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Rock surface micro-roughness, Schmidt hammer rebound and weathering rind thickness within LIA Skálafellsjökull foreland, SE Iceland

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Abstract: Glacially abraded basaltic rock surfaces found within a Little Ice Age (LIA) foreland of Skálafellsjökull (SE Iceland) were studied at eight sites of different age applying different weathering indices. They include surface micro-roughness parameters measured with the Handysurf E35-B electronic profilometer – a new tool in geomorphology, Schmidt hammer rebound (R-values) and weathering rind thickness. Values of these indices obtained from study sites exposed to subaerial weathering for more than *ca.* 80 years are significantly different than those from younger moraines closer to the glacier snout. Despite a wide scatter of readings within each study site, there is a significant correlation between the ages and the values of the indices. It is concluded that the micro-roughness parameters provided by the Handysurf E35-B profilometer, Schmidt hammer R-values and weathering rind thickness are robust indices of rock surface deterioration rate in short time-scales. There is mounting evidence that rock surface undergoes relatively rapid weathering during first decades since deglaciation.

Key words: Arctic, Iceland, rock surface micro-roughness, weathering rind, Schmidt hammer.

Introduction

The aim of the study was to evaluate the usefulness of multiple indices of rock surface weathering, *i.e.* (i) micro-roughness parameters obtained with a use of an electronic portable profilometer Handysurf E35-B, (ii) Schmidt hammer rebound values (R-values) and (iii) weathering rind thickness measured on rock surfaces within moraines deposited since the Little Ice Age (LIA) by Skálafellsjökull in SE Iceland. Consecutively, the study aimed to determine the rate of weathering in freshly deglaciated terrains, as it is an important issue in a light of contemporary retreat of mountain glaciers and paraglacial modification of landscapes in alpine and polar regions. Furthermore, there is an on-going discussion about the timing of

LIA in southern Iceland (Evans *et al*. 1999; Bradwell 2001, 2004; Dąbski 2002, 2007, 2010; McKinzey *et al*. 2004; McKinzey *et al*. 2005; Bradwell *et al.* 2006; Orwin *et al*. 2008; Chenet *et al*. 2010, 2011; Kirkbride and Winkler 2012), therefore, developing tools for relative dating of glacial landforms seems an urging necessity. The marginal zone of Skálafellsjökull constitutes a full LIA and recent moraine sequence, similar to that of Fláajökull, allowing easy access to the oldest as well as the youngest parts of moraines.

Previous studies of bedrock or boulder surface roughness as a proxy of glacial landform age are rather sporadic. The best known works were performed on gneiss surfaces in the forelands of Storbreen in Norway (McCarroll 1992; McCarroll and Nesje 1996). A hand profilometer was used for measuring micro-relief amplitude of 0.5–6 mm usually, and increase in rock surface roughness was detected from moraine deposited 250 BP (LIA max) to glacial landforms developed about 9 000 BP. The electronic profilometer is an innovative tool in geomorphological studies, allowing measurements of rock surface micro-roughness with a resolution of 0.01 µm, previously tested only by Dąbski (2012) and Dąbski and Tittenbrun (2013) on moraines of Fláajökull (SE Iceland) and Biferten (Switzerland) glaciers and therefore requires further testing on different glacier forelands.

Many previous tests of Schmidt hammer were performed on glacial landforms developed over long timescales, usually spanning through whole Holocene or even into Pleistocene (Matthew and Shakesby 1984; McCarroll 1989, 1991; McCarroll and Nesje 1993, 1996; AA and Sjåstad 2000; Kotarba *et al*. 2002; Winkler 2005; Shakesby *et al*. 2006; Owen *et al*. 2007; Nicholson 2009). However, it was found that rebound values R can also differentiate age of glacial landforms developed since LIA (Evans *et al*. 1999; Matthews and Owen 2008; Dąbski 2009; Dąbski and Tittenbrun 2013).

Age differences of landforms, developed over several thousand years, were also determined by measuring the weathering rind thickness (Carroll 1974; Porter 1975; Chinn 1981; Nicholson 2009). However, this technique was seldom used in LIA glacier forelands. One exception is the work of Etienne (2002), who found differences in thickness of weathering rind, developed due to iron oxidation, action of micro-organisms and mechanical fracturing of basaltic boulders within recently deposited moraines of Solheimajökull (S Iceland). Age-dependant growth of weathering rind was also observed on glacially abraded basalts within the LIA Fláajökull foreland (SE Iceland) by Dąbski and Tittenbrun (2013), however the rind was produced rather by mechanical fracturing, not by chemical weathering.

