The glacial landsystem of Hoffellsjökull, SE Iceland: contrasting geomorphological signatures of active temperate glacier recession driven by ice lobe and bed morphology

David J A Evans[1], Marek W. Ewertowski[2] and Chris Orton[1]

1. Department of Geography, Durham University, South Road, Durham DH1 3LE, UK
2. Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, Krygowskiego 10, 61-680 Poznań, Poland

Abstract

A 1:14,500 scale glacial geomorphology and surficial geology map of the foreland of Hoffellsjökull, southeast Iceland is used to assess the glacial landsystem signature of the contrasting glacier-climate interactions of two separate flow lobes within one outlet glacier. This constitutes a valuable modern analogue for employing glacial geomorphological signatures as palaeoclimate indicators in ancient deglaciated terrains. The landsystem signatures of the glacier's two flow lobes, Svínafellsjökull and Hoffellsjökull, are distinctly different. Svínafellsjökull displays inset and seasonally climatically-tuned push moraine sequences and subglacially streamlined surfaces typical of active temperate glaciers on sloping piedmont forelands. Hoffellsjökull displays the landform-sediment assemblages typical of outwash-head/depositional overdeepening scenarios, upon which closely-spaced composite push moraines reflect a long term quasi-stationary snout at and near the Little Ice Age maximum prior to 2000. Moraine spacing on the Svínafellsjökull foreland reflects an overall trend of annual recession punctuated by quasi-stability and/or readvance in the mid-1950s-1960 and 1975-2000 as recorded by two arcuate zones of closely-spaced and partially overprinted sawtooth and hairpin moraines. The pattern of moraine distribution here also reflects spatio-temporal changes in moraine-forming processes as dictated by changes in a combination of proglacial drainage characteristics and structural glaciology or crevasse architecture. The subglacial footprint of the Svínafellsjökull foreland contains features worthy of future research attention, including an arcuate zone of overridden moraines potentially indicative of a regional Holocene ice advance, prominent flutings and debris stripes potentially indicative of groove-ploughing and point-source bedrock plucking respectively, and relatively large drumlins.

Key words: Glacial landsystem; Hoffellsjökull; push moraines; flutings and debris stripes; drumlin; overdeepening

Introduction

The retreat of the Icelandic south coast glaciers since shortly after reaching their Little Ice Age (LIA) maximum limits in the late 19th Century is well documented both in historical archives and aerial imagery (Figure 1). With the exception of surge activity at Skeiðarárjökull and east Breiðamerkurjökull (Boulton et al. 2001; Russell et al. 2001; Evans & Twigg 2002; Bjornsson et al. 2003; Waller et al. 2008), the southern outlets of Vatnajökull are active temperate in character and hence their historical recession has been characterised by short annual readvances each winter. This gives rise to the diagnostic landform signature of inset sequences of push moraines up to a few metres high, with one moraine being created every year by the emplacement of a sub-marginally deforming till wedge (Price 1969, 1970; Boulton 1986; Krüger 1995; Evans & Twigg 2002; Bradwell 2004; Evans et al. 2018a). Some more substantial advances or the development of quasi-stationary snouts have taken place over the post-LIA period, resulting in the construction of large push moraine complexes (Evans & Hiemstra 2005). The most prominent of these was that of the early to mid-1990s, which has been alternatively related to either a positive North Atlantic Oscillation (NAO) index in 1989-1994 (Evans & Chandler 2018), a negative NAO index (Bradwell et al. 2006), or longer term cooling trends (Sigurðsson et al., 2007) as recognised in the Skaftafellsjökull moraine record for example (Þórarinsson 1956; Thompson 1988; Marren 2002; Evans et al. 2017a).

As the active temperate outlet lobes of Vatnajökull are sensitive to climatic changes over such short timescales and sub-marginal till wedges are advected to the glacier margins annually, the ubiquitous recessional push moraines of the glacier forelands record climatically-driven snout oscillations at unusually high resolution (Bradwell *et al.*, 2006; Bradwell *et al.*, 2013, Chandler et al. 2016a, b, c; Evans et al. 2017a). Consequently the south Vatnajökull glacier forelands have become not only exemplars for the active temperate glacier landsystem (Evans 2003, 2005, 2013, 2016; Evans & Twigg, 2002; Evans & Orton 2015) but also prime sites for developing our understanding of glacier snout susceptibility to short timescale climate drivers (Þorarinsson 1943; Aðalgeirsdóttir et al. 2011; Hannesdóttir et al. 2014, 2015; Chandler et al. 2016a, b; Evans & Chandler 2018; Evans et al. sub.). High resolution mapping of the south Iceland glacier forelands has, through the analysis of push moraine spacing, facilitated a better understanding of the relationships between ice-margin recession rates and specific climate variables. This has highlighted a clear correlation between annual summer air temperature anomalies and glacier retreat (Bradwell 2004; Bradwell et al. 2013; Chandler et al. 2016a; Evans et al. sub.). Additionally, mapping of recently exposed foreland areas in and beyond Iceland has prompted a re-assessment of our assumption that an active temperate glacier will always construct one push moraine every year (cf. Boulton 1986; Evans & Twigg 2002; Beedle et al. 2009; Lukas 2012), as demonstrated by Chandler et al. (2016a, b, c) in their recognition of sub-annual ridge development since 2006 at Skálafellsjökull. Indeed, on a number of southern Icelandic forelands, recent moraine construction has resulted in very complex and overprinted sawtooth moraines and the production of multiple moraine ridges over single seasons, especially in locally poorly-drained topographic settings where sub-marginal till is both pushed and squeezed into the snout pecten defined by radial crevassing (Evans et al. 2016, 2017a, b, 2018b).

Consequently, in addition to the glacier-climate relationships inherent within the recessional push moraine record, glacial landsystem mapping in southern Iceland has identified significant spatial and temporal variability in the development of landform-sediment assemblages of active temperate snouts. These include changes in push moraine morphology, from more linear to increasingly till squeeze-dominated and sawtooth plan forms over time. These changes appear to be linked to a switch from well-drained foreland areas, on which snouts are coupled to proglacial streams draining over sandur fans, to increasingly more poorly-drained settings, in which proglacial drainage is constricted between ice-margin parallel, overridden moraine arcs that emerge from beneath retreating snouts (Chandler et al. 2016a, b, c; Evans et al. 2016, 2017a). There has been a concomitant change in snout morphology in that an apparently more divergent ice flow regime has developed over time in response to thinning snouts, thereby initiating stronger radial crevassing. Poor drainage has been further exacerbated by the more recent uncovering of overdeepenings, either in bedrock and/or inside outwash heads, leading to the development of proglacial lakes, iceberg calving and the switching from subglacial signatures of flutings and push moraines to ice-contact fans, englacial esker networks and kame and kettle topography (Bradwell et al. 2013; Phillips et al. 2013, 2014, 2018; Evans & Orton 2015;

Everest et al. 2017; Everest & Bradwell 2018a, b; Swift & Cook 2018). The charting of glacier recession and mapping of glacier forelands have also enabled the identification and quantification of important process-form regimes in active temperate snouts, including subglacial bedforms (Boulton 1987; Boulton & Hindmarsh 1987; Benn & Evans 1996; Jónsson et al. 2016; Evans et al. 2018a), englacial to subglacial meltwater drainage features (Price 1969; Howarth 1971; Spedding & Evans 2002; Storrar et al. 2015), proglacial outwash tracts (Hjulstrom 1954; Krigström 1962; Price 1969, 1971, 1982; Price & Howarth 1970; Thompson 1988; Thompson & Jones 1986; Maizels 1993; Marren 2002), supraglacial landforms (Eyles 1979, 1983a; Spedding & Evans 2002; Evans 2009; Bennett et al. 2010; Bennett & Evans 2012) and the sediment-landform assemblages of ice-dammed lakes (Arnborg 1955a, b; Bennett et al. 2000; Evans & Orton 2015), in addition to landsystem overprinting (Evans & Twigg 2002; Waller et al. 2018).

This study presents a glacial landsystems map for Hoffellsjökull, the largest outlet glacier of southeastern Vatnajökull (Figure 2), with the aim of identifying the variable geomorphic signature of its historical recession. Hoffellsjökull's recession as charted by Aðalgeirsdóttir et al. (2011) has been remarkable in that its two flow lobes (Svínafellsjökull and Hoffellsjökull; the former not be confused with the outlet of Öræfajökull located further to the west) have behaved entirely differently to post-LIA climate warming, with the eastern flow lobe of Hoffellsjökull having remained quasi-stationary until 2000 (Arnborg 1955a, b; Hannesdóttir et al. 2015). Hence the glacial landsystem signature of this major Vatnajökull outlet glacier captures a uniquely complex geomorphic signature of glacier-climate relationships that is likely tuned by variable hypsometry (Furbish & Andrews 1984) dictated by topographic controls on marginal lobes, the details of which have been made available by recent assessments of subglacial topography (Björnsson & Pálsson 2004).

Hoffellsjökull – the glacier system and its recession history

Hoffellsjökull flows south from the SE sector of the Vatnajökull ice cap towards the Hornafjörður marine embayment and in 2001 had a drainage basin area of ca. 212 km^2 (Aðalgeirsdóttir et al. 2011). It is renowned glaciologically as one of Hans Ahlmann's stations for his North Atlantic glaciological monitoring network and was subject to intensive research during the Swedish-Icelandic Expeditions of 1936-1938 (Ahlmann & Þorarinsson 1937, 1938, 1939; Ahlmann 1948). The glacier flows from its accumulation zone, located between the two subglacial mountain ranges of Breiðabunga and Goðahnúkar, in two flow units moving either side of the nunatak summit of Nýjunúpar before coalescing again downflow. The current equilibrium line altitude lies at around 1100 m asl. The glacier then flows through a 2 km wide ice fall at 600–700 m asl and drops by 300 m over 4 km (Aðalgeirsdóttir et al. 2011). Below the ice fall, the glacier spreads to form a piedmont lobe but is sub-divided into two flow lobes that are directed either side of a bedrock ridge (Figures 2-5). The west flow lobe (Svínafellsjökull) encompasses two thirds of the Hoffellsjökull snout. It has developed the more lobate form in contrast with the smaller eastern flow lobe, which is more elongate due to being confined within a narrow bedrock valley (Figures 2b, 3 and 4). The floor of this valley is an elongate overdeepening that extends down to 300 m below sea level (Figure 3; Björnsson & Pálsson 2004; Aðalgeirsdóttir et al. 2011), which has partially hosted a proglacial lake since the receding ice margin withdrew from the LIA maximum moraine and outwash head in 1945. However, this lake only expanded to its present size in 2010, when the snout was observed to be subject to a rapid break-up and calving event.

Compilations of historical accounts by Jónsson (2004) and Aðalgeirsdóttir et al. (2011) reveal that the glacier advanced 5-7 km in the 18th and 19th centuries over a vegetated plain and hence the overdeepening appears to have been filled with sediment prior to the onset of the LIA. If so, the erosion of the sediment fill indicates that some 1.6 km^3 of material was removed during the LIA (Björnsson & Pálsson 2004). However, our present understanding of the typical erosion rates by active temperate glaciers in this region suggests that direct glacial erosion was likely not responsible for all of this sediment removal (Björnsson 1996). Instead, a large amount of sediment was probably removed by jökulhlaups from marginal lakes in front of the advancing glacier snout; jökulhlaups were reported to have started in the area around 1840 (Björnsson 1976; Hjulström 1954; Arnborg 1955a, b) and then increased in frequency and magnitude from 1920–1960 during glacier recession.

Like many other glaciers in Iceland, Hoffellsjökull's recession was monitored from the 1930s onwards but unlike other snouts this continued only up to 1960 (Figure 1). An assessment of snout thinning and recession over a longer period (1890-2001) has been compiled based on historical archives and aerial imagery by Aðalgeirsdóttir et al. (2011) and this reveals the contrasting behaviour of the two flow lobes (Figure 4). The west flow lobe has receded at a rate compatible with other southern Iceland outlet glaciers (Figure 1), which since the 1930s broadly correlates with air temperature variations (Sigurðsson et al., 2007). During the period 1931–1960, rapid ice-front retreat regionally was initiated by relatively high air temperatures, particularly during the 1930s. This was reversed after 1965 in response to climate cooling and a number of snouts advanced during the period 1975–1990, culminating in the mid 1990's readvance (Sigurðsson et al., 2007). Since 1995 the SE Iceland glaciers have been in marked recession mode in response to rapidly rising air temperatures (Figure 1). A lack of direct moraine dating at Hoffellsjökull makes it difficult to assess its response to these regional trends, although steady retreat of the west flow lobe is in clear contrast to that of the east flow lobe, because the east flow lobe remained largely stable from the LIA maximum of around 1890 until the start of the 21st Century. However, the rapid calving episode that began in 2010 did follow on from a period of reduced thinning over the overdeepening from 1986-2001, a period that was characterised also by stability of the margin of the west flow lobe (Figure 4). It appears that a combination of recent accelerated warming and the greater extent and depth of the overdeepening beneath the snout of the east flow lobe has been the driver of its post-2010 collapse. Prior to this, the larger surface extent of the west flow lobe (Svínafellsjökull), a distinctly different hypsometry to that of the east lobe in its narrow valley, made it more responsive to the summer temperature drivers of ablation and hence the overall marginal recession of a typical piedmont lobe in the region (cf. Chandler et al. 2016a, b).

Prior to the compilations of Aðalgeirsdóttir et al. (2011), the only other maps of glacier marginal recession and evolving proglacial landforms are those of Þorarinsson (1939) and Arnborg (1955b). Þorarinsson's (1939) map and ground photographs show the early stages of slow downwasting and recession up until the late 1930s and specifically reveal the emergence of the previously submerged bedrock ridge (Svínahryggur) that divides Hoffellsjökull into its two flow lobes. The closely spaced and partially overprinted recessional moraines of the east flow lobe are also captured by a 1937 ground photograph, which reveals the geomorphic signature of very slow recession in the area since the abandonment of the 1890 LIA maximum limit. In addition to these details, Ahlmann and Þorarinsson (1939) created a map depicting the large but presumably shallow proglacial lake on the emerging foreland of the west flow lobe that was draining into the main proglacial river Suðurfljót, as well as four ice-dammed lakes in the small valleys draining the uplands towards the east of snout. The largest of these was Gjánúpsvatn (Gjávatn) and the others included Múlavatn, Pollur and Efstafellsvatn (Figure 5), the formerly higher levels of each being marked by prominent shorelines. Arnborg's (1955b) map of the foreland beyond the east flow lobe depicts the gradual confinement of the river Austurfljót by 1946 to a single shallow gorge, after it had previously drained along a number of channels on the valley floor from 1903-1938. By 1945 the precursor proglacial lake (Hoffellslón) in front of the east ice flow lobe (Hoffellsjökull) had developed but was not connected directly to the proglacial drainage channel. By 1951 the lake had quadrupled in size and was draining directly into the Austurfljót, entrenching the river and confining it to its gorge until it ceased to flow in 2008 due to a fall in lake level. This development is interesting in that the drainage of Hoffellsjökull now flows entirely westward into Svínafellslón and ultimately through the Suðurfljót, as demonstrated by recent satellite imagery (2016) showing a narrow strip of water between the calving ice margin and the northern end of Svínahryggur, linking the two lakes. As the margin of this part of the Svínafellsjökull snout presently occupies the crest of the adverse slope of the overdeepening (Figure 4a) it will likely soon undergo a similar catastrophic break up and calving event to that experienced by the east flow lobe in 2010.

