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# Hypothesis for the last stage of glaciation in the Černé Lake area (Bohemian Forest, Czech Republic)

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**Abstract**
This contribution presents a hypothesis for the last stage of glaciation in the Černé Lake area in the Bohemian Forest (the Šumava Mts.). The hypothesis results from geomorphologic research of the area based on bathymetrical measurements and a diving survey of part of the bottom of the lake, which was executed in order to verify a hypothesis about the existence of a submerged part of a moraine. The main geomorphologic methods used were: morphometrical and morphographical analysis of DEM performed using GIS tools (analysis of slopes inclination, aspect of slope, shading of relief, longitudinal and cross section, degree of cirque deepening), geomorphologic GPS mapping, particle size analysis.

*Key words:* geomorphology, glaciation, Černé Lake

## Introduction

The period of the Pleistocene was characterized by a range of climate changes – alternation of interglacial and glacial periods, which had an impact on the development of the natural environment. A part of evidence for colder climatic conditions during the glacial stages of the Pleistocene is, among other things, the presence of glacial deposits and interrelated relief forms in the Bohemian Forest. The first glaciation research of the Czech and German part of the Bohemian Forest was carried out 150 years ago. Since then, the most notable studies were performed at the end of 19$^{th}$ and during the first half of 20$^{th}$ century. On the Czech side of the Bohemian Forest, the research was reduced due to political reasons (except for Votýpka 1975, 1979). New opportunities did not appear until 1989.

Even in older literature, various theories exist about the extent of glaciation in surrounding of Černé Lake as reviewed by Kunský (1933) and Chábera (1975). For example Rathsburg (in Kunský 1933) placed the lower boundary of glaciation 120 m below the present surface of Černé Lake which corresponds approximately to 880–890 m a.s.l. Rathsburg tended to support the idea of local glaciation of the Bohemian Forest by the cirque glaciers with short glacier tongue.

Priehäusser (in Kunský 1933) determined the lower boundary of the glacier of Černé Lake to be 830 m a.s.l. Unlike Rathsburg he advocated that the glaciation of the mountain range was much more extensive. Treml (1976) considered the maximum glacier expansion boundary to be 870 m a.s.l. All the figures mentioned do not differ significantly.

On the basis of terrain mapping executed for this study, the extension boundary of Černé Lake glacier was placed at approximately 850 m a.s.l., while its tongue reached minimally distance of 700 m from the present lake (Vočadlová & Křížek 2005).

The latest research on both sides of the Bohemian Forest support the opinion of the smaller extent of the Pleistocene glaciation (Votýpka 1979, Raab 1999, Mentlík 2004, 2005). The small extent of glacial accumulations in the study area is not an exception in the Bohemian Forest and it confirms the smaller extent of glaciation in this area.

Studies of Hercynian Mountains glaciation lag behind research of the Alpine areas, where the relief glacial modelling has been significantly more intensive (Prosová 1958, Hauner 1980, Rother 1995, Mercier et al. 1999, Engel 2003, Raab & Völkel 2003). The importance of the investigation of Hercynian Mountains is that it can contribute to understanding the development of European nature during the Pleistocene and offers a possibility of spatial connection between the stratigraphic systems of Nordic and Alpine glaciations (Raab & Völkel 2003).

The main purpose of this article is to present a hypothesis for the last stage of the glaciation in the area of Černé Lake. This hypothesis arises from the current state of research aimed above all at accumulative parts of the relief with glacial forming of relief.

The aims are summarised in the following points: (i) specification of probable extension and localization of the glaciation based on position of glacial accumulations; (ii) to outline genesis of the Pleistocene glaciation in the area of interest by means of morphometrical and morphographical analysis, position and character of glacial accumulations; and (iii) to verify the hypothesis for the existence of a submerged part of a moraine on the bottom of this lake.

## Study area

The study area was primarily defined as the catchment of Černé Lake and the Černý Potok stream. This area was enlarged to include all relics of glacial activities and forms of the neighbouring relief, which could directly influence the development of glacial processes during the Pleistocene. Morphometrical and morphographical analysis adjacent to the summit plateaux and other summit parts among the Špičák Mt. (1202 m a.s.l.), Rozvodí Mt. (1159.1 m a.s.l.), Jezerní Hora Mt. (1343.4 m a.s.l.), and Svaroh Mt. (1333.6 m a.s.l.) were also involved.

