THE ORIGIN OF ROUNDED GRANITE ELEVATIONS IN THE NORTHERN FOOTHILLS OF THE JIZERA MOUNTAINS

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This paper deals with small granite elevations in the Smědá river catchment. These elevations are elongated and asymmetrically shaped, resembling roches moutonnées, but their origin is obscure. Morphometric methods were used to clarify their origin. The direction of elongation, slope angles and joint orientations were measured on each elevation. The results show that the majority of elevations (16) are elongated in the direction of the glacier advance, and that this is not predetermined by the joint system. The orientation of the gentle slope corresponds to the stoss side in 17 of 23 elevations. These results, as well as a comparison with similar sites in the Czech Republic, suggest that the elevations studied were glacially scoured and can be termed roches moutonnées.

Key words: roches moutonnées, Jizera Mountains, granite elevation

INTRODUCTION

Roches moutonnées are asymmetrical bedrock elevations, of which the smoother stoss side was exposed to glacial detersion and the lee side to glacial plucking (BENN and EVANS 1998). These landforms are usually aligned with the ice flow (LOWE and WALKER 1997), but this condition is not necessary under many definitions (BENN and EVANS 1998, GLASSER and BENNET 2004).

In the foothills of the northern slopes of the Jizera Mountains, one can find elongated asymmetrical elevations reminiscent of typical roches moutonnées (**Fig. 1**). The origin of these elevations has not been conclusively explained. KRÁLÍK (1989) regarded these formations as roches moutonnées, formed by the

Fig. 1 The elevation above Hejnice. The arrow indicates the probable ice flow direction

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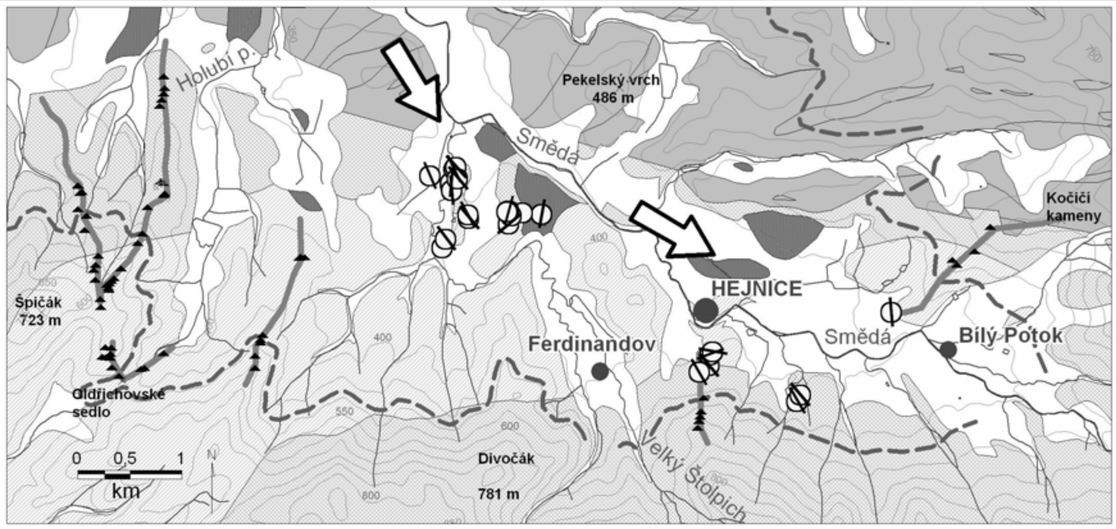
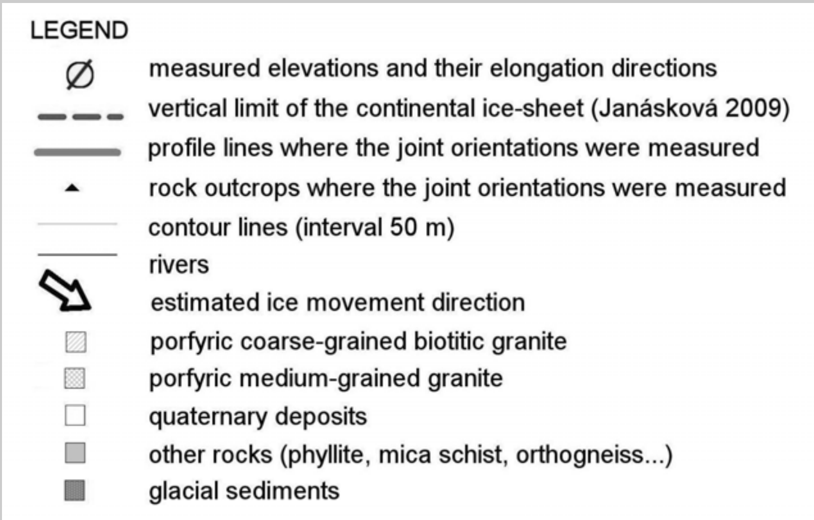


Fig. 2 Map of the study area with the measured elevations marked. Map source: Digital archive ČGS



Elster and Saale Glaciers. According to CZUDEK (2005), these are small exfoliation domes (ruwares), which developed from the beginning as asymmetric elevations; glacier modelling had practically no impact on their morphology.

