Large - Scale Glaciation in the Bohemian Forest Mountains: New insights

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Localities glaciated during the Last Glacial Maximum (LGM) in central European uplands are of interest for their location between Alpine glaciation and the Fenno-Scandinavian ice sheet (Ehlers et al. 2011, Mentlík et al. 2013). Research of these localities can bring new paleoclimatic proxies that are so far limited. The Bohemian Forest is a Hercinian central European upland situated at the border of the Czech Republic, Germany, and Austria (Fig. 1). Both past and modern research focuses mainly on i) 8 glacial cirques with lakes (Raab and Völkel 2003, Mentlík et al. 2010, Vočadlová et al. 2015) and glacial cirques without any lakes (Mentlík et al. 2010, Křížek et al. 2012), or ii) glacial landforms across the whole mountain range (Hauner et al. 2019, Krause and Margold 2019). However, the opinion about glacial type and extension is not consistent. Most of recent works (e.g. Raab and Völkel, 2003; Reuther, 2007, Mentlík et al., 2010, Vočadlová et al. 2015) argue for limited glaciation, consisting of cirque glaciers mainly on the leeward flanks, some of them advancing to relatively short (with maximum length of 3000 m) alpine glaciers. Ergenzinger (1967), Hauner (1980), Hauner et al. (2019), Krause and Margold (2019) argue for more extensive glaciation (valley glaciers with maximum length of 7000 m). We consider the solution of this discrepancy crucial for a correct paleoclimatic reconstruction, therefore, the main goal of this research is to determine which of the abovementioned hypotheses is relevant.
There is more evidence for the first hypothesis (small valley glaciers and cirque glaciers) scattered across the mountain range (Mentlík et al. 2013, Hauner et al. 2019) - sequences of distinct moraine ridges correspond to regional LGM chronology of deglaciation and development of glacially remodelled cirque floors or cirque headwalls indicate that glaciers occupied the cirques several times. On the other hand, the second hypothesis of large-scale glaciation is based on not that much convincing evidence, such as only few sedimentary outcrops and a few not too significant ridges (Ergenzinger 1967, Hauner 1980, Hauner et al. 2019). These features have not been numerically dated yet. Therefore, it is possible that they are older than the last glacial cycle. Hauner et al. (2019) presume even the Riss age of such large glaciers. The glacially modelled landforms (i.e., moraine ridges) of such age could be smoothed out by other geomorphological processes and/or could be superimposed by geliflucion covers of the LGM glaciation (Ballantyne 2002) and its surface manifestation could be only limited or none at all. Therefore, we decided to carry out a basic geophysical survey which provides non-invasive insight at the internal structure (Musset and Khan 2000, Milsom and Eriksen, 2011). We used two electrical resistivity tomography (ERT) profiles (profiles A and B in Fig. 1 and Fig. 2) to determine the borderline of the hypothetical extension of large-scale pre-Würmian glaciation (sensu Hauner et al. 2019).

