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Morphology, Sorting and Microclimates of Relict Sorted Polygons, Krkonoše Mountains, Czech Republic

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ABSTRACT

The influence of past microclimates on the morphology and distribution of clasts is considered for relict large-scale sorted polygons in the Krkonoše Mountains (Czech Republic). Sixty-two sorted polygons with an average length of 194 cm and an average height of 21.5 cm were measured at four sites on Mt Luční hora, at elevations of 1455 to 1555 m asl. The polygons consist of tabular clasts with a mean length of 11 cm at the borders and 5 cm in the interiors. Smaller polygons are better sorted because of the shorter distances for the clasts to reach their borders. Polygons with greater relative height are better sorted due to more intensive slope processes associated with differential frost heaving. Better sorted and more domed polygons at higher altitudes suggest more severe and longer-lasting microclimates suitable for the development of sorted polygons. The altitudinal gradient in polygon morphology and sorting suggests the dominant role of microclimate in the periglacial environment of the summit area of the Krkonoše Mountains during the Last Glacial/Holocene period. Polygon development probably involves positive feedback between morphology and frost susceptibility, driven by microclimate. The proposed method for evaluating frost sorting allows for rapid non-invasive assessment of sorting using modern methods including high-resolution remote sensing (especially terrestrial photogrammetry). Copyright © 2013 John Wiley & Sons, Ltd.

KEY WORDS: sorted polygons; frost sorting; morphometry; Krkonoše Mountains; central Europe

INTRODUCTION

The development of periglacial patterned ground is related to freeze-thaw cycles, the frequency and/or intensity of which is determined by regional climatic factors and site-specific factors that influence the local microclimate, such as relief, lithology, snow cover, drainage and vegetation (Washburn, 1979; Harris, 1982; Ballantyne, 2007). Prevailing wind flow is also important as it produces uneven spatial distribution of snow cover, which generates different thermal and moisture regimes (Seppälä, 2004), and therefore influences the spatial distribution and morphology of patterned ground (e.g. Luoto and Hjort, 2004, 2006; Hjort and Luoto, 2006; Grab *et al*., 2009; Treml *et al*., 2010; Feuillet *et al*., 2012). Thus, patterned ground provides a geoindicator (André, 2009) that is sensitive to climate and environmental changes (e.g. Ballantyne and Matthews, 1982, 1983; Haugland, 2004, 2006).

The occurrence, activity or morphology of sorted patterned ground in relation to environmental conditions has been studied more frequently than the arrangement of clasts (e.g. Ballantyne and Matthews, 1982, 1983; Van Vliet-Lanoë, 1991; Kling, 1998; Matthews *et al*., 1998; Holness, 2003; Haugland, 2004, 2006; Luoto and Hjort, 2004, 2006; Hjort and Luoto, 2006; Treml *et al*., 2010; Feuillet, 2011; Feuillet *et al*., 2012; Feuillet and Mercier, 2012). For sorted circles (Harris, 1990; Grab, 1997, 2002; Kling, 1997; Holness, 2003), sorted polygons (Ballantyne and Matthews, 1983; Grab, 1997), sorted nets (Dąbski, 2005), sorted stripes (Nelson, 1982) or circle-stripe transitional forms (Sumner, 2004), most researchers have described the orientation or size distribution of clasts, but neglected the variability in clast arrangement relative to environmental conditions (Ballantyne and Matthews, 1983) or patterned-ground morphology (Kling, 1997), although the clast arrangement (as a manifestation of frost sorting) is closely related to the origin of sorted patterned ground. Clast arrangement in large-scale sorted polygons is unknown.

The aims of this paper are: (1) to determine the relations between relict large-scale sorted polygon morphology and clast distribution in the Krkonoše Mountains; (2) to determine

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the extent to which the morphology and clast distribution of the polygons were influenced by past microclimates; and (3) to present palaeoenvironmental evidence from the periglacial environment of the summit area of the Krkonoše Mountains during the Last Glacial/Holocene period.

STUDY AREA

The Krkonoše Mountains, on the border of the Czech Republic and Poland (Figure 1), are a Hercynian mountain range with planation surfaces at elevations of 1300–1555 m asl (Kunský, 1948) built by crystalline rocks (Chaloupský *et al*., 1989). The study area is located on Mt Luční hora (1555 m asl; 50°43’40"N; 15°40’57"E), close to the highest peak of the Krkonoše Mountains, Mt Sněžka (1602 m asl).