Methods

The geomorphology of the foreland of the Hoffellsjökull was mapped on a coloured ink film overlain on high-resolution satellite imagery captured by the WorldView-2 satellite of Digital Globe on 12/07/2012. An ortho-ready product covering approximately 41 km^2 was purchased, containing a panchromatic band with 0.5 m ground sampling distance (GSD) and four multispectral bands with 2 m GSD. The imagery was orthorectified utilising digital elevation model (DEM) and pansharpened to produce a 0.5 m GSD 4-band multispectral image. The projection used was UTM zone 28N based on the WGS 1984 datum. Contours with 5 m interval were generated from the DEM and overlain on the surficial geology and geomorphology. Data were processed in ArcGIS Desktop 10.6.

Images and DEMs of large scale landform detail were created in order to aid mapping in areas of high geomorphological complexity. This was undertaken using a using a small, lightweight UAV quadcopter equipped with a 12-megapixel, wide-angle lens camera. Images were acquired at an elevation of 40 m above the launching point, producing a ground image pixel size of ~0.016 m. Further details of the protocols employed with the UAV image acquisition and DEM production are presented in Ewertowski et al. (2019).

Mapping involved the simultaneous interpretation of surface materials and landforms based on ground truth fieldwork in the summer of 2014 and the desk top viewing of stereoscopic images taken at various dates back to 1975. Fieldwork involved the logging of stratigraphic exposures and compilation of lithofacies architecture and structural features on section sketches in order to aid in the interpretation of landform-sediment assemblages. The glacier surface and most of the terrain lying outside the limits of the LIA maximum are represented on the map by the 2012 satellite imagery. The map overlay containing the base data for landforms and surficial geology was manually digitized on a large format Cal-Comp tablet digitizer using MapData vector digitizing software. The digitized vector files were converted from MapData format into ArcInfo 'generate' format for importing into Adobe Illustrator. The map (Figure 6) is at a scale of 1:14,500 when printed on an A1 sheet and is available for download also as Supplementary Information Figure 1.

Glacial geomorphology and surficial geology of the Hoffellsjökull foreland

The surficial geology and geomorphology map of the Hoffellsjökull snout and foreland (Figure 6 & Supplementary Information Figure 1), displays a foreland dominated by three surficial material types or sediment-landform associations that are typical of the active temperate glacier forelands of Iceland: till and moraines, including subglacial landforms, and dating to the LIA maximum and younger historical glacier retreat; glacifluvial deposits, including eskers; and glacilacustrine deposits. Extensive areas of glacially eroded bedrock also exist and are described and interpreted below in association with the till and moraine material type. Additionally, small areas of paraglacially modified material have accumulated on steeper slopes of the western and eastern margins of the foreland. Beyond the extent of the LIA maximum of ca. 1890, older tills and associated glacigenic deposits are heavily degraded and wind-deflated and are mapped together with small areas of weathered bedrock as residuum.

Till and moraines and glacially eroded bedrock

Like all active temperate glacier forelands in Iceland, the till and moraine surficial geology unit is characterized by fluted and drumlinized subglacial traction till (cf. Boulton 1987; Benn & Evans 1996; Evans et al. 2010, 2016, 2018a, b) and inset sequences of closely-spaced recessional push moraines, often with crenulate or sawtooth plan forms (e.g. Price 1970; Kruger 1994, 1995; Sharp 1984; Boulton 1986; Evans & Twigg 2002; Evans et al. 2009, 2016, 2017a; Chandler et al. 2016a, b, c). The recessional moraines on the outer part of the Svínafellsjökull foreland, constructed in the period 1890-1903, are superimposed over an arcuate zone of smoothed and weakly fluted ridges (Figure 7a), interpreted as overridden moraines similar to those displayed on many other Icelandic glacier forelands (e.g. Krüger 1994; Evans et al. 1999, 2009, 2016; Evans & Orton 2014; Jónsson et al. 2014). In contrast, on the Hoffellsjökull foreland, the initially slower recession of the quasi-stable eastern flow lobe produced an intensely overprinted sequence of multiple push moraines, captured in Þorarinsson's (1939) ground photograph of 1937 (Figure 7b). The tills are generally thin (<2 m thick) but thicken to form recessional push moraines and geometric ridge networks up to 3 m high. They are predominantly silt/clay matrix-dominated with the exception of the outermost, pre-1930s moraines on the Svínafellsjökull part of the foreland, where they comprise glacitectonically deformed, coarse stratified gravels (Figure 7c), likely displaced from the shallow depression now occupied by the waters of Svínafellslón. Indeed, a number of push moraines on the west side of the Svínafellslón depression have been constructed by the bulldozing of ice-contact glacifluvial deposits (see below). Over the low bedrock ridge that forms the western boundary of the Svínafellsjökull part of the foreland, the tills are boulder-rich and thin enough in many areas to expose the underlying bedrock, but thicken abruptly into closely-spaced and locally partially overprinted crenulate push moraines with short (≤50 m long) flutings (Figure 8). Over the gentler slopes and surfaces of Svínahryggur, a thin and patchy till veneer partially covers a prominently glacially plucked and abraded bedrock surface that displays some excellent examples of roches moutonnées, whalebacks and cross-cutting striae (Figure 9). These observations on till texture, cover and thickness reveal that the former subglacial surface of the glacier constitutes a mixed-bed imprint comprising the juxtaposed products of glacier sliding and till deformation (cf. Eyles & Doughty 2016; Evans et al. 2018a).

Diagnostic features of subglacial till deformation, operating specifically in the sub-marginal zone within a few hundred meters of the ice margin at any time, include flutings, geometric ridge networks and drumlins (Figures 10-12). The longest flutings on the foreland have been exposed only recently by ice recession and comprise ≤500 m long, densely-spaced, low amplitude (<2m) ridges and stripes with conspicuously variable colours (Figure 10). The most prominent of the colour stripes are light grey or white in appearance and unlike the flutings, which are ridges and clearly continue underneath individual push moraines, these stripes have no clear morphology. The material that is contained within them is also visible as patches on the surface of the push moraines or as clusters of surface boulders. These patterns are similar to the supraglacially lowered flow stripes or foliation-parallel ridges observed draping flutings in perfect parallel lines on Svalbard glacier forelands (Glasser et al. 1998; Glasser & Hambrey 2003; Jennings et al. 2015; Ewertowski et al. 2016). However, there are no such flow stripes on Hoffellsjökull and nor have any been captured in aerial imagery of the glacier. They are similar also to lineations on the beds of palaeo-ice streams in the Canadian Arctic, where subglacial entrainment and dispersal of discrete bedrock outcrops by fast flowing ice has created lithologically distinct flutings and debris stipes (cf. Dyke & Morris 1988; Dyke et al. 1992). Such colour banding in minor fluting fields is unusual and the origins of the discrete colour changes, best exemplified by the light grey/white stripes, is difficult to explain other than as attenuations of debris excavated from point source outcrops, potentially rhyolite, located in the overdeepening. The flutings extend from the overdeepening to the location of the late 20th Century quasi-stable glacier margin, dating to 1975-2000 based on aerial imagery, indicating that material plucked from the bed was dispersed as debris stripes over a prolonged period of sustained unidirectional flow. This fluting and debris stripe assemblage is clearly a prime location for future research into the patterns and processes of subglacial sediment dispersal.

Fluting genesis in Iceland has been linked to subglacial deforming layer processes in relation to either: a) cavity infill downflow of lodged stoss boulders (Benn 1995; Benn & Evans 1996); b) ploughing of grooves by boulders protruding from the ice base and being dragged over the substrate (cf. Boulton 1975, 1982; Boulton et al. 1979; Nelson et al. 2005; Kjær et al. 2006; Evans 2018); or c) till squeezing into grooves carved into the glacier sole as the ice slides over lodged boulders (cf. Boulton 1976; Evans & Rea 2003). Although numerous large boulders are visible on the glacier foreland, very few are at the initiation point of flutings and hence a ploughing and/or grooving origin for many is the most likely hypothesis for future testing at this site.

Some significant, and regionally relatively rare, drumlins occur on the elongate peninsula in Svínafellslón, with a height of ≤8 m and maximum length and width of 450 m and 100m respectively (Figure 11). Small scale drumlins have been reported from various Icelandic glacier forelands, especially those related to surging snouts (cf. Krüger & Thomsen 1984; Krüger 1987; Hart 1995; Johnson et al. 2010; Jónsson et al. 2014, 2016; Benediktsson et al. 2016; Ingolfsson et al. 2016; McCracken et al. 2016) but drumlins are less widely recognised on the active temperate glacier forelands of southern Vatnajokull, with the classic example being that of Breiðamerkurjökull (Boulton 1987). More recently, Jónsson et al. (2016) have identified small drumlins on the foreland of Fláajökull, which are of much smaller size and with lower elongation ratios than those at Breiðamerkurjökull. These subglacial bedforms appear to be cored with the stratified gravels and sands of overridden glacifluvial outwash fans, giving credence to Boulton's (1987) rigid, stable seed point hypothesis, in which deforming till is plastered over a well-drained and immobile substrate. The Svinafellslon peninsula drumlins are adorned with flutings, whose axes parallel those of the drumlins, as well as sawtooth push moraines and geometric ridge networks. These superimposed features indicate that the surface till emplacement was by subglacial deformation but there are no exposures through the drumlin cores to enable an assessment of their exact origins.

Sparse geometric ridge networks are conspicuous in an area of densely-spaced sawtooth push moraines at the southern end of the Svínafellslón peninsula (Figure 6). The close association between extreme sawtooth forms or hairpin-shaped moraines, ridge networks and flutings is typical of a number of recently exposed forelands in front of retreating active temperate glaciers in southeast Iceland. This has been related to the combined operation of crevasse-squeezing and push moraine construction at the thickening end of sub-marginal till wedges in localised poorly-drained settings, especially inside the older moraine loops of the LIA and/or on the adverse slopes of overdeepenings (Price 1970; Evans et al. 2015, 2017a, 2018b; Chandler et al. 2016a, b, c). The role of marginal crevassing in the moulding of these landform assemblages is especially clear on aerial imagery of the Svínafellsjökull snout (Figure 11a). Glaciological theory and numerical modelling indicate that the sub-marginal environment in which these features are evolving is most likely one where the till is being squeezed out from underneath the glacier rather than being subglacially deformed under the applied shear stress (van der Veen 1999), but it is a zone where the deforming till is advected from up-ice and is thickening towards the margin to form a 'till bulge' or 'propagating till wave' (Leysinger-Vieli & Gudmundsson 2010). Hence these landforms represent a process-form regime of sub-marginal to marginal squeezing and till flowage due to weak ice–bed coupling, and their size and extent relies on a constant supply of deforming till at the glacier snout.

Glacifluvial deposits

The glacifluvial landforms and deposits on the Hoffellsjökull foreland are contained within two assemblage types that are commonly displayed around the glacier lobes of SE Iceland (Figure 12; e.g. Maizels, 1993; Marren, 2002, 2005; Price, 1969; Evans 2003, 2005, 2013; Evans & Orton 2015; Evans et al. 2009, 2016, 2017a, b). These coarse-grained gravels and sands occur either in proglacial sandur fans beyond the LIA maximum moraines, where meltwater flow was largely unimpeded (Figure 12a), or in linear sandar that are confined by inset sequences of recessional push moraines wherever they constitute closely-spaced or partially superimposed multiple ridges (Figure 12b). A smaller number and less extensive examples of both assemblage types occur on the outer Svínafellsjökull foreland; for example, linear sandar also exist between the overridden moraine arcs of the outer Svínafellsjökull foreland exposed between 1890 and the 1930s, and small sandur fans emerge from breaches in the push moraine arcs around the southern margins of Svínafellslón. The prominently terraced proglacial sandur of the Austurfljót (Figure 12a) has been the subject of intensive research in the region dating back to the Swedish-Icelandic Expeditions of 1936-1938 (Hjulström 1954; Arnborg 1955a, b) and is representative of an unusually stable meltwater efflux point on the south shore of Hoffellslón that persisted from the LIA maximum up until 2008 when the Austurfljót ceased flowing.

The linear sandur that have developed along the receding western margin of Svínafellsjökull since ca. 1945 have been deposited between push moraine arcs and glacier ice and hence sedimentation has been ice-contact in nature. Consequently, the sandar are locally prominently terraced and pitted due to ice melt-out and resemble kame terraces in a number of locations (Figure 12b). The sandar widen rapidly at their downstream ends to form small fans along the western shore of Svínafellslón. Contemporaneous glacier snout oscillations have constructed small push moraines in many locations, especially on terrace edges that are composed of glacifluvial outwash, and hence these moraines are also characterised by widespread collapse and the occurrence of water-filled kettle holes. A similar morphology also characterises an area of push moraines developed on the apexes of sandur fans on the south shore of Svínafellslón (Figure 12c), most likely as a consequence of ice-marginal bulldozing of ice-contact fans. This style of shallow glacier snout burial by marginal outwash is typical for active temperate glacier margins in Iceland wherever they emerge from upland areas to form piedmont lobes and in places can be related to the decanting of ice-dammed lakes in tributary valleys (cf. Price 1971; Evans & Twigg 2002; Evans et al. 2018c).

Additional areas mapped as glacifluvial deposits include recently deposited alluvium that has been reworked from glacial lake deltas and moraines by both glacier melt and nival runoff from uplands in the east of the map area. These deposits are contained within incised and terraced valley-floor fans in the drainage basins of the former Gjánúpsvatn (Gjávatn), Múlavatn, Pollur and Efstafellsvatn ice-dammed lakes (Figure 5) and grade towards the receding east margin of Hoffellsjökull and its sequentially lowering levels of shrinking ice-contact lakes.

Eskers are rare on the glacier forelands of southern Iceland. The lack of eskers on the Hoffellsjökull foreland likely reflects the fact that the locations of the main drainage axes are beneath lake water. Similar to other glacier snouts in the region that have recently uncovered overdeepenings due to recession and lake drainage, eskers may emerge over time where their englacial and subglacial drainage tunnels eventually melt-out from the downwasting ice (cf. Bennett et al. 2010; Bennett & Evans 2012; Bradwell et al. 2013; Evans & Orton 2015; Everest et al. 2017; Evans et al. 2018b). Indeed the 2012 satellite imagery has captured the ongoing emergence of englacial eskers previously deposited in a sub-marginal tunnel on the east side of Hoffellsjökull (Figure 13a). Tunnels at this location have been decanting ice-dammed lake waters throughout the post-LIA period (Figure 13b) and their enclosed debris appears to have been thrust up within the glacier at this location to form controlled moraine ridges (cf. Evans 2009) and a significant supraglacial debris spread.

Glacilacustrine deposits

Narrow strips of glacilacustrine deposits fringe the margins of the proglacial lakes Hoffellslón & Svínafellslón and in many areas form only thin veneers over till and moraines, where they are consequently not mapped as a surficial unit. The most extensive areas and thickest sequences of glacilacustrine deposits occur in the eastern ice-dammed valleys of the former lakes of Gjánúpsvatn (Gjávatn), Múlavatn, Pollur and Efstafellsvatn (Figure 5) and along the southern shore of Hoffellslón (Figure 6). In the eastern ice-dammed valleys, these deposits are composed predominantly of terraced sand and gravel deltas that formerly prograded into the lakes (Figure 14a) but also include extensive abandoned, gravel-rich lake shorelines (Figure 14b). On the southern shore of Hoffellslón, ice recession and lake lowering since 2008 has exposed fine-grained rhythmite sequences and localised pockets of subaqueous fan sands and gravels, all displaying evidence of glacitectonic disturbance and locally bulldozed into subaqueous moraine ridges (Figure 14c).

