Silva Gabreta	vol. 28	p. 1–16	Vimperk, 2022

Geophysical survey of glacial landscape in four Bohemian Forest cirques

Václav Duffek[1,2,*] **& Pavel Mentlík**[2]

[1] *Faculty of Science, University of Ostrava, 30. dubna 22, CZ-70103 Ostrava, Czech Republic*
[2] *Faculty of Education, University of West Bohemia, Veleslavínova 42, CZ-30614 Plzeň, Czech Republic*
[*] duffekv@fpe.zcu.cz

Abstract
This article addresses issues related to the geomorphology of previously glaciated areas of the Bohemian Forest, for which exact data have so far been lacking. This includes the development of cirque walls, the existence of glacial forms or sediments older than the Marine Isotope Stage 2 glaciation, the more precise differentiation of glacial sediment complexes, especially in front of the Bohemian Forest glacial lakes and the detection of an infilled lake as an important source of palaeoclimatic proxies. The importance of gravitational processes (e.g. rotational shear surface) for the morphology of the cirque wall above the Stará Jímka was proved. Probable older glacial sediments overlain by slope sediments were detected in front of Prášilské Lake. Geophysical research detected at least three probable glacial phases (stadials) in the glacial sediment complex in front of Laka lake. A potential infilled glacial lake was identified in the Großer Schwarzbach cirque on the Bavarian side of the Bohemian Forest. Although the findings do not provide clear evidence of the problems or their solutions, they provide indications confirming the data resulting from the geomorphological analysis. At the same time, they serve as a stimulus and guide for further research.

Key words: Bohemian Forest, electric resistivity tomography, palaeoglacial landscape

Introduction

Glaciation and subsequent deglaciation are associated with unique processes that create specific landforms in the georelief (Martini et al. 2001, Benn & Evans 2010). The analysis of the internal structure of complex geomorphological forms provides very valuable information for the overall understanding of the genesis of a former glacial landscape (Mentlík 2010, Engel et al. 2017, Diallo et al. 2019). Analysing the internal structure is now possible thanks to geophysical survey methods, which have been successfully applied to glacial relief by Kilner et al. (2005), Parkes et al. (2009), Hiemstra et al. (2011), McClymont et al. (2011), Colombero et al. (2014) and Diallo et al. (2019). One commonly used geophysical method is electrical resistivity tomography (ERT), which measures the electrical properties and provides electrical resistivity distribution models of the subsurface environment (Loke 2000). Sediments of infilled glacial lakes have been detected using ERT (e.g. by Mentlík et al. 2010, Tábořík 2012), as they are characterized by extremely low resistivity, due to their strong groundwater saturation (Loke 2000, Parkes et al. 2009). ERT has also been used to survey cirques and cirque walls (e.g. Sass 2006) or to analyse glacial sediments (Kilner et al. 2005, Parkes et al. 2009, Mentlík et al. 2010). Glacial sediments are in resistivity models characterized by high resistivities (Parkes et al. 2009, Tábořík 2012), mainly caused by the different clast sizes and air-filled spaces between them (Reynolds 1997, Kilner et al. 2005).

In the Bohemian Forest, the border mountains of the Czech Republic with Germany and Austria, we find several localities where Pleistocene glacial action and resulting landforms have been demonstrated. Specifically, there are eight glacial cirques with lakes (Ergenzinger 1967, Steffanová & Mentlík 2007) and several glacial cirques without such water bodies (Hauner 1980, Křížek et al. 2012, Hauner et al. 2019, Vondrák et al. 2019). Infilled lakes are thought to occur in some of them (Hauner et al. 2019, Vondrák et al. 2019). A typical example is the bottom of the Stará Jímka cirque, where the existence of a lake was subsequently demonstrated by sediment sampling and sedimentological and palaeoecological analyses (Mentlík et al. 2010, Procházka et al. 2017, Kletetschka et al. 2018, Vondrák et al. 2019). Relatively recent research has confirmed a palaeolake in the cirque of Plešné lake, demonstrating the presence of a lake and an infilled lake in the same cirque (Vondrák et al. 2021).

Although the evolution rate and timing of glacial cirques is still debatable (Barr et al. 2019), we can assume (according to Brook et al. 2006, Barr & Spagnolo 2015), that the dimensions and overdeepening of the Bohemian Forest cirques (Křížek et al. 2012, Hauner et al. 2019) likely indicate a repeated development of glaciation (e.g. Mentlík 2006). Glacial sediments in the Bohemian Forest are dated only to the youngest phases of the last glacial cycle: Marine isotope stages 2 (MIS 2) (Raab & Völkel 2003, Reuther 2007, Mentlík et al. 2010, Reuther et al. 2011, Mentlík 2013, Vočadlová et al. 2015). This situation is the same in some other Central European uplands, such as the Vosges (Mercier & Jeser 2004), Black Forest (Hofmann et al. 2022) and the Giant (Krkonoše) Mountains (Engel et al. 2014). However, Ergenzinger (1967), Hauner (1980) and Hauner et al. (2019) also mentioned older glacial sediments in the Bohemian Forest, but these studies are not supported by numerical dating (Hauner 1980, Hauner et al. 2019), or the age of dated samples is at the limits of the dating method used (Ergenzinger 1967).

In the Bohemian Forest, the processes involved in the development of cirque walls have not been further investigated. An exception is the research of Holocene debris flows in the cirque of Prášilské Lake (Hartvich & Mentlík 2010, Mentlík et al. 2010). It is assumed that glacial erosion is fundamentally important for the development of cirque walls (Benn & Evans 2010), but the influence of subsequent mass wasting after glacial retreat is also possible (Ballantyne 2002, McColl 2012).

The present study, using the geophysical method of electrical resistivity tomography, has the following objectives: (i) try to verify for four selected glacial cirques whether glacial action initiated other (e.g. gravitational) geomorphological processes (occurring even after deglaciation); (ii) for selected glacial accumulation forms, determine whether it is possible to identify buried relics of older glaciations; (iii) for the selected accumulation landforms, specify the local chronology of deglaciation; and (iv) for the selected glacial cirques, test the potential existence of now infilled lakes and to determine their characteristics.

Regional Setting

The research was carried out at four localities in the Bohemian Forest. On the Czech side: i) in the Stará Jímka cirque; ii) in the Prášilské Lake cirque; (iii) in the Laka lake cirque. On the German side: (iv) in the Großer Schwarzbach cirque (Bärenriegelkar sensu Hauner 1980). Glacial development in all localities is assumed to date to the Last Glacial Maximum (LGM) on the basis of several works (Rathsburg 1928, Ergenzinger 1967, Hauner 1980, Steffanová & Mentlík 2007, Mentlík et al. 2010, Křížek et al. 2012, Hauner et al. 2019). As mentioned in the introduction, some authors also considered signs of glacial development during older phases of the local glaciation (Ergenzinger 1967, Hauner 1980, Hauner et al. 2019), but their hypotheses have not been proven by numerical dating.

Stará Jímka cirque locality

The site is located about 3.7 km south of the village of Prášily in the catchment area of the Jezerní Potok stream. The elongated and relatively narrow bottom of the cirque (Mentlík 2006) connects to the closure of the Jezerní Potok stream valley and is filled with glacial sediments (Mentlík et al. 2010). The maximum altitude of the cirque wall is 1242 m above sea level and the minimum altitude of current surface of the cirque bottom is 1050 m above sea level (Mentlík 2006). The bottom of the cirque is covered by an asymmetrical accumulation, the width of which decreases to the south (Mentlík 2006). The area is made up of relatively homogenous geological conditions of paragneiss (Pelc & Šebesta 1994). The site has been the subject of quite detailed sedimentological research (Mentlík et al. 2010, Procházka et al. 2017, Kletetschka et al. 2018, Vondrák et al. 2019), which has been used to establish the detailed development of the site in the Late Glacial and Holocene. The lake was created about 14 ka (Mentlík et al. 2010, Procházka et al. 2017) and infilled by about 4 ka (Mentlík et al. 2010). Moraine ridges have not been dated here.