A similar viewpoint is suggested even in the area of younger glaciation, where the landforms are better preserved. For instance, LINDSTRÖM (1988), who studied the landforms of the Visla glaciation, believes that roches moutonnées are a result of preglacial erosion and were glacially altered only very slightly. According to BENN and EVANS (1998, p. 326) the two points of view regarding the origin of roches moutonnée are not mutually exclusive, because there is a wide range of landforms, from those exhibiting typical glacial modelling, up to those only slightly altered by glacial erosion.

The goal of this paper is to contribute to explaining the origin of rounded elevations in the foothills of the Jizera Mountains, using measurements of their morphometric and structural properties. The basic hypothesis was as follows: If the rounded elevations are glacially modelled (or remodelled), their shape will be mostly elongated in the direction of the ice movement. If these forms are roches moutonnées, their lee side will be steeper than their stoss side, and the direction of elongation will not be predetermined by the joint system. On the contrary, if the elevations were affected by the glacier only slightly or not at all, their shape and elongation would be dependent mostly on the joint system.

THE STUDY AREA

The area of interest is limited to the granite part of the upper Smědá catchment area (**Fig. 2**). The topography in this region is very diverse. It encompasses the northern slopes of the Jizera Mountains, broken by deep erosion valleys as well as gentle foothill areas gradually descending to the recent riverbed of the Smědá River. Rounded elevations are found especially in the foothill area at altitudes under 450 m a.s.l. (**Fig. 2**).

Geologically, this region belongs to the Varis granitoid group, namely to the Krkonoše-Jizera granitoid massif. The granite is present in two types, porfyric coarse-grained biotitic granite and porfyric medium-grained granite (CHALOUPSKÝ 1989). The unific lithological composition of the studied area allows for a good comparison of the resulting measurements.

In the Pleistocene, the studied region was affected by the continental glacier, which advanced through the Frýdlant Uplands to the northern slopes of the Jizera Mountains. According to KRÁLÍK (1989) this happened in the Elster and in the older Saale glacial stage. In the area of Oldřichov Col (478 m), the glacier also affected the southern part of the mountains, the catchment of the Jeřice River (KRÁLÍK 1989 and NÝVLT 2003). There are several relics of glacigenic or glacifluvial sediments (**Fig. 2**) from both the older (Elster) and younger (Saale) glaciation (KRÁLÍK 1989) near the foothills in the studied area and along the present flow of the Smědá River.

The vertical extent of the glacier in the northern slopes of the Jizera Mountains was estimated at 560 to 600 m by CHALOUPSKÝ (1989), at 400 – 500 m by KRÁLÍK (1989), at 425 m by TRACZYK and ENGEL (2006) and at 450 – 500 m by JANÁSKOVÁ (2009). It can be deduced from these altitudes that the thickness of the glacier in the Smědá valley was around 100 m.

METHODS

Elevations protruding solitarily above the surrounding landscape were chosen for measurement. The maximum height of the measured elevations reached 6 m; the length of the longer axis was no more than 80 m. Elevations of larger sizes were not considered in this study, because the probability that they were significantly remodelled by a glacier is relatively small.

Because of their small size, the majority of the studied elevations were not noticeable on the maps or the digital relief model. They had to be mapped and measured directly in the field. The position of the elevations was recorded by GPS, and their proportions and height were measured. The methodology of VÍDEŇSKÝ et al. (2007), designed for the study of elevations in the Žulová granitic massif, was used for the following measurements:

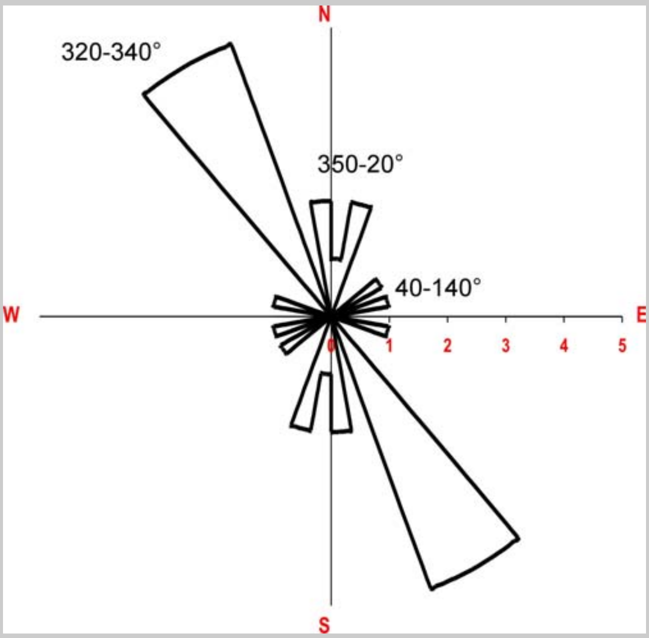


Fig. 3 Rose diagram of the elongation directions of the measured elevations

Elevation name	Altitude (m)	Elevation proportions (m)			Elevation elongation direction (°)	Estimated ice flow direction (°)	Difference in elongation direction and ice flow direction (°)	Gentler slope orientation (°)	Orientation of the gentler slope corresponds to the quadrant of ice flow	Difference in the slope angles of the stoss and lee side (°)
		length	width	height						
O-01	414	33	15	2	330	300	30	150	no, is opposite	2
O-02	422	23	10	1,0	320	300	20	140	no, is opposite	6
O-03	406	31	17	1,0	70	300	50	340	yes	5
O-04	405	25	7,5	2,0	280	300	20	280	yes	6
O-05	425	85	45	6,0	320	300	20	320	yes	4
O-06	417	60	40	6,0	330	300	30	150	no, is opposite	4
O-07	374	45	25	2,5	10	330	40	10	yes	7
O-08	367	85	80	6,0	no	330	x	360	yes	2
O-09	373	10	6	1,6	50	330	80	140	no, is opposite	11
O-10	374	45	45	3,0	no	330	x	360	yes	10
O-11	376	13	3	1,5	15	330	45	15	yes	3
O-12	382	10	5	2,5	no	330	x	no	x	x
O-13	354	55	20	1,0	355	330	25	355	yes	15
O-14	351	30	20	1,5	5	330	35	5	yes	6
O-15	365	35	20	1,5	335	330	5	355	yes	22
O-16	451	70	20	4,0	355	300	55	355	yes	11
O-17	344	34	15	1,7	337	330	7	157	no, is oposite	6
O-18	358	55	55	3,0	no	330	x	360	yes	5
O-19	329	47	25	3,0	323	330	7	323	yes	5
O-20	348	15	11	2,5	320	330	10	320	yes	9
O-21	351	60	10	3,0	332	330	2	332	yes	10
O-22	351	50	25	2,5	320	330	10	320	yes	2
O-23	340	20	8	2,5	318	330	12	318	yes	7

Tab. 1 Basic characteristics of the measured elevations

If the elevation was elongated, the direction of the longer axis was determined.

Five measurements of the slope angles on four sides of the elevation (the two in the direction of elongation and the two perpendicular to them) were taken, and then averaged. In cases where the elongation could not be determined, the slope angles were measured in the directions N, S, W, and E.

The joint orientation was measured at the elevation, if possible.

For further details about the measurement methodology please see the publication by VÍDEŇSKÝ et al. (2007).

In order to enable comparison, joint orientations were measured not only at rounded elevations, but also at additional outcrops throughout the whole study area. The outcrops were situated in six profile lines, each including a relief from the foothills up to the summits, to gain joint measurements representative of the whole slope.

To interpret the measurements, the elevations were divided into two groups according to the estimated direction of the former ice movement, which most likely varied in different parts of the study area. Based on the surrounding topography and the orientation of the valley, two ice movement directions were established: 300 and 330° (**Fig. 2, Tab. 1**). However, these are only approximate directions, which could vary significantly within the local area.

The estimated ice flow directions were compared with the orientation of the longer axis of each elevation, as well as with the angles of their slopes. The angle of the stoss side was always compared with the lee side angle. Slope angles at the elevations were measured only in four directions, therefore each slope oriented in the quadrant of estimated ice flow direction (the estimated direction of ice movement ± 45°) was regarded as the stoss side. For instance, if some elevations were elongated in a direction other than that of the ice movement