The current mean annual air temperature in the highest parts of the Krkonoše Mountains ranges from 0 to 2 °C (Mt Sněžka 1961–2000: 0.1 °C; Głowicki, 1997) and mean annual precipitation is up to 1500 mm (Jeník and Sekyra, 1995). Sorted patterned ground in the Krkonoše Mountains, including the studied sorted polygons on Mt Luční hora (Figure 2), is considered to be mostly inactive (Sekyra, 1960; Křížek *et al*., 2010). Only the sorted circles at the top of Mt Luční hora and in the Modré sedlo Saddle are active (Sekyra and Sekyra, 1995; Křížek, 2007). The sorted polygons in the Krkonoše Mountains were most likely formed during the Last Glacial period (Sekyra and Sekyra, 1995; Traczyk and Migoń, 2000; Sekyra *et al*., 2002) in the presence of permafrost (Jahn, 1977; Czudek, 2005). The study area is above the Holocene alpine timberline (Treml *et al*., 2008).

The sorted polygons studied on Mt Luční hora are 1455 to 1555 m asl, on slopes of up to 2° (Figure 1). They occur on westerly oriented cryoplanation terraces (Figure 1) on homogeneous quartzite bedrock covered by coarse sand to gravel regolith (Treml *et al*., 2010) of low frost susceptibility (*sensu* Beskow, 1935). These sites were influenced by strong westerly winds in the Last Glacial period and the Holocene (Jeník and Sekyra, 1995), as indicated by glacial cirques and snowfields leeward of the summit plateaus (Migoń, 1999). Even today these sites experience severe climatic conditions (Sekyra *et al*., 2002). Higher altitudes of Mt Luční hora are exposed to strong westerly winds which cause thinner snow cover and earlier snow melting and promote deeper ground freezing and intensive freeze-thaw cycles (Harčarik, 2002; Sekyra *et al*., 2002; Table 1). Thus, the distribution and morphology of periglacial landforms in the Krkonoše Mountains during the Last Glacial period and the Holocene were controlled by similar factors as today (Křížek *et al*., 2010), which allows us to consider altitude as a proxy measure of past microclimate.

MATERIAL AND METHODS

Morphometric Characteristics

Sixty-two randomly selected sorted polygons in the summit area (LH A – sites LH A1, LH A2, LH A3) and on the northwestern slope of Mt Luční hora (LH B; Figure 1) were studied.

The sorted polygons were characterised by length (L), width (W) and height (H) (Figure 3). The length of a sorted polygon refers to the greatest horizontal dimension. The width corresponds to the direction perpendicular to the length axis and