The study area is situated on the slope and on one part of the mountain range of the highest part of the Bohemian Forest approximately 6 km northwest from Železná Ruda in the former Klatovy district. It belongs to the protected area "CHKO Šumava" and partly to the nature reserve "Černé a Čertovo jezero" . The altitude difference between the highest and lowest points of the study area – the peak of the Jezerní Hora Mt. and the outfall of the Černý Potok stream (709 m a.s.l.), respectively – exceeds 600 m. Based on geomorphologic classification (Demek 1987) the study area can be ranked as follows into the geomorphological unit "Šumava", the geomorphological subunit "Železnorudská Hornatina" highland, and the geomorphologic area "Královský Hvozd".

The study area is geologically created by the geological unit series of the area "Královský Hvozd", which is built up by mica schist and gneiss. Furthermore, intercalations of quartzite, limestone, slates, and amphibolite occur here (Vejnar 1961).

An important part of the study area is taken up by Černé Lake which is the most extensive (18.79 ha), the deepest (40.1 m) and the lowest placed (1007.5 m a.s.l.) glacial lake on the Czech side of the Bohemian Forest (Janský et al. 2005). The weir is anthropogenically modified and the lake functions as a retention reservoir for a small, still operational, pumped storage hydroelectric power station in Hamry.

## Methods

The hypothesis for the development of the study area during the last phase of glaciation arose primarily based on geomorphologic mapping and then on evaluating morphometrical and morphographical characteristics (Vočadlová & Křížek 2005). The geomorphologic mapping was executed in the field from June to November 2005 with the application of GPS. The mapping focused mainly on glacial landforms. Boundaries of glacial accumulations, boundaries and ridge-like forms, steps in moraines, edge of cirque headwall, peat bogs, gully, erosion cuts, and water courses were mapped. Older and younger moraines were distinguished based on their morphology (degree of preservation and similarity of form) and relative position.

Based on DEM (digital elevation model), an analysis of shading of the cirque headwall was made in GIS. It shows places with the highest potential for accumulation and snow persisting in the cirque headwall along with the map of inclination. The degree of deepening of the cirque was determined by calculation using the k-curve according to the method developed by Haynes (1968).

Samples from the profile for particle size analysis were taken from the bottom of a nivation hollow in the southern part of the cirque wall (oriented to the north). Eight samples from the profile were taken at the depths: 6–14 cm, 15–19 cm, 28–37 cm, 42–48 cm, 53–56 cm, 56–71 cm, 84–94 cm, and 113–123 cm. The samples were dried, weighed (electrical balance VIBRA, type CG, class III) and laboratory particle size analysis was executed on a grading screen machine FVR C9S sieves with mesh sized 2, 1, 0.5, 0.25, 0.063, 0.05, and 0.04 mm.

The field research was completed by scubadiving in Černé Lake, in June 2006. The diving research was executed by a team from the Faculty of Science of the Palacký University. They studied ecology of the hydrophyte *Isoëtes lacustris* L. The scuba divers were directed by means of a walkie-talkie placed on a boat in order to maintain the direction of the cross profile of this elevation despite limited visibility. The direction of the cross profile was recorded by GPS. Altogether they explored a belt of 80 m long and 20 m wide crossing the elevation, which divides the 2 basins of the lake. The total time of the diving survey was 35 min and the maximum depth was 18 m. The temperature of the water was 2 °C.

## Results

The glacial accumulation landforms can be found in several morphologically different forms around Černé Lake such as ridge-like forms, steps or flat low accumulations (Vočadlová & Křížek 2005). Five generations of moraines were defined in total, based on geomorphological mapping. They reach from 1115 m a.s.l. (right moraines) and 1040–1035 m a.s.l. (left moraines) to 850 m a.s.l. (frontal moraines), and to 930 m from the lake. Accumulations on both sides of Černé Lake and along the Černý Potok stream were differentiated. Many smaller peat bogs, not deeper than 2 m, were found between the moraines.

The area of the glacial accumulations can be divided according to the moraine disposition into a few sections: frontal moraines furthest from the lake (the moraines meet), middle section with parallel disposition, and the upper part of moraines surrounding Černé Lake (parallel with the shore line of Černé Lake).