Limited number of studies focusing on indices of weathering rate and development of weathering micro-relief in recently deglaciated landscapes as well as uncertainties about the timing of LIA in southern Iceland called for further research. A hypothesis was put forward that the values of micro-roughness parameters as well as Schmidt hammer R-values and weathering rind thickness are controlled by the age of moraine, and thus can be used as relative dating tools and provide information

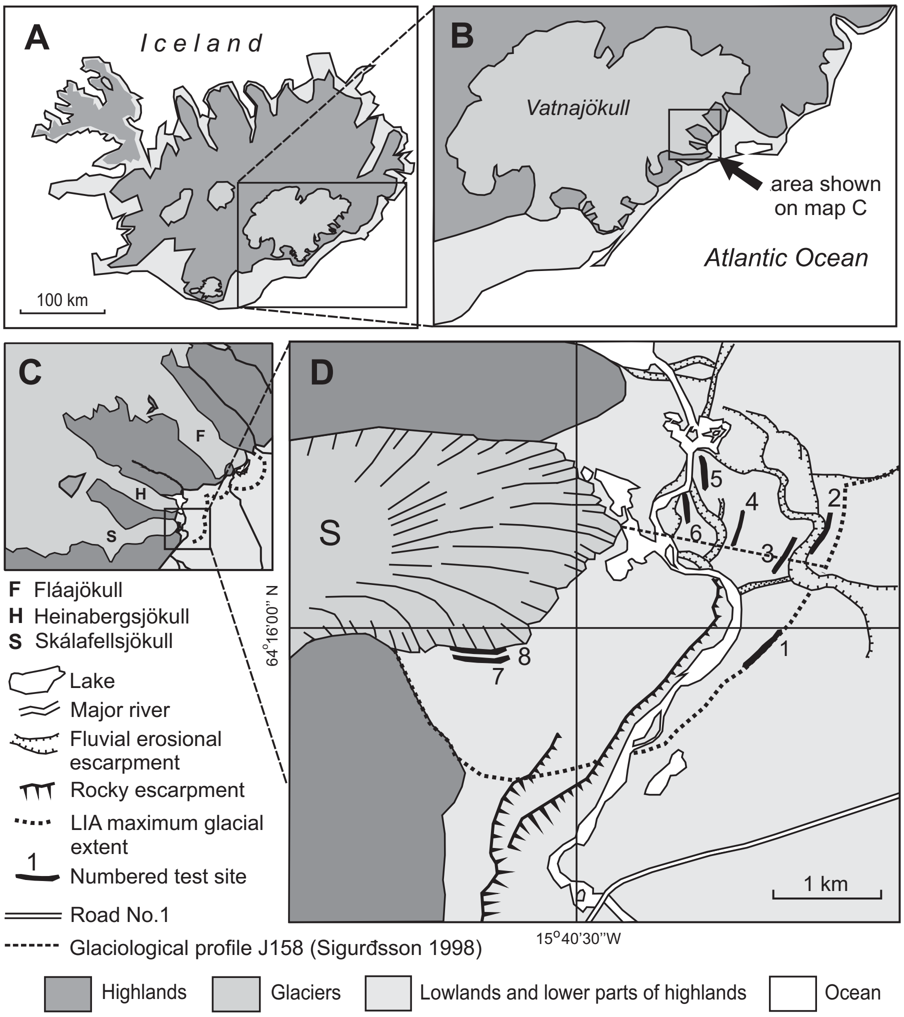

Fig. 1. Location of the study site.

about rock surface weathering rate on LIA moraine sequence of Skálafellsjökull in SE Iceland. Furthermore, it was assumed that rock surface deterioration occurs rapidly within just a few decades after release from glacier ice, and later the process slows down, as it was found in previous studies performed within marginal zones of Fláajökull and Biferten glaciers (Dąbski 2012; Dąbski and Tittenbrun 2013).

Study site location and age of the moraines

Skálafellsjökull flows SE from the Vatnajökull ice cap in Iceland and its marginal zone is located at an altitude of 40 to 100 m a.s.l. (Figs 1, 2A). Historical accounts of Skálafellsjökull behaviour summarised by Ahlmann and Thorarinsson (1937) and Thorarinsson (1943) allow to infer that the glacier reached a very advanced position around AD 1750, AD 1857 and finally in years AD 1870–1887 when it reached its LIA maximum (Fig. 3). However, this was questioned by McKinzey *et al* (2005) who critically assessed the historical data and concluded that LIA glacier maximum occurred in S Iceland in the late 18th to early 19th century. There are lichenometrical datings of the outermost Skálafellsjökull moraines pointing at the end of the 19th century (Gordon and Sharp1983; Evans *et al.* 1999), but other date the oldest moraines rather to the mid 19th century (McKinzey *et al.* 2004; Chenet *et al.* 2010), depending on the lichenometrical technique used, which is also discussed in Orwin *et al.* (2008) and Bradwell (2009).

