Journal of Maps

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tjom20

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To cite this article: Sarah Walton, Robert Storrar, Naomi Holmes, Jonathan Bridge, Marek Ewertowski, Aleksandra Tomczyk & Andrew Jones (2024) Post-little ice age glacial geomorphology of contrasting topographic settings at Skálafellsjökull, southeast Iceland, Journal of Maps, 20:1, 2329163, DOI: 10.1080/17445647.2024.2329163

To link to this article: https://doi.org/10.1080/17445647.2024.2329163

Published online: 20 Mar 2024.

JOURNAL OF MAPS
2024, VOL. 20, NO. 1, 2329163
https://doi.org/10.1080/17445647.2024.2329163

Science

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Post-little ice age glacial geomorphology of contrasting topographic settings at Skálafellsjökull, southeast Iceland

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ABSTRACT
Glacial geomorphological mapping from the southern margin of Skálafellsjökull, southeast Iceland, depicts a topographically diverse mountainside, influencing glacier dynamics, landform formation and glacier retreat since the Little Ice Age maximum in ∼1890. The glacial landforms present are typical of southeast Icelandic temperate glaciers, comprising recessional push moraines, including sawtooth moraines, and associated fluting. Study area A demonstrates an abandoned lobe confined by steep V-shaped topography, displaying moraines and minimal fluting, suggesting low preservation of landforms, and changes in glacier behaviour. At study area B, the sawtooth moraine morphology demonstrates changes in the glacier margin as the ice interacted with a series of topographic benches during active recession. The steep-sided valley at study area C illustrates densely spaced arcuate moraines, reflecting subtle changes in ice elevation. This mapping provides a framework for further investigations into glacier retreat rates and the influence of local topography and climate.

ARTICLE HISTORY
Received 26 February 2023
Revised 11 August 2023
Accepted 5 March 2024

KEYWORDS
Skálafellsjökull; little ice age; glacier retreat; moraines; topography

1. Introduction

Understanding controls on glacier behaviour has become an important topic of interest due to recent glacier retreat and the current period of atmospheric warming (Aðalgeirsdóttir et al., 2020; Chandler et al., 2016b; Hannesdóttir et al., 2015a; Kaufman et al., 2020; Sigurðsson et al., 2007). Glacier retreat is influenced by several factors such as climate (Kirkbride & Winkler, 2012), topography (Carr et al., 2015), glacier hypsometry (Raper & Braithwaite, 2009), thermal regime (Reinardy et al., 2013) and debris cover (Anderson & Mackintosh, 2012), creating differences in glacier response to climate change (Furbish & Andrews, 1984). Variations in climate are known to cause changes in glacier mass balance (Kirkbride & Winkler, 2012), with climate mechanisms such as the North Atlantic Oscillation (NAO) heavily influencing glacier fluctuations in the wider North Atlantic region and Iceland (e.g. Bradwell et al., 2006; Chandler et al., 2016a; Kirkbride, 2002).

The link between topography and glacier behaviour has been explored at several sites worldwide including the Himalayas (e.g. Garg et al., 2017), Canada (e.g. DeBeer & Sharp, 2009) and Greenland (e.g. Warren, 1991). Topographic factors such as altitude, slope, aspect, and hypsometry all play an important role in glacier response time to changes in climate (Garg et al., 2017; Raper & Braithwaite, 2009). These factors can cause variations in the response to climate change within the same region (Garg et al., 2017) and within the same glacier system (e.g. Evans et al., 2019). Shorter, steeper glaciers in maritime climates have shorter response times of only a few years in comparison to larger valley glaciers which could have response times of up to a century (Kirkbride & Winkler, 2012). These factors are important when modelling glacier response to climate change and projections for future sea level rise (Raper & Braithwaite, 2009) and water availability (Garg et al., 2017).

Iceland lies at the boundary between major atmospheric and oceanic currents, and changes to these currents are known to have a direct impact on terrestrial temperatures in Iceland (Geirsdóttir et al., 2009). Outlet glaciers of the southeast Vatnajökull ice cap are particularly sensitive to annual and decadal fluctuations due to the maritime North Atlantic setting, steep gradients, and high mass turnover (Phillips et al., 2014). Iceland's glaciers have been retreating since the end of the Little Ice Age (LIA; ca. 1250-1900 AD; Geirsdóttir et al., 2009; Hannesdóttir et al., 2021), which was

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Supplemental map for this article is available online at https://doi.org/10.1080/17445647.2024.2329163.

broadly synchronous across Iceland. However, disparate responses have been observed locally due to variations in glacier type and characteristics (Evans et al., 2017; Hannesdóttir et al., 2015a; Kirkbride & Dugmore, 2008), and topographic factors such as hypsometry and slope (Chenet et al., 2010). Understanding the timing, nature and influence of glacier advance and retreat at the Vatnajökull ice cap will be critical for improving our understanding of glacial history and behaviour in Iceland, as well as understanding glacier retreat and response times in a wider context (Chandler et al., 2016c).