Prášilské Lake cirque locality

The locality is about 3.5 km south of the village of Prášily in the catchment area of the Jezerní Potok stream. Two cirques, one above the other, have been identified here. Prášilské Lake is located in the lower cirque which has a more closed shape than the higher cirque (Mentlík et al. 2010, Křížek et al. 2012, Hauner et al. 2019). Both cirques formed a glacial system where ice flowed from the upper to the lower cirque (Mentlík 2006). The maximum altitude of the cirque wall is 1210 m above sea level and the minimum altitude of the of the cirque bottom (below the water surface) is 1062 m above sea level (Křížek et al. 2012). The locality is formed by metamorphic rocks such as paragneiss, migmatite, and quartzite (Pelc & Šebesta 1994), but two small areas of granite, which determined the formation of the cirque, play a very important role here (Mentlík et al. 2010). Mentlík et al. (2010) assume the existence of a small valley glacier in the LGM, when the entire end of the Jezerní Potok stream valley was filled with ice. In front of the lower cirque, there are two moraine ridges radiometrically dated to 13.7 +/- 1.3 ka (Mentlík et al. 2013), which dam the today's lake. The oldest sediments (dated to 17.9 +/- 1.5 ka) descend to an altitude of 1000 m above sea level (Mentlík et al. 2013).

Laka lake cirque locality

The locality is situated approximately 7.5 km southeast of the town of Železná Ruda. The Laka lake cirque is wide and stepped (Mentlík et al. 2010, Křížek et al. 2012, Hauner et al. 2019). The maximum altitude of the cirque wall is 1304 m above sea level and the minimum altitude of the cirque bottom (below the water surface) is 1081 m above sea level (Křížek et al. 2012). According to Pelc & Šebesta (1994), almost the entire area is made up of crystalline rocks, such as paragneiss, migmatite and, in the higher parts of the cirque wall, granodiorite. The results of dating (Mentlík et al. 2013) point to two stages of moraine development. The outer moraines, which descend to an altitude of 1060 m above sea level, are dated to 16.2 +/– 1.9 ka. The inner moraine was dated to 14.1 +/– 1.3 ka (Mentlík et al. 2013).

The chronologies of deglaciation (for Stará Jímka, Prášilské Lake and Laka lake) were placed in a regional context by Mentlík et al. (2010, 2013), and a partial correlation was found with the chronologies of the deglaciation of other Central European mountains, e.g. the Vosges (Mercier & Jeser 2004, Braucher et al. 2006), the Giant (Krkonoše) Mountains (Migoń 1999, Engel et al. 2010, Engel et al. 2014) or the Black Forest (Fiebig et al. 2004, Hemmerle et al. 2016, Hofmann et al. 2022). However, the glaciers in the Bohemian Forest probably disappeared much earlier than from those mountains, as there is no reliable evidence for a presence of glaciers in the Bohemian Forest in the Younger Dryas so far (Raab & Volkel 2003, Reuther 2007, Mentlík et al. 2010). However, the question of small glaciers in Bohemian Forest during this period has not yet been sufficiently answered (Hauner et al. 2019).

Großer Schwarzbach cirque locality

The locality is located less than 4 km northwest of the German town of Finsterau. The cirque is relatively wide (Křížek et al. 2012, Hauner et al. 2019) and, similarly to the Stará Jímka locality, with no lake, but there are wetlands and a peat bog at the bottom of the cirque. The maximum altitude of the cirque wall is 1272 m above sea level and the minimum altitude of the current surface of the cirque bottom is 1016 m above sea level (Křížek et al. 2012). According to Bauberger (1977), the area is made of gneiss alternating with granite. Pfaffl (1997) made basis geomorphological research here, but detailed geomorphological research based on a digital elevation model (DEM) has not yet been carried out here and data on the age of the glacial forms are missing. According to several authors (Hauner 1980, Pfaffl 1997, Hauner et al. 2019, Vondrák et al. 2019), there may be an infilled lake of an unknown depth, but its presence has not been proven.

Methodology

Research method

The following methodology was proposed to meet the objectives of the article (Fig. 1). The research was based on a detailed digital elevation model (DEM), which was lent by the State Administration of Land Surveying and Cadastre and the Bavarian Forest National Park Administration. The DMR 5g (ČÚZK 2016) was used for the localities in the Czech Republic and DGM 1 m (LDBV, 2022) was used for the locality in Germany. Both DEMs have high resolution (1×1 metre) and height accuracy is in centimetres for both models (ČÚZK

2016, LDBV 2022). Mean error in height is 0.18 m in exposed terrain and 0.3 m in forested terrain in DMR 5g (ČÚZK 2016). Mean error in height is +/– 0.5 m in DGM1 (LDBV 2022). In the first step, detailed geomorphological mapping was carried out in the field based on the DEM and its derivates (hillshaded relief, slope gradient and slope orientation). The output of the mapping was a detailed geomorphological map. In the second step, a geophysical survey of the selected localities was carried out, the outputs of which were geophysical models (see methodology below). In the third step, geomorphological and geophysical interpretations of the localities were created. The synthesis of these interpretations (4th step) provides information on the internal structure of specific landforms, which we see as means of supplementing the knowledge to gain an understanding of the origin and development of both individual geomorphological landforms and the georelief as a whole.

Methodology of geophysical profiling

Multi-electrode resistivity and subsequent processing using electrical resistivity tomography (ERT) was used for the geophysical surveys of all the localities. ERT was chosen primarily due to (i) its versatility of use in determining the structure of various geomorphological forms and thus an understanding of their genesis and chronology (Pánek et al. 2009, Raška et al. 2014, Kasprzak 2015, Engel et al. 2017, Stemberk et al. 2017), (ii) its depth range (Blecha et al. 2018, Chalupa et al. 2018), (iii) its relatively fast data processing and evaluation (Loke & Barker 1996, Loke 2000) and (iv) its high resolution (Rizzo et al. 2004, Maillet et al. 2005). The data were processed in Res2Dinv software (Geotomo Software 2018) using tomographic inversion and topographic corrections. The topography was derived in ArcMap (Esri 2021) from the detailed digital elevation model (basic characteristics are above).

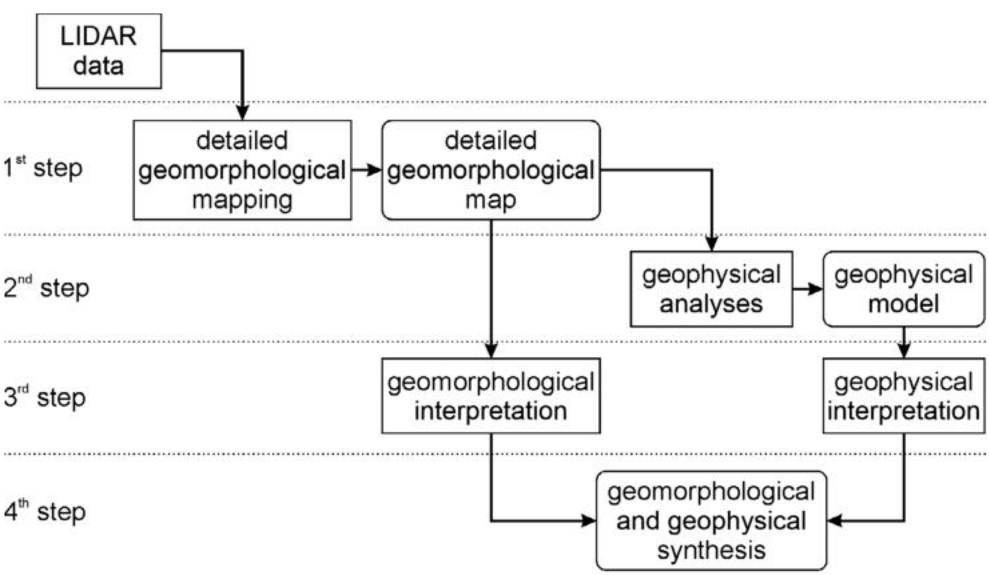

Fig. 1. Schematic of the methodology with the four basic steps.