The sedimentology of the glacilacustrine deposits is well illustrated by a number of sections exposed in gullies on the southern shore of Hoffellslón. These include examples of glacitectonically disturbed subaqueous (grounding-line) fans, documenting proximal sedimentation, and more distal rhythmites sequences containing abundant dropstones, iceberg dump features and normal faults (Figure 15). In addition to the normal faulting observed in sedimentary exposures, tension cracks developed on the surfaces of the lake sediments indicate that they drape glacier ice in some locations; indeed glacier ice is exposed in small retrogressive slumps, visible as dark concentric scarps on Figure 14c.

The glacial landsystem of Hoffellsjökull and its implications for glacial process-form regimes

An expanding database on modern glacial landsystems continues to improve our understanding of glacial process-form regimes in a variety of environmental and topographic settings. Additionally, the recent reconciliation of high resolution glacial landform mapping with historical climate trends (e.g. Bradwell et al. 2013; Chandler et al. 2016a, b) has verified that glacial geomorphological signatures may be employed with increasing confidence as palaeoclimate indicators in deglaciated terrains. The success of this procedure lies in the expansion and development of modern analogue glacial landsystems, especially those with complex glacier dynamics. The variable responses and geomorphic signatures of the two flow lobes of Hoffellsjökull constitute one such valuable case study.

The variable response of Hoffellsjökull's two flow lobes (Svínafellsjökull and Hoffellsjökull; Aðalgeirsdóttir et al. 2011) to post-LIA climate warming is likely a result of different hypsometries, with the larger surface extent of the west flow lobe (Svínafellsjökull) making it more responsive to the summer temperature drivers of ablation prior to 2000 (cf. Chandler et al. 2016a, b). This is reflected in distinctly different landsystem signatures. The most significant land elements (*sensu* Eyles 1983b) in this respect are the moraines and their distribution pattern on the forelands. On the Svínafellsjökull foreland this comprises inset sequences of closely-spaced recessional, largely sawtooth push moraines, superimposed on overridden moraines. In contrast, on the Hoffellsjökull foreland the pattern is one of intensely overprinted multiple push moraines located on the ice-contact face of an outwash head, inside of which glacilacustrine deposits have been glacitectonised by an oscillating ice margin since the turn of the 21st century. These signatures reflect east Hoffellsjökull's pre-2000 quasi-stationary behaviour and Svínafellsjökull's climatically-tuned gradual recession since the historical LIA maximum. Consequently, Svínafellsjökull's landsystem imprint resembles that of sloping piedmont forelands such as those at Skaftafellsjökull and Fláajökull (Evans et al. 2016, 2017a), whereas Hoffellsjökull's landsystem is similar to that of outwash-head settings such as Heinabergsjökull (Evans & Orton 2015), although its stability at and near the LIA maximum position is unique for southern Iceland.

The lack of moraine dates hampers any assessment of glacier-climate responses but the spacing of push moraine clusters depicted on Figure 6 on the Svínafellsjökull foreland can be reconciled with measurements of ice front activity more widely in the region by the Icelandic Glaciological Society that show slowing retreat and/or readvance in the mid-1930s, 1940-1945 and mid-1950s-1960 (cf. Sigurðsson et al., 2007; Aðalgeirsdóttir et al. 2011; Chandler et al. 2016). Recent aerial photographs then record relative stability from 1975-2000 coinciding with the negative summer temperature anomaly in SE Iceland. During the two latter phases in particular, two arcuate zones of dense networks of closely-spaced and partially overprinted sawtooth and hairpin moraines were constructed (Figures 10 & 11). In contrast, at Hoffellsjökull, ice margin stability until 1960 and then only downwasting until 1985 and catastrophic collapse since 2010 is reflected in a composite push moraine arc, the innermost subaqueous ridges of which were only recently abandoned by the calving front (Figure 6 & 14c).

This complex geomorphic signature of historical glacier marginal oscillations represents variable climate tuning of the two ice flow lobes within the same glacier, likely tempered by topographic controls on snout hypsometry. Whereas Svínafellsjökull's climatically-tuned recession has not been influenced by an overdeepened subglacial topography, Hoffellsjökull maintained stability while occupying the crest of the adverse slope of its depositional overdeepening or outwash head. Both snouts were relatively stable from 1986-2001, the period of negative summer temperate anomaly, and a phase of rapid thinning of Hoffellsjökull was temporarily halted during that time interval. However, Hoffellsjökull underwent rapid calving in 2010 in response to accelerated warming, which in combination with its overdeepened bed brought about catastrophic collapse (cf. Cook & Swift 2012) and the rapid sedimentation of ice-contact glacilacustrine deposits, in places overlying glacier ice. Future recession of the margin of Svínafellsjökull will likely initiate a similar catastrophic response, as it presently occupies the crest of the adverse slope of an overdeepening (Figure 4a).

The fluted and drumlinized subglacial footprint and inset sequences of closely-spaced, sawtooth, recessional push moraines at west Hoffellsjökull (Svínafellsjökull) are not unlike those of other active temperate glacier forelands in Iceland, and are indeed diagnostic of such glacier types. Assessments of glacial landsystem maps on the forelands of such glaciers have revealed a pattern of moraine distribution that appears to be reflective of spatio-temporal change in moraine-forming processes as a result of changes in a combination of proglacial drainage characteristics and structural glaciology or crevasse architecture (Evans et al. 2016, 2017a, 2018b). This specifically entails a change in recessional push moraine morphology over time. Early post-LIA moraines are more linear and broadly arcuate but more recent moraines are increasingly till squeeze-dominated and sawtooth in plan form. This is thought to result from a switch from well-drained and glacier/meltwater coupled forelands to increasingly poorly-drained settings in which proglacial drainage flows between emerging overridden moraine arcs (cf. Benn et al. 2003). At the same time, the development of increasingly stronger radial crevassing, likely controlled by more divergent flow in a thinning snout, has led to the development of a more exaggerated sawtooth moraine plan form, to the extent that many recent moraines display extreme limb construction and are therefore classified as “hairpin-shaped moraines” (Evans et al. 2017a). The post-1945 development of increasingly exaggerated sawtooth moraines and crevasse-squeeze ridges at Svínafellsjökull has been coincident with an obvious change in foreland drainage, manifest in the uncovering of a shallow depression and the growth of the extensive lake of Svínafellslón. A lack of sawtooth moraine construction prior to 1945 may also be a reflection of the absence of a matrix-rich and hence deformable sub-marginal till, as the outermost moraines on the Svínafellsjökull foreland are composed of relatively well-drained coarse stratified gravels that were likely displaced from the shallow depression. The development of these outer recessional moraines from 1890-1903, on top of an arcuate zone of overridden moraines provides further evidence of a regionally widespread phenomenon of a Holocene ice advance of similar magnitude to that of the LIA (cf. Krüger 1994; Evans et al. 1999, 2009, 2016; Evans & Orton 2014; Jónsson et al. 2014).

The subglacial bedforms of the Svínafellsjökull foreland and the ice sliding/till deformation, mixed-bed imprint of Svínahryggur constitute an excellent modern analogue of the ice-bed interface process-form regime, part of what has been recently documented as a regional type area for subglacial deforming layer till by Evans et al. (2018a). Of note are the flutings and stripes, the former potentially constituting groove-ploughed landforms (cf. Boulton 1975, 1976, 1982; Boulton et al. 1979; Evans & Rea 2003; Nelson et al. 2005; Kjaer et al. 2006; Evans 2018) and the latter potentially representing point-source debris stripes emanating from distinctive plucked bedrock outcrops. Drumlins also are relatively rare in southern Iceland (cf. Boulton 1987; Jónsson et al. 2016) and hence the well-developed Svínafellsjökull examples are prime targets for future study, providing ground penetrating radar is employed in order to compensate for the lack of natural exposures.

Conclusion

The compilation of a 1:14,500 scale glacial geomorphology and surficial geology map of the foreland of Hoffellsjökull, southeast Iceland, based on WorldView-2 satellite imagery dating to 2012, combined with field-based observations on glacigenic stratigraphic exposures, has facilitated an assessment of the glacial landsystem signature of the contrasting glacier-climate interactions of two separate flow lobes within one outlet glacier since the LIA maximum. This complexity in process-form regimes in a single active temperate glacier lobe constitutes a valuable modern analogue in the expanding database on the employment of glacial geomorphological signatures as palaeoclimate indicators in ancient deglaciated terrains.

The variable responses and landsystem signatures of Hoffellsjökull's two flow lobes, Svínafellsjökull and Hoffellsjökull, reflect the climatically-tuned gradual recession of the former and the pre-2000 quasi-stationary behaviour of the latter since the historical LIA maximum. This variability is due to the different basin widths and bed topographies of the two lobes. The inset and annually-tuned push moraine sequences and subglacially streamlined surfaces of Svínafellsjökull's landsystem imprint is typical of other sloping piedmont forelands in southern Iceland. This is in contrast to Hoffellsjökull's outwash-head type landsystem signature with its additional, regionally unique component of closely-spaced composite push moraines, indicative of long term stability at and near the LIA maximum. Moraine spacing is a potentially valuable climate indicator also on the Svínafellsjökull foreland, where quasi-stability and/or readvance in the two periods of the mid-1950s-1960 and 1975-2000 resulted in the construction of two arcuate zones of closely-spaced and partially overprinted sawtooth and hairpin moraines.

Additionally, the pattern of moraine distribution on the Svínafellsjökull foreland, not unlike other active temperate forelands in SE Iceland, reflects spatio-temporal change in moraine-forming processes dictated by changes in a combination of proglacial drainage characteristics and structural glaciology or crevasse architecture. This is manifest in the change from more linear and broadly arcuate moraine of the early post-LIA period to increasingly till squeeze-dominated and sawtooth/hairpin plan forms since the mid-20th Century, evidently a product of a switch from well-drained to increasingly poorly-drained settings, as proglacial drainage became more constrained between emerging overridden moraine arcs, as well as the development of increasingly stronger radial crevassing.

The subglacial footprint of the Svínafellsjökull foreland contains some significant features worthy of future research attention, including an arcuate zone of overridden moraines potentially indicative of a regional Holocene ice advance of similar magnitude to that of the LIA, prominent flutings and debris stripes potentially indicative of groove-ploughing and point-source bedrock plucking respectively, and relatively large drumlins. Additionally, continued snout recession, especially of the Hoffellsjökull flow lobe, will uncover further details of the landform-sediment assemblages indicative of ice-dammed and proglacial lake linkages to englacial and subglacial drainage pathways in depositional overdeepenings.

Acknowledgements

Research permits to undertake fieldwork at Hoffellsjökull were provided by Regína Hreinsdóttir on behalf of Skaftafell National Park and by RANNIS (The Icelandic Centre for Research). Reviews by

Jessica Slomka and Harold Lovell provided valuable comments that helped improve this paper. Thanks to land owner Gísli Sigurbergsson for permitting access to the foreland of Svínafellsjökull and to Þorvarður Árnason, Snævarr Guðmundsson and Þrúðmar Þrúðmarsson for help with fieldwork logistics and welcome coffee breaks with a fine view.

References

Aðalgeirsdóttir, G., Guðmundsson, S., Björnsson, H., Pálsson, F., Jóhannesson, T., Hannesdóttir, H., Sigurðsson, S. Þ., Berthier, E. 2011. Modelling the 20th and 21st century evolution of Hoffellsjökull glacier, SE-Vatnajökull, Iceland, The Cryosphere 5, 961–975.

Ahlmann, H.W. 1948. Glaciological Research on the North Atlantic Coasts. Royal Geographical Society Research Series 1, London.

Ahlmann, H.W., Þorarinsson, S. 1937. Vatnajökull. Scientific results of the Swedish–Icelandic investigations 1936–37–38. Chapter III. Previous investigations of Vatnajökull. Marginal oscillations of its outlet glaciers, and general description of its morphology. Geografiska Annaler 19, 176–211.

Ahlmann, H.W., Þorarinsson, S. 1938. Vatnajokull. Scientific results of the Swedish–Icelandic investigations 1936–38. Chapter V. The Ablation. Geografiska Annaler 20, 171–233.

Ahlmann, H.W., Þorarinsson, S. 1939. Vatnajökull. Scientific Results of the Swedish-Icelandic Investigations 1936-37-38. Chapters VII-IX.

Arnborg, L. 1955a. Hydrology of the glacial river Austurfljot, Geografiska Annaler 37, 185–201.

Arnborg, L. 1955b. Ice-marginal lakes at Hoffellsjokull. Geografiska Annaler 37, 202–228.

Beedle, M.J., Menounos, B., Luckman, B.H., Wheate R. 2009. Annual push moraines as climate proxy. Geophysical Research Letters 36, L20501, doi:10.1029/2009GL039533

Benediktsson, Í. Ö., S.A. Jónsson, A. Schomacker, M.D. Johnson, Ó. Ingólfsson, L. Zoet, N.R. Iverson and J. Stötter 2016. Progressive formation of modern drumlins at Múlajökull, Iceland: stratigraphical and morphological evidence. *Boreas* 45, 567-583.

Benn, D.I. 1995. Fabric signature of subglacial till deformation, Breidamerkurjokull, Iceland. Sedimentology 42, 735 -747.

Benn D.I. and D.J.A. Evans 1996. The interpretation and classification of subglacially-825 deformed materials. Quaternary Science Reviews 15, 23-52.

Benn, D. I., Kirkbride, M. P., Owen, L. A. and Brazier, V. 2003. Glaciated valley landsystems. In: Evans D.J.A. (ed.), Glacial landsystems. Arnold, London, pp. 372–406.

Bennett, G. L., Evans, D. J. A. 2012. Glacier retreat and landform production on an overdeepened glacier foreland: The debris-charged glacial landsystem at Kviarjokull, Iceland. Earth Surface Processes and Landforms 37, 1584–1602.

Bennett, G. L., Evans, D. J. A., Carbonneau, P., Twigg, D. R. 2010. Evolution of a debris-charged glacier landsystem, Kviarjokull, Iceland. Journal of Maps 2010, 40–76.

Bennett, M. R., Huddart, D., McCormick, T. 2000. The glaciolacustrine landform-sediment assemblage at Heinabergsjokull, Iceland. Geografiska Annaler 82A, 1–16.

Bjornsson, H. 1976. Marginal and supraglacial lakes in Iceland. Jökull 26, 40–50.

Björnsson, H. 1996. Scales and rates of glacial sediment removal: a 20 km long, 300 m deep trench created beneath Breiðamerkurjökull during the Litle Ice Age. Annals of Glaciology 22, 141–146.

Björnsson, H., Pálsson, F. 2004. Jöklar í Hornafirði. In: Björnsson, H., Jónsson, E., Runólfsson, S. (eds.), Jöklaveröld, Náttúra og Mannlíf. Skrudda, Reykjavík, pp. 125–164.

Björnsson, H., Pálsson, F., Sigurðsson, O., Flowers, G.E. 2003. Surges of glaciers in Iceland. Annals of Glaciology 36, 82-90.