Based on their position towards the glacier tongue, the moraines can be divided into right lateral moraines (1P, 2Pa, 2Pb, 4P, 5P), left lateral moraines (1L, 2L, 3L, 4L, 5L), and areas

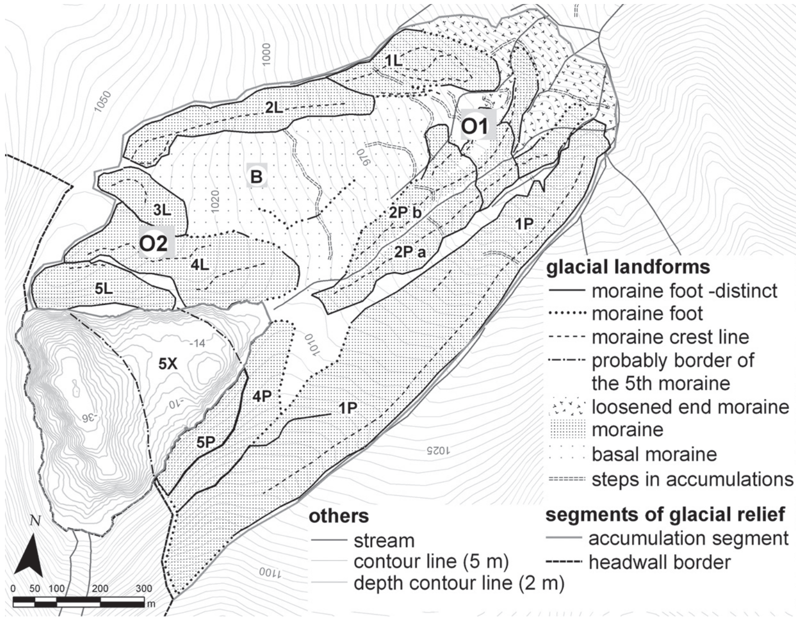



**Fig. 1.** Position of accumulation glacial landforms in the study area. Numbering of the moraine generation continues from the oldest to the youngest and it is derived from the number of left lateral moraines (right lateral moraines: 1P, 2P, 4P, 5P; left lateral moraines: 1L, 2L, 3L, 4L, 5L; area of glacier oscillation: O1, O2; area of basal moraine: B, moraine on the bottom of lake: 5X).

of terminal (frontal) moraines (Fig. 1). The third right lateral moraine corresponding to the third left lateral moraine was not preserved. This side division refers to an axis of space bounded by moraines and headwall cirque where the glacier tongue moved.

In the study area there were 4 or 5 generations of moraines defined on the basis of well--preserved relics of right and left lateral moraines. The oldest generation of moraines (1L, 1P) is situated between 890–970 m a.s.l., and the end of the left lateral moraine 1L was preserved. The head of the terminal moraine of this stage, which closes the valley of the Černý Potok stream, is significantly degraded by fluvial and slope processes. In the north-western part (1L), there is a distinctive front, which rises 50 m over an asphalt road.

The moraine itself need not reach this height, glacial sediments probably spread on a structurally contingent slope. The right external lateral moraine 1P has the biggest extent (up to 200 m wide) of all the identified moraines. The second generation of moraines is situated near (50–100 m) the first generation. It is formed by 2Pa and 2Pb moraines. The moraine is well preserved; it is significantly damaged only in the front part. An area of front moraines of the first and the second generation was damaged by fluvial erosion of glacier meltwaters and it had to be reconstructed based on the biggest inclination. Between lateral moraines of the second generation, there is a zone of approximately 600 m long and maximum 350 m wide, which is covered by a basal moraine (area B in Fig. 1). The third generation of moraines (3L) has been preserved only on the left side; on the right side its equivalent was not identified. The fourth generation (4L and 4P) closes Černé Lake. The distance between the front of the third (actually fourth) generation of moraines and the second generation of moraines is approximately 450–550 m. The fifth generation, which is the youngest, is represented by moraines 5L and 5P on the shores of the lake.