Table 1. Characteristics of individual profiles. The landforms are presented on the basis of historical geomorphological mapping with geomorphological analysis (MENTLÍK 2006, MENTLÍK et al. 2010, DUFFEK & MENTLÍK 2019). RMS/Abs error mean root mean square (RMS) or absolute (Abs) error.

	Stará Jímka	**Prášilské Lake**	**Laka lake**	**Gr. Schwarzbach**
Length (m)	315	315	355	395
Direction	W → E	W → E	E → W	E → W
Electrode spacing (m)	2.5	5.0	2.5	5.0
RMS/Abs error	RMS = 2.2	RMS = 2.3	RMS = 8.8	Abs. = 3.1
Landforms	cirque wall – cirque base – moraine	no glacial surface – lateral moraine – glacial surface	lateral moraine – glacial surface – lateral moraine	lateral moraine – cirque base – cirque wall

Depending on the assumed internal structures (LOKE et al. 2015), least squares inversion and robust inversion were used (see Table 1). To ensure the lowest root mean square (RMS) or absolute (Abs) errors. The damping factor were optimized for each resistivity model (e.g. SASAKI 1992, LOKE et al. 2015).

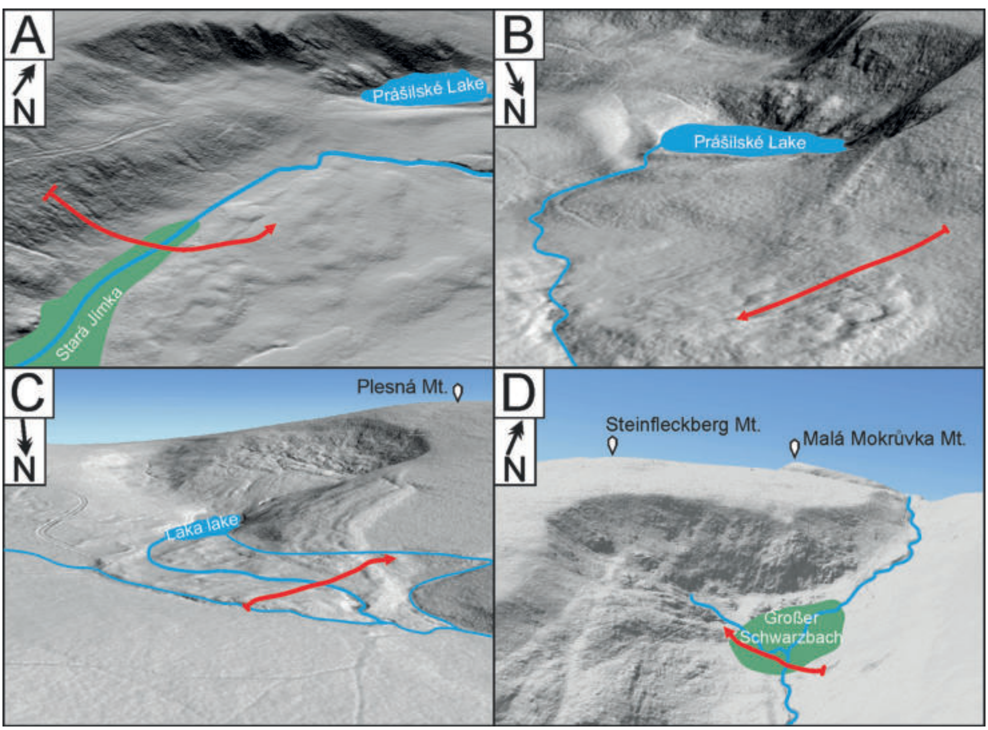

Fig. 2. Position of ERT profiles at each locality: A) Stará Jímka, B) Prášilské Lake, C) Laka lake, D) Großer Schwarzbach cirque. Blue areas indicate cirque lakes, green areas indicate cirque floors with wetlands. The scale of all images is distorted due to being three-dimensionally displayed in ArcSCENE (ESRI 2021).

Automatic Resistivity System (ARES and ARES II, GF Instruments s.r.o.) was used for the survey, and, because both vertical and horizontal subsurface features were assumed at the localities, all measurements were performed using the Schlumberger electrode arrangement (Loke 2000, Schrott & Sass 2008). The profiles differed in the position, length and spacing of the electrodes. The different spacing of electrodes was chosen in relation to the specific research question that was set for the particular profile (see text below). See Table 1 for detailed characteristics of the profiles and Fig. 2 for the exact position of the profiles.

In the Stará Jímka locality (Fig. 2A), the profile started above the place where we can find change in the curvature of the cirque wall. The profile continued along the cirque wall and intersected the infilled part of Stará Jímka and continued until the accumulation of glacial sediments (Mentlík et al. 2010). The profile started 70 metres above the cirque base, so that any internal structures in the cirque wall could be detected. The profile in the locality of Prášilské Lake (Fig. 2B) was spread in the area below the lake. It started on a slope without assumed glacial traces (Mentlík et al. 2010), crossed a relict lateral moraine formed by prominent blocks, and ended in a glacially shaped plateau (Mentlík et al. 2010). The beginning of the profile was determined in order to identify the contact between the glacial sediments and the adjacent slope. The profile at Laka lake (Fig. 2C) passed transversely across the valley directly connected to the cirque base and the cirque wall (Mentlík 2006). Along its course, it crosses a lobe of glacial sediments, which are bounded on both sides by moraine ridges, about 10 metres high (Mentlík et al. 2013). The characteristics of the profile (its length and the spacing of the electrodes) were determined in order to compare the internal structure of both lateral moraines. The profile in the Großer Schwarzbach area (Fig. 2D) started on one of the retreat moraines (Duffek & Mentlík 2019, Hauner et al. 2019), continued (perpendicular to the moraine) through the cirque base and ended in the cirque wall (15 metres above the current bottom of the cirque). The profile was spread in order to analyse the infill of the cirque floor.

Results and Discussion

Stará Jímka cirque

The model of subsurface resistivity distribution (Fig. 3) in the Stará Jímka locality can be divided into seven parts. The first part (I. in Fig. 3) is characterized by protruding bodies with high resistivity directly at the surface. The second part (II. in Fig. 3) is characterized by a shallow layer of medium resistivity, which overlays a layer of high resistivity at a depth of a few metres. The third part (III. in Fig. 3) consists of two bodies with high resistivity, between which there is a zone of lower resistivity which creates a concave structure at depth. The fourth part (IV. in Fig. 3) is again characterized by a shallow layer of medium resistivity, which at a depth of a few metres overlays a layer of high resistivity. The fifth part (V. in Fig. 3) is formed by low (to minimal) resistivity, which continues into the depths below. The sixth part (VI. in Fig. 3) is formed by a near-surface layer with medium resistivity, below which we observed low resistivity. The seventh part (VII. in Fig. 3) is characterised by a relatively shallow layer of medium resistivity, below which we observe high resistivity. Looking at the resistivity distribution in the third part of the model, we detect a noticeable concentric curvature of the lower resistivity layer (white dashed line in the figure), which again overlays the high resistivity zone at a higher depth.