Boulton, G.S. 1975. Processes and patterns of subglacial sedimentation: a theoretical approach. In:

Wright, A.E., Moseley, F. (Eds.), Ice Ages: Ancient and Modern. Seel House Press, Liverpool, pp. 7–42.
Boulton, G.S. 1976. The origin of glacially fluted surfaces: observations and theory. Journal of Glaciology 17, 287–309.
Boulton, G.S. 1982. Subglacial processes and the development of glacial bedforms. In: Davidson-Arnott, R., Nickling, W., Fahey, B.D. (Eds.), Research in Glacial, Glacio-fluvial and Glacio-lacustrine Systems. GeoBooks, Norwich, pp.1–31.
Boulton, G.S. 1986. Push-moraines and glacier-contact fans in marine and terrestrial environments. Sedimentology 33, 677-698.
Boulton, G. S. 1987. A theory of drumlin formation by subglacial sediment deformation. In J. Menzies & J. Rose (Eds.), Drumlin symposium (pp. 25–80). Rotterdam: Balkema.
Boulton G.S., Hindmarsh R.C.A., 1987. Sediment deformation beneath glaciers: rheology and sedimentological consequences. Journal of Geophysical Research: Earth Surface 92, 9059–9082.
Boulton, G.S., Dobbie, K.E., Zatsepin, S., 2001. Sediment deformation beneath glaciers and its coupling to the subglacial hydraulic system. Quaternary International 86, 3–28.
Boulton, G.S., Morris, E.M., Armstrong, A.A., Thomas, A. 1979. Direct measurement of stress at the base of a glacier. Journal of Glaciology 22, 3–24.
Bradwell, T. 2004. Annual moraines and summer temperatures at Lambatungnajökull, Iceland. Arctic, Antarctic, and Alpine Research 36, 502-508.
Bradwell, T., Dugmore, A.J. & Sugden, D.E. 2006. The Little Ice Age glacier maximum in Iceland and the North Atlantic Oscillation: evidence from Lambatungnajökull, southeast Iceland. Boreas 35, 61-80.
Bradwell, T., Sigurđsson, O. & Everest, J. 2013. Recent, very rapid retreat of a temperate glacier in SE Iceland. Boreas 42, 959-973.
Chandler, B.M.P., Evans, D.J.A. & Roberts, D.H. 2016a. Characteristics of recessional moraines at a temperate glacier in SE Iceland: Insights into patterns, rates and drivers of glacier retreat. Quaternary Science Reviews 135, 171-205.
Chandler, B.M.P., Evans, D.J.A. & Roberts, D.H. 2016b. Recent retreat at a temperate Icelandic glacier in the context of the last ~80 years of climate change in the North Atlantic region. Arktos 2, article 24.
Chandler B.M.P., Evans D.J.A., Roberts D.H., Ewertowski M. & Clayton A.I. 2016c. Glacial geomorphology of the Skálafellsjökull foreland, Iceland: A case study of 'annual' moraines. Journal of Maps 12, 905-916.
Danish General Staff 1904. Öræfajökull, Sheet 87. Topographic map 1:50,000 scale. Geodetic Institute, Copenhagen.
Durham University Iceland Expedition 1951. Breiðamerkurjökull map 1951. 1: 25000 scale map. Durham University.
Dyke, A.S., Morris, T.F. 1988. Drumlin fields, dispersal trains and ice streams in Arctic Canada. Canadian Geographer 32, 86-90.
Dyke, A.S., Morris, T.F., Green, D.E.C., England, J. 1992. Quaternary Geology of Prince of Wales Isand, Arctic Canada. Geological Survey of Canada, Memoir 433.
Evans, D. J.A. 2003. Ice-marginal terrestrial landsystems: Active temperate glacier margins. In: D.J.A. Evans (Ed.), Glacial landsystems. Arnold, London, pp. 12–43.
Evans, D. J. A. 2005. The glacier-marginal landsystems of Iceland. In: C. J. Caseldine, A. J. Russell, J. Harjardottir, & O. Knudsen (Eds.), Iceland: Modern processes and past environments. Elsevier, Amsterdam, pp. 93–126.
Evans, D. J. A. 2009. Controlled moraines: Origins, characteristics and paleoglaciological implications. Quaternary Science Reviews 28, 183–208.
Evans, D. J. A. 2013. The glacial and periglacial research – Geomorphology and retreating glaciers. In:

J. Shroder (Editor in Chief), R. Giardino, J. Harbor (Eds.), *Treatise on geomorphology*. Academic Press, San Diego, CA, vol. 8, *Glacial and Periglacial Geomorphology*, pp. 460–478.
Evans, D.J.A., 2016. Vatnajökull National Park (South Region). Guide to a glacial landscape legacy. Vatnajökull National Park, Reykjavík.
Evans, D.J.A. 2018. Till: A Glacial Process Sedimentology. Wiley-Blackwell, Chichester.
Evans, D.J.A., Chandler, B.M.P. 2018. Geology, physiography and glaciology of SE Iceland. In, Evans D.J.A. (ed.) Glacial Landsystems of Southeast Iceland: Quaternary Applications – Field Guide. Quaternary Research Association, London, pp. 1-19.
Evans, D. J. A., Rea, B. R. 2003. Surging glacier landsystem. In D. J. A. Evans (Ed.), Glacial landsystems. Arnold, London, pp. 259–288.
Evans, D. J. A., Hiemstra, J. F. 2005. Till deposition by glacier submarginal, incremental thickening. Earth Surface Processes and Landforms 30, 1633–1662.
Evans D.J.A., Orton C. 2015. Heinabergsjökull and Skalafellsjökull, Iceland: Active Temperate Piedmont Lobe and Outwash Head Glacial Landsystem. Journal of Maps 11, 415–431.
Evans, D.J.A., Twigg, D.R. 2002. The active temperate glacial landsystem: a model based on Breiðamerkurjökull and Fjallsjökull, Iceland. Quaternary science reviews 21, 2143-2177.
Evans, D.J.A., Archer, S. & Wilson, D.J.H. 1999. A comparison of the lichenometric and Schmidt hammer dating techniques based on data from the proglacial areas of some Icelandic glaciers. Quaternary Science Reviews 18, 13-41.
Evans D.J.A., Ewertowski M. & Orton C. 2016. Fláajökull (north lobe), Iceland: active temperate piedmont lobe glacial landsystem. Journal of Maps 12, 777–789.
Evans D.J.A., Ewertowski M. & Orton. C. 2017a. Skaftafellsjökull, Iceland: glacial geomorphology recording glacier recession since the Little Ice Age. Journal of Maps 13, 358–368.
Evans D.J.A., Ewertowski M. & Orton C. 2017b. The glaciated valley landsystem of Morsárjökull, southeast Iceland, Journal of Maps 13, 909-920.
Evans D.J.A., Ewertowski M., Orton C. & Graham D.J. 2018c. The glacial geomorphology of the ice cap piedmont lobe landsystem of East Myrdalsjokull, Iceland. Geosciences 8, 194; doi:10.3390/geosciences8060194.
Evans D.J.A., Ewertowski M. & Roberts, D.H. 2018b. Glacial landsystem development at Fjallsjokull. In: Evans D.J.A. (ed.), Glacial Landsystems of Southeast Iceland – Quaternary Applications: Field Guide. Quaternary Research Association, London, 224-241.
Evans, D.J.A., Guðmundsson, S., Vautrey, J.L., Fernyough, K., Southworth, W.G. sub. A new lichenometric growth-rate (curve) for the Breiðamerkurjökull foreland, Iceland, and the analysis of potential climatic drivers of glacier recession. Geografiska Annaler.
Evans, D.J.A., Nelson, C.D., Webb, C. 2010. An assessment of fluting and till esker formation on the foreland of Sandfellsjökull, Iceland. Geomorphology 114, 453–465.
Evans, D.J.A., Roberts, D.H., Hiemstra, J.F., Nye, K.M., Wright, H. & Steer, A. 2018a. Submarginal debris transport and till formation in active temperate glacier systems: the southeast Iceland type locality. Quaternary Science Reviews 195, 72-108.
Evans, D. J. A., Shand, M., Petrie, G. 2009. Maps of the snout and proglacial landforms of Fjallsjökull, Iceland (1945, 1965, 1998). Scottish Geographical Journal 125, 304–320.
Everest, J., Bradwell, T. 2018a. Glacial landsystem development at Svinafellsjökull. In, Evans D.J.A. (ed.) Glacial Landsystems of Southeast Iceland: Quaternary Applications – Field Guide. Quaternary Research Association, London, pp. 149-156.
Everest, J., Bradwell, T. 2018b. The glacial landsystem at Virkisjökull-Falljökull. In, Evans D.J.A. (ed.) Glacial Landsystems of Southeast Iceland: Quaternary Applications – Field Guide. Quaternary Research Association, London, pp. 167-176.
Everest, J., Bradwell, T., Jones, L.D, Hughes, L. 2017. The geomorphology of Svínafellsjökull and Virkisjökull-Falljökull glacier forelands, southeast Iceland. Journal of Maps 13, 936-945.
Ewertowski, M.W., Evans, D.J.A., Roberts, D.H., Tomczyk, A.M. 2016. Glacial geomorphology of the

terrestrial margins of the tidewater glacier, Nordenskiöldbreen, Svalbard. Journal of Maps 12, 476-487.
Ewertowski, M.W., Tomczyk, A.M., Evans, D.J.A., Roberts, D.H., Ewertowski, W. 2019. Operational framework for rapid, very-high resolution mapping of glacial geomorphology using low-cost unmanned aerial vehicles and structure-from-motion approach. Remote Sensing 11, 65. doi:10.3390/rs11010065.
Eyles, N., 1979. Facies of supraglacial sedimentation on Icelandic and alpine temperate glaciers. Canadian Journal of Earth Sciences 16, 1341–1361.
Eyles, N., 1983a. Modern Icelandic glaciers as depositional models for ‘‘hummocky moraine’’ in the Scottish highlands. In: Evenson, E.B., Schluchter, C., Rabassa, J. (Eds.), Tills and Related Deposits. Balkema, Rotterdam, pp. 47–59.
Eyles, N., 1983b. Glacial Geology: A Landsystems Approach. In: Eyles, N. (ed.), Glacial Geology. Pergamon, Oxford, pp. 1-18.
Eyles, N., Doughty, M. 2016. Glacially-streamlined hard and soft beds of the paleo-Ontario Ice Stream in Southern Ontario and New York State. Sedimentary Geology 338, 51-71.
Furbish, D.J., Andrews, J.T., 1984. The use of hypsometry to indicate long-term stability and response of valley glaciers to changes in mass transfer. Journal of Glaciology 30, 199–211.
Glasser, N.F., Hambrey, M.J. 2003. Ice-marginal terrestrial landsystems: Svalbard polythermal glaciers. In: Evans, D.J.A. (Ed.), Glacial Landsystems. Arnold, London, pp. 65–88.
Glasser, N.F., Hambrey, M.J. Crawford, K., Bennett, M.R., Huddart, D. 1998. The structural glaciology of Kongsvegen, Svalbard and its role in landform genesis. Journal of Glaciology 44, 136–148.
Guðmundsson, S. 2014. Reconstruction of late 19th century geometry of Kotárjökull and Breiðamerkurjökull in SE-Iceland and comparison with the present. Unpublished MSc thesis, University of Iceland.
Guðmundsson, S., Björnsson, H., Pálsson, F. 2017. Changes of Breiðamerkurjökull glacier, SE-Iceland, from its late nineteenth century maximum to the present. Geografiska Annaler 99A, 338-352
Hannesdóttir H., Björnsson H., Pálsson F., Aðalgeirsdóttir G., Guðmundsson S. 2014. Variations of southeast Vatnajökull ice cap (Iceland) 1650–1900 and reconstruction of the glacier surface geometry at the Little Ice Age maximum. Geografiska Annaler 97A, 237-264.
Hannesdóttir H., Björnsson H., Pálsson F., Aðalgeirsdóttir G., Guðmundsson S. 2015. Area, volume and mass changes of southeast Vatnajökull ice cap, Iceland, from the Little Ice Age maximum in the late 19th century to 2010. The Cryosphere 9, 565–585.
Hart, J.K. 1995. Recent drumlins, flutes and lineations at Vestari-Hagafellsjökull, Iceland. Journal of Glaciology 41, 596-606.
Hjulström, F. 1954. The geomorphology of the alluvial outwash plains (sandur) of Iceland and the mechanics of braided rivers. Proceedings 25th Congress, IGU Washington, 337-342.
Howarth, P.J. 1971. Investigations of two eskers at eastern Breiðamerkurjökull, Iceland. Arctic and Alpine Research 3, 305–318.
Howarth, P. J., Welch, R. 1969a. Breiðamerkurjökull, South-east Iceland, August 1945. 1:30,000 scale map, University of Glasgow.
Howarth, P. J., Welch, R. 1969b. Breiðamerkurjökull, South-east Iceland, August 1965. 1:30,000 scale map, University of Glasgow.
Hurrell, J. & National Center for Atmospheric Research Staff 2016. The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index (station-based). Accessed at https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-indexstation-based on 29/01/17.
Ingólfsson, Ó., Benediktsson, Í. Ö., Schomacker, A., Kjær, K., Brynjólfsson, S., Jónsson, S.A., Korsgaard, N.J. and Johnson M.D. 2016. Glacial geological studies of surge-type glaciers in Iceland – research status and future challenges. Earth Science Reviews 152, 37-69.
Jennings, S.J.A., Hambrey, M.J., Glasser, N.F., James, T.D., Hubbard, B. 2015. Structural glaciology of Austre Brøggerbreen, northwest Svalbard. Journal of Maps 12, 790-796.

Jóhannesson, T., Björnsson, H., Magnússon, E., Guðmundsson, S., Pálsson, F., Sigurðsson, O, Þorsteinsson, Þ., Berthier, E. 2013. Ice-volume changes, bias-estimation of mass-balance measurements and changes in subglacial lakes derived by LiDAR-mapping of the surface of Icelandic glaciers. Annals of Glaciology 54, 63–74.

Johnson, M.D., Schomacker, A., Benediktsson, Í.Ö., Geiger, A.J., Ferguson, A. and Ingólfson Ó. 2010. Active drumlin field revealed at the margin of Múlajökull, Iceland: a surge type glacier. Geology 38, 943–946.

Jónsson, E. 2004. Í veröld jökla, sanda og vatna, edited by: Björnsson, H., Jónsson, E., and Runólfsson, S., Jöklaveröld, Náttúra og Mannlíf, Reykjavík, Skrudda, 11–86.

Jónsson, S. A., Schomacker, A., Benediktsson, Í.Ö., Ingólfsson, Ó. and Johnson, M.D. 2014. The drumlin field and the geomorphology of the Múlajökull surge-type glacier, central Iceland. Geomorphology 207, 213–220.

Jónsson, S.A., Benediktsson, Í.Ö., Ingólfsson, Ó., Schomacker, A., Bergsdóttir, H.L., Jacobson, W.R. and Linderson, H. 2016. Submarginal drumlin formation and late Holocene history of Fláajökull, southeast Iceland. Annals of Glaciology 57, 128-141.

Kjær, K.H., Larsen, E., van der Meer, J.J.M., Ingólfsson, Ó., Krüger, J., Benediktsson, Í.Ö., Knudsen, C.G., Schomacker, A. 2006. Subglacial decoupling at the sediment/bedrock interface: a new mechanism for rapid flowing ice. Quaternary Science Reviews 25, 2704–2712.

Krigström, A. 1962. Geomorphological studies of sandur plains and their braided rivers in Iceland. Geografiska Annaler 44, 328-346.

Krüger, J. 1987. Relationship of drumlin shape and distribution to drumlin stratigraphy and glacial history, Mýrdalsjökull, Iceland. In: Menzies, J., J. Rose (eds), Drumlin Symposium. Rotterdam, Balkema, 257-266.