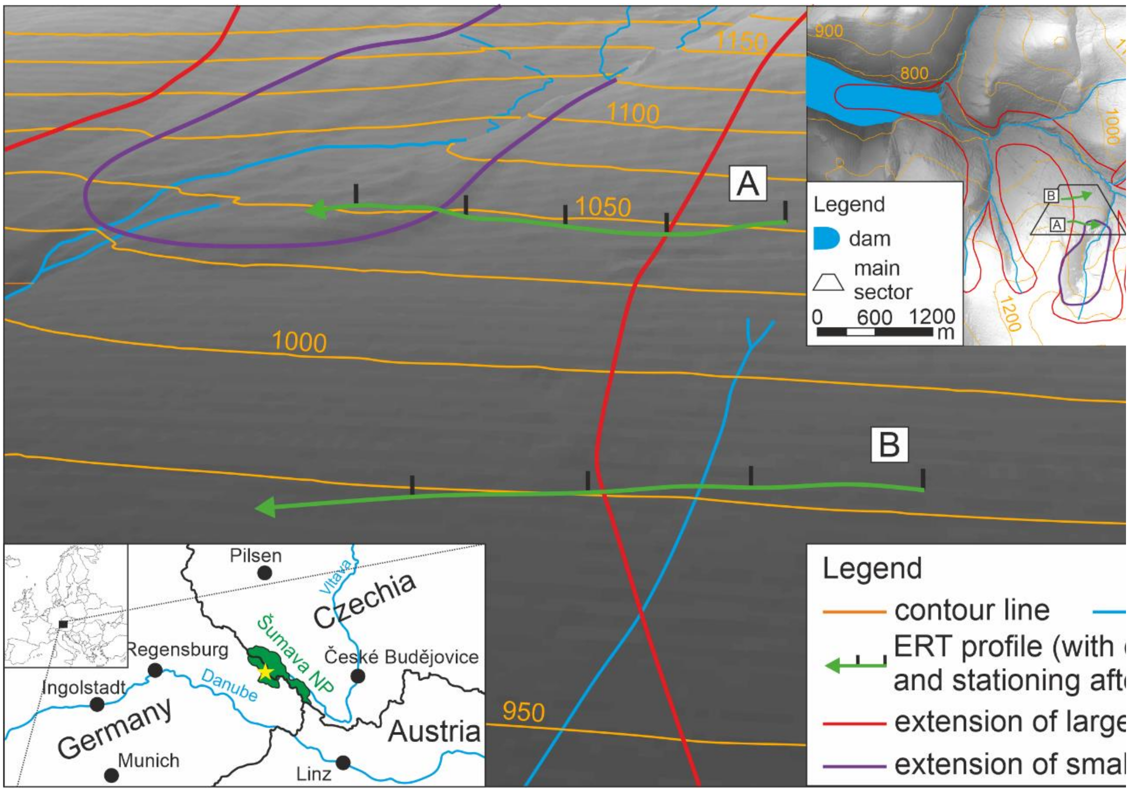

Figure 1 Morphology (data obtained by Bayerischer Wald NP management) of the studied location with the hypothetic glaciogenic sediment borderline (red line = large-scale glacier extension, purple line = smaller-scale glacier extension). The overall view of the glacier's extension presented by the two hypotheses is visible at the upper right corner. Green arrows mark the positions and directions of the geophysical profiles, and small black vertical lines display the stationing (after 80 metres) along each profile. Note that the scale of the main picture is distorted due to the representation from ArcScene. The local and regional location of the study site are visible in the smaller and smallest map at the bottom left corner, respectively. Profiles A and B are identical with the A and B profiles in Fig. 2.

The first profile (Fig. 2A) started on the slope with hypothetic non glaciogenic origin (0-85 m), continued to the 85-255 m suggested as part of the larger (and older) glaciation (sensu Hauner et al. 2019) and finished on the slope probably originated during the more limited and the youngest glaciation (255-355 m) (assumed LGM age). The sediments of hypothetic large glacier in the middle part of the profile are not morphologically significant. On the other hand, hypothetic glacigenic sediments at the end of the profile create multiple significant moraine ridges (Fig. 2A). We can find extreme resistivity bodies randomly alternating with relatively low resistivity bodies in the first part of the profile. The high resistivity body around the 80-110 m corresponds to the mapped border of the large-scale glacial extension. The shallow surface layer with lower resistivity between 180 and 230 m on the profile may indicate the previously mentioned geliflution cover. The glaciogenic sediments from 255 to 355 m are stratigraphically higher (two white dashed lines in Fig. 2A) than the hypothetic glaciogenic sediments of larger (and older) glaciation. This could point to a different age and/or different origin.
The second profile (Fig. 2B) was stretched solely on the slope without hypothetic glaciogenic sediments (0-155 m) and the slope with sediment of hypothetic large glacier (155-315 m) (sensu Hauner et al. 2019). No high resistivity bodies were found on the second profile. The

slope with sediment of hypothetic large glacier (155-315 m) is characterised by slightly higher resistivities than the first part of the profile, but subsurface conditions are not at all similar to the subsurface conditions of the slope with sediment of hypothetic large glacier on the first profile (compare the part 85-255 m in Fig. 2A with the part 155-315 m in Fig. 2B). The relatively high conductivity in the deeper parts of the profile (Fig. 2B) may be caused by the higher saturation by underground water.