Parts of the subsurface resistivity distribution model (Fig. 3) in the Stará Jímka locality partially correspond to the forms identified using geomorphological mapping by Mentlík (2006), Mentlík et al. (2010), Mentlík & Novotná (2010) and Mentlík et al. (2013) and also with previously geophysical research (see geophysical profile 2 and 3 in Mentlík et al. 2010). The first to fourth parts (I.–IV. in Fig. 3) correspond to the cirque wall, where Mentlík et al. (2010) considered (based on the ERT) a landslide. The fifth part of the model with low resistivity (V. in Fig. 3) corresponds to the cirque base, where the infilled lake is located (Mentlík et al. 2010) and in the resistivity model of Mentlík et al. (2010) is also visible. The positions of the sixth and seventh parts of the model (VI. and VII. in Fig. 3) correspond to the moraine which dams the cirque base (see Mentlík et al. 2010 for details). The resistivity characteristics of the moraine are almost the same as for the moraines geophysically explored by Mentlík et al. (2010). The low resistivities in the fifth part of the model (V. in Fig. 3) are most likely caused by heavily saturated lake sediments and peat (Loke 2000, Tábořík 2012), which are located in the depression of the former lake, as confirmed by results of coring surveys presented by Mentlík et al. (2010), Procházka et al. (2017), and Vondrák et al. (2019). The high resistivity in the seventh part of the model (VII. in Fig. 3) is consistent with the resistivity of glacial sediments (Kilner et al. 2005, Parkes et al. 2009, Tábořík 2012). The sixth part of the model (VI. in Fig. 3) is probably also composed of glacial sediments, which are, however, strongly saturated here.

The division of the cirque wall into four parts (I.–IV. in Fig. 3) where the concentric curvature of the less resistive layer (marked by the white dashed line) in the third part of the model (III. in Fig. 3) provides information about the internal structure of the cirque wall. Rotational glacial erosion is thought to occur in cirques (Benn & Evans 2010), however, slope deformations (rock avalanches, rock falls, landslides or deep-seated slope deformations) are also common in deglaciated areas (Ballantyne 2002, McColl 2012, Geertsema & Chiarle

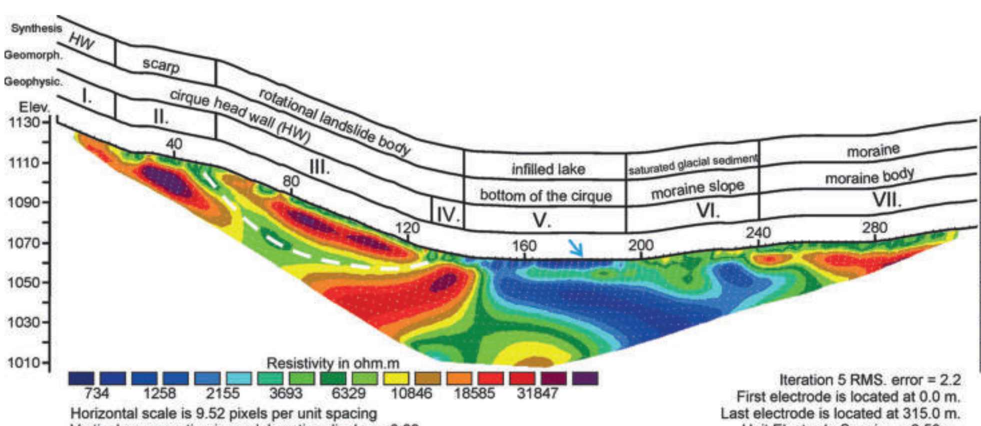

Fig. 3. ERT subsurface resistivity distribution model in Stará Jímka locality with both dissections and synthesis. Note round curved structure (dashed white line) with low resistivity in the third part of the model. Blue arrow indicates the location of a stream which drains the Stará Jímka cirque.

2013). Mass wasting in the cirque wall can also be predisposed here by foliation of crystalline shales. The curvature of the less resistive layer (dashed white line in Fig. 3), could be considered as the shear surface of a rotational landslide (see similar result in Tábořík 2012, Perrone et al. 2014). Based on the review (Perrone et al. 2014), the second part (II. in Fig. 3) probably represents a scarp of the landslide and the third part (III. in Fig. 3) represents the landslide body itself. These landforms may be associated with deglaciation and processes in the paraglacial phase of the system (debuttressing and subsequent stress release), but they have not been dated yet. They could be also younger forms. In the vicinity, there are younger (postglacial) slope deformations, which were described in this part of the Bohemian Forest as debris flows by Mentlík et al. (2010). However, it would not be possible to find a low-resistivity zone (representing a slip surface in the resistivity model for such forms (Perrone et al. 2014). Hartvich & Mentlík (2010) dated the oldest debris flow path (only shallow slope processes) in the Prášilské Lake locality to 6 ka BP. This is more than 6 ka after the expected final deglaciation of the area, therefore the authors did not confirm the association of the slope processes with the paraglacial phase of the system sensu Ballantyne (2002). Rather, they leaned towards climatic disturbances as a trigger mechanism (Hartvich & Mentlík 2010), which is in accordance with the climate disturbance (cooler temperatures and higher precipitation) described for the Bohemian Forest by Carter et al. (2018) and Moravcová et al. (2021). According to the information obtained in the Bohemian Forest, the rotational landslides in the cirque wall have not been examined in detail at all. In the Stará Jímka cirque locality and possibly in other previously glaciated localities, we therefore raise the question of the effect of rotational landslides on postglacial evolution of the cirque walls.

Prášilské Lake cirque

The model of subsurface resistivity distribution in the area of Prášilské Lake (Fig. 4) can be divided into four parts. The first part of the model (I. in Fig. 4) is characterized by a near-surface, relatively shallow layer of medium resistivity, which gradually transitions to higher resistivity. The second part of the model (II. in Fig. 4) again consists of a near-surface,

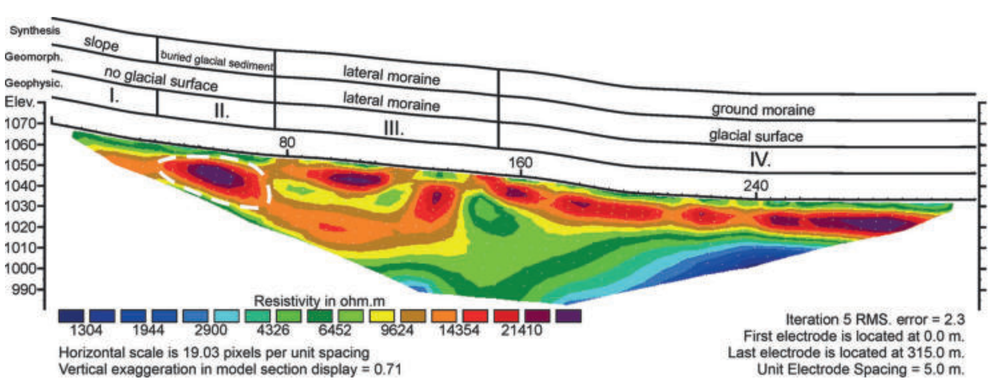

Fig. 4. ERT subsurface resistivity distribution model in Prášilské Lake locality with both dissections and synthesis. Note the high resistivity body in the second part (II.) of the model (white dashed line).

relatively shallow layer of medium resistivity, below which (at a depth of about 20 metres) there is a distinct high-resistivity body (marked by a dashed white line). The third part of the model (III. in Fig. 4) is characterized by a chaotic arrangement of bodies with higher and medium resistivity. This arrangement is evident down to a depth of 30 metres. The fourth part of the model (IV. in Fig. 4) consists of a near-surface layer of medium resistivity, which at a depth of several metres overlays a compact (160 m long) high-resistivity layer with a constant (about 15 m) thickness.