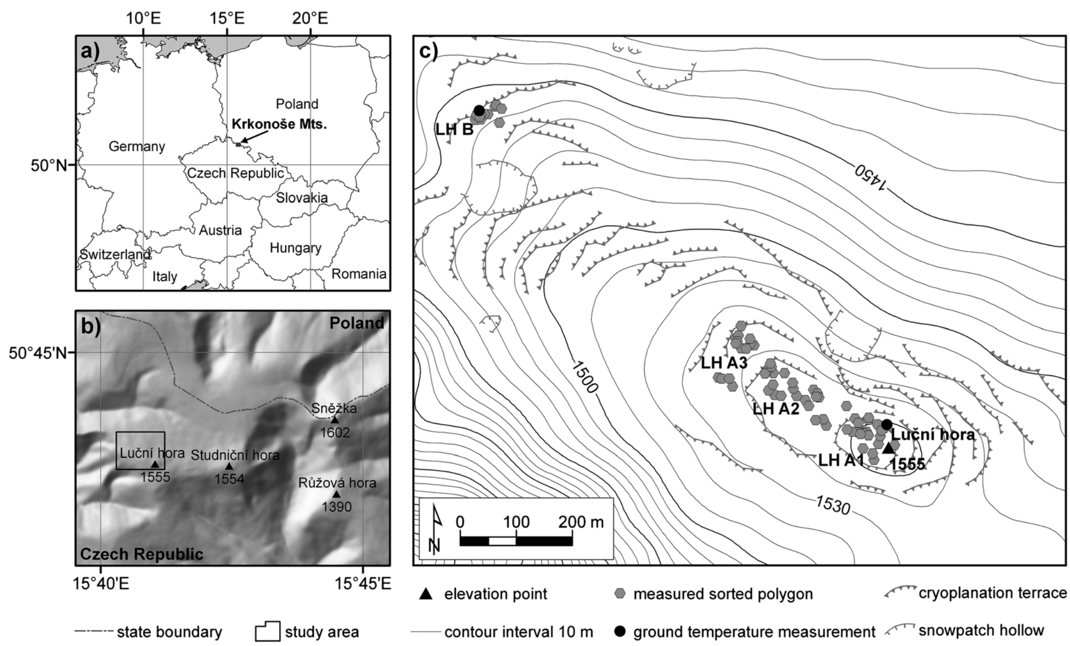

Figure 1 Location of (a) the Krkonoše Mountains; (b) the study area; and (c) the study sites (LH A1, LH A2, LH A3, LH B) with spatial distribution of relict sorted polygons and ground temperature measurements.

Figure 2 (a) Sorted polygons on a cryoplanation terrace of Mt Luční hora; (b) detailed view of a sorted polygon at the top of Mt Luční hora.

Table 1 Maximum snow-cover thickness and ground thermal regime at 15-cm depth within sorted polygons on the top (LH A), and at the lowest (LH B) site, of Mt Luční hora in the winter of 2010–11.

Site characteristics	LH A	LH B
Altitude (m asl)	1555	1455
Maximum snow cover thickness (cm)	21	47
Days with minimum temperature $<0\,°C$	182	154
$0\,°C$-crossing cycles	21	15
Minimum temperature (°C)	-8.9	-7.4
Freezing degree-days (*sensu* Kade *et al*., 2006)	497.3	332.6

crosses the centre of the polygon. The height of a sorted polygon corresponds to the difference between the lowest point on the border and the up-domed centre of the landform. The elongation index (L/W) represents the ratio of the length to the width of a sorted polygon. The relative height (H/W) (Treml *et al*., 2010) is the ratio of the height to the width of a sorted polygon.

Size and Shape of the Clasts

The size of ten randomly chosen clasts greater than 10 mm in the a-axis (the longest axis; Hubbard and Glasser, 2005) was measured at the centre of the sorted polygon (C), on the borders (B), and at one-third (1/3) and two-thirds (2/3) of the distance from the border to the centre along the length and width axes (Figure 3). In total, 7740 clasts from 62 sorted polygons were analysed.

The mean clast size ($\bar{a}$) of a sorted polygon was determined as the arithmetic mean of the lengths of the clasts located on the borders and at the one-third and two-third positions. The centres were excluded from the calculation because some sorted polygons were partly overgrown with vegetation.

In 12 of the studied sorted polygons, the dimensions of all three orthogonal axes of clasts were measured (a – the longest, b – the middle, c – the shortest; Hubbard and Glasser, 2005). These values were used to describe the clast shape, which was subsequently analysed using the TRI-PLOT spreadsheet