Moraines of Skálafellsjökull were in contact with moraines of Heinabergsjökull and Fláajökull (Fig. 1) and the three glaciers created a single piedmont lobe in AD 1860–1870 (Evans *et al.* 1999). All of the available data show that the glacier has been quickly retreating at least since the end of 19th century (Fig. 3). However, according to the maps of Thoroddsen from AD 1905 as well as of Wadell from AD 1919 (Ahlman and Thorarinsson 1937) the terminus of the glacier was still in contact with Heinabergsjökull during the first two decades of the 20th century. The recession was punctuated by short advances in AD 1932/33, AD 1957–1960 and AD 1990–1995 (Sigurđsson 1998). Rate of recession significantly decreased in years AD 1965–1995, but subsequently increased again (Fig. 2).

Methods

Methods used in this study were very similar to that of Dąbski and Tittenbrun (2013) and included measurements of micro-roughness, Schmidt hammer rebound and weathering rind thickness. The analyses were performed in AD 2011 (test sites 1–6) and AD 2013 (test sites 7–8) on eighty basaltic surfaces including glacially-abraded boulders and whalebacks (Fig. 2B–D); ten rock surfaces in each of eight test sites of different age. The sites were numbered from the oldest moraine ridge (LIA maximum) to the youngest site located near the margin of the glacier (Fig. 1D). All analyzed rock surfaces, apart from having the same or very similar petrography (fine grained grey basalts, older then 0.7 My), had smooth surfaces abraded by the glacier. This allowed to infer that the boulders must have been transported in the subglacial traction zone, experienced similar abrasion as whalebacks, and were subject to weathering only since their release from glacier ice. Furthermore, it was assumed that any former weathering rinds had been eroded prior to deposition. Glacially-abraded surfaces were facing the glacier (W, NW) with only few exceptions of horizontal surfaces. The lengths of the shortest axis of the selected boulders were at least 30 cm and weight exceeded 80 kg in order not to

Fig. 2. General view on Skálafellsjökull marginal zone from SW corner towards NE (**A**); the Handysurf E35-B electronic profilometer (**B**); measurement of micro-roughness of glacially-abraded bedrock (**C**); obtaining Schmidt hammer rebound values from an abraded boulder (**D**); a boulder after chipping off a rock fragment for measuring weathering rind thickness (**E**), notice difference in colour between oxidised weathering rind and a fresh interior of rock; and measurement of the weathering rind thickness using a micrometer and a magnifying glass (**F**).