The four parts of the subsurface resistivity distribution model (I.–IV. in Fig. 4) in the Prášilské Lake cirque locality almost correspond to the forms identified by geomorphological mapping (Mentlík 2006, Mentlík et al. 2010). The first and second parts of the model (I. and II. in Fig. 4) correspond to a part of the slope which, according to Mentlík (2006) and Mentlík et al. (2010), was not glacially affected (flat wooded slope). The third part of the model (III. in Fig. 4), where bodies with higher and medium resistivity alternate chaotically, corresponds to a relict lateral moraine, which appears at the surface as distinct blocks whose longest axes are more than 4 metres (Mentlík 2006). The fourth part of the model (IV. in Fig. 4) corresponds to the ground moraine described by Mentlík et al. (2010). The high resistivities in the third and fourth parts of the model correspond to the resistivity values of glacial sediments reported by Kilner et al. (2005), Parkes et al. (2009) and Tábořík (2012). The resistivity characteristics in these parts also correspond to resistivity characteristics of glacial sediments described by Mentlík et al. (2010) (see geophysical profile 1). A continuous layer of high resistivity in the third part of the model is most likely formed by ground moraine sediments.

The resistivity characteristics of the deep high resistivity body (marked by the white dashed line) in the second part of the model (II. in Fig. 4) also correspond to those of glacial sediments (Parkes et al. 2009, Tábořík 2012). However, based on geomorphological analysis, glacial traces are not expected here (Mentlík 2006, Mentlík et al. 2010, 2013). The body could thus be from an older and more extensive glaciation. Older, because it is buried by a colluvium, which is reflected in the model by a shallow subsurface layer of medium resistivity, and more extensive because it is located outside the currently mapped glaciated area for the extent of the LGM glacier.

Laka lake cirque

The subsurface resistivity distribution model in the Laka lake locality (Fig. 5) can be divided into nine parts. The first to fifth parts (I.–V. in Fig. 5) are formed by high-resistivity bodies (outlined by solid black lines in Fig. 5), which overlay a layer of lower resistivity. In the first part of the model (I. in Fig. 5), this high-resistivity body sits at a depth of about 15 metres on a body with extremely low resistivity values. The sixth part of the model (VI. in Fig. 5) consists of a relatively compact layer of medium resistivity which transitions to higher resistivity at a depth of about 40 metres. The seventh to ninth parts of the model (VII.–IX. in Fig. 5) again consist of bodies with high resistivity (also outlined in black in Fig. 5), which overlay a layer of lower resistivity.

The parts of the subsurface resistivity distribution model (I.–IX. in Fig. 5) in the Laka lake cirque locality do not match the forms identified by geomorphological mapping (Mentlík 2006, Mentlík et al. 2010). The eastern lateral moraine, which is adjacent to the Jezerní Potok stream bed at the beginning of the profile, is strongly differentiated below the surface (according to the model in Fig. 5, the lateral moraine corresponds to at least 5 separate high-resistivity bodies). The western lateral moraine consists of one high-resistivity body (IX. in Fig. 5). However, towards the centre of the profile we can observe two more bodies with higher resistivity below the surface (VII. and VIII. in Fig. 5). According to the subsurface model, the ground moraine (in Fig. 5) identified by the previous geomorphological mapping survey between the moraine ridges (Mentlík 2006, Mentlík et al. 2010) is also inhomogeneous.

The absolute resistivity values appear to be strongly reduced in the model by streams (see Fig. 2 and blue arrows in Fig. 5) and high subsurface saturation (Loke 2000, Kilner et al. 2005, McClymont et al. 2011), which is remarkable in the first, seventh, eighth and ninth parts of the model (I., VII., VIII. and IX. in Fig. 5). High-resistivity bodies forming the eastern and western lateral moraines are consistent with the resistivity that has been reported for glacial sediments (Kilner et al. 2005, Tábořík 2012). Similarly, bodies with high resistivity in parts VII. and VIII. of the model could be considered glacial sediments (Kilner et al. 2005, Tábořík 2012). The abundance of high-resistivity bodies implies the subsurface differentiation of both lateral moraines. This theory is also supported by the relatively close spacing of the electrodes (2.5 m), which allows the detection of even small subsurface structures (Loke 2000). It is therefore likely that the eastern lateral moraine (see Mentlík 2006) is actually a series of lateral moraines, and the western moraine is only one of a series of lateral moraines (Benn & Evans 2010). Thus, the geophysical model probably distinguishes at least three phases of the glacier's advance during the Marine Isotope Stage 2 (Martini et al. 2001, Benn & Evans 2010).

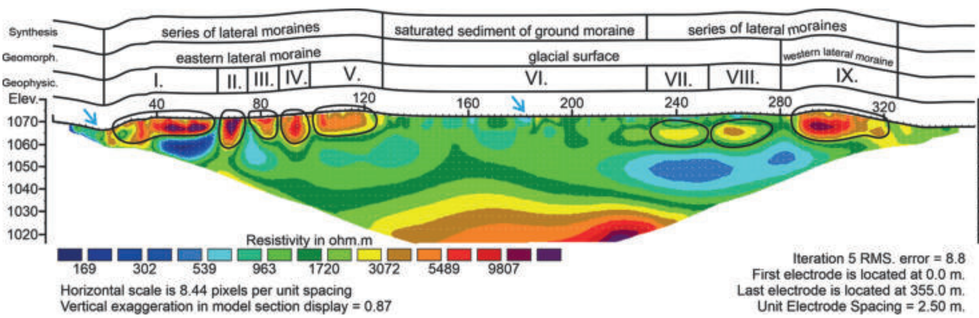

Fig. 5. ERT subsurface resistivity distribution model in the Laka lake locality with both dissections and synthesis. Note the lot of separated relatively high resistivity bodies in the model (outlined in black). Blue arrows indicate the locations of streams which drain the locality.

Großer Schwarzbach cirque

The subsurface resistivity distribution model (Fig. 6) in the Großer Schwarzbach locality can be divided into five parts. The first part (I. in Fig. 6) is characterized by a compact high-resistivity body, which is evident down to 20 metres. The second part (II. in Fig. 6) shows a transition from very high resistivity in the first part to very low resistivity in the third part. The third part (III. in Fig. 6) is formed by a compact body of extremely low resistivity, which reaches a depth of about 25 metres. At about 25 metres, there is a relatively sharp transition to medium and higher resistivities. The fourth part (IV. in Fig. 6) consists of a shallow near-surface layer of low resistivity, which transitions quite sharply at a depth of several metres into a zone of medium resistivity. The fifth part (V. in Fig. 6) is characterised by a slightly chaotic arrangement of bodies with medium resistivity values.