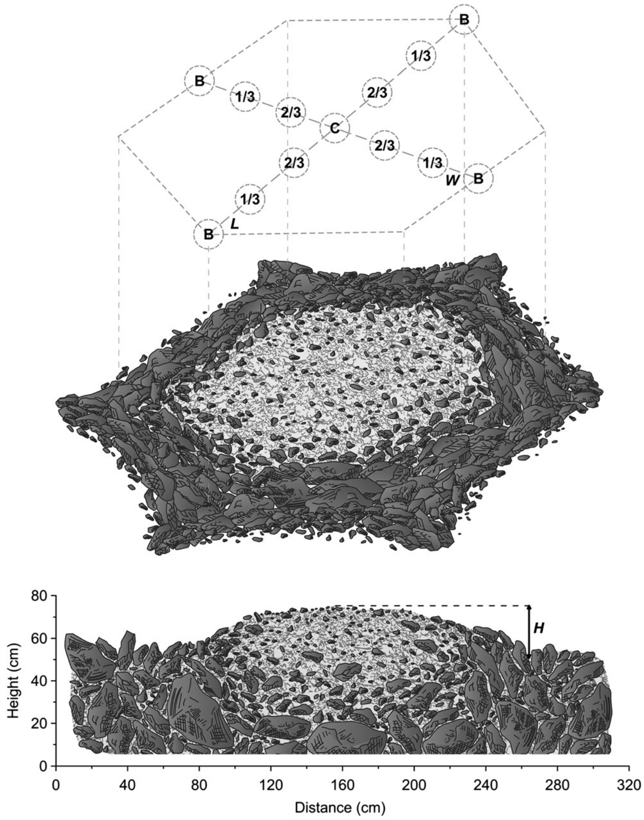

Figure 3 Measured characteristics of a sorted polygon: L = length; W = width; H = height; B = measured a-axis of ten randomly chosen clasts on the border of a polygon; 1/3 = measured a-axis of ten randomly chosen clasts at one-third of the distance from the border to the centre; 2/3 = measured a-axis of ten randomly chosen clasts at two-thirds of the distance from the border to the centre; C = measured a-axis of ten randomly chosen clasts at the centre of the polygon.

(Graham and Midgley, 2000) and classified according to Sneed and Folk (1958).

Sorting Degree

All evaluated sorted polygons had to have similar-sized clasts at the corresponding (border or one-third or two-third) positions on the length and width axes, respectively, to preclude errors in the sorting indices due to processes unrelated to frost sorting.

The sorting index (SI) represents the degree of clast segregation according to size. The index value is proportional to the size difference between the clasts from the border and those from the interiors. The SI for single parts of the sorted polygons is defined as the ratio of the mean clast size on the border ($\bar{a}_B$) and at the one-third ($\bar{a}_{1/3}$) or two-third ($\bar{a}_{2/3}$) positions (i.e. for one-third ($SI_{1/3} = \bar{a}_B/\bar{a}_{1/3}$) and for two-thirds ($SI_{2/3} = \bar{a}_B/\bar{a}_{2/3}$)).

A total sorting index (TSI) was formulated to characterise the total sorting of a sorted polygon:

$$TSI = \frac{\overline{a}_B}{\overline{a}} / \frac{\overline{a}_{1/3}}{\overline{a}} / \frac{\overline{a}_{2/3}}{\overline{a}} = \frac{\overline{a}_B \cdot \overline{a}}{\overline{a}_{1/3} \cdot \overline{a}_{2/3}}.$$

The SI is more appropriate for relict sorted polygons than comparisons of the percentage weight of single grain size fractions (e.g. Ballantyne and Matthews, 1983; Grab, 1997) because its calculation excludes fine-grained fractions modified by Holocene pedogenesis (e.g. Haugland, 2004, 2006) and wind action (e.g. Grab, 1997; Matthews *et al.*, 1998; Sekyra *et al.*, 2002) after patterned-ground activity had ceased.

Statistical Analysis

The parameters above were tested for normality using the Shapiro-Wilk test (Shapiro and Wilk, 1965), and a log transformation was applied to the parameters H, H/W, $\bar{a}$, $SI_{1/3}$, $SI_{2/3}$ and TSI in order to meet the criterion of normality (Meloun *et al.*, 2005). Relationships between the parameters were analysed by the Pearson correlation coefficient and a t-test. Differences between the climatically most exposed and least exposed sites were assessed by one-way ANOVA and F-tests. Confidence levels for the t-tests and F-tests were p = 0.05. Statistical operations were performed using the software STATISTICA (StatSoft, Inc., 2009).

RESULTS

Polygon Size and Morphology

The polygons are on average 194 cm long, 21.5 cm high and slightly elongated (mean elongation index = 1.33). Their distribution can be grouped by altitude (which reflects climatic severity) into sorted polygons at the top of Mt Luční hora (LH A – sites LH A1, LH A2, LH A3), with greater microclimatic severity, and those on the lowest cryoplanation terrace (LH B), with less severe microclimates (Table 1).

Mean polygon width is significantly smaller atop Mt Luční hora, whereas relative height and the elongation index have significantly larger values than for polygons at lower elevation (Table 2). Larger sorted polygons are higher and formed from larger clasts (Table 3). Larger sorted

Table 2 Comparison of the morphometric characteristics of sorted polygons at the top of Mt Luční hora (LH A: N = 49) and on the lowest cryoplanation terrace (LH B: N = 13).