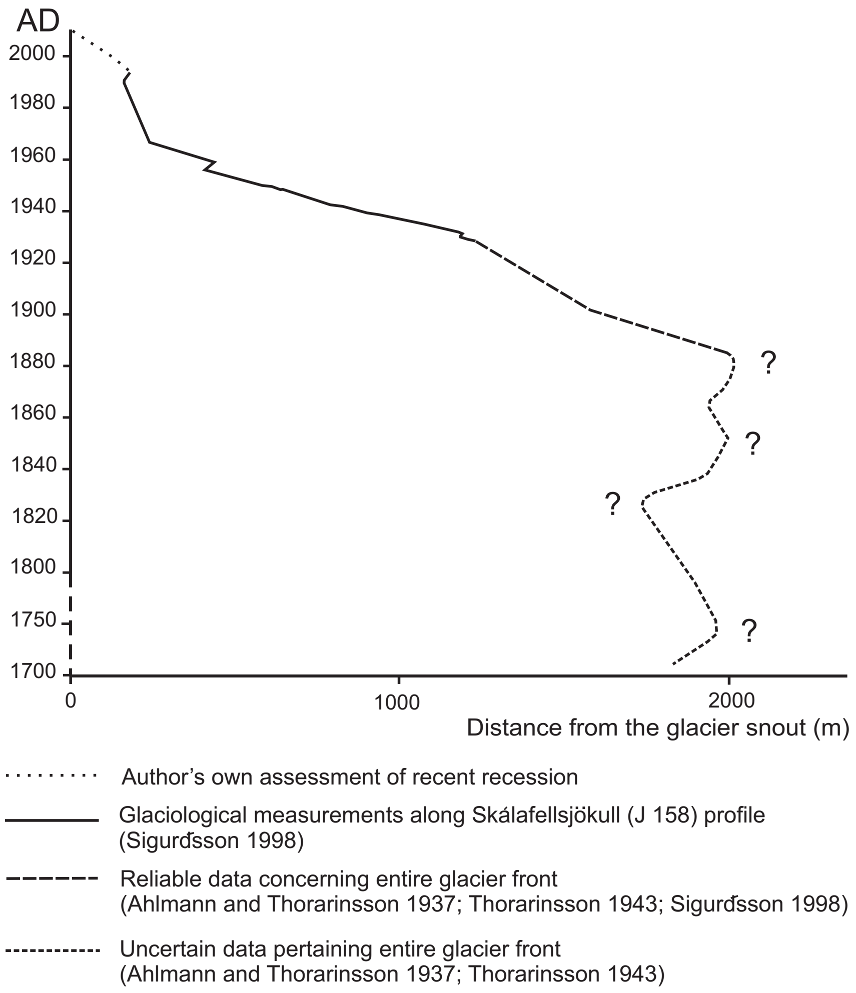

Fig. 3. Fluctuations of the Skálafellsjökull glacier front.

allow for any movements of the rock upon impact of the Schmidt hammer, which might result in inconsistency of R-values (Sumner and Nel 2002).

Silt or single grains of fine sand, if found on the analyzed surface, were removed, and micro-roughness was measured in three smoothest lichen-free spots (thirty measurements per test site) parallel to striation in order to omit visible micro-erosional features on the run of the profilometer (Fig. 2B, C). This allowed to infer that a weathering micro-relief, rather than erosional, was measured. Calibration of the profilometer was checked at every test site using the reference roughness specimen provided by the manufacturer.

Length of the micro-roughness measuring profile was set for 4 mm, which is a distance typically used by engineers measuring industrial steel elements. The Handysurf E35-B electronic profilometer is equipped with a built-in stylus (Fig. 2B) registering rock surface micro-roughness with a vertical resolution of 0.01 μm by automatic dragging of a diamond tip against the measured surface along the profile (Fig. 2C). Micro-roughness parameters expressed in micrometers include Ra – integral value of roughness profile; Rz – average micro-relief amplitude (average vertical distance between peaks and lows); Rzmax – maximum micro-relief amplitude; and Rsm – average wave length (horizontal distance between peaks or lows). Handysurf E35-B can register micro-relief amplitude only up to 320 μm, therefore it is rather unsuitable for coarse-grained rocks (Dąbski and Tittenbrun 2013).

After registering micro-roughness, the rock surface was subjected to ten Schmidt hammer N-type blows (Fig. 2D) at least 1 cm apart from each other and at least 6 cm away from any visible irregularity on the rock surface according to the recommendations of Day and Goudie (1977). R-values were corrected according to inclination of the rock surface in order to account for gravitation force (Runkiewicz and Brunarski 1977). This gave a total value of one hundred readings per test site, meeting the requirements of a minimum sample size for this analysis according to Niedzielski *et al*. (2009). Finally, a sample of the studied surface was chipped off (Fig. 2E) and the weathering rind thickness was measured with the use of an electronic micrometer and a magnifying glass (Fig. 2F) in three representative places.

Selected samples were taken for petrographical analyses under an optical microscope and a scanning electron microscope (SEM) equipped with a microprobe Cameca SX100 (EPMA BSE). The aim of the analyses was to check mineral composition, porosity and texture of basalts and alternations within the weathering rinds.

Specific age of the test sites (Table 1) was determined based on following sources of information: (i) lichenometric dating of test sites 1–6 (in AD 2011), based on: (a) measurements of enveloping circles of two hundred sixty relatively circular thalli of the *Rhizocarpon* subgenus (Benedict 1988), (b) a method of mean of five largest thalli (5LL), (c) a changing growth rate of 0.725 mm year^{-1} for lichens younger than fifty five years and a rate of 0.585 mm year^{-1} for older thalli (Thompson and

Table 1

Ages of study sites (1–6) and means of five largest *Rhizocarpon* thalli (5LL); bold numbers denote dates taken into consideration.

Test site	Direct measurements	5LL (mm) AD 2011	Lichenometric age (AD) 0.725/0.585 lag time 10 yr	5LL (mm) AD 1993	Lichenometric age (AD) Evans *et al.* (1999) lag time 6.5 yr
6	**1942/43**	36.8	1950	15.5	1967
5	**1937/38**	35.6	1952	26.0	1954
4	**1931**	46.0	1936	30.6	1948
3		56.2	**1918**	44.4	1931
2		64.8	**1904**	62.0	1909
1		76.0	**1884**	76.0	1892

Jones 1986), and (d) a colonisation lag time of ten years; (ii) lichenometric dates provided by Gordon and Sharp (1983) and Evans *et al.* (1999); (iii) historical data published by Ahlman and Thorarinsson (1937) and Thorarinsson (1943); (iv) glaciological measurements of glacier recession along the profile J158 available in the database of the Icelandic Glaciological Society (Sigurđsson 1998) and performed annually in years AD 1930–1995; the measurements were correlated with the position of the glacier snout as shown on aerial photographs taken in AD 1954 and 1969; and (v) author's own assessment of the most recent position of the glacier snout, based on analysis of aerial photographs, Google Earth imagery and field inspection.