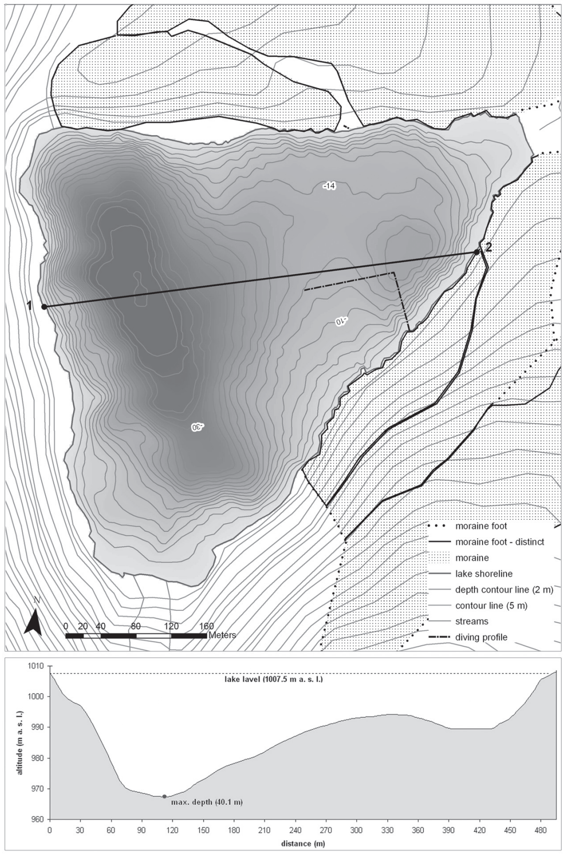
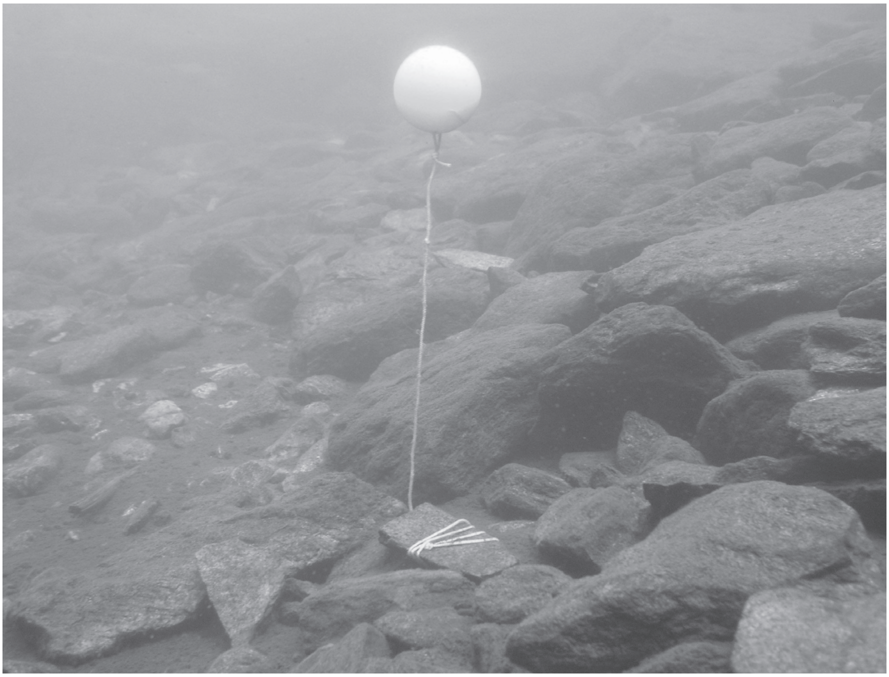