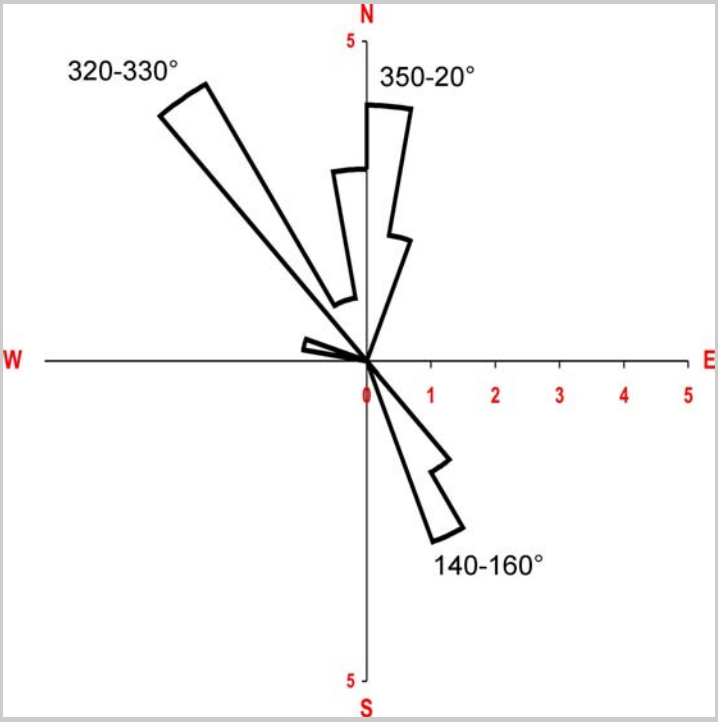


Fig. 4 Rose diagram of the orientation of gentler slopes at the measured elevations

quadrant, the angles of their shorter slopes were compared.

RESULTS

THE ELONGATION DIRECTIONS OF THE ELEVATIONS

Measurements were taken at a total of 23 elevations (**Fig. 2, Tab. 1**). Nineteen of them were elongated, while the remaining four do not have a longitudinal form. The directions of elongation are depicted in a rose diagram (**Fig. 3**) and a map (**Fig. 2**). The direction 320 – 340° clearly dominates; only a smaller portion (5) of the elevations are elongated in the direction 350 – 20°. On the other hand, the elevations are elongated only rarely in the wide interval 40 – 140°.

A comparison of the elongation directions with the estimated ice movement direction (**Tab. 1**) shows that 10 of the 19 elongated elevations deviate from the ice direction by less than 20°. A total of 16 elevations show a deviation of less than 45°. Only three elevations differ profoundly from the ice movement direction. However, if we consider the whole quadrant (±45°), 50 % of the data belongs here out of mere statistical probability. Even so, the measured elevations are clearly more often elongated in the estimated direction of ice movement.

THE SLOPE ANGLES

An evaluation of the orientation of the gentler slopes is depicted in **Fig. 4.** The gentler slopes are most often oriented in a direction of 320 – 330°, and also 350 – 20°. A smaller number (5 elevations) have gentler slopes oriented at 140 – 160°, which is exactly opposite to the prevailing direction. At the O-01, O-02 and O-06 elevations, a gentle slope on the lee side could be caused by the elevation's position in the slope. All three elevations are found in the 15° slope south of Hejnice. The lee side of the elevations ties together with the continuing slope and is therefore not pronounced. Even if they were glacially scoured, these three elevations would probably have an atypical shape.

The orientation of the gentler slope corresponds to the quadrant of ice movement (stoss side) in 17 elevations, or 74 % of the total of 23. Furthermore, the elevations situated in the slope represent another three cases of possible glacier modelation. Consequently, only three remaining elevations have slope angles which don’t correspond to the roches moutonnée morphology. However, it is necessary to point out again that 50 % of the elevations would have a steeper lee side just through statistical probability.

Differences in the slope angles of the stoss and lee sides of the elevations are significant, more than 7° on average. Elevations with a gentler stoss side show a greater difference in

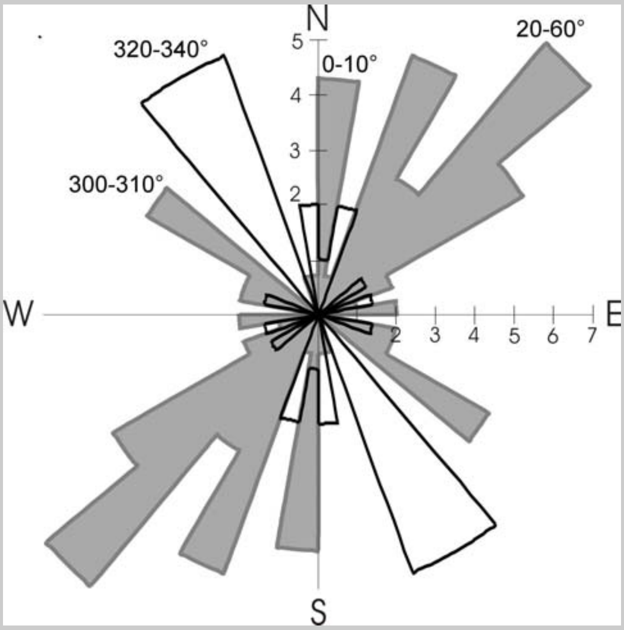


Fig. 5 Rose diagram showing the direction of elongation of the measured elevations (black outline, vertical axis) and direction of the joint planes on the measured elevations (grey, horizontal axis)

slope angles (7.6° on average) than elevations with a gentler slope on the lee side (5.6° on average).