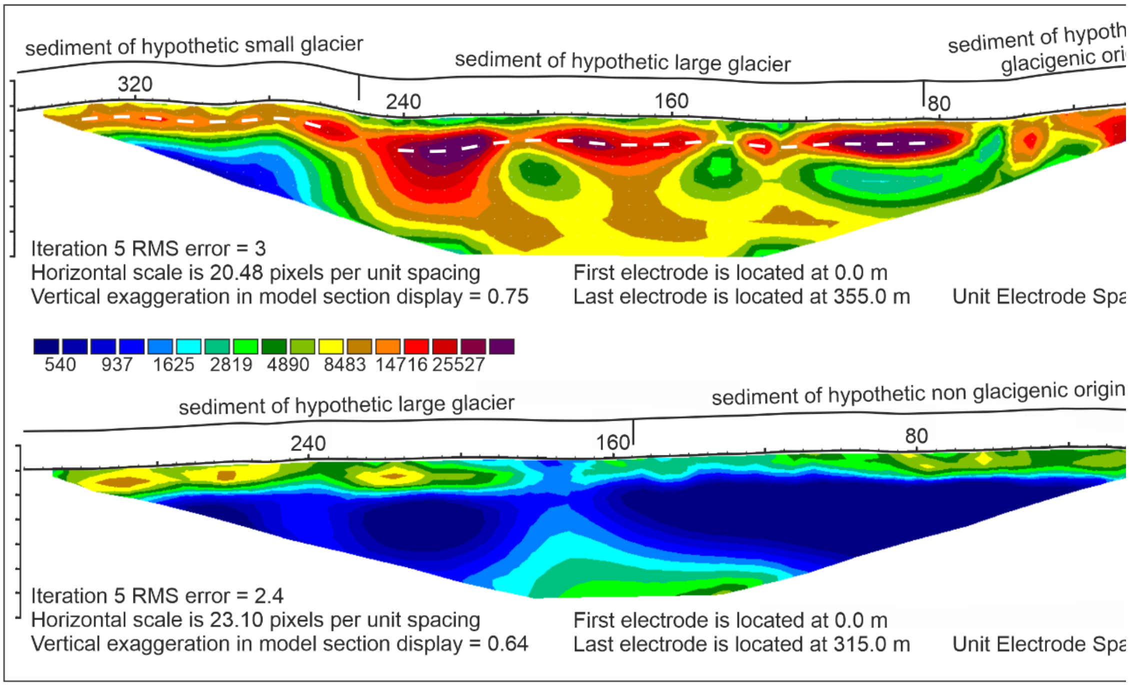

Figure 2 Two resistivity models (A, B) of different subsurface conditions. Extension of hypothetic glaciation from Hauner et al. 2019. Resistivity scale is the same for both models. The direction of both profiles is the same as in Fig. 1. Note the different subsurface resistivity characteristics for the sediment of the hypothetic large glacier in both models. The white dashed lines in Fig. 2A demonstrate the different stratigraphical positions of the high resistivity zones.

Based on the geophysical survey, we were unable to prove or exclude the idea of the larger glaciation. The high resistivity bodies in Fig. 2A may correspond to glaciogenic sediments (Mentlík et al. 2010, Engel et al. 2017), which would probably be compressed and somewhere even overlaid. The stratigraphic position of particular high resistivity zones may point to a different age. Therefore, the first geophysical profile factually confirms the hypothesis of a more extensive glaciation. In contrast, we cannot find high resistivity bodies in the second profile, therefore, we incline to a different origin of the slope. It would be very useful to pair this geophysical survey with detailed sedimentological exploration, which should clearly determine the origin of different sediments.

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