Krüger, J. 1993. Moraine-ridge formation along a stationary ice front in Iceland. Boreas 22, 101–109.

Krüger, J. 1994. Glacial processes, sediments, landforms, and stratigraphy in the terminus region of Mýrdalsjökull, Iceland. Folia Geographica Danica 21, 1-233.

Krüger, J. 1995. Origin, chronology and climatological significance of annual-moraine ridges at Myrdalsjökull, Iceland. The Holocene 5, 420-427.

Krüger, J. and Thomsen, H.H. 1984. Morphology, stratigraphy, and genesis of small drumlins in front of the glacier Mýrdalsjökull, South Iceland. Journal of Glaciology 30, 94-105.

Leysinger-Vieli, G.J.M.C., Gudmundsson, G.H. 2010. A numerical study of glacier advance over deforming till. The Cryosphere 4, 359–372.

Lukas, S. 2012. Processes of annual moraine formation at a temperate alpine valley glacier: insights into glacier dynamics and climatic controls. Boreas 41, 463–480.

Maizels, J.K., 1993. Lithofacies variations within sandur deposits: the role of runoff regime, flow dynamics and sediment supply characteristics. Sedimentary Geology 85, 299–325.

Marren, P. M. 2002. Glacier margin fluctuations, Skaftafellsjökull, Iceland: Implications for sandur evolution. Boreas 31, 75–81.

Marren, P.M. 2005. Magnitude and frequency in proglacial rivers: A geomorphological and sedimentological perspective. Earth Science Reviews 70, 203–251.

McCracken, R.G., Iverson, N.R., Benediktsson, Í.Ö., Schomacker, A., Zoet, L.K., Johnson, M.D., Hooyer, T.S. and Ingólfsson Ó. 2016. Origin of the active drumlin field at Múlajökull, Iceland: New insights from till shear and consolidation patterns. Quaternary Science Reviews 148, 243-260.

Nelson, A.E., Willis, I.C., Ó Cofaigh, C. 2005. Till genesis and glacier motion inferred from sedimentological evidence associated with the surge-type glacier, Bruarjökull, Iceland. Annals of Glaciology 42, 14–22.

Phillips, E. R., Finlayson, A., Bradwell, T., Everest, J., Jones, L. 2014. Structural evolution triggers a dynamic reduction in active glacier length during rapid retreat: Evidence from Falljökull, SE Iceland. Journal of Geophysical Research, Earth Surface 119, 2194–2208.

Phillips, E. R., Finlayson, A., Jones, L. 2013. Fracturing, block-faulting and moulin development

associated with progressive collapse and retreat of a polar maritime glacier: Virkisjökull-Falljökull, SE Iceland. Journal of Geophysical Research, Earth Surface 118, 1–17.
Phillips, E.R., Finlayson, A., Everest, J., Jones, L., Bradwell, T. 2018. Changes in the structure and dynamics of Falljökull during the ongoing phase of rapid retreat. In, Evans D.J.A. (ed.) Glacial Landsystems of Southeast Iceland: Quaternary Applications – Field Guide. Quaternary Research Association, London, pp. 157-166.
Price, R.J. 1969. Moraines, sandar, kames and eskers near Breiðamerkurjökull, Iceland. Transactions of the Institute of British Geographers 46, 17-43.
Price, R. J. 1970. Moraines at Fjallsjökull, Iceland. Arctic and Alpine Research 2, 27–42.
Price, R. J. 1971. The development and destruction of a sandur, Breiðamerkurjökull, Iceland. Arctic and Alpine Research 3, 225–237.
Price, R.J. 1982. Changes in the proglacial area of Breiðamerkurjökull, southeastern Iceland: 1890–1980. Jökull 32, 29–35.
Price, R.J., Howarth, P.J. 1970. The evolution of the drainage system (1904–1965) in front of Breiðamerkurjökull, Iceland. Jökull 20, 27–37.
Russell, A.J., Knight, P.G., van Dijk, T.A.G.P. 2001. Glacier surging as a control on the development of proglacial, fluvial landforms and deposits, Skeiðarársandur, Iceland. Global and Planetary Change 28, 163-174.
Sharp, M.J. 1984. Annual moraine ridges at Skálafellsjökull, southeast Iceland. Journal of Glaciology 30, 82–93.
Sigurđsson, O., Jónsson, T. & Jóhannesson, T. 2007. Relation between glacier-termini variations and summer temperature in Iceland since 1930. Annals of Glaciology 46, 170-176.
Spedding, N., Evans, D.J.A. 2002. Sediments and landforms at Kviarjökull, southeast Iceland: A reappraisal of the glaciated valley landsystem. Sedimentary Geology 149, 21–42.
Storrar, R.D., Evans, D.J.A., Stokes, C.R., Ewertowski, M. 2015. Controls on the location, morphology and evolution of complex esker systems at decadal timescales, Breiðamerkurjökull, southeast Iceland. Earth Surface Processes and Landforms 40, 1421-1438.
Swift, D.A., Cook, S.J. 2018. Glaciological processes associated with the terminal overdeepening at Svinafellsjökull. In, Evans D.J.A. (ed.) Glacial Landsystems of Southeast Iceland: Quaternary Applications – Field Guide. Quaternary Research Association, London, pp. 124-136.
Thompson, A. P. 1988. Historical development of the proglacial landforms of Svínafellsjökull and Skaftafellsjökull, southeast Iceland. Jökull 38, 17–31.
Thompson, A. & Jones, A. 1986. Rates and causes of proglacial river terrace formation in southeast Iceland: an application of lichenometric dating techniques. Boreas 15, 231-246.
Þórarinsson S. 1939. Vatnajökull. The scientific results of the Swedish-Icelandic investigations 1936-37-38. Chapter IX. The ice dammed lakes of Iceland with particular reference to their values as indicators of glacier oscillations. Geografiska Annaler 21, 216–242.
Þórarinsson, S. 1943. Vatnajökull: Scientific results of the Swedish–Icelandic investigations 1936–37–38. Chapter XI. Oscillations of the Icelandic glaciers in the last 250 years. Geografiska Annaler 25, 1–54.
Þórarinsson, S. 1956. On the variations of Svinafellsjökull, Skaftafellsjökull and Kvíárjökull in Öræfi. Jökull 6, 1–15.
van der Veen, C.J. 1999. Fundamentals of Glacier Dynamics. Balkema, Rotterdam.
Waller, R.I., Evans, D.J.A., Hiemstra, J.F. 2018. Glacial landsystem development at Skeiðarárjökull. In, Evans D.J.A. (ed.) Glacial Landsystems of Southeast Iceland: Quaternary Applications – Field Guide. Quaternary Research Association, London, pp. 86-101.
Waller, R.I., van Dijk, T.A.G.P., Knudsen, Ó. 2008. Subglacial bedforms and conditions associated with the 1991 surge of Skeiðarárjökull, Iceland. Boreas 37, 179-194.

Figure captions

Figure 1: Variations since 1931 of the non-surge glacier margins of the Vatnajökull South Region glaciers, using data from the Icelandic Glaciological Society (from Evans & Chandler 2018).

Figure 2: Location map (a) and oblique aerial photograph (b) of Hoffellsjökull in SE Iceland. The western flow lobe of Svínafellsjökull forms the lobate margin on the left side of the aerial image and the eastern flow lobe is confined by the valley on the right (photograph kindly provided by Snævarr Guðmundsson).

Figure 3: The bedrock topography beneath Hoffellsjökull in 2001, with blue area indicating elevations below sea level (from Björnsson & Pálsson 2004).

Figure 4: The historical changes of Hoffellsjökull: a) longitudinal profiles and cross sections through Hoffellsjökull, showing the bed topography and ice surface changes over time. The long profiles A-A' and B-B' are for the two independent flow lobes of Svínafellsjökull and Hoffellsjökull respectively. Inset map shows profile locations and historical ice margins (from Aðalgeirsdóttir et al. 2011); b) map of the extent of the glacier and its lakes over time (after Hannesdóttir et al. 2015).

Figure 5: Ahlmann and Þorarinsson's (1939) map depicting the glacier snout and the proglacial lake draining into the main proglacial river Vesturfljót (now names Suðurfljót). Also mapped are the four ice-dammed lakes of Gjánúpsvatn (Gjávatn), Múlavatn, Pollur and Efstafellsvatn.

Figure 6: Glacial geomorphology and surficial geology map of Hoffellsjökull, depicting the landform-sediment assemblages of the glacial landsystem as they appears in 2012. A higher resolution version is available for download as supplementary information.

Figure 7: Moraines of the Hoffellsjökull glacial landsystem: a) satellite image extract (2012; 870 m across) of recessional moraines on the outer Svínafellsjökull foreland, constructed from 1890-1903 and superimposed over an arcuate zone of smoothed and weakly fluted ridges (overridden moraines); b) aerial photograph extract (Landmælingar Islands 1975) of the intensely overprinted sequence of multiple push moraines on the Hoffellsjökull foreland and documenting the initially slower recession of the quasi-stable snout; c) ground photograph and stratigraphic section from the pre-1930s push moraines on the Svínafellsjökull foreland, showing glacitectonically deformed, coarse stratified gravels.

Figure 8: Satellite image extract (2012) of the low bedrock ridge to the west of the Svínafellsjökull foreland, showing patchy, boulder-rich tills and localised areas of bedrock, with tills thickening abruptly into closely-spaced and locally partially overprinted crenulate push moraines and short flutings. Image is 800 m across.

Figure 9: Thin and patchy till veneer (upper view) partially covering plucked and abraded bedrock surfaces, displaying roches moutonnées, whalebacks and cross-cutting striae (middle and lower views), on the lower slopes of the Svínahryggur ridge.

Figure 10: Flutings and debris stripes on the Svínafellsjökull foreland: a) satellite image extract (2012) of the flutings and debris stripes, showing their association with sawtooth and hairpin push moraines on the post-1975 foreland; b) aerial oblique view of the same area taken in 2016 by Þorvaður Árnason.

Figure 11: Drumlins and associated landforms on the Svinafellslon peninsula: a) extract from 1975 aerial photograph (Landmælingar Islands); b) a 6 cm hillshade DEM derived from UAV imagery; c) ground photograph viewed from the northeast in 2014.

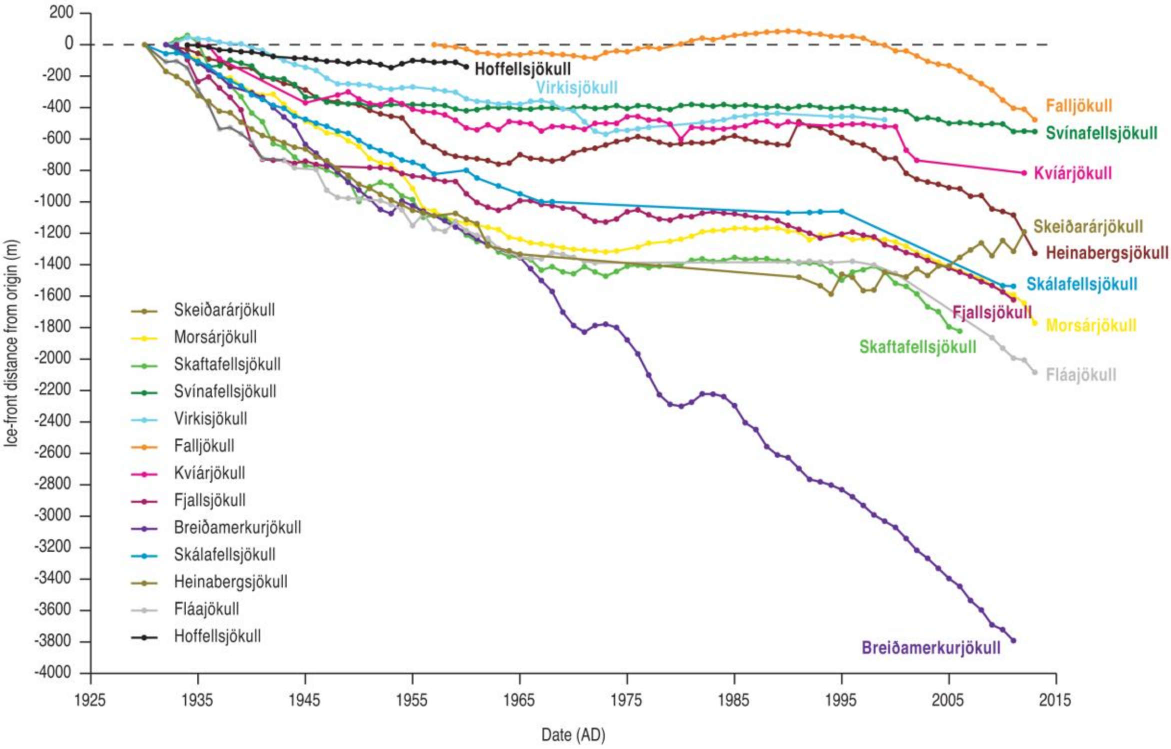
Figure 12: Examples of the prominent glacifluvial landforms and deposits on the Hoffellsjökull foreland: a) aerial photograph extract (Landmælingar Islands 1989) of the terraced proglacial Hoffellssandur, beyond the LIA maximum moraines; b) satellite image extract (2012) of the linear sandar confined by inset sequences of recessional push moraines on the west side of the Svínafellsjökull foreland; c) satellite image extract (2012) of the push moraines developed by bulldozing of the pitted apexes of ice-contact sandur fans on the south shore of Svínafellslón.

Figure 13: The evolution of englacial eskers related to glacier sub-marginal tunnel development by decanting ice-dammed lake waters on the east side of Hoffellsjökull: a) satellite image extract (2012) showing the emergence of englacial esker segments and associated controlled moraine ridges; b) aerial photograph extract (Landmælingar Islands 1975) showing tunnel development due to decanting ice-dammed lake waters.

Figure 14: Glacilacustrine deposits and landforms: a) satellite image extract (2012) of the north arm of Gjánúpsvatn (Gjávatn), showing incised and terraced delta terraces; b) aerial photograph extract (Landmælingar Islands 1989) of the south arm of Gjánúpsvatn (Gjávatn), showing prominent flights of abandoned, gravel-rich lake shorelines; c) the southern shore of Hoffellslón, showing subaqueous moraine ridges uncovered by ice recession and lake lowering since 2008. The light tone indicates that these features are composed of glacitectonised rhythmite sequences and subaqueous fans.

Figure 15: Typical glacilacustrine deposits exposed on the southern shore of Hoffellslón and visible on Figure 14c; a) overview looking east of subaqueous moraine ridges and gullies through glacilacustrine deposits; b) glacitectonically disturbed subaqueous (grounding-line) fan (ice flow from right to left); c) rhythmites with dropstones and iceberg dump features; d) normally faulted rhythmite sequence.

