elongated in character (L/W index = 1.34 for the Laka Lake cirque and 1.25 for the Černé Lake cirque; after Křížek et al. 2012).

These Bohemian Forest cirques (and probably all cirques) can thus be divided into two categories based on their structural-geological conditions and morphology: slope cirques with a more circular shape (typical of the Prášilské Lake cirque and the Großer Schwarzbach cirque) and a lesser degree of allometric development (according to Evans & Cox 1995), and schrundline cirques with an elongated triangular shape (typical of the Laka Lake cirque and the Kleiner Rachelbach cirque) and a greater degree of allometric development (according to Evans & Cox 1995). The results of our two cirque investigations and the analysis of previously published papers (Votýpka 1979, 1997, Mentlík 2006, Steffanová & Mentlík 2007, Mentlík et al. 2010, Vočadlová 2011, Křížek et al. 2012) show that:

1) Cirques in the Bohemian Forest originated in association with westward deflation plateaus with different surface areas. Slope cirques are linked to the eastern slopes and the westerly situated plateaus. Schrundline cirques are linked to valley closures with westerly situated plateaus. Because the Großer Schwarzbach slope cirque is connected with a larger deflation plateau than some schrundline cirques (Table 1), it can be hypothesised that larger deflation plateaus did not condition the formation of more developed schrundline cirques. This is supported for selected Bohemian Forest schrundline cirques by the weaker correlation of the L/W index or cirque area with deflation plateau area (Steffanová & Mentlík 2007).
2) Both types of cirques are probably formed in relation to specific structural-geological conditions, which are reflected in their morphology:
    a) Slope cirques (e.g., the Prášilské Lake cirque and the Großer Schwarzbach cirque) are linked to more varied geological conditions, and therefore they are probably less abundant in the Bohemian Forest (Table 1). These cirques are conditioned by the boundaries of different rocks (granites and crystalline schists) with different joint systems.
    b) Schrundline cirques originate in geologically more uniform valley closures linked to major tectonic lines. Joint directions and associated joint systems were essential

for the increase in area (in particular in the westward direction). If a cirque develops predominantly in granite (the Plešné Lake cirque) it is controlled by a distinctly SQ joint system (VOTÝPKA 1979, 1997).

When the morphological characteristics of the two investigated cirques are compared with published allometric development (GORDON 1977, EVANS & COX 1995, BROOK et al. 2006, EVANS 2006, BARR & SPAGNOLO 2015), they appear less and more developed respectively. When we add the times assumed for the origin of the cirque types or shapes (BROOK et al. 2006, BARR & SPAGNOLO 2015), we find that the Großer Schwarzbach slope cirque developed over a period of at least 300 ka and the Kleiner Rachelbach schrundline cirque over a period of 600 ka. However, the completely different structural-geological conditions, the different sizes of the deflation plateaus and apparently different preglacial relief may indicate that the cirques could have developed over a similar period of time.

This also suggests that the investigated cirques could not have been formed during a single glacial cycle, but it is likely that (if we assume the length of one glacial cycle in the Younger Pleistocene to be about 100 ka) three or more cycles were needed for their formation. This figure may be influenced by the fact that non-glacial processes (e.g. periglacial and slope processes) were involved in the development of the cirques.

Conclusion

We investigated two types (based on the morphological classification) of cirques that we have distinguished across the Bohemian Forest: slope and schrundline cirques. Specific structural-geological conditions were essential for morphological development of these investigated cirques. The shape of the Großer Schwarzbach slope cirque is predisposed by more varied geological conditions (crystalline schists and granite boundaries and their different joint systems). On the other hand, the Kleiner Rachelbach schrundline cirque is characterised by a geologically more uniform valley closure. The presence of deflation plateaus to the west of both cirques appears to be an essential condition for the formation of cirques. However, the size of the plateaus was probably less important for the cirque morphology itself. The shapes of the two cirques and consequently the assumed time needed for their development suggest that both cirques developed during a period of over 300 ka and thus during more than one glacial cycle.

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