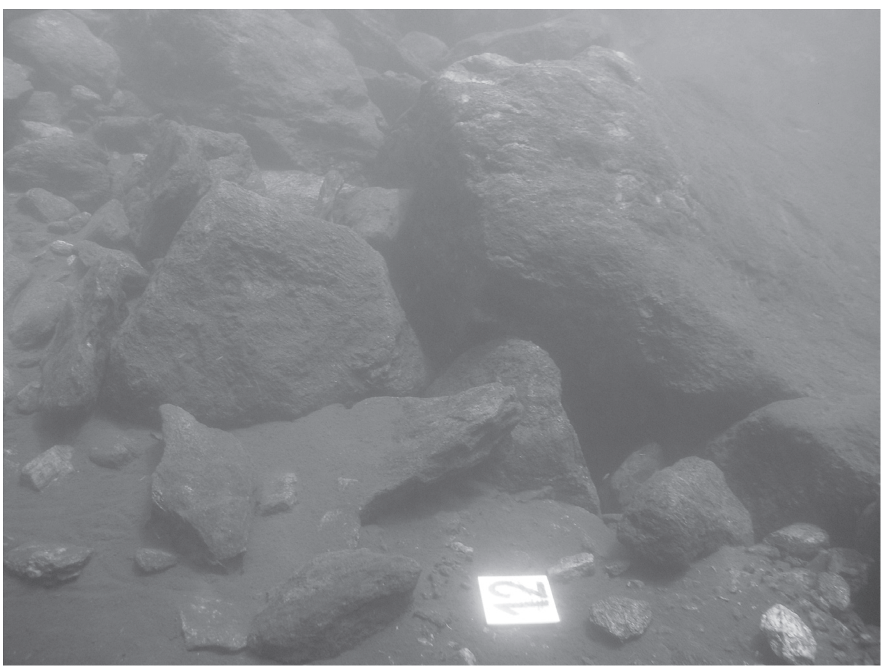

**Fig. 2.** Cross-section profile through the elevation on the bottom of Černé Lake. (exaggeration 3×).

Morphometrical analysis of DEM, based on the bathymetrical map of Černé Lake made by Janský et al. (2005), shows that its bottom is divided into two basins by an elongated elevation across the lake (Fig. 2). This elevation is formed by big boulders, which were confirmed by scubadiving in June 2006. Flat parts and places between boulders are covered by quite shallow fine-grained sediment with a large component of organic material with the thickness locally exceeding 1 m (Figs. 3–5).

In the south part of the cirque headwall with a northern aspect, a nivation hollow was found bounded by a 1–2 m high protalus rampart. In the 123 cm profile, which was dug at the bottom of the nivation hollow, its upper half (up to 53 cm) was formed by black coloured soil with a high volume of peat. At 53–123 cm the soil was swart and slimy. Mica schist boulders with sandy-clay filling were found on the basis of the profile .

Two sandy layers of silvery colour at 6–14 cm and 53–56 cm were uncovered in the profile. A variation of rough particles (size above 2 mm) was registered. However, size of rough particles normally increases with depth. These layers of sandy sediment prove the influence of fluvial processes during the formation of the depression filling. Representation of individual grain fractions in samples taken is displayed in Fig. 6.






**Figs. 3 and 4.** Boulders of the fifth moraine generation on the bottom (depth 3–6 m) of Černé Lake. Photo by: P. Hekera, 2006.

**Fig. 5.** Fine grained sediment covers most parts (above all flat) of moraine on the bottom of Černé Lake. Photo by: P. Hekera, 2006.

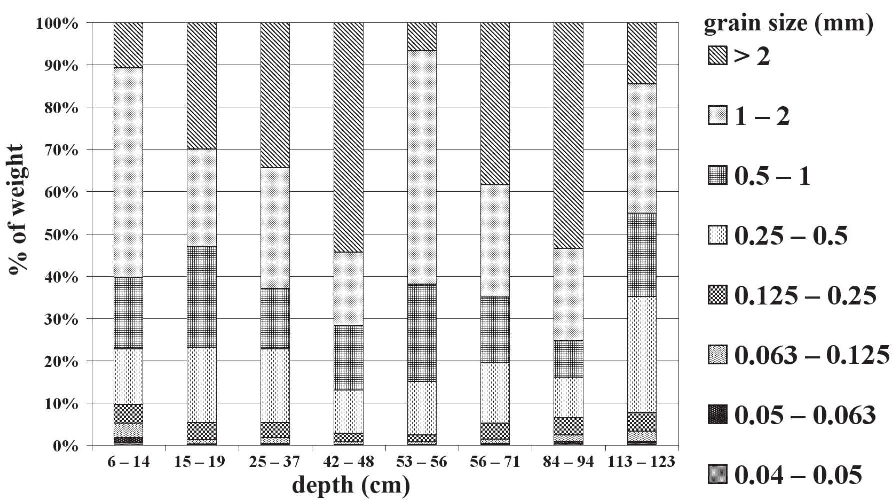



**Fig. 6.** Percentage representation of granularity of sedimentary filling in the nivation hollow.

## Discussion

Side separation of moraines cannot be applied towards the Černý Potok stream, as nowadays it flows eccentrically in relation to the axis of the glacier tongue where it was most likely anthropogenically removed.