Collected data regarding micro-roughness, Schmidt hammer and weathering rind thickness were subject to statistical tests using Statistica 10.0 software. The Shapiro-Wilk test proved that the populations of readings were predominantly normally distributed, therefore the one-way ANOVA and post-hoc Games-Howell tests were used in order to find whether populations of readings obtained at one study site are significantly different from other test sites. Coefficients of determination (R^2) were calculated based on correlation between study site ages and mean values of studied indices (Table 2). All tests were performed assuming significance level $\alpha = 0.05$.

Table 2

Correlations between study site age and selected weathering indices. Bold numbers denote statistically significant correlations ($\alpha = 0.05$); p-value indicates probability of uncorrelation.

Indices	R^2	p-value
Ra	**0.56**	**0.032**
Rz	0.44	0.073
Rzmax	**0.65**	**0.015**
Rsm	**0.72**	**0.007**
Rind thickness	**0.79**	**0.003**
R-values	**0.57**	**0.029**

Results

Determination of study sites age. — Ages of the oldest moraines (test sites 1–3) were determined based on the lichenometrical dating assuming changing growth rate (0.725/0.585 mm year^{-1}) and ten-year-colonisation lag, because they correlate relatively well with historical data provided by Ahlman and Thorarinsson (1937) and Thorarinsson (1943). Obtained lichenometric ages (Table 1) are older then those of Evans *et at.* (1999) who used linear growth rate of 0.8 mm year^{-1} and exceptionally short colonisation lag time which is contradictory to numerous lichenometrical studies (Gordon and Sharp 1983; Bradwell 2001; Angiel and Dąbski 2012). Evant *et al.* 1999 concluded that such an approach produces underestimated dates for certain moraines of neighbouring Heinabergsjökull, which apparently also applies to younger moraines of Skálafellsjökull.

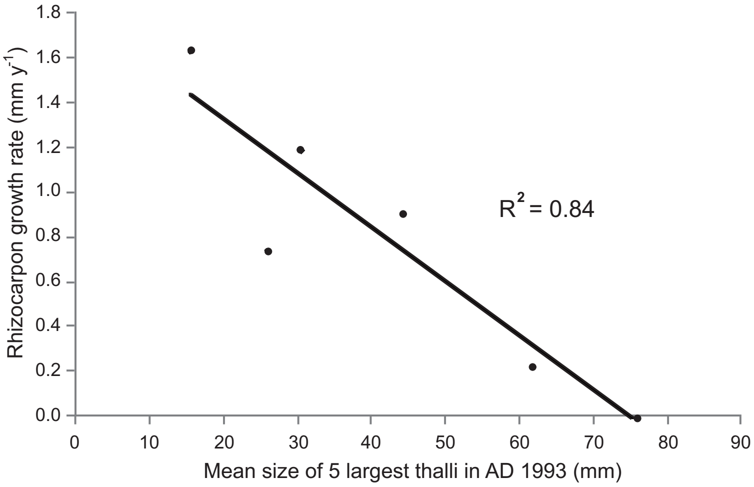

Fig. 4. Approximated radial *Rhizocarpon* subgenus lichen growth rate versus mean size of five largest lichen thalli on moraines of Skálafellsjökull.

Comparison of five largest lichens (5LL) measured in AD 1993 by Evans *et al*. (1999) with 5LL measured in AD 2011 (Table 1), even though the measured thalli were probably not the same, proves that the *Rhizocarpon* lichen growth rate significantly decreases over the studied time span (Fig. 4). Ages of test sites 4–6 were determined based on direct measurements of glacier retreat which cover the period of AD 1930–1995 (Sigurđsson 1998) as they are more reliable than lichenometry (Table 1). The youngest sites (7–8) were deglaciated in years following AD 2000, which is determined based on lack of any lichens and close proximity to the glacier terminus, within 150 m from the glacier. Age of site 7 is assessed for AD 2007–2008 and age for site 8 at AD 2011–2012.

Petrography and weathering rind character. — Microscopic analysis showed that studied basalts are fine-grained with dominating crystals of plagioclase (labradorite-andezine), pyroxenes (augite) and iron-oxides (ilmenite and magnetite). In some places, along planes of weakness and fissures, there is a highly hydrated amorphous silicate substance.