Joint orientation measurements

Altogether, 98 measurements of joint planes orientation have been taken at the studied elevations. The measurement results are shown in **Fig. 5** (grey areas). Especially prevalent are the directions 20 – 60°, followed by 0 – 10° and 300 – 310°. The rounded elevations themselves unfortunately do not afford enough exposed joints for measurement.

As a result, more measurements have been taken at rock outcrops on the whole granitic northern slope of the Jizera Mountains. At the six profiles mentioned earlier, 562 joint orientation measurements were taken. The results are shown in **Fig. 6** (grey areas). The directions 20 – 60° and 290 – 320° are prevalent. With the exception of the northern direction (0 – 10°), the orientation of joints at the measured elevations is the same as in the whole study area.

For purposes of comparison, the joint orientation (grey) was shown in **Fig. 5 and Fig. 6** together with the elevation's direction of elon-

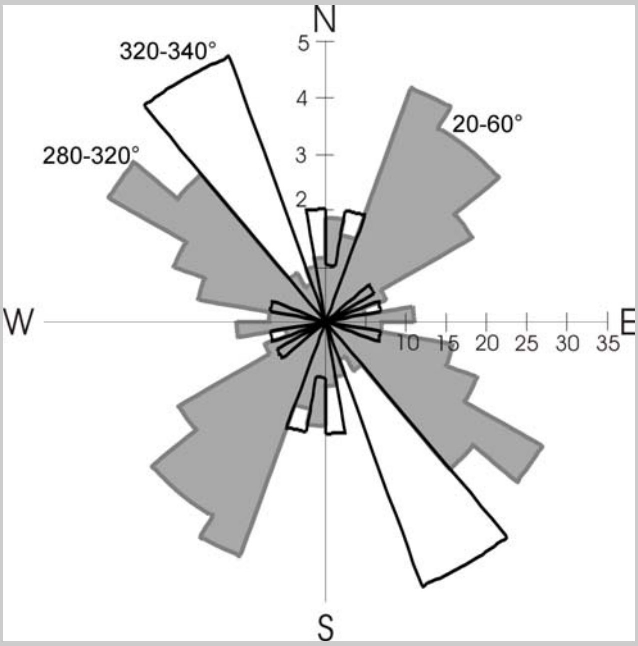


Fig. 6 Rose diagram showing the direction of elongation of the measured elevations (black outline, vertical axis) and direction of the joint planes in the whole northern slope of the Jizera Mountains (grey, horizontal axis)

gation (black outline). It can be seen in both cases that the elevations are elongated in directions which are different than the joint directions. According to these results the elongation of the measured elevations is not predetermined by the joint system.

DISCUSSION

Origins of the studied elevations

If we compare the results obtained to the hypothesis in the introduction, a total of 13 out of 23 elevations meet both characteristics of glacially modelled roches moutonnée – their stoss side is gentler and they are elongated in the quadrant of glacier movement, yet this direction is not predetermined by joints. Seven measured elevations meet at least one of these characteristics. Only three elevations do not meet the definition of roches moutonnée at all.

We could also consider some elevations to be whalebacks, which in contrast to roches moutonnée have lee sides that are not plucked and are approximately symmetrical with the stoss side. (ROBERTS and LONG 2005, BENN and EVANS 1998, p. 326). According to EVANS (1996), whalebacks typically form under a thick ice sheet – generally several hundred meters. It is therefore reasonable to suggest that roches moutonnée rather than whalebacks occur in the study area, even though some elevations can resemble whalebacks in shape.

If we consider those elevations for which the difference between the stoss and lee slope angle is 5° or less to be approximately symmetrical, then there are nine such elevations in the sample. The majority of them, 14 elevations, have asymmetrical shapes. According to JOHANSSON et al. (2001), the asymmetry of elevations is not a criterion for plucking on the lee side, and by itself does not prove glacial mode-lling. However, even the originally typical morphology of plucked lee sides could have been completely obliterated in our study area during the long period of post-glacial weathering. This fact not only prevents us from reliably distinguishing between roches moutonnées and whalebacks, but also makes the identification of roches moutonnée themselves very difficult. The difference between the lee and stoss slope angle can therefore be used as just one more studied characteristic. It has to be assumed that the elevation's asymmetry was caused by glacial plucking.