The question is whether the two parallel moraines (2Pa a 2Pb), between which the Černý Potok stream flows, are residues of one moraine, which was secondarily cut by a stream or they are two independent moraines, as suggested by Treml (1976). He classified either one according to its position towards the Černý Potok stream (on the left bank there are left lateral moraines and on the right bank there are right lateral moraines). Another question is which direction the glacier tongue passed in, and so, which moraines can be considered as left and which as right. As moraine indicates lateral or frontal expansion of a glacier (Hubbart & Glasser 2005), the area between these moraines should correspond with the place of expansion or retreat of the glacier. In the study area there is a territory with a relatively flat relief without considerable ridges, with only small elevations, depressions and steps (Fig. 1, area B). It is located between the left outer/external moraine, which creates the northwest boundary of the glacial accumulation segment of relief, and ridges along the Černý Potok stream. The glacier tongue was probably situated in this area. With respect to the character of this area it is possible that there is the hummocky moraine, which is seemingly a chaotic configuration of irregular hummocks and depressions (Hubbart & Glasser 2005). This type of moraine is formed by a slow melting, stagnating glacier covered by debris. It accumulates along the sides of a retreating glacier or it is formed by loose material from proglacial or englacial accumulations. It means that this part of the relief could be a zone where the glacier tongue was retreating and where its melting waters ran off. The glacier's movement can be deduced from this. During deglaciation, the glacier was retreating at first to the southwest, and after the second phase, the retreat of the glacier changed to the south by glacial oscillation on the border of the cirque. The origin of accumulations in the area between right and left lateral moraines will be classified by their detailed sedimentary analysis.

Based on the confirmed (by diving and visual reconnaissance) occurrence of an accumulation of big boulders, a working hypothesis about a flooded moraine crossing the lake bed was supported. This hypothesis is also based on the succession of moraines 5L a 5P. On the contrary, the working hypothesis about the structural origin of this elevation, which came from the equivalent direction as local strips of more resistant quartzite, i.e. north-west, south-east seems most likely.

It can be presumed that the right lateral moraine 1P, which is the largest of all identified moraines, accumulated the highest quantity of material. Engel (2003) also describes a similar phenomenon in the Giant Mts. The great thickness of moraines in this phase of glaciation can be explained by an earlier longer period of the rest when a large amount of material available for constructing moraines was created by intensive frost weathering in periglacial conditions (sensu Engel 2003). It can be assumed that a longer period of the time without a significant change of glacier movement preceded the formation of the first generation moraines. An extension of the second generation moraines proves that glaciation during this oscillation was similar in extent to that during the formation of the first generation moraines. Thus, the first oscillation began during a period of maximal glaciation (area O1, Fig. 1). After this a longer period of continual glaciation backdown into the area of the cirque, (most likely ensued). This was when the second period of oscillation occurred, during which the third, fourth and fifth generation moraines were created (O2, Fig. 1).

The relics of moraines found in the study area were most likely formed during the Würmian glacial, as suggested by the higher degree of intactness of moraines. No other research in

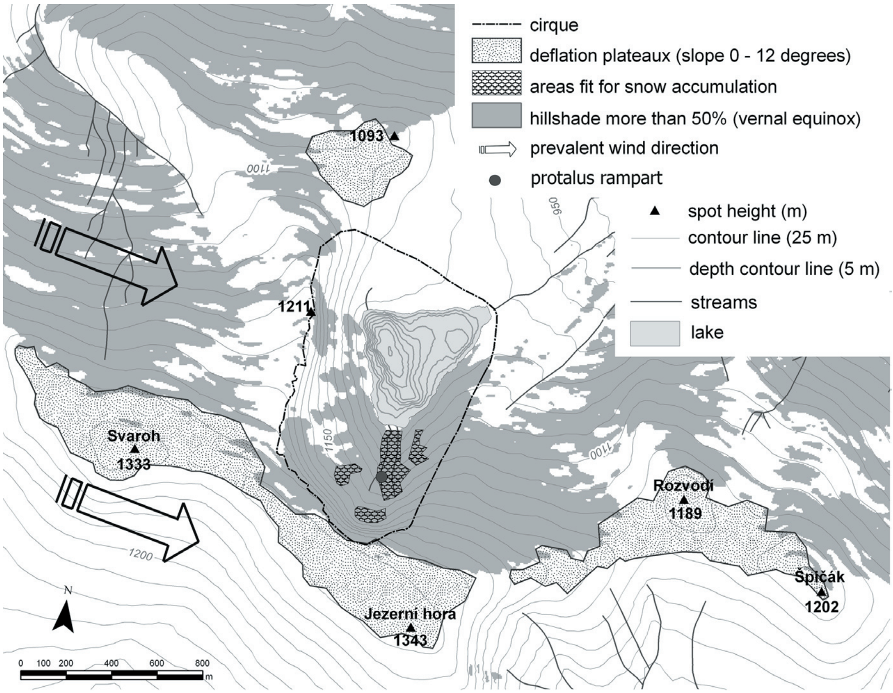



**Fig. 7.** Areas with the most suitable conditions for accumulation of the snow and its abidance within the cirque. Arrows show dominant direction of wind during the Pleistocene (according to Jeník 1961) and hatched surface shows slopes 0–27° (slope 27° as limit headwall-foot, Evans & Cox 1995) in the cirque headwall which are fit for snow accumulation.

the other areas with glacial relief in the Bohemian Forest (e.g. Raab 1999) has found any evidence of the glaciation older than Würmian.