Grayish red coulor of weathering rind (2.5YR4/2 in Munsell scale) or orange (5YR6/6) within discrete glacial striation marks, very similar to that noted by Etienne (2002) on basalts deposited by Solheimajökull, is a product of oxidation of iron compounds (Yoshida *et al*. 2011). The studied rinds possess a loosen structure owing to mechanical weathering. Presence of micro-organisms was not checked, nevertheless, possible contribution of biological weathering must be assumed (Etienne 2002).

Micro-roughness, rind thickness and Schmidt hammer R-values. — Obtained values of the four micro-roughness parameters Ra, Rz, Rzmax and Rsm

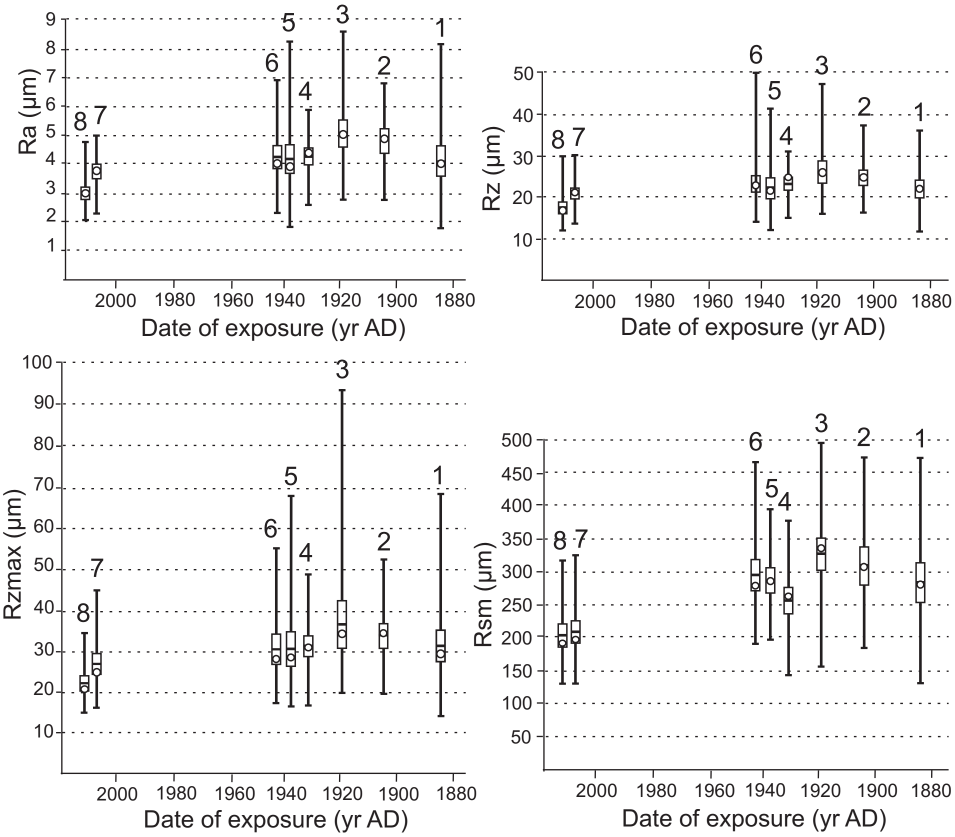

Fig. 5. Values of micro-roughness parameters Ra, Rz, Rzmax and Rsm on different test sites (1–8); diagram includes means (dashes), medians (circles), 95% confidence intervals for means (boxes), minima and maxima.

vary in a relatively similar fashion between the test sites (Fig. 5). The parameters measured on older sites (1–6) have statistically significantly higher values than those from the younger sites (7–8). General decrease in micro-roughness parameters from oldest to youngest study site is observed, however it is not linear and there is a considerable wide range of values within each of the sites. Mean values of Ra decrease from 4.08±0.53 µm on site 1 to 2.99±0.21µm on site 8 and this is accompanied by decrease in Rz from 21.47±2.17 µm to 17.37±1.33 µm, Rzmax from 31.43±4.04 µm to 22.38±5.27 µm and decrease in Rsm from 285.27±31.05 µm to 200.92±49.22 µm. Moreover, most of micro-roughness parameters exhibit a significantly decrease in values from site 7 to site 8, despite only a few years of difference in weathering duration. This rapid change is visible in mean values of Ra, Rz and Rzmax which decrease by 19.2%, 16.1% and 18.6%, respectively. However, mean values of Rsm decrease only by 2.1% between the two sites. One must notice a peculiar increase in micro-roughness from the oldest site 1 to site 3 which is counter to expectations. This can be explained accounting for possible differences