The next question is whether the elevations were formed by glacial erosion or just remodelling. The pre-glacial topography in the study area is not precisely known, although it controls the effects of glacial erosion and the shape of the landforms (LINDMAR-BERGSTRÖM 1997, JOHANSSON et al. 2001, LINDSTRÖM 1988). JOHANSSON et al. (2001) emphasizes that a flat relief cannot be reshaped by glacial erosion into an undulating terrain, but rather the erosion can only reshape already existing hills. It is therefore likely that small

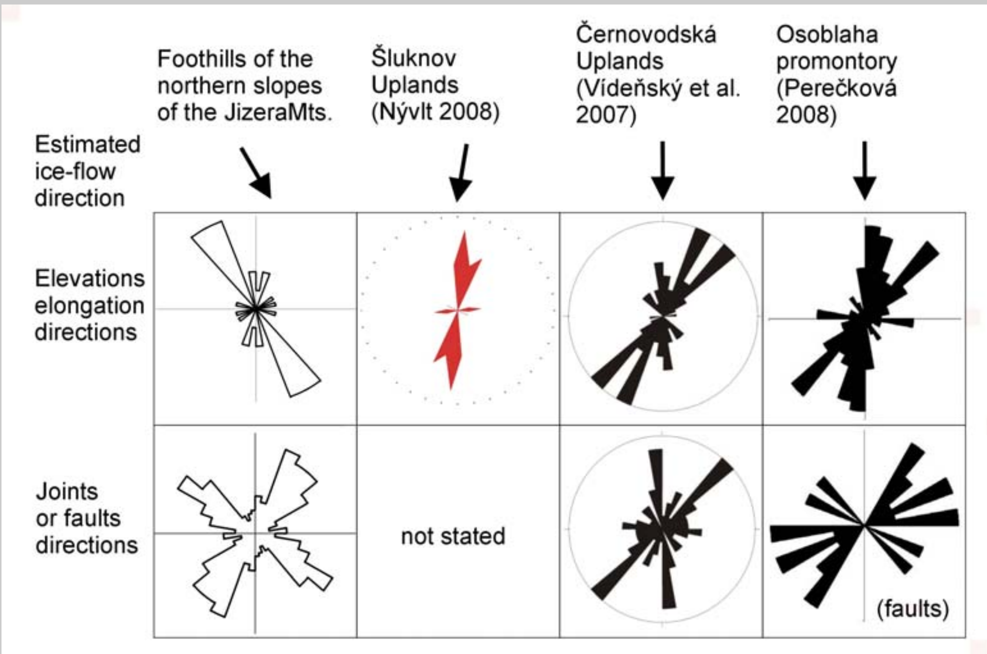


Fig. 7 Rose diagrams showing the directions of elevation elongations in comparison with joint or fault directions at four locations in the Czech Republic

elevations existed in the study area before glaciation. These landforms were subsequently remodelled by the glacier.

The results show that none of the elevations are elongated in a 300° direction, which was one of the suggested former ice movement directions. Nevertheless, this fact is not important for our interpretation, because the real direction of ice movement is unknown and the suggested directions were only indicative. If the direction of ice movement in the study area was 330° instead, the elongation of elevation O-04 would differ from that direction by more than 50°. Otherwise, the elongation direction of the other four elevations would correspond much more precisely than the current calculation suggests.

Any evaluation of results must take into account the fact that most of the measured elevations were affected by anthropogenic interference in the past. Many rock outcrops in the foothills of the Jizera Mountains were formerly used by the local denizens as a source of construction stone, and some of the outcrops were partially altered by quarrying. Even though the greatest effort has been made to account for these anthropogenic influences, some distortion of the slope angle measurements cannot be completely ruled out.

In addition, measuring was performed on a relatively small sample of 23 elevations. This number was determined by limiting the study area to the granite part of the northern slopes and foothills of the Jizera Mountains. In order to obtain data from more elevations, it would have been necessary to widen the study area, for example, to include the whole region of Frýdlant Uplands; however, this would have added a lithological variation factor. Collection and comparison of data from the wider area of the Frýdlant Uplands represents one possibility for further research.

It remains a controversial point: for how many elevations, and to what degree, must the measured morphological characteristics correspond with the definition of roches moutonnée in order to prove their glacial modelation? The answer to this problem lies partly in a comparison with other similar regions.

COMPARISON WITH OTHER REGIONS IN THE CZECH REPUBLIC

Attention is currently being given to rounded elevations in other regions of the Czech Republic which were affected by continental glaciation. A paper about elevations in the Černovodská Uplands (part of the Žulovská Uplands) was published by VÍDEŇSKÝ et al. (2007). They took measurements at a total of 39 elevations of medium-grained granite bedrock. Their research was based on estimated ice movement from the north, and they used the whole quadrant of 315 – 45° for comparison with the elevation elongation. When compared, 19 out of 39 elevations, almost exactly one half, exhibited gentler sloping in the northern quadrant. They found a strong correlation between elevation elongations and the joint system: a direction of 20 – 50° was prevalent in both cases (**Fig. 7**). Based on the collected data, the authors (VÍDEŇSKÝ et al. 2007) conclude that the measured elevations are irregularities of the basal weathering surface, as previously suggested by IVAN (1983). Given the complex geomorphologic situation and the finding of Nordic rocks, they assume that the measured elevations were under a thick rock mantle during the glacial period and were exposed later, which means they have never had any contact with the glacier.