Figure 1



200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
-2200
-2400
-2600
-2800
-3000
-3200
-3400
-3600
-3800
-4000
Ice-front distance from origin (m)
1925
1935
1945
1955
1965
1975
1985
1995
2005
2015
Date (AD)
Skeiðarárjökull
Morsárjökull
Skaftafellsjökull
Svínafellsjökull
Virkisjökull
Falljökull
Kvíárjökull
Fjallsjökull
Breiðamerkurjökull
Skálafellsjökull
Heinabergsjökull
Fláajökull
Hoffellsjökull
Hoffellsjökull
Virkisjökull
Falljökull
Svínafellsjökull
Kvíárjökull
Skeiðarárjökull
Heinabergsjökull
Skálafellsjökull
Fjallsjökull
Morsárjökull
Skaftafellsjökull
Fláajökull
Breiðamerkurjökull

Figure 2a

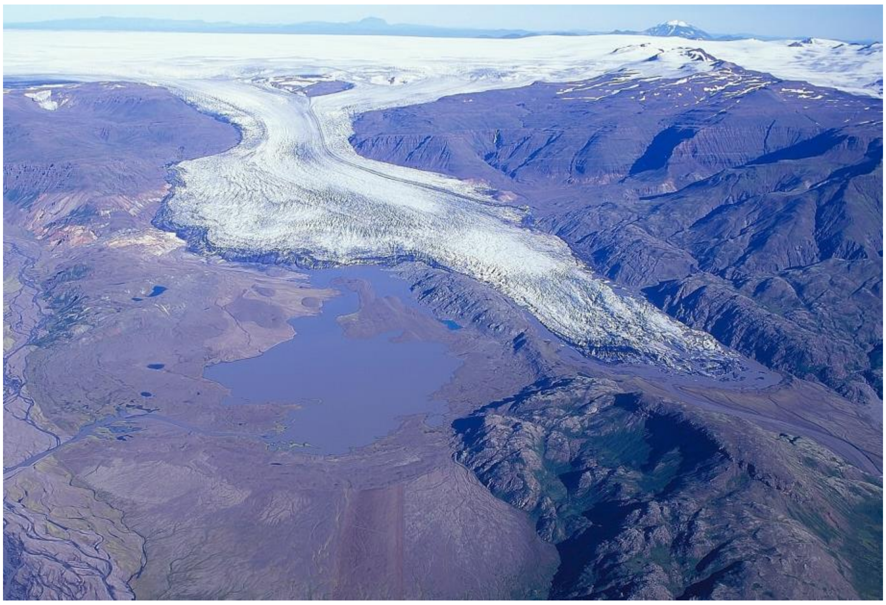
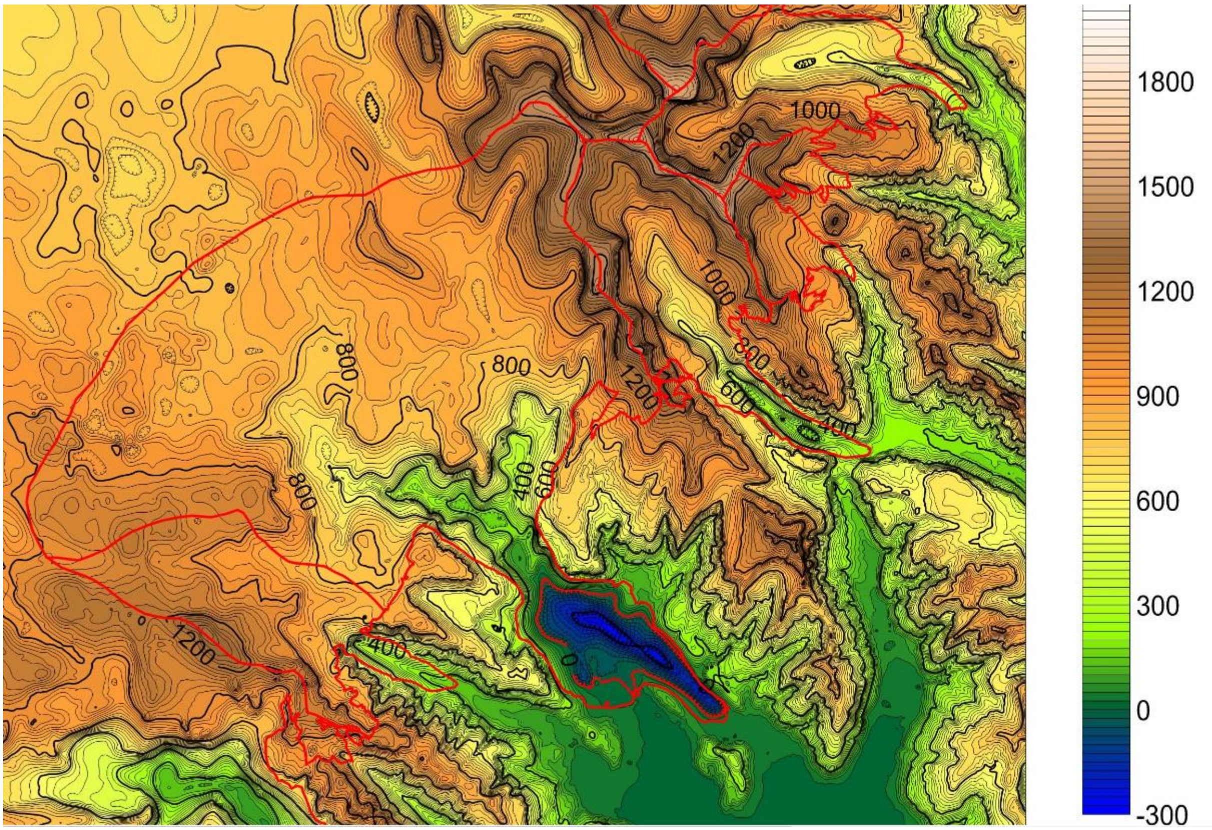


Figure 2b


1800
1500
1200
900
600
300
0
-300
1000
1200
1000
800
600
400
800
800
800
1200
400
600
400
1200
0
Figure 3

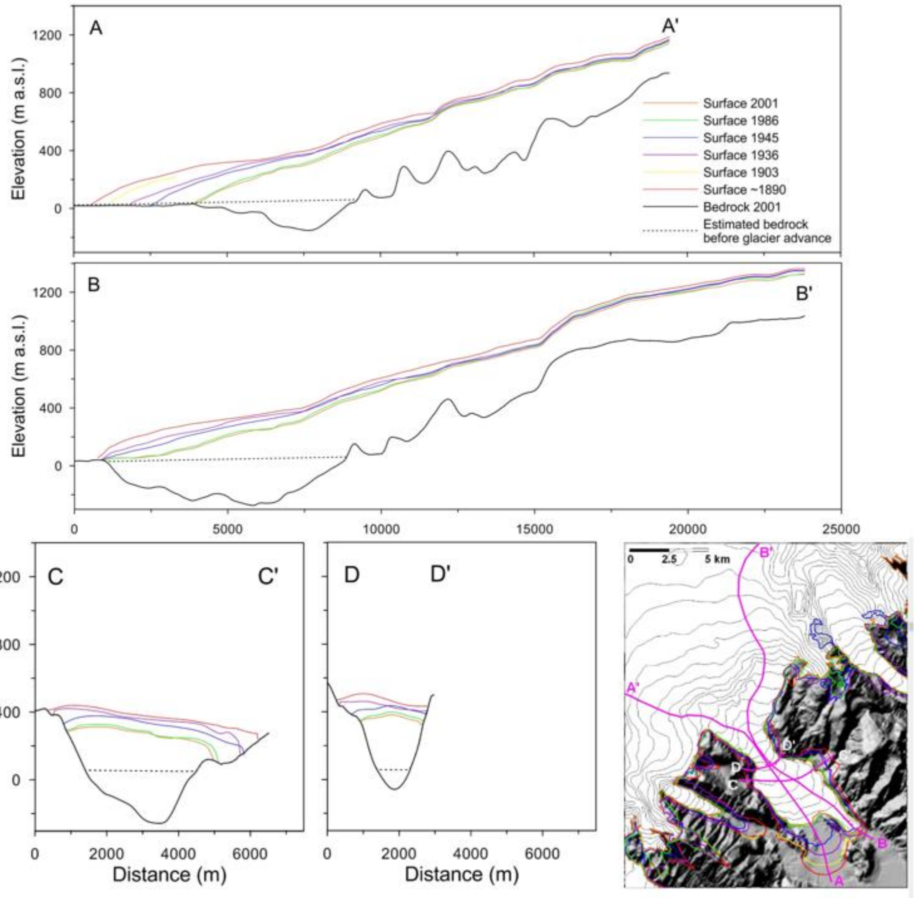

A
A'
B
B'
C
C'
D
D'
Elevation (m a.s.l.)
Distance (m)
Surface 2001
Surface 1986
Surface 1945
Surface 1936
Surface 1903
Surface ~1890
Bedrock 2001
Estimated bedrock before glacier advance
0
2.5
5 km

Figure 4a

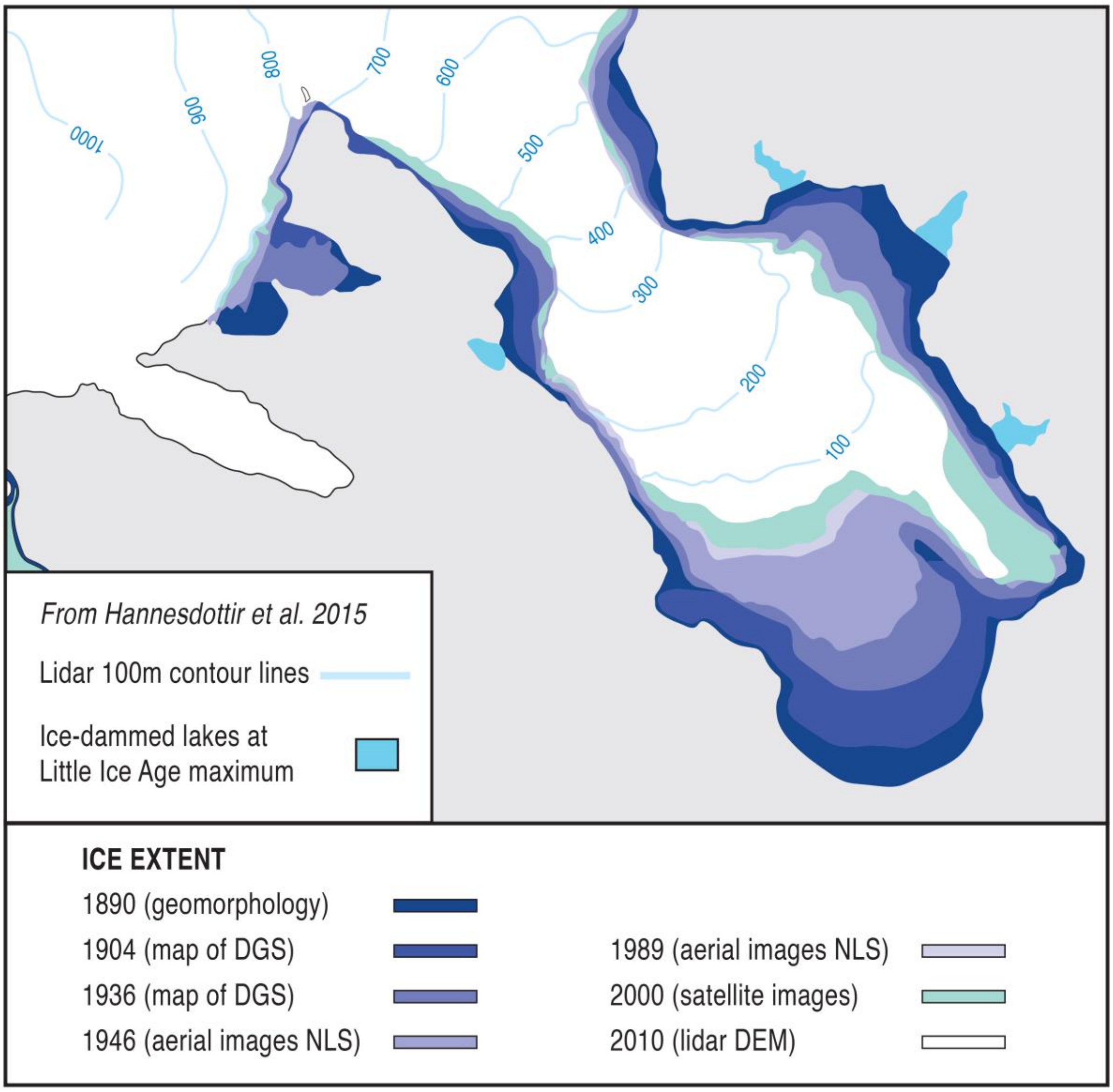
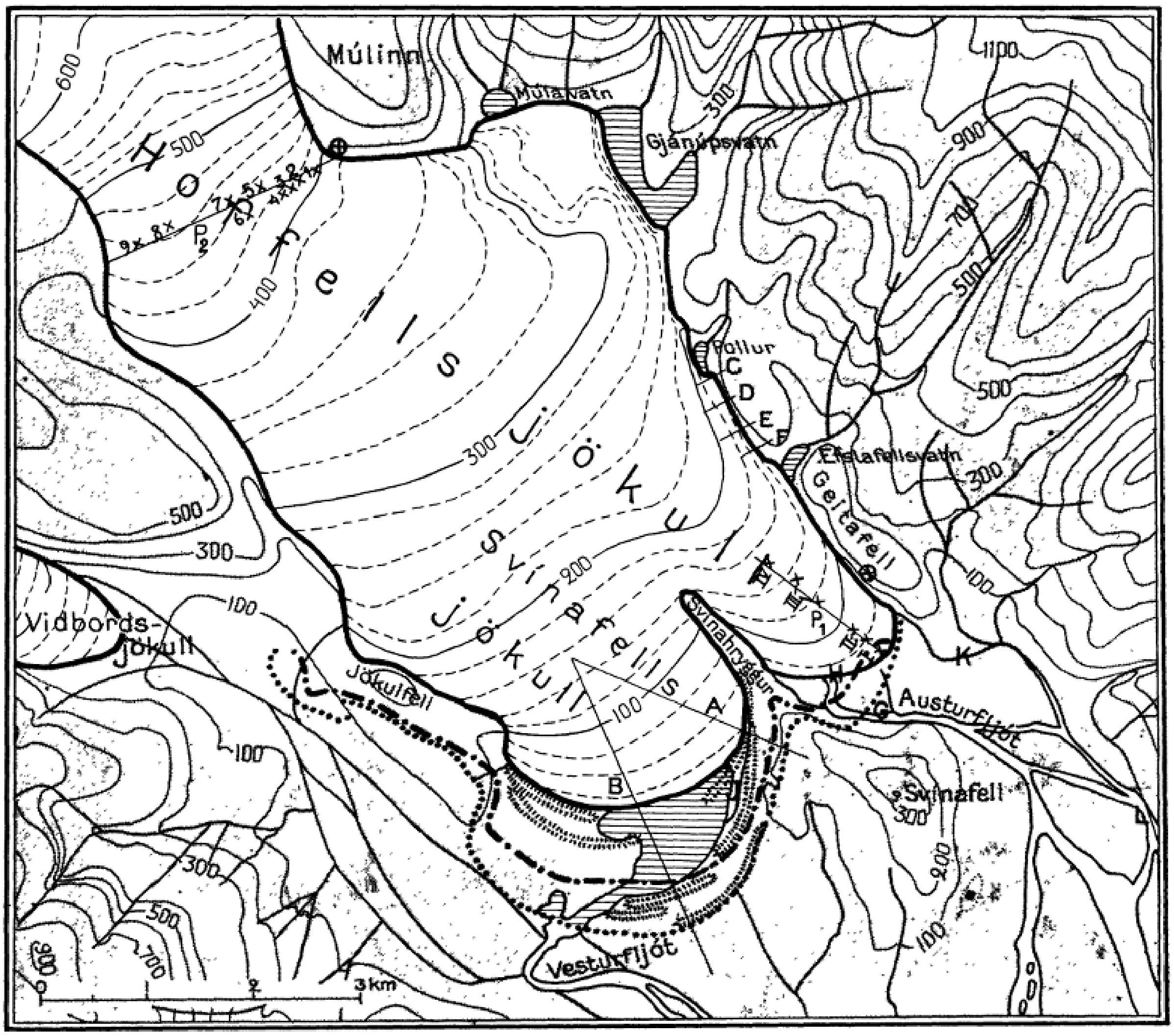