The parts of the subsurface resistivity distribution model (Fig. 6) in the Großer Schwarzbach locality almost match the landforms identified by the previous geomorphological mapping surveys (Duffek & Mentlík 2019, Hauner et al. 2019). The first part (I. in Fig. 6), which consists of a high-resistivity body corresponds to the lateral moraine, which dams the bottom of the cirque (Pfaffl 1997, Duffek & Mentlík 2019, Hauner et al. 2019). The second part of the model (II. in Fig. 6) corresponds to the mapped edge of the cirque base. The third part of the model (III. in Fig. 6), characterized by very low resistivity, corresponds to the cirque base (Duffek & Mentlík 2019, Hauner et al. 2019). The fourth part of the model (IV. in Fig. 6) corresponds to the opposite edge of the cirque base. The fifth part with medium resistivity corresponds to the foot of the cirque wall (Duffek & Mentlík 2019, Hauner et al. 2019). The high resistivity in the first part of the model matches the resistivity of glacial sediments (Kilner et al. 2005, Tábořík 2012).

The low-resistivity body that dominates the model (III. in Fig. 6) most likely represents an infilled lake (see similar data for other infilled lakes in Mentlík et al. 2010, Tábořík 2012). This hypothesis, originally proposed by Pfaffl (1997), is also supported by the existence of a moraine ridge (part I in Fig. 6), which dams the base of the cirque (Duffek & Mentlík 2019, Hauner et al. 2019), or the assumed deepening of the base of the cirque by rotational erosion (Benn & Evans 2010). The lake is currently filled with heavily saturated sediments, which are always characterized by very low resistivity (Loke 2000, Tábořík 2012). Based on the resistivity model, the area of the lake corresponds to the mapped base of the cirque. The lake could be over 350 metres long and over 200 metres wide and it could reach 25 metres deep. The lake phase must be confirmed, e.g. by a palynological research of a sediment core.

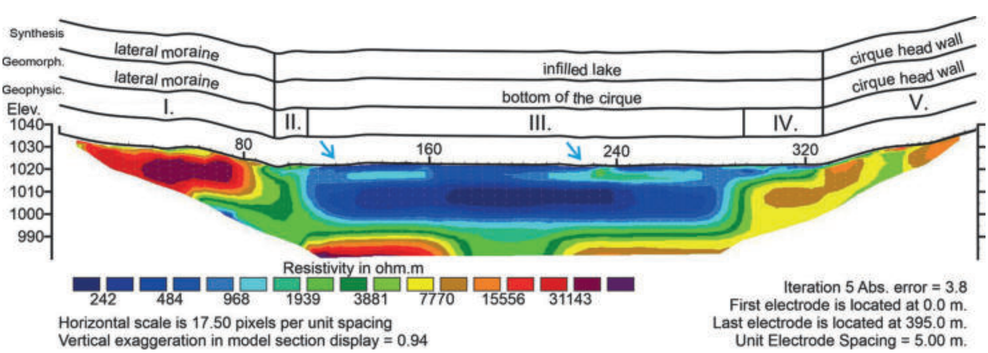

Fig. 6. ERT subsurface resistivity distribution model in the Großer Schwarzbach locality with dissections and synthesis. Note the low resistivity massive body in the third part of the model (III.). Blue arrows indicate the locations of streams which drain the Großer Schwarzbach cirque.

Conclusion

The article presents the ERT results from four Bohemian Forest cirques in two ways: to complement regional geomorphological knowledge, which may form the basis for further geomorphological research and other research; and to show the potential of use of this geophysical method in the research of glacial landforms.

The basic geophysical research at individual localities: (i) detected the curved structure in the Stará Jímka cirque wall locality, which could imply a rotational landslide; (ii) identified buried forms near the Prašilské Jezero lake locality which could be glacial sediments older than the local LGM; (iii) contributed to understanding the relative chronology of glaciation in the Laka lake locality; and (iv) identified a very probable infilled lake in the Großer Schwarzbach cirque, which could be up to 25 metres deep. These new findings are valuable for further research of the particular localities and the glaciation history of the Bohemian Forest.

The above-mentioned interpretations demonstrate that ERT can be used to analyse the internal structure of glacial sediments. Such analysis could detect buried structures that have no effect on the relief, which can be used for indication of an older (pre-LGM) glaciation or improving the relative chronology of a glacial system within a single glaciation. ERT reveals the internal structure of glacially eroded landforms which can indicate mass wasting processes. The ERT method can also be used to detect potential infilled lakes and to estimate extent and depth of their sediments. This method also refines the information about the deepening of cirque bases. The hypotheses outlined above highlight the importance of local research and the importance of research using geophysical methods together with geomorphological research in the field.

Acknowledgement. The paper was created with the support of the grant competition of the Faculty of Education of the University of West Bohemia (number: Grak 2022 DS/02). The authors would like to thank the State Administration of Land Surveying and Cadastre and the Bavarian Forest National Park Administration for the loan of their detailed digital elevation model data and for research permits. We also thank J.M. King for the translation and proofreading. We are grateful to D. Vondrák, J. Zenáhlíková and one anonymous reviewer who were very helpful in improving previous versions of the manuscript.

References

Ballantyne C.K., 2002: Paraglacial geomorphology. *Quaternary Science Reviews*, 21: 1935–2017.

Barr D.I. & Spagnolo M., 2015: Glacial cirques as palaeoenvironmental indicators: Their potential and limitations. *Earth-Science Reviews*, 151: 48–78.

Bauberger W., 1977: *Erlauterungen zur Geologischen Karte von Bayern, Blatt 7046 Spiegelau und 7047 Finsterau* [*Explanatory notes to the Geological Map of Bavaria, sheet 7046 Spiegelau and 7047 Finsterau*]. Nationalpark Bayerischer Wald, 183 pp. (in German).

Benn D. & Evans D., 2010: *Glaciers and Glaciation*. Routledge. 816 pp.

Blecha V., Fischer T., Tábořík P., Vilhem J., Klanica R., Valenta J. & Štěpančíková P., 2018: Geophysical evidence of the eastern marginal fault of the Cheb basin (Czech Republic). *Studia Geophysica et Geodaetica*, 62: 660–680.

Braucher R., Kalvoda J., Bourlès D., Brown E., Engel Z. & Mercier J.L., 2006: Late Pleistocene deglaciation in the Vosges and the Krkonoše mountains: correlation of cosmogenic 10Be exposure ages. *Geografický časopis*, 58: 3–14.

Brook M.S., Kirkbride M.P., & Brock B.W., Cirque development in a steadily uplifting range: rates of erosion and long-term morphometricchange in alpine cirques in the Ben Ohau Range,New Zealand. *Earth Surface Processes and Landforms*, 31: 1167–1175.

Carter V.A., Moravcová A., Chiverrell R.C., Clearc J.L., Finsinger W., Dreslerová D., Halsall K., & Kuneš P., 2018: Holocene-scale fire dynamics of central European temperate spruce-beech forests. *Quaternary Science Reviews*, 191: 15–30.

Chalupa V., Pánek T., Tábořík P., Klimeš J., Hartvich F. & Grygar R., 2018: Deep-seated gravitational slope deformations controlled by the structure of flysch nappe outliers: Insights from large-scale electrical resistivity tomography survey and LiDAR mapping. *Geomorphology*, 321: 174–187.

Colombero CH., Comina C., Gianotti F. & Luigi Sambuelli L., 2014: Waterborne and on-land electrical surveys to suggest the geological evolution of a glacial lake in NW Italy. *Journal of Applied Geophysics*, 105: 191–202.

ČÚZK, 2016: Český úřad zeměměřický a katastrální. Online http://www.cuzk.cz/ (accessed on 14 June 2022).

Diallo M.C., Cheng L.Z., Rosa E., Gunther CH. & Chouteau M., 2019: Integrated GPR and ERT data interpretation for bedrock identification at Cléricy, Québec, Canada. *Engineering Geology*, 248: 230–241.