Morphometric characteristic	LH A				LH B				Statistical significance of ANOVA
	Mean (cm)	SD (cm)	Min (cm)	Max (cm)	Mean (cm)	SD (cm)	Min (cm)	Max (cm)	
Length	188	51	110	290	215	66	120	320	F (1; 60) = 1.998; p = 0.1627
Width	143	47	70	265	180	59	100	260	**F (1; 60) = 4.644; p = 0.0352**
Elongation index	1.36	0.21	1.08	2.00	1.22	0.16	1.04	1.67	**F (1; 60) = 7.395; p = 0.0085**
Height	21.8	9.5	11	55	20.1	10.7	6	37	F (1; 60) = 1.912; p = 0.1719
Relative height	0.16	0.05	0.08	0.34	0.11	0.04	0.05	0.18	**F (1; 60) = 14.898; p = 0.0003**
Mean clast size	7.4[a]	2.2[a]	5.0[a]	14.6[a]	7.5[b]	1.7[b]	5.1[b]	10.1[b]	F (1; 55) = 0.1000; p = 0.7530

Marked differences (bold) are significant at $p < 0.05$ as determined by the F-test.
[a]N = 46 (number of sorted polygons with at least 20 clast measurements from the two-third position).
[b]N = 11 (number of sorted polygons with at least 20 clast measurements from the two-third position).

Table 3 Correlations between selected morphometric characteristics and sorting indices of the polygons.

Variable	Length	Width	Height	Relative height	Mean clast size	$SI_{1/3}$	$SI_{2/3}$	TSI
Length	1.00	**0.91**	**0.62**	-0.14	**0.66**[a]	**-0.48**	**-0.35**[a]	**-0.63**[a]
Width	**0.91**	1.00	**0.60**	-0.25	**0.58**[a]	**-0.54**	**-0.41**[a]	**-0.66**[a]
Height	**0.62**	**0.60**	1.00	**0.62**	**0.59**[a]	-0.04	0.15[a]	-0.15[a]
Relative height	-0.14	-0.25	**0.62**	1.00	0.15[a]	**0.48**	**0.54**[a]	**0.43**[a]
Mean clast size	**0.66**[a]	**0.58**[a]	**0.59**[a]	0.15[a]	1.00	**-0.36**[a]	**-0.33**[a]	**-0.56**[a]
$SI_{1/3}$	**-0.48**	**-0.54**	-0.04	**0.48**	**-0.36**[a]	1.00	**0.84**[a]	**0.82**[a]
$SI_{2/3}$	**-0.35**[a]	**-0.41**[a]	0.15[a]	**0.54**[a]	**-0.33**[a]	**0.84**[a]	1.00	**0.85**[a]
TSI	**-0.63**[a]	**-0.66**[a]	-0.15[a]	**0.43**[a]	**-0.56**[a]	**0.82**[a]	**0.85**[a]	1.00

Marked correlations (bold) are significant at $p < 0.05$ as determined by the t-test (N = 62).
[a]N = 57 (number of sorted polygons with at least 20 clast measurements from the two-third position). See text for abbreviations.

polygons tend to be vegetated by grass, moss or heather, while smaller polygons have little or no grass cover. The size difference between the two groups of sorted polygons (with and without vegetation cover) is statistically significant (ANOVA, L = 263 cm vs 175 cm: $F (1; 60) = 45.468$; $p < 0.0001$; W = 221 cm vs 131 cm: $F (1; 60) = 51.523$; $p < 0.0001$).

Clast Shape and Size

Tabular clasts dominate the sorted polygons (Figure 4). Polygon borders consist of coarse clasts (mean a-axis length = 11 cm), with several clasts 25 to 30 cm long, whereas the inner parts of the polygons (positions one-third, two-thirds and C) consist of smaller clasts (mean length = 5 cm). The greatest differences in clast size are commonly between clasts on the border and at the one-third position (Figure 5). The smallest differences in clast size are between the two-third position and the polygon centre (Figure 5). In the inner parts, 67 per cent of the polygons display secondary sorting and 94 per cent of such polygons are located at the top of Mt Luční hora.

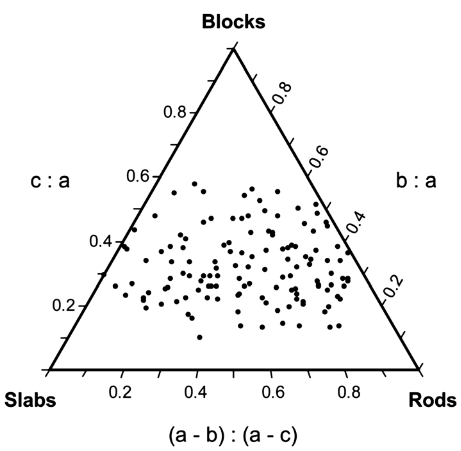

Figure 4 Clast shapes (*sensu* Sneed and Folk, 1958) in sorted polygons at the top of Mt Luční hora.