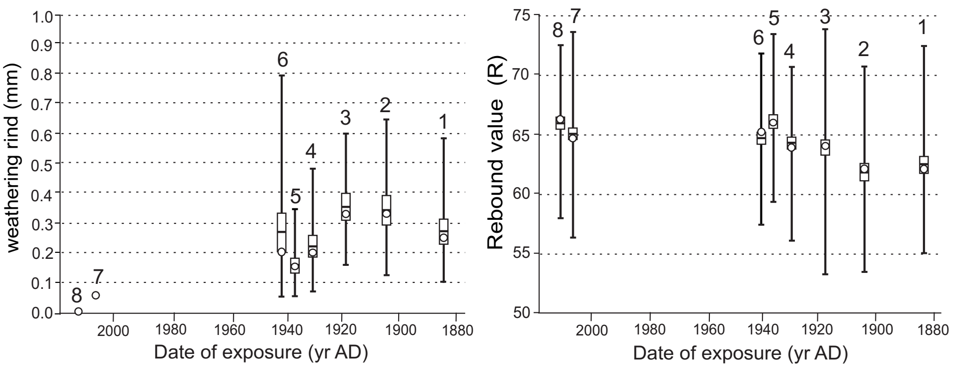

Fig. 6. Weathering rind thicknesses and Schmidt hammer R-values on different test sites (1–8); diagram includes means (dashes), medians (circles), 95 % confidence intervals for means (boxes), minima and maxima.

in petrography of studied boulders and exfoliation of basalts operating in a micro-scale (Etienne 2002), which may produce relatively smooth surfaces (Dąbski and Tittenbrun 2013).

Mean values of weathering rind thickness decreases from 0.27±0.04 mm on the oldest moraine (site 1) to 0 mm on the youngest site (Fig. 6), where abraded basaltic surfaces were dark grey, with no signs of reddish varnish resulting from oxidation. On the other hand, studied surfaces, found on the second youngest site (site 7) located 50–100 m away from the glacial margin, have already undergone oxidation. However, the weathering rinds were so thin that it was impossible to measure their thickness in a field. In a sample taken from site 7, thickness of oxidized rind was so little that it could not be measured in a microprobe, therefore it must constitute only a superficial varnish. For the purposes of the data visualization a medial value of 0 mm was determined for site 8 and 0.05 mm for site 7 (Fig. 6). Statistical tests proved that weathering rinds developed on older moraines (1–3) are significantly thicker than those on younger moraines with the exception of site 6 where unexpectedly thick rinds were measured.

Significantly lower Schmidt hammer R-values were recorded on the oldest test sites (1–2), as compared to younger ones (3–8) (Fig. 6). The highest R-values were recorded on the youngest site 8 and, surprisingly, on site 5. However, there is an overall increase in R-values from the oldest moraine (site 1), where mean R = 62.32±0.67, to the youngest (site 8), where R = 65.94±0.51. Moreover, R-values significantly increase from site 7 (R = 64.94±0.49) to site 8 (R = 65.0±0.51), which is consistent with differences in weathering rind thickness and micro-roughness.

Correlation between the study site age and the mean values of studied indices is relatively strong and statistically significant with the exception of Rz (Table 2). The best correlation is obtained between the age of moraines and the weathering rind thickness and Rsm, indicating mean lengths of micro-roughness profile elements.

Discussion

Significantly high coefficients of determination (Table 2) allow to infer that values of the weathering indices are time-dependant and therefore can be used in relative dating of glacial landforms. However, there is no increase in micro-roughness and weathering rind thickness on moraines exposed to weathering for more then 60–80 years after deposition. This may be explained by exfoliation of basaltic surfaces on older moraines (Etienne 2002) leading to smoothening of rock surfaces (Dąbski and Tittenbrun 2013) or by diversified structure and texture of studied rocks, which is frequently impossible to notice in the field. Therefore, it is inferred that the indices used are unsuitable for precise dating of glacial landforms created since the Little Ice Age, and they do not provide additional arguments in the ongoing discussion about timing of LIA maximum in Iceland (Evans *et al*. 1999; Bradwell 2001, 2004; Dąbski 2002, 2007, 2010; McKinzey *et al*. 2004; McKinzey *et al*. 2005; Bradwell *et al.* 2006; Orwin *et al*. 2008; Chenet *et al*. 2010; Chenet *et al*. 2011; Kirkbride and Winkler 2012).