The final glaciation phase before complete deglaciation is related to the nivation hollow bounded by a protalus rampart in the southern part of the cirque headwall. It can be found in areas with the most suitable conditions for accumulation of snow and its abidance within the cirque (the longest time period of shade, proximity of deflation plateaux, and favourable location towards dominant direction of wind during the Pleistocene, see Fig. 7). There was probably a permanent snowfield in this nivation hollow . The protalus rampart was formed in its head. Whalley & Azizi (2003) state that based on the succession of this landform to glacial conditions, the protalus rampart can be classified as a glacial environment rather than periglacial. There are also opinions that these are initial rock glaciers, which originated in permafrost (Barch in Whalley & Azizi 2003). Based on a degree of deepening and other features already mentioned, the locality of the nivation hollow is probably situated in the area of formation and termination of the local glaciation. According to the position of rough sediments (size above 2 mm) on the bottom of the nivation hollow and their share in the sample's weight, this profile used to be washed out here. This process probably has been related to the changes of the channel position, which sometimes flows through the bottom of this nivation hollow. Normally (i.e. without disturbances caused by fluvial processes) the rate of coarse-grained particles would increase in the direction of depth. In this case, the rate of coarse-grained particles varies and the gradation does not correspond to a steady development in this location.

## Conclusions

Based on the spatial distribution of glacial accumulations it can be stated that the glaciation in the neighbourhood of Černé Lake had the character of a cirque glacier with a tongue with a maximum length of about 700 m. During the first period of oscillation the glacier formed moraines of the oldest phase of the glaciation belonging to the first and the second generations. After this, a period of continual glaciation retreat into the cirque area ensued. This area, where the glacier passed and where its melting waters ran off, is located between lateral moraines of the second generation. This territory has a mostly flat relief and several steps. During the second period of oscillations, when the glacier practically did not reach out of the cirque, it formed moraines of the third, fourth and fifth generation. All relics of glaciation probably originate from the Würmian glaciation. The nivation hollow bounded by nivation found in the south part of the cirque corresponds to the final phase of deglaciation. The sedimentation of a coarse material with a loamy-sand filling occurred on the bottom of the nivation hollow during the oldest phase of its development after deglaciation.

After this, a period of sedimentation rest and creation of soil horizons took place. It was interrupted by a few events of alternating fluvial erosion and sedimentation.

A diving survey confirmed the existence of the moraine under the lake surface. This is a continuation of the fifth generation moraines on the adjoining areas on the lake shore.

Future research should lead to the determination of the precise direction of movement of the glacier and differentiation of the age of individual generations of moraines. Some field and laboratory methods of research there was probably a permanent snowfield to enable description and analysis of glacial sediments there was probably a permanent snowfield (for example structural analysis, analysis of quartz grain surface and absolute dating).

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## References

Demek J. (ed.), 1987: *Zeměpisný lexikon ČSR. Hory a nížiny* [*Geographical Lexicon of the CSR. Mountains and Lowlands*]. Academia, Praha, 584 pp. (in Czech).

Engel Z., 2003: Vývoj pleistocénního zalednění české části Krkonoš [Development of the Pleistocene glaciations in the Czech part of the Krkonoše (Giant) Mts.]. Ph.D. thesis, Charles University, Prague, 168 pp. (Geographical library of the Faculty of Sciences, Charles university, Prague) (in Czech).

Evans I.S. & Cox N.J., 1995: The forms of glacial cirques in the English Lake District, Cumbria. *Zeitschrift für Geomorphologie N. F.*, 39: 175–202.

Hauner U., 1980: Untersuchungen zur klimagesteuerten tertiären und quartären Morphogenese des Inneren Bayerischen Waldes (Rachel-Lusen) unter besonderer Berücksichtigung pleistozän kaltzeitlicher Formen und Ablagerungen. *Regensburger Geografische Schriften*, 14: 198 pp.