The conclusion of this paper is important for a comparison with elevations in the northern foothills of the Jizera Mountains. The Černovodská Uplands represent a region which is lithologically and morphologically very similar to our study area. The research provides detailed data, extracted through the same methodology used for those elevations which were not affected by glacial erosion. The measurements clearly show that if the elevations are not glacially modelled, their elongation corresponds to the joint system, and the distribution of gentler slopes in the stoss and lee quadrants does not exceed the probability values. Seen in this light, the elevation morphology in the foothills of the Jizera Mountains shows glacial modelation more clearly.

Another area where similar elevations were studied is the Osoblaha promontory. Measurements were taken there by PEREČKOVÁ (2008) using the VÍDEŇSKÝ et al. (2007) methodology. She measured morphological characteristics of a total of 82 elevations, situated on various types of bedrock. The measurements suggest that the elevations are elongated primarily in the 0 – 20° direction, as well as the 40 – 50° direction (**Fig. 7**). The gentler slopes are most often oriented in a similar direction (0 –10° and 40 – 50°). Unfortunately, PEREČKOVÁ (2008) did not perform any joint measurements; she uses the fault directions or ridge positions in the surrounding topography to estimate structural predispositions. The author defined four elevation groups according to location. In two of the groups, most elevations fulfill at least one of the criteria for roches moutonnée. The remaining groups do not match these requirements very closely, which the author explains by structural predisposition and the altitude, at which the ice was not very thick. PEREČKOVÁ (2008), however, does not state a clear conclusion about the origins of the elevations.

A comparison of measurements from the foothills of the Jizera Mountains with those in the PEREČKOVÁ (2008) paper is interesting, mainly in regard to the elongation directions. Similarly to VÍDEŇSKÝ et al. (2007), she found that the northeastern direction dominated, with a smaller proportion of southern directions. By contrast, in the foothills of the Jizera Mountains the northeastern direction is completely missing in the elevation elongations, whereas the direction 320 – 340°, consistent with presumed ice movement, prevails.

From a structural predisposition viewpoint all three areas are comparable, even though the rocks are different in the Osoblažsko area. The results of the joint direction measurements (VÍDEŇSKÝ et al. 2007) agree with the directions determined in the study area in the Jizera Mountains. The directions of local faults, used by PEREČKOVÁ (2008), have a significant northeastern component, which affects the elevation elongation. In the foothills of the Jizera Mountains this northeastern joint direction is strongly present not only on the whole slope, but even more significantly at the measured elevations. The absence of this direction in elevation elongations can be explained according to the results obtained by glacial modelation.

Rounded elevations were also the subject of research by NÝVLT (2008) in the Šluknov Upland. In his paper he presents the elongation directions of 25 elevations of granodiorite and granite bedrock (**Fig. 7**). In his evaluation the author admits that the elevation elongation directions correspond to the ice movement, a fact which is proven by the clast orientation in the subglacial till (185 – 205°) in the eastern part of the Šluknov promontory. However, at the same time the author points out the correspondence with the direction of the faults and emphasizes the possibility of the structural predispositions of elevation orientations.

In the same paper, NÝVLT (2008) presented the results of radiometric dating using cosmogenic nuclides, which helped to date the deglaciation to about 606 ka BP. Based on radiometric dating of three rounded elevations, he derived the erosion rate of elevation surfaces to be 16.9 ± 4 m/Ma, which means the terrain has been lowered by 10.3 ± 2.4 m since deglaciation. Areal denudation was so high, according to these data, that the current surface of the measured elevations did not come into direct contact with the glacier; this basically disproves the glacial origin of these landforms.

According to data from other authors, the values of areal denudation of granite bedrock are much lower, most often 1 – 2 m/Ma (PHILLIPS et al. 2006, ANDRÉ 2002 and BIERMAN et al. 1999). At such low values of areal denudation a glacier surely could have modelled the current surface. However, the real denudation rate for the study area remains unclear.

CONCLUSION

Based on measurements taken from 23 elevations in the foothills of the northern slopes of the Jizera Mountains, the following was found: a total of 16 out of 19 elevations are elongated in a quadrant of the presumed ice movement. Nevertheless, the directions of elevation elongations do not correspond to the prevailing directions of the rock joints, and thus are not structurally predetermined. Gentle slopes form the majority (17 out of 23) of the measured elevations oriented in the direction of the suggested ice movement quadrant.

As the collected data suggest, the shape of most of the measured elevations shows characteristics of roches moutonnée. This cannot be explained by structural control. It is therefore very probable that these elevations (most likely of pre-glacial origin) were glacially modelled and hence can be called roches moutonnées.

This conclusion was supported by a comparison with other regions, especially with the Černovodská Upland, where the elevations were not affected by a glacier (VÍDEŇSKÝ et al. 2007). The shape of those elevations is completely controlled by the structure, which contrasts with the observed properties of the elevations in the foothills of the northern slopes of the Jizera Mountains.