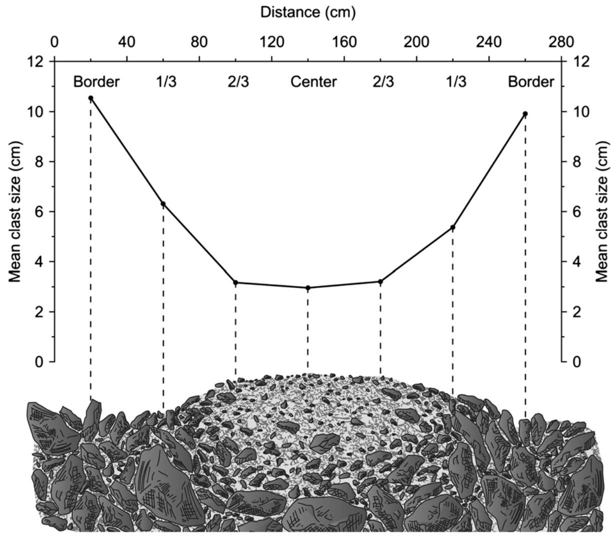

Figure 5 Mean clast size along the length axis of sorted polygon at the top of Mt Luční hora.

Sorting

The sorting indices correlate negatively with pattern dimensions and mean clast size, and positively with relative height (Table 3). Relationships between sorting and height are not statistically significant (Table 3).

Since a strong relationship exists between sorting and most morphometric characteristics (Table 3), only sorted polygons of similar dimensions were used to analyse the influence of microclimate on sorting. The contribution of relative height to the variance of sorting was not removed because up-doming is dominantly a function of microclimatic severity (e.g. Holness, 2003; Treml *et al*., 2010), and is probably the main driving mechanism of frost sorting (Kling, 1997; Matsuoka *et al*., 2003). The sorted polygons at the top of Mt Luční hora (LH A) were chosen as a reference because of their smaller size variability (Table 2). For comparison, sorted polygons with widths in range of mean W at LH A ± standard deviation of W at LH A (143 ± 47; Table 2) were selected. Thirty polygons in the summit area (LH A) and seven at the site LH B met this criterion and did not display a significant difference in width (ANOVA, F (1;35) = 0.0085; p = 0.9272).

The sorting indices of similar-sized polygons are significantly higher at the top of Mt Luční hora (LH A) than at site LH B (Figure 6). Thus, the polygons located at higher altitudes are better sorted than the sorted polygons at lower altitudes ($SI_{1/3}$: r = 0.56; $SI_{2/3}$: r = 0.49; TSI: r = 0.53; significant at $p < 0.05$). Increased sorting with increased altitude is also observed within the summit sites LH A1, LH A2, LH A3. However, this dependence is not significant at a confidence level of p = 0.05 ($SI_{1/3}$: r = 0.27; $SI_{2/3}$: r = 0.23; TSI: r = 0.14) because of the limited number of sorted polygons from individual sites.

The relative height of similar-sized polygons is greater at the summit area (ANOVA, F (1; 35) = 9.2460; p = 0.0044) and has a strong relationship with sorting (Figure 7).

DISCUSSION

Relationship between Sorted Polygon Morphology and Clast Distribution

Smaller polygons are better sorted than larger ones because of the shorter distances for the clasts to move to the polygon borders. Thus, smaller polygons do not need as high frequency and/or intensity of processes to move clasts (e.g. Goldthwait, 1976; Washburn, 1979; Grab, 2002) and achieve the same sorting as larger polygons. This hypothesis is supported by experimental results (Matsuoka *et al.*, 2003) and field evidence (Ballantyne and Matthews, 1983), which revealed a positive correlation between the sorting of miniature polygons and an increasing number of freeze-thaw cycles or time since deglaciation.

Faster sorting of smaller polygons is likely accelerated by positive feedback. Since frost sorting affects all grain size fractions (Ballantyne and Matthews, 1983), sorting increases frost susceptibility in polygon centres, which in turn leads to more intensive ice segregation and cryogenic processes and therefore to further sorting – a self-sustaining or self-perpetuating process (Ballantyne, 1996, 2007). These effects lead to mass displacement and frost disturbances, likely restricting vegetation succession (e.g. Haugland and Beatty, 2005; Haugland, 2006) over the smaller polygons at Mt Luční hora, while the larger ones show a denser vegetation cover.