Matthews and Owen (2008) working on gneiss boulders within LIA maximum of Storbreen (Norway) found that Schmidt hammer R-values obtained from surfaces colonized by *Lecidea auriculata* lichens gradually decreases from the glacier margin to moraines 30–50 years old, supporting the notion of a rapid but relatively short-term proglacial weathering. However, R-values from Skálafellsjökull foreland were relatively stable within sites 3–8, and significantly decreased only on the oldest sites 1 and 2, exposed to subaerial weathering for more than a century (Fig. 6). Furthermore, it was found that Schmidt hammer R-values does not depend on whether blows hit bedrock or a boulder. This proves that the minimum size of a boulders was chosen correctly, at least 30 cm of the smallest axis but usually much larger, and the boulders were firmly embedded into glacial till.

Evidence for rapid mechanical (Dąbski and Tittenbrun 2013), chemical and biological (Etienne 2002; Matthews and Owen 2008) proglacial weathering is consistent with a rapid rate of sorted patterned ground development on recently deglaciated areas (Dąbski 2005). It was found that patterned grounds can be stabilized within fifty years of exposure of the ground due to amelioration of ground temperature regime and reduction in soil moisture (Ballantyne and Matthews 1982), however it depends on the rate of deglaciation and numerous micro-environmental factors, *e.g.* grain size, vegetation (Ballantyne and Matthews 1983; Matthews *et al.* 1998).

Micro-roughness parameters provide interesting insight into development of initial stages of weathering micro-relief. Handysurf E-35B allows not only to qualify different surfaces by determining which is more rough, but also to quantify the micro-relief amplitude with a very high resolution. Change in the micro-roughness parameters within LIA foreland of Skálafellsjökull is consistent with previous studies performed by Dąbski (2012) in a foreland of Biferten Glacier in Glarnen Alps, Switzerland, as well as in a foreland of Fláajökull in SE Iceland (Dąbski and

Table 3

Mean values of micro-roughness of rock surfaces subject to weathering on moraines of different age of Skálafellsjökull and Fláajökull (SE Iceland), and Biferten Glacier (Switzerland); based on current research and after Dąbski (2012) and Dąbski and Tittenbrun (2013).

		Ra (µm)	Rz (µm)	Rzmax (µm)	Rsm (µm)
Skálafellsjökull	>2000 AD	3.0 ± 0.2	17.4 ± 1.3	22.4 ± 5.3	200.9 ± 49.2
	LIA max	4.1 ± 0.5	21.5 ± 2.2	31.4 ± 4.0	285.3 ± 31.1
Fláajökull	>2000 AD	4.0 ± 0.4	21.8 ± 1.8	30.8 ± 2.8	258.7 ± 19.4
	LIA max	5.4 ± 0.4	29.0 ± 2.0	39.4 ± 3.2	274.1 ± 19.0
Biferten	>2000 AD	3.1 ± 7.3	17.6 ± 2.3	23.6 ± 3.8	170.4 ± 19.4
	LIA max	7.3 ± 0.6	39.7 ± 2.6	53.1 ± 4.2	256.9 ± 22.7

Tittenbrun 2013). In all of these recently deglaciated landscapes, significant change in rock surface deterioration occurred only within the younger parts of the moraines. Basaltic surfaces studied on Fláajökull moraines were subject to frost weathering and no traces of oxidation, nor solution were found. On the other hand, studied rock surfaces in the marginal zone of Biferten Glacier were abraded Jurassic limestone rocks undergoing karstification. Despite these differences in petrography and weathering processes, magnitude of change in micro-roughness parameters between rock surfaces near the glacier margins and those from the LIA maximum is comparable (Table 3). One must notice that decrease in micro-roughness towards the glacier snout is the greatest within foreland of Biferten Glacier, which can be explained by the greater weathering susceptibility of limestone surfaces in comparison with basalts.

Conclusions

The study revealed that the micro-roughness parameters provided by the Handysurf E35-B profilometer, Schmidt hammer R-values and weathering rind thickness are robust indices of rock surface deterioration rate in short (decadal) time-scales. Values of the studied indices are controlled by the young age of moraines. However, no significant differences were found amongst moraines subject to weathering for more than 80 years, which requires explanation in a course of further studies.

It is very difficult to control all possible factors which may influence readings of used tools, *e.g.* internal structure and texture of rocks, micro-climates, moisture, therefore calibration of proper dating curves seems very difficult to achieve. However, there is mounting evidence that glacial sediments undergo relatively rapid weathering during first decades after deposition.

The Handysurf E35-B electronic profilometer, a new tool in geomorphological studies, can be used to assess the rate of initial development of weathering micro-relief of fine-grained rocks and supplement already established methods of proglacial relief development.

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