Duffek V. & Mentlík P., 2019: Reconstruction of the phases of glaciation in the Schwarzbach cirque (the Bohemian Forest). In: *State of Geomorphological Research in 2019*, Klimeš J., Hartvich F. (eds) Czech Association of Geomorphologists. Book of abstracts, 19: 37.

Engel Z., Braucher R., Traczyk A., Laetitia L. & Aster Team., 2014: 10Be exposure age chronology of the last glaciation in the Krkonoše Mountains, Central Europe. *Geomorphology*, 206: 107–121.

Engel Z., Křížek M., Kasprzak M., Traczyk A., Hložek M. & Krbcová K., 2017: Geomorphological and sedimentary evidence of probable glaciation in the Jizerské hory Mountains, Central Europe. *Geomorphology*, 280: 39–50.

Engel Z., Nývlt D., Křížek M., Treml V., Jankovská V. & Lisá L., 2010: Sedimentary evidence of landscape and climate history since the end of MIS 3 in the Krkonoše Mountains, Czech Republic. *Quaternary Science Reviews*, 29: 913–927.

Ergenzinger P., 1967: Die eiszeitliche Vergletscherung des Bayerischen Waldes [The ice age glaciation of the Bavarian Forest]. *Eiszeitalter und Gegenwart* (E&G Quaternary Science Journal), 18: 152–168. (in German).

Fiebig M., Buiter S.H.J. & Ellwanger D., 2004: Pleistocene glaciation of South Germany. In: *Quaternary Glaciations Extent and Chronology – Part I: Europe*, Ehlers J. & Gibbard P.L. (eds) *Developments in Quaternary science*, 2: 147–154.

Geertsema M. & Chiarle M., 2013: Mass-Movement Causes: Glacier Thinning. In: *Treatise on Geomorphology*, Shroder J.F., Marston R.A. & Stoffel M. (eds) *Mountain and Hillslope Geomorphology*, 7: 217–222.

Hartvich F. & Mentlík P., 2010: Slope development reconstruction at two sites in the Bohemian Forest Mountains. *Earth Surface Processes and Landforms*, 35: 373–389.

Hartvich F., Zvelebil J., Slabina M. & Havlíček D., 2007: Multidisciplinary analysis of a slope failure at the Obří Hrad site in the Šumava Mts. *Geomorphologia Slovaca et Bohemica*, 7: 47–57.

Hauner U., 1980: *Untersuchungen zur klimagesteuerten tertiären und quartären Morphogenese des Inneren Bayerischen Waldes (Rachel-Lusen) unter besonderer Berücksichtigung pleistozän kaltzeitlicher Formen und Ablagerungen* [*Investigations on the climate-controlled Tertiary and Quaternary morphogenesis of the Inner Bavarian Forest (Rachel-Lusen) with special emphasis on Pleistocene cold-age forms and deposits*]. Regensburger Geographische Schriften. 145 pp. (in German).

Hauner U., Lehrberger G. & Brugger M., 2019: *Der Naturraum Bayerischer Wald – Šumava in den Eiszeiten* [*The natural region of the Bavarian Forest – Šumava in the ice ages*]. Nationalpark Bayerischer Wald, Wissenschaftliche Reihe, Heft 20: 1–132 (in German).

Hemmerle H., May J.H. & Preusser F., 2016: Übersicht über die pleistozänen Vergletscherungen des Schwarzwaldes [Overview of the Pleistocene glaciations of the Black Forest]. Berichte der Naturforschenden Gesellschaft zu Freiburg i. Br., 106: 31–67. (in German).

Hiemstra J.F., Kulessa B., King E.C. & Ntarlagiannis D., 2011: The use of integrated sedimentological and geophysical methods in drumlin research – a case study of Pigeon Point, Clew Bay, Northwest Ireland. *Earth Surface Processes and Landforms*, 36: 1860–1871.

Hofmann M.F., Preusser F., Schimmelpfennig I., Léanni L., & Aster Team, 2022: Late Pleistocene glaciation history of the southern Black Forest, Germany: 10Be cosmic-ray exposure dating and equilibrium line altitude reconstructions in Sankt Wilhelmer Tal. *Journal of Quaternary Science*, 37: 688–706.

Kasprzak M., 2015: High-resolution electrical resistivity tomography applied to patterned ground, Wedel Jarlsberg Land, south-west Spitsbergen. *Polar Research*, 34: 25678.

KILNER M. WESTA L.J. & MURRAYB T.T., 2005: Characterisation of glacial sediments using geophysical methods for groundwater source protection. *Journal of Applied Geophysics*, 57: 293–305.

KLETETSCHKA G., VONDRÁK D., HRUBÁ J., PROCHÁZKA V., NÁBĚLEK L., SVITAVSKÁ-SVOBODOVÁ H., BOBEK P., HOŘICKÁ Z., KADLEC J., TAKÁČ M., & STUCHLÍK E., 2018: Cosmic-impact event in lake sediments from central Europe postdates the Laacher See eruption and marks onset of the Younger Dryas. *The Journal of Geology*, 126 6: 561–575.

KŘÍŽEK M., VOČADLOVÁ K. & ENGEL Z., 2012: Cirque overdeepening and their relationship to morphometry. *Geomorphology*, 139–140: 495–505.

LDBV, 2022: Landesamtes für Digitalisierung, Breitband und Vermessung. Digitales Geländemodell. Online www.ldbv.bayern.de/service/kundenservice.html (accessed on 25 June 2022).

LEOPOLD M., WILLIAMS M.W., CAINE N., VÖLKEL J. & DETHIER D., 2011: Internal structure of the Green Lake 5 rock glacier, Colorado Front Range, USA. *Permafrost and Periglacial Processes*, 22: 107–119.

LOKE M.H. & BARKER R.D., 1996: Rapid least-squares inversion of apparent resistivity pseudosections using a quasi-Newton method. *Geophysical Prospecting*, 44: 131–152.

LOKE M.H., 2000: Electrical imaging surveys for environmental and engineering studies. A practical guide to 2-D and 3-D surveys. Geotomo software (1997-2000), 67 pp. Online http://www.geotomosoft.com (accessed on 30 April 2020).

LOKE M.H., KIFLU H., WILKINSON P.B., HARRO D. & KRUSE S., 2015: Optimized arrays for 2D resistivity surveys with combined surface and buried arrays. *Near Surface Geophysics*, 13: 505–517.

MAILLET G.M., RIZZO E., REVIL A. & VELLA C., 2005: High Resolution Electrical Resistivity Tomography (ERT) in a Transition Zone Environment: Application for Detailed Internal Architecture and Infilling Processes Study of a Rhône River Paleo-channel. *Marine Geophysical Researches*, 26: 317–328.

MARTINI I.P., BROOKFIELD M.E. & SADURA S., 2001: *Principles of Glacial Geomorphology and Geology*. California: Prentice Hall, 381 pp.

MCCOLL S.T., 2012: Paraglacial rock-slope stability. *Geomorphology*, 153–154: 1–16.

MCCLYMONT A.F., ROY J.R., HAYASHI M., BENTLEY L.R., MAURER H. & LANGSTON G., 2011: Investigating groundwater flow paths within proglacial moraine using multiple geophysical methods. *Journal of Hydrology*, 399: 57–69.

MENTLÍK P., 2006: Geomorfologická analýza a tvorba GmIS okolí Prášilského jezera a jezera Laka na Šumavě [The geomorphological analysis and creating of GmIS of the Prášilské Lake and Laka Lake surrounding]. Ms., PhD thesis, Comenius University, Bratislava, 252 pp. (Library of the Faculty of Sciences, Comenius University Bratislava).