Haynes V.M., 1968: The influence of glacial erosion and rock structure on corries in Scotland. *Geografiska Annaler, Serie A, Physical Geography*, 50: 221–234.

Hubbart B. & Glasser N., 2005: *Field Techniques in Glaciology and Glacial Geomorphology*. Wiley, Chichester, 400 pp.

Chábera S., 1975: Přehled vývoje názorů na otázku zalednění Šumavy [Summary of the development of opinions of the Bohemian Forest glaciation]. *Šumava*, 5: 5–7 (in Czech).

Janský B., Šobr M., Kocum J. & Česák J., 2005: Nová batymetrická mapování glaciálních jezer na české straně Šumavy. [New mapping of bathymetry of glacial lakes in the Bohemian Fores (Czech part)]. *Sborník České geografické společnosti*, 109(3): 176–187.

Jeník J., 1961: *Alpinská vegetace Krkonoš, Kralického Sněžníku a Hrubého Jeseníku* [*The Alpine vegetation of the Krkonoše Mts., Kralický Sněžník Mts. and Hrubý Jeseník Mts.*]. ČSAV, Praha, 409 pp. (in Czech).

Kunský J., 1933: Zalednění Šumavy a šumavská jezera [Bohemian Forest glaciation and Bohemian Forest glacial lakes]. *Sborník Československé společnosti zeměpisné*, 39: 3–16 (in Czech).
Mentlík P., 2004: Stav geomorfologických výzkumů v okolí Prášilského jezera a jeho další perspektivy [The state of geomorphological research and its prospects in the area around the Prášilské Lake]. *Miscellanea Geographica*, 10: 145–159 (in Czech).
Mentlík P., 2005: The preliminary results of research of accumulation glacial forms in the surroundings of Laka Lake. *Miscellanea Geographica*, 11: 37–46.
Mercier J. Bourles D., Kalvoda,J., Braucher R. & Paschen A., 1999: Deglaciation of the Vosges dated using $^{10}$Be. *Acta Universitatis Carolinea – Geographica*, 2: 139–155.
Prosová M., 1958: Kvartér Hrubého Jeseníku (vrcholová část hlavního hřebene) [Quaternary of the Hrubý Jeseník Mts.(top part of the main ridge)]. Ph.D. thesis, Charles University, Prague, 125 pp. (in Czech) (Geological library of the Faculty of Sciences, Charles University, Prague).
Raab T. & Völkel J., 2003: Late Pleistocene glaciation of the Kleiner Arber area in the Bavarian Forest, south Germany. *Quaternary Science Reviews*, 22: 581–593.
Raab T., 1999: Würmzeitliche Vergletscherung des Bayerischenwaldes im Arbergebiet. *Regensburger Geografische Schriften*, 327 pp.
Rother K., 1995: Die eiszeitliche Vergletscherung der deutschen Mittelgebirge im Spiegel neuerer Forschungen. *Petermanns Geographische Mitteilungen*, 139: 45–52.
Treml V., 1976: Zpráva o výsledcích inventarizačního průzkumu geologických a geomorfologických poměrů Státní přírodní rezervace Černé a Čertovo jezero [Report about results of the inventory of geological and geomorphological research in the State Nature Reserve Černé and Čertovo Lake]. Ms., unpubl., 26 pp. (in Czech).
Vejnar Z., 1961: Svorová oblast série Královského hvozdu na Šumavě [Mica-schists area of the Královský hvozd unit]. *Sborník Ústředního ústavu geologického, oddíl geologický*, 28: 107–142 (in Czech).
Vočadlová K. & Křížek M., 2005: Glacial landforms in Černé Lake area. *Miscellanea geographica*, 11: 47–63.
Votýpka J., 1975: Kvartérní modelace zarovnaných povrchů masívu Plechého na Šumavě [Quaternary modeling of levelled surfaces in Plechý massif, the Bohemian Forest]. *Acta Universitatis Carolinae – Geographica*, 12: 43–60 (in Czech).
Votýpka J., 1979: Geomorfologie granitového masívu Plechého [Geomorphology of Plechý granite massif]. *Acta Universitatis Carolinae – Geographica*, 16: 55–83 (in Czech).
Whalley W.B. & Azizi F., 2003: Rock glaciers and protalus landforms: Analogous forms and ice sources on Earth and Mars. *Journal of Geophysical Research*, 108: 1–17.

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