The relationship between polygon size and sorting is in agreement with the observations of Jeong (2006), which showed a positive correlation between sorted circle diameters and ^{14}C ages and suggested size-dependent circulatory movements (e.g. Ray *et al.*, 1983; Hallet and Prestrud, 1986) during circle formation and the lateral sorting of

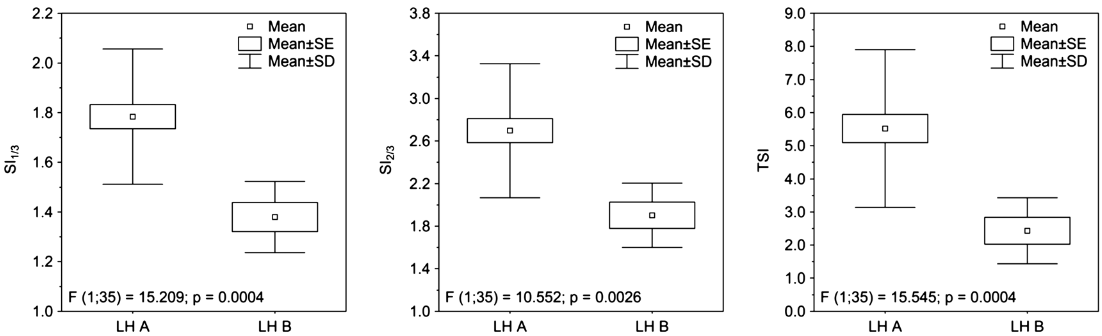

Figure 6 Differences in sorting indices ($SI_{1/3}$, $SI_{2/3}$, TSI) of sorted polygons between the top of Mt Luční hora (LH A) and the lowest site (LH B). Only similar-sized polygons were compared. See text for abbreviations.

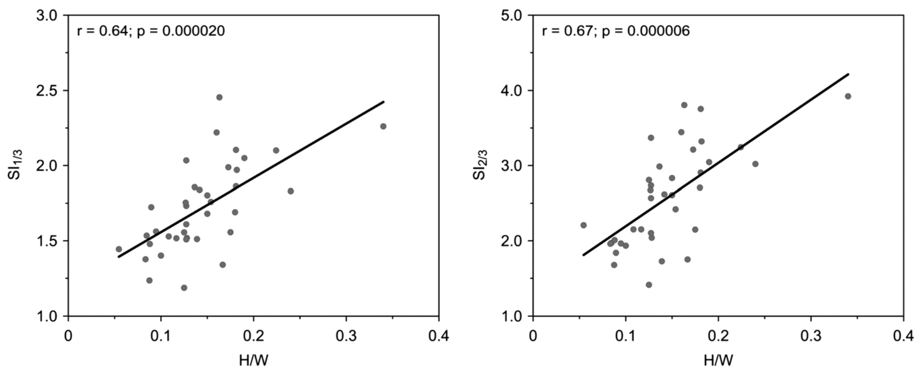

Figure 7 Relationship between relative height (H/W) and sorting indices ($SI_{1/3}$ and $SI_{2/3}$) of similar-sized sorted polygons. See text for abbreviations.

clasts. Therefore, they may also have played a role in the formation of sorted polygons on Mt Luční hora.

The better sorting of polygons with greater relative height (Figure 7) is associated with the steeply inclined surfaces of these polygons, where more intensive slope processes, such as frost creep and needle-ice creep (Ballantyne, 1996; Matsuoka *et al*., 2003), take place. The magnitude of clast movement is directly proportional to the slope of the sorted polygon surface (Kling, 1997; Matsuoka *et al*., 2003). In addition, increasing frost susceptibility due to better sorting is likely enhancing frost heaving of polygon centres (e.g. Van Vliet-Lanoë, 1991; Matsuoka *et al*., 2003; Ballantyne, 2007) and promoting accelerated sorting.

Influence of Microclimate on Sorted Polygon Morphology and Clast Distribution

Larger sorted polygons tend to occur in more severe microclimates (Washburn, 1979). However, microclimate is modified by complex interactions of site-specific factors, therefore considerable heterogeneity exists in the relationship of polygon size and altitude (cf. Grab, 1997; Kling, 1996, 1998; Holness, 2003; Rączkowska, 2003; Marvánek, 2010a, 2010b; Treml *et al*., 2010; Feuillet *et al*., 2012).