1000
900
800
700
600
500
400
300
200
100
From Hannesdottir et al. 2015
Lidar 100m contour lines
Ice-dammed lakes at
Little Ice Age maximum
ICE EXTENT
1890 (geomorphology)
1904 (map of DGS)
1936 (map of DGS)
1946 (aerial images NLS)
1989 (aerial images NLS)
2000 (satellite images)
2010 (lidar DEM)

Figure 4b



Múlinn
Múlavatn
Gjánúpsvatn
Pallur
Efstafellsvatn
Geitafell
Svínahryggur
Austurfljót
Svínafell
Vesturfljót
Jökulfell
Vidbords-
jökull
Hofellsjökull
Svínafellsjökull
3km

Figure 5

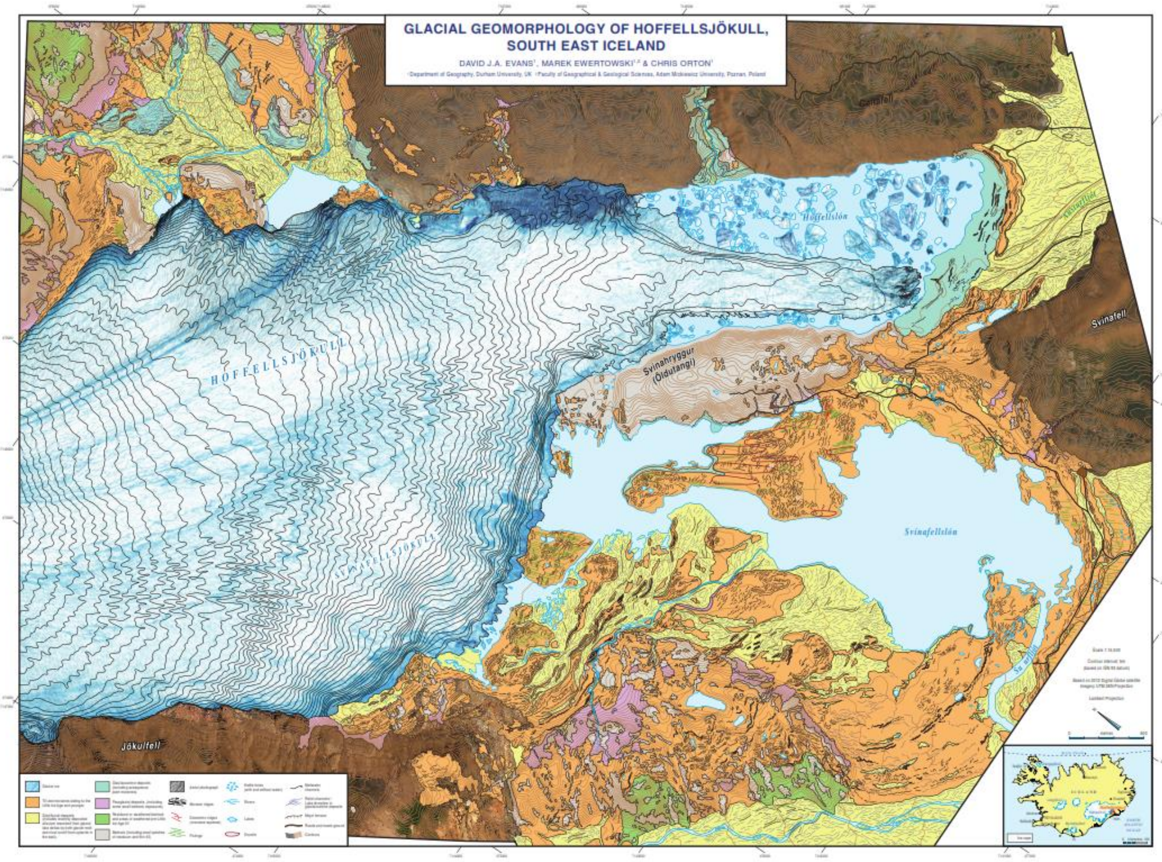

GLACIAL GEOMORPHOLOGY OF HOFFELLSJÖKULL, SOUTH EAST ICELAND
DAVID J.A. EVANS[1], MAREK EWERTOWSKI[1,2] & CHRIS ORTON[1]
[1]Department of Geography, Durham University, UK [2]Faculty of Geographical & Geological Sciences, Adam Mickiewicz University, Poznan, Poland
HOFFELLSJÖKULL
Hoffellslón
Svínafell
Svínahryggur (Öldutangi)
Svínafellslón
Jökulfell