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REFERENCES

ANDRÉ, M-F. (2002). Rates of postglacial rock weathering on glacially scoured outcrops (Abisko-Riksgränsen area, 68°N). *Geografiska Annaler*, 84 A, 3 - 4, 139 – 150.

BENN, D., EVANS, D. (1998). *Glaciers and Glaciation*. Arnold Publishers, London, 734 p.

BIERMAN, P. R., KIMBERLY, A. M., PATTERSON, C., DAVIS, P. T., CAFFEE, M. (1999). Mid-Pleistocene cosmogenic minimum-age limits for pre-Wisconsinan glacial surfaces in southwestern Minnesota and southern Baffin Island: a multiple nuclide approach. *Geomorphology*, 27, 1 – 2, 25 – 39.

CHALOUPSKÝ, J. (1989). *Geologie Krkonoš a Jizerských hor*. UUG, AV ČR, Praha, 288 p.

CHALOUPSKÝ, J., KRÁLÍK, F. (2001). *Geologická mapa. List 03-14 Liberec*. ČGS, Praha.

CZUDEK (2005). *Vývoj reliéfu krajiny České republiky v kvartéru*. Moravské zemské muzeum, Brno, 238 p.

EVANS, I. S. (1996). Abraded rock landforms (whalebacks) developed under ice streams in mountain areas. *Annals of Glaciology*, 22, 9 – 16.

GLASSER, N. F., BENNETT, M. R. (2004). Glacial erosional landforms: origins and significance for paleoglaciology. *Progress in Physical Geography*, 28, 1, 43-75.

IVAN, A. (1983). Geomorfologické poměry Žulovské pahorkatiny. *Zprávy Geografického ústavu ČSAV*, 20, 4, 49-69.

JANÁSKOVÁ, B. (2009). Reconstruction of the continental glaciation in the northern slope of the Jizera Mountains. *Sborník geologických věd - Antropozoikum*, in print.

JOHANSSON, M., OLVMO, M., LINDMAR-BERGSTRÖM, K. (2001). Inherited landforms and glacial impact of different palaeosurfaces in southwest Sweden. *Geografiska Annaler*, 83 A, 1-2, 67-89.

KRÁLÍK, F. (1989). Nové poznatky o kontinentálních zaledněních severních Čech. *Sborník geologických věd – Antropozoikum*, 19, 9 – 74.

LINDMAR-BERGSTRÖM, K. (1997). A long-term perspective on glacial erosion. *Earth Surface Processes and Landforms*, 22, 3, 297 – 306.

LINDSTRÖM, E. (1988). Are roches moutonnées mainly preglacial forms? *Geografiska Annaler*, A70, 4, 323 – 331.

LOWE, J. J., WALKER, M. J. C. (1997). *Reconstructing Quaternary Environments*. 2nd edition, Longman, Harlow, 446 p.

NÝVLT, D. (2003). Geomorphological aspects of glaciation in the Oldřichov Highland, Northern Bohemia, Czechia. *Acta Universitatis Carolinae*, *Geographic*a, 35, Suppl., 171-183.

NÝVLT, D. (2008*). Paleogeografická rekonstrukce kontinentálního zalednění Šluknovské pahorkatiny*. Dizertační práce, Přírodovědecká fakulta UK, Praha, 103 p.

PEREČKOVÁ, N. (2008). *Geneze a morfometrie oblíkovitých forem reliéfu v Osoblažském výběžku*. Bakalářská práce, Přírodovědecká fakulta MU, Brno, 42 p.

PHILLIPS, W. M., HALL, A. M., MOTTRAM, R., FIFIELD, K., SUGDEN, W. M. (2006). Cosmogenic 10Be and 26 Al exposure agens of tors and erratics, Cairngorm Mountains, Scotland: Timescales for the development of classic landscape of selective linear glacial erosion. *Geomorphology*, 73, 3 – 4, 222 – 245.

ROBERTS, D. H., LONG, A. J. (2005). Streamlined bedrock terrain and last ice flow. Jakobshavns Isbrae, West Greenland: implications for ice stream and ice sheet dynamics. *Boreas*, 34, 1, 25 – 42.

TRACZYK, A, ENGEL, Z. (2006). Maximální dosah kontinentálního zalednění na úpatí Ořešníku a Poledníku v severním svahu Jizerských hor. *Geografie – Sborník ČGS*, 111, 2, 141 – 151.

VÍDEŇSKÝ, A., NÝVLT, D., ŠTĚPANČÍKOVÁ, P. (2007). Příspěvek k otázce vzniku granitoidních elevací v západní části Černovodské pahorkatiny, žulovský batolit. *Geologické výzkumy na Moravě a ve Slezsku v roce 2006*, 35 – 39.