In the study area, polygons at the lowest site (LH B) are significantly wider than those from the top of Mt Luční hora (LH A; Table 2) despite higher temperatures and thicker snow cover at lower altitudes (Table 1). Since homogeneous bedrock likely produces similar mean clast size throughout the study area (Table 2), the larger sizes of these sorted polygons could be attributed either to the higher moisture content or higher groundwater table at the time of polygon formation (e.g. Nicholson, 1976; Kling, 1996, 1998). This is also consistent with the lower relative height of polygons at site LH B, which is typical for poorly drained sites (Van Vliet-Lanoë, 1991). Higher moisture contents and a higher groundwater table in the lower part of the study area (LH B) are indicated by nearby springs and thicker snow cover (Table 1) that supply water to the regolith. Nevertheless, the summit sites most likely have sufficient moisture for effective freeze-thaw action (e.g. Matsuoka and Murton, 2008), especially during spring thaw (Lukešová *et al*., 2010).

The increasing relative height of similar-sized polygons with increasing altitude is attributed to both lower moisture content (e.g. Van Vliet-Lanoë, 1991) and more severe microclimates (e.g. Holness, 2003; Treml *et al*., 2010) on the top of Mt Luční hora. Thinner snow cover due to more intense wind action and lower air temperatures cause considerable ground temperature oscillations and deeper freezing at higher altitudes of the study area (Table 1). Thus, more frequent and intense cryogenic processes operate at these sites (Harčarik, 2002; Sekyra *et al*., 2002). As wind directions were approximately the same in the Last Glacial period and the Holocene as at present (Jeník and Sekyra, 1995), more domed and better sorted polygons in the summit area (Figure 6) likely record greater microclimatic severity, which enhanced differential frost heaving and frost sorting (e.g. Washburn, 1979; Ballantyne and Matthews, 1983; Traczyk, 1995). The altitudinal gradient in polygon morphology and sorting is consistent with climate-topography patterns in the summit area of the Krkonoše Mountains (Jeník, 1961), suggesting the dominant role of microclimate in polygon formation during the Last Glacial period.

Although the polygons in the study area are of the same age (Sekyra and Sekyra, 1995; Traczyk and Migoń, 2000; Sekyra *et al*., 2002), the better sorting and greater relative height of those from higher altitudes may have been influenced by a longer period of activity or less intensive pattern degradation. Higher altitudes typically exhibit more severe microclimates and delayed vegetation succession, which could weaken cryogenic processes (e.g. Haugland and Beatty, 2005; Haugland, 2006). This could explain the formation of the secondary sorting centres (*sensu* Warburton, 1990), which are developed almost exclusively within the summit sorted polygons and are most likely related to the reactivation of frost sorting during the colder periods of the Holocene (Kociánová, 2002). However, since the secondary sorting centres are an order of magnitude smaller than the respective sorted polygons, we believe that the reactivation did not lead to any significant changes in the overall structure of sorted polygons and therefore was of marginal importance. Pattern degradational processes, such as rillwash erosion or colluviation, were also of marginal importance, owing to the flat or convex topography of the study sites and permanent forest-free area (Treml *et al*., 2008, 2010).

CONCLUSION

The following conclusions are drawn from the study of relict large-scale sorted polygons in the Krkonoše Mountains:

1. Larger sorted polygons are formed by larger clasts and tend to occur in poorly drained sites at lower altitudes.
2. Smaller polygons and polygons with greater relative height are better sorted.
3. More up-domed and better sorted polygons are located at the summit area of Mt Luční hora.
4. The up-doming of fine centres of sorted polygons and the displacement of clasts towards the borders of sorted polygons are a result of positive feedback between polygon morphology and frost susceptibility, driven by microclimate.
5. Differences in the morphology and distribution of clasts in sorted polygons, preserved since the Last Glacial period, indicate the high palaeoenvironmental potential of the relict large-scale sorted polygons located on flat or convex parts of the terrain.
6. The proposed method for evaluating frost sorting (based on clast size measurements) allows for rapid non-invasive assessment of sorting using modern methods, including high-resolution remote sensing (especially terrestrial photogrammetry) and modifications of the sampling strategy and repetitive measurements within individual sorted patterned-ground features. This method is designed for general use in periglacial landscapes.

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