Figure 6

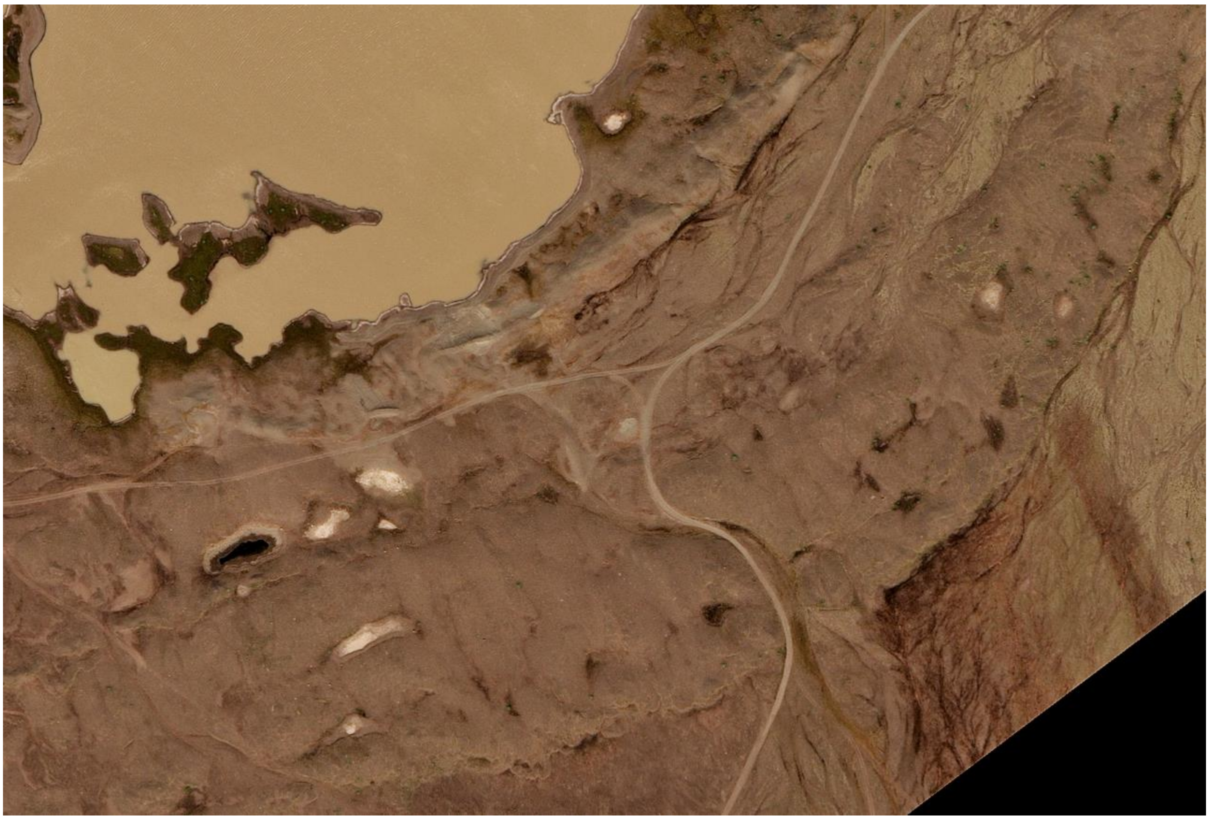


Figure 7a


Figure 7b

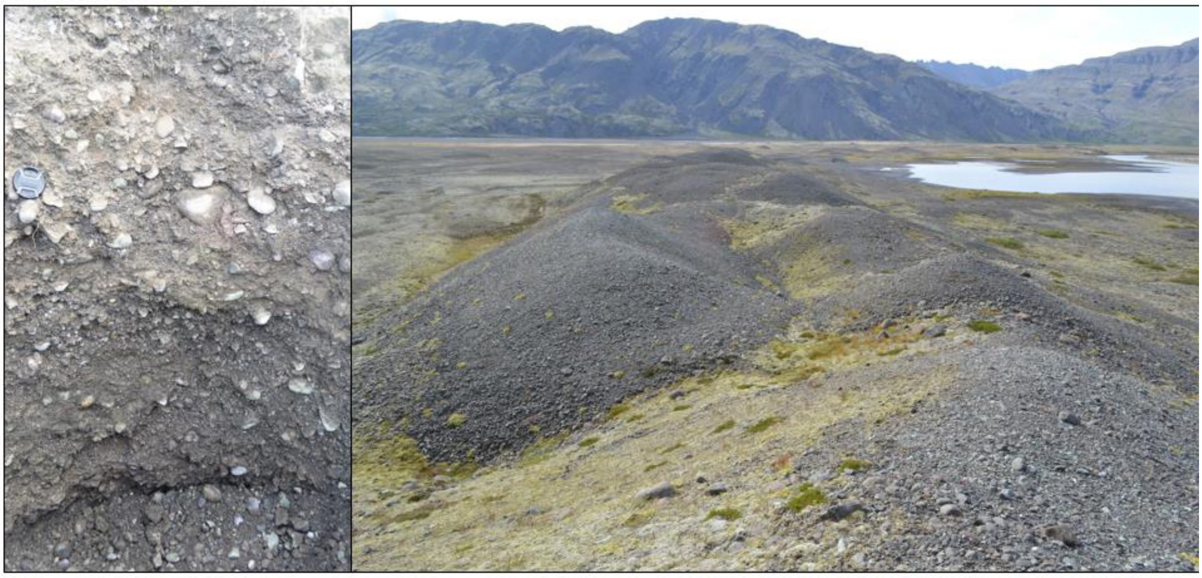


Figure 7c


Figure 8

Figure 9

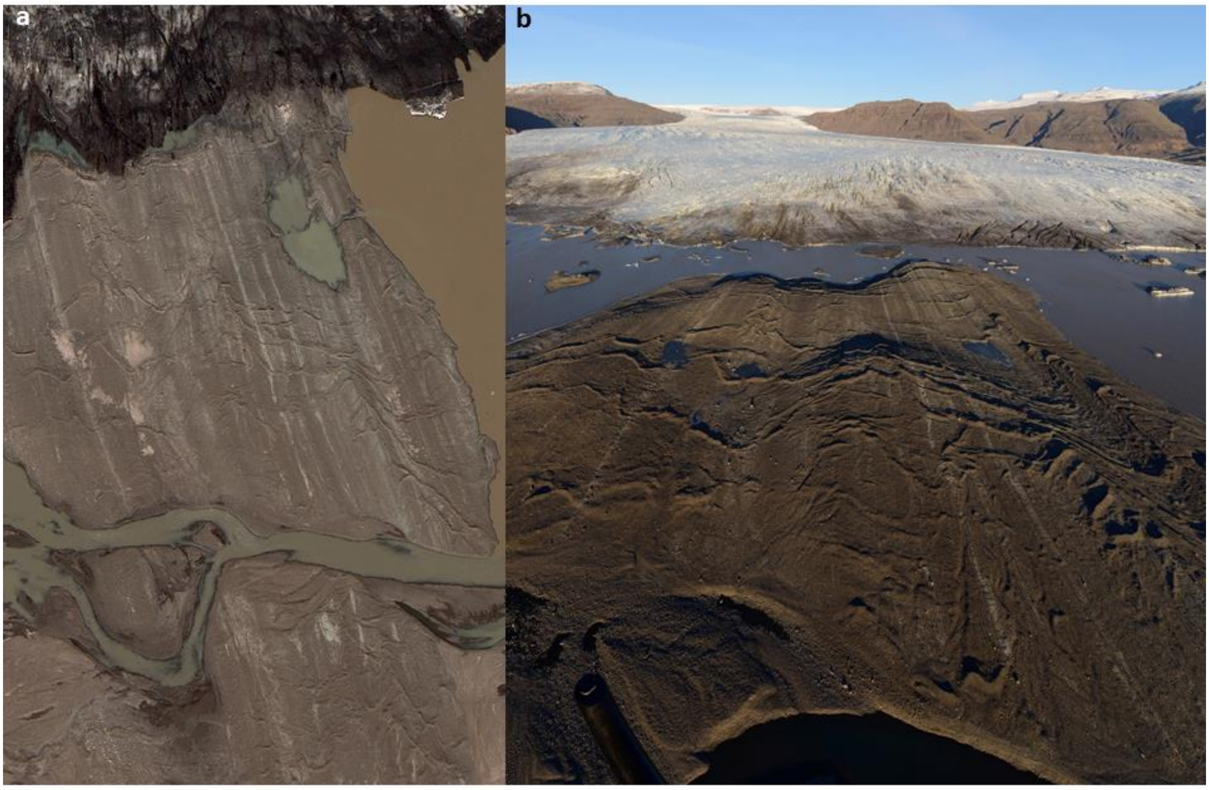


Figure 10

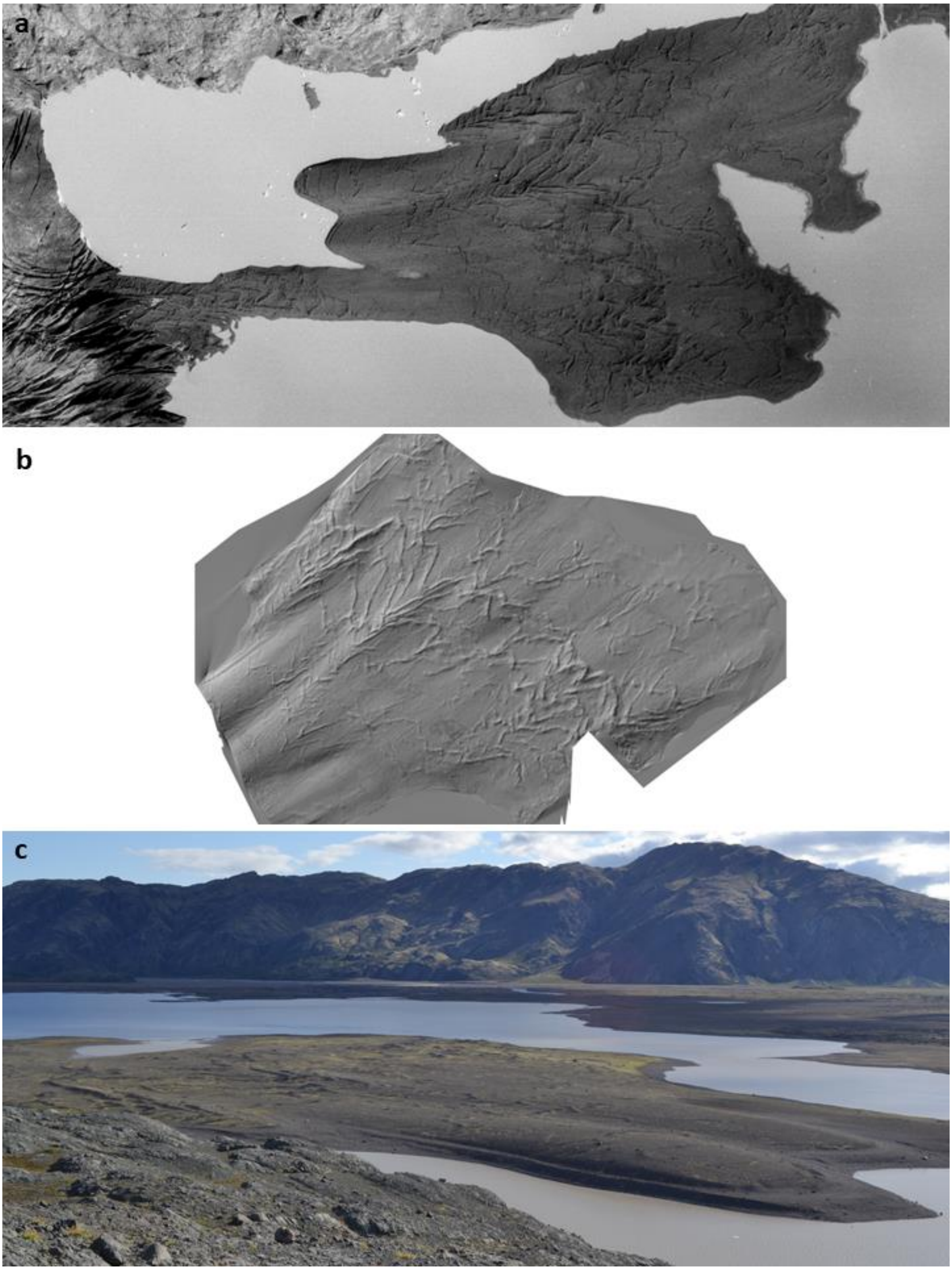


Figure 11

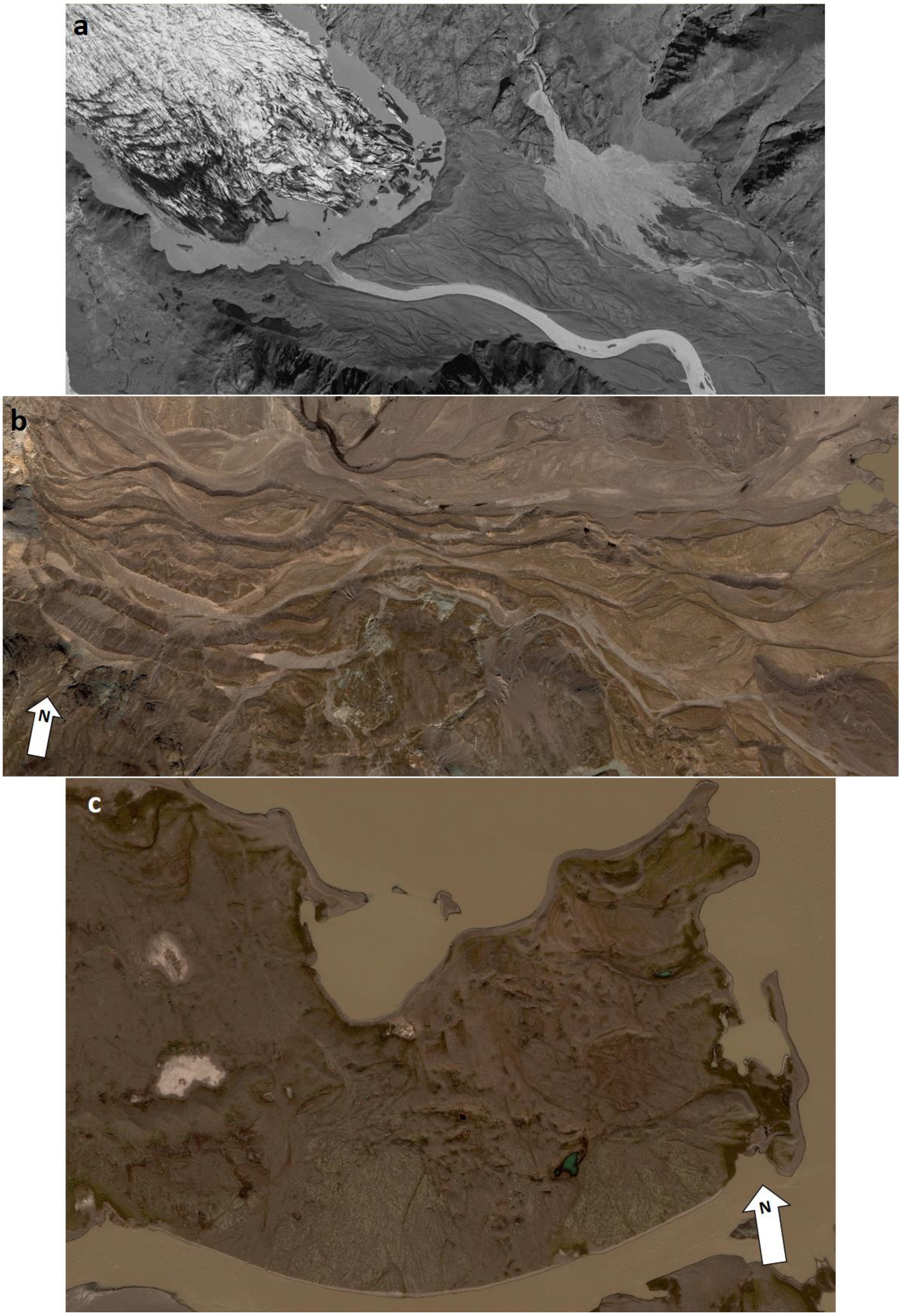


Figure 12

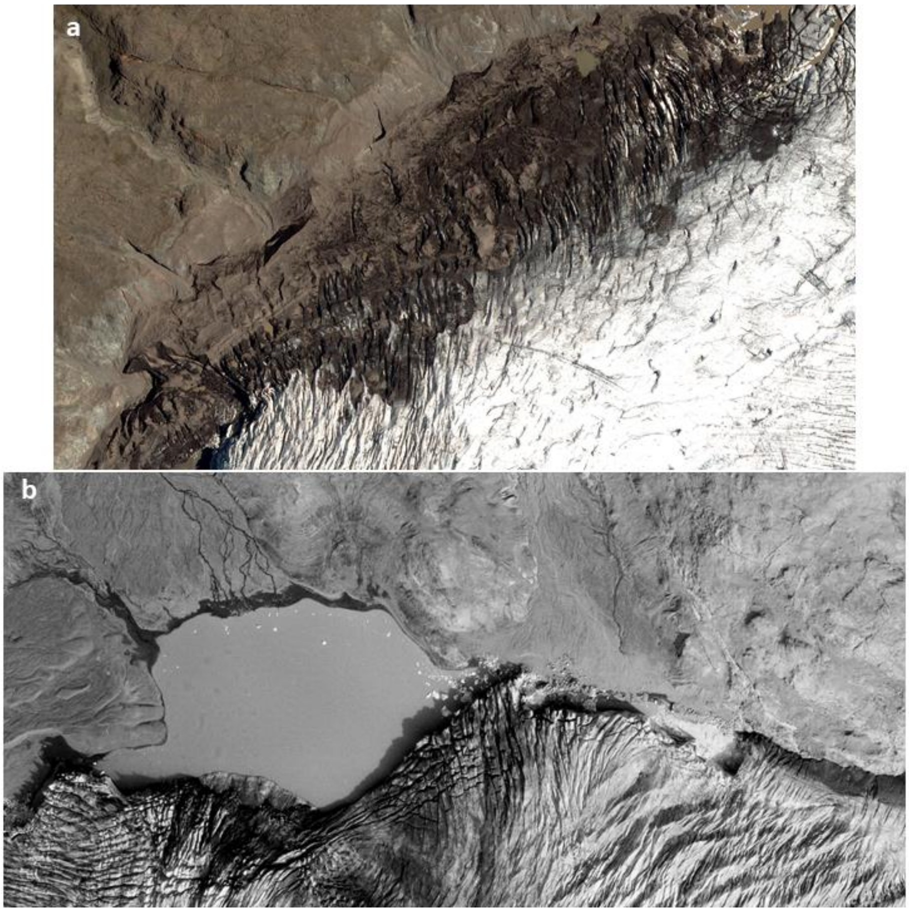


Figure 13

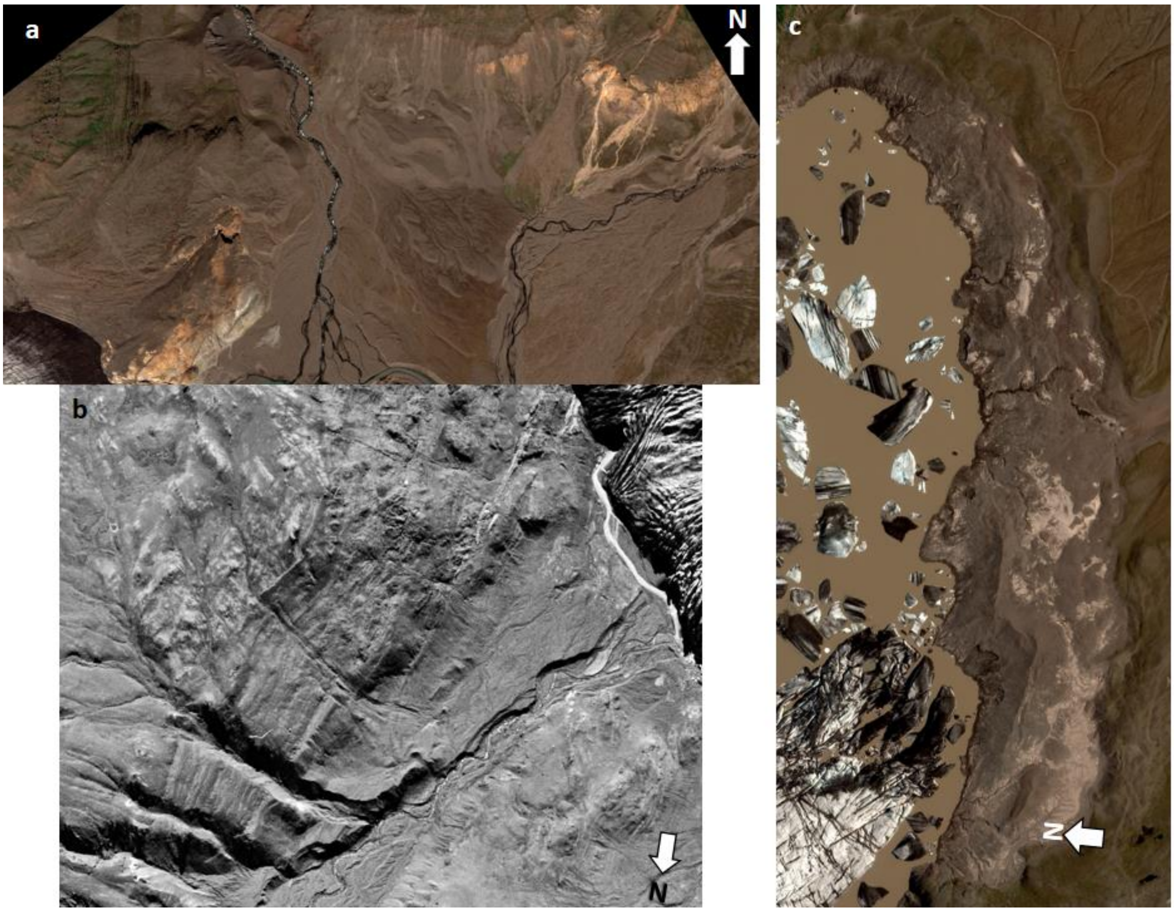


Figure 14

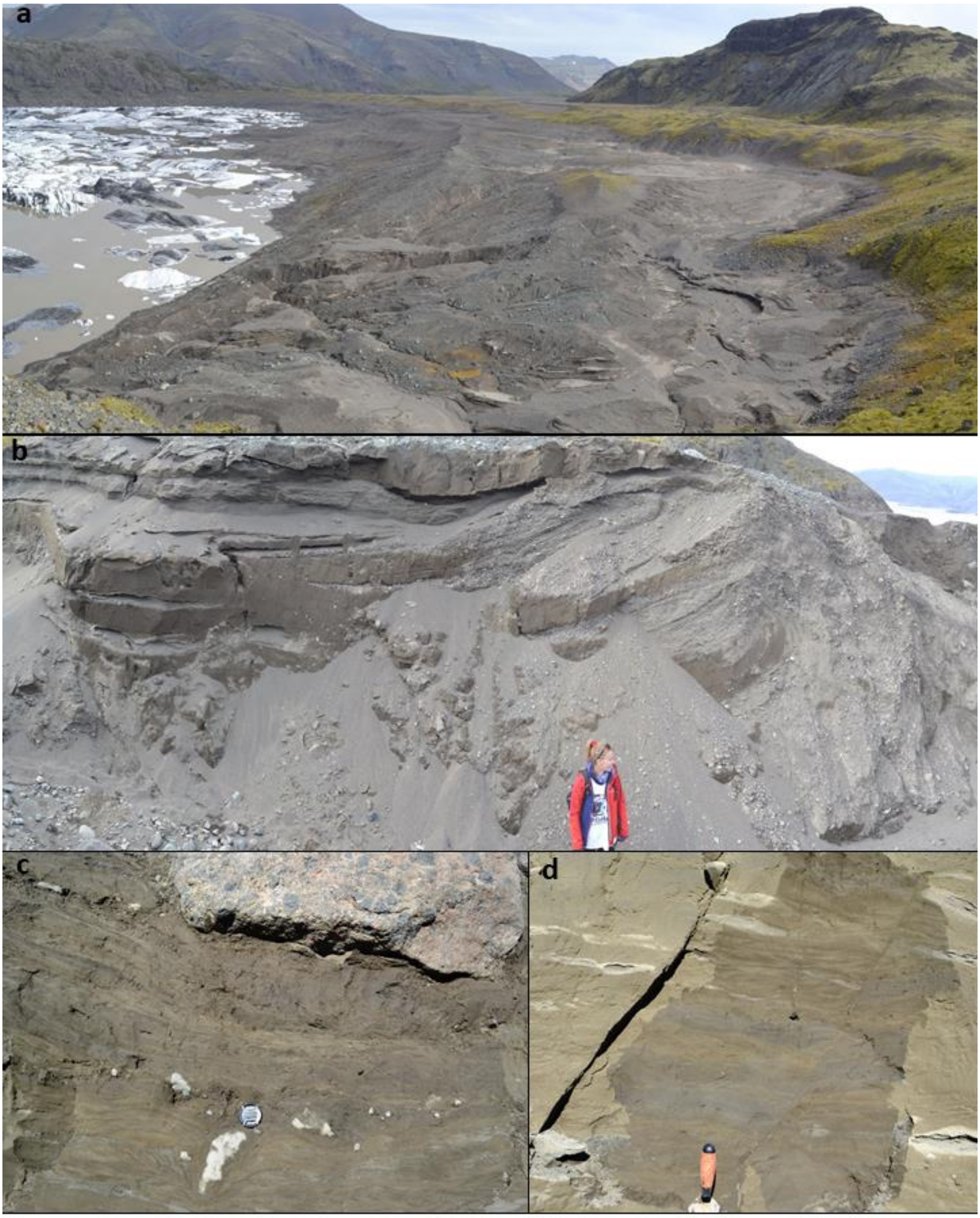


Figure 15