MENTLÍK P., ENGEL Z., BRAUCHER R., LÉANNI L. & ASTER TEAM, 2013: Chronology of the Late Weichselian glaciation in the Bohemian Forest in Central Europe. *Quaternary Science Reviews*, 65: 120–128.

MENTLÍK P., MINÁR J., BŘÍZOVÁ E., LISÁ L., TÁBOŘÍK P. & STACKE V., 2010: Glaciation in the surroundings of Prášilské Lake (Bohemian Forest, Czech Republic). *Geomorphology*, 117: 181–194.

MENTLÍK P. & NOVOTNÁ M., 2010: Elementary forms and "scientific reliability" as an innovative approach to geomorphological mapping. *Journal of Maps*, 6 1: 564–583.

MERCIER J.-L. & JESER N., 2004: The glacial history of Vosges Mountains. In: *Quaternary Glaciations Extent and Chronology – Part I: Europe*, EHLERS J. & GIBBARD P.L. (eds) *Developments in Quaternary science*, 2: 113–117.

MIGOŃ P., 1999: The role of preglacial relief in the development of mountain glaciation in the Sudetes, with the special references to the Karkonosze Mountains. *Zeitschrift für Geomorphologie*, 113: 33–44.

MORAVCOVÁ A., TICHÁ A., CARTER V.A., VONDRÁK D., ČTVRTLÍKOVÁ M., VAN LEEUWEN J.F.N., HEURICH M., TINNER W., & KUNEŠ P., 2021: Mountain aquatic Isoëtes populations reflect millennial-scale environmental changes in the Bohemian Forest Ecosystem, Central Europe. *The Holocene*, 31 5: 746–759.

OTTO J.C. & SASS O., 2006: Comparing geophysical methods for talus slope investigation in the Turmann valley (Swiss Alps). *Geomorphology*, 76: 257–272.

PÁNEK T., HRADECKÝ J., MINÁR J., HUNGR O. & DUŠEK R., 2009: Late Holocene catastrophic slope collapse affected by deep-seated gravitational deformation in flysch: Ropice Mountain, Czech Republic. *Geomorphology*, 103: 414–429.

PARKES A.A., WALLER R.I., KNIGHT P.G., STIMPSON I.G., SCHOFIELD D.I. & MASON K.T., 2009: A morphological, sedimentological and geophysical investigation of the Woore Moraine, Shropshire, England. *Proceedings of the Geologists' Association*, 120: 233–244.

PELC Z. & ŠEBESTA J., 1994: *1994: Geomorfologická mapa ČR. List 22–33 Kašperské Hory* [Geological Map of the Czech Republic. Sheet 22–33 Kašperské Hory] 1 : 50 000. Czech Republic (in Czech).

PERRONE A., LAPENNA V., & PISCITELLI S., 2014: Electrical resistivity tomography technique for landslide investigation: A review. *Earth-Science Reviews*, 135: 65–82.

PFAFFL F., 1997: Das Bärnriegel-Kar und seine Moränenlandschaft im Nationalpark Bayerischer Wald bei Finsterau. *Der Bayerischer Wald*, 11(2): 22–23.

PROCHÁZKA V., MIZERA J., KLETETSCHKA G. & VONDRÁK D., 2017: Late Glacial sediments of the Stará Jímka paleolake and the first finding of Laacher See Tephra in the Czech Republic. *International Journal of Earth Sciences*, 108: 357–378.

RAAB T. & VÖLKEL J., 2003: Late Pleistocene glaciation of the Kleiner Arbersee area in the Bavarian Forest, south Germany. *Quaternary Science Reviews*, 22: 581–593.

RATHSBURG A., 1928: Die Gletcher des Böhmerwaldes zur Eiszeit [The glaciers of the Bohemian Forest during the ice age]. *Sonderardruck aus dem 22. Bericht der Naturwissenschaftlichen Gesellschaft zu Chemnitz*, 22: 65–161 pp. (in German).

RAŠKA P., HARTVICH F., CAJZ V. & ADAMOVIČ J., 2014: Structural setting of the Čertovka landslide (Ústí nad Labem, Czech Republic): morphostructural analysis and electrical resistivity tomography. *Geological Quaterly*, 58: 85–98.

REUTHER A.U., 2007: Surface exposure dating of glacial deposits from the last glacial cycle. Evidence from the Eastern Alps, the Bavarian Forest, the Southern Carpathians and the Altai Mountains. *Relief Boden Palaeoklima*, 21: 1–213.

REUTHER A.U., FIEBIG M., IVY-OCHS S., KUBIK P.W., REITNER J.M., JERZ H., & HEINE K., 2011: Deglaciation of a large piedmont lobe glacier in comparison with a small mountain glacier – new insight from surface exposure dating. Two studies from SE Germany. *Quaternary Science Journal*, 60: 248–269.

REYNOLDS J.M., 1997: *An Introduction to Applied and Environmental Geophysics*. John Wiley & Sons, 712 pp.

RIZZO E., COLELLA A., LAPENNA V. & PISCITELLI S., 2004: High-resolution images of the fault controlled High Agri Valley basin (Southern Italy) with deep and shallow Electrical Resistivity Tomographies. *Physics and Chemistry of the Earth*, 29: 321–327.

SASAKI Y., 1992: Resolution of resistivity tomography inferred from numerical simulation. *Geophysical Prospecting*, 40: 453–463.

SASS O., 2006: Determination of the internal structure of alpine talus using different geophysical methods (Lechtaler Alps, Austria). *Geomorphology*, 80: 45–58.

SCHROTT L. & SASS O., 2008: Application of field geophysics in geomorphology: advances and limitations exemplified by case studies. *Geomorphology*, 93: 55–73.

STEFFANOVÁ P. & MENTLÍK P., 2007: Comparison of morphometric characteristics of cirques in the Bohemian Forest. *Silva Gabreta*, 13: 191–204.

STEMBERK J., HARTVICH F., BLAHUT J., RYBÁŘ J. & KREJČÍ O., 2017: Tectonic strain changes affecting the development of deep-seated gravitational slope deformations in the Bohemian Massif and Outer Western Carpathians. *Geomorphology*, 289: 3–17.

TÁBOŘÍK P., 2012: Možnosti využití elektrické odporové tomografie ve výzkumu horského reliéfu [Use of electrical resistivity tomography in the research of mountain relief]. Ms., PhD thesis, University of Ostrava, Ostrava, 184 pp. (Library of the Faculty of Sciences, University of Ostrava) (in Czech).

VOČADLOVÁ K., PETR L., ŽÁČKOVÁ P., KŘÍŽEK M., KŘÍŽOVÁ L., HUTCHINSON S.M. & ŠOBR M., 2015: The Lateglacial and Holocene in Central Europe: a multi-proxy environmental record from the Bohemian Forest, Czech Republic. *Boreas*, 44: 769–784.

VONDRÁK D., KOPÁČEK J., KLETETSCHKA G., CHATTOVÁ B., SUCHÁNEK V., TÁTOSOVÁ J. & KUNEŠ P., 2019: Lithostratigraphy and age of the Bohemian Forest lake sediments: A first assessment. *Geoscience Research Reports*, 52: 75–83.

VONDRÁK D., KRAUSE D., HRUBÁ J. & KLETETSCHKA G., 2021: The paleolake Stifter Hollow and signs of the last stage of Quaternary glaciation in the Plešné Lake cirque. *Silva Gabreta*, 27: 1–15.

Received: 29 May 2022
Accepted: 19 July 2022