This study presents a detailed mapping of the glacial geomorphology surrounding the southern margin of Skálafellsjökull in southeast Iceland, where ice previously over-spilled a col and interacted with a topographically diverse mountainside. This mapping provides the framework to examine the pattern and rates of retreat at Skálafellsjökull and the influence of the local topographic setting.

2. Study area

Skálafellsjökull is a non-surging outlet glacier at the southeast margin of the Vatnajökull ice cap, flowing west to east from the Breiðabunga plateau, and resting on mafic and intermediate extrusive rocks of blue–black basalt lava, with intercalated sediments, originally soil horizons, from Miocene and Lower Pliocene age (Icelandic Institute of Natural History, n.d; Jóhannesson, 2014). The snout of Skálafellsjökull is confined by Hafrafellsháls mountain spur in the north and Skálafellshnúta to the south, where the glacier descends to form a piedmont lobe where a pro-glacial lake is present (Figure 1). At its LIA maximum, Skálafellsjökull coalesced with neighbouring outlet glacier Heinabergsjökull until AD 1929–1945 (Chandler et al., 2016c; Hannesdóttir et al., 2015a).

The southern margin of Skálafellsjökull is constrained by diverse topography, which we now describe from west to east in three main study areas (A-C; Figure 1). Study area A is the foreland of Sultartungnajökull (also named Eyvindstungnajökull), a small south flowing lobe that currently terminates above the Jöklasel road (F985) at ~480 m a.s.l. and extended ~2-3 km beyond its present limits during the LIA (McKinzey et al., 2005). To the east of Sultartungnajökull lies a valley that contains a series of topographic benches formed by NE-SW trending basaltic dykes, where an abandoned lobe of Skálafellsjökull advanced during the LIA (Hannesdóttir et al., 2015b), down to a mountain ledge named Miðbotnafjall, which forms study area B. Present day ice lies at ~630 m a.s.l. and once extended ~1.8 km beyond its present location. Study area C lies northeast of Miðbotnafjall, at the lateral margin of Skálafellsjökull, that is constrained by the steep slopes of the mountain Skálafellshnúta. Present day ice lies at ~470 m a.s.l., and once extended ~280 m south to the LIA moraine and near the margin of Káravatn.

2.1. Previous studies

Skálafellsjökull has been the subject of a variety of studies which explore the geomorphology of the glacial landsystem (e.g. Chandler et al., 2016c; Evans & Orton, 2015; Hart et al., 2018), glacial hydrological system (e.g. Hart et al., 2015), landform sedimentology (e.g. Evans, 2000; Sharp, 1984), lichenometric dating of LIA moraines (e.g. McKinzey et al., 2004, 2005) and reconstructions of glacier extent and ice volume (e.g. Hannesdóttir et al., 2015a, 2015b). Previous geomorphological mapping at Skálafellsjökull has focused on glacial geomorphology at the foreland of the main glacier outlet (Figure 1), examining the recessional push moraines (e.g. Chandler et al., 2016c) and surficial geology (e.g. Evans & Orton, 2015). Chandler et al. (2016c) present detailed geomorphological mapping of recessional push moraines, with distinctive sawtooth planform geometries and often found in association with flutings. Remote sensing investigations and lichenometric dating revealed sequences of both annual and sub-annual forming recessional moraines at Skálafellsjökull (Chandler et al., 2016a).

A map of generalised geomorphology has previously been produced for Sultartungnajökull (study area A) (mapped area outlined in Figure 1), alongside dating of the LIA moraines at this lobe using lichenometry and tephrochronology (McKinzey et al., 2004, 2005). Hannesdóttir et al. (2015a) mapped the extent of Skálafellsjökull, including Sultartungnajökull, since the LIA based on geomorphology, maps from the Danish General Staff and aerial images. However, no geomorphological mapping has been published for the abandoned lobe at Miðbotnafjall (study area B) or the upland lateral margin of Skálafellsjökull at Skálafellshnúta (study area C).

3. Methods

3.1. Data sets

Several high-resolution data sets were used for geomorphological mapping across the study areas (Figure 2). Study area A was mapped from hillshade with 2 m resolution derived from ArcticDEM tiles (Figure 2(C); Porter et al., 2018) and the Esri ArcGIS Desktop 10.6.1 World Imagery Basemap (Figure 2(D); approximately 0.50 m resolution). Study areas B and C were surveyed using a range of Uncrewed Aerial Vehicles (UAVs) to produce orthophotos and Digital Elevation Models (DEMs) using photogrammetry, which is described in section 3.2. Study area B was surveyed from the 22nd to 24th August 2018 using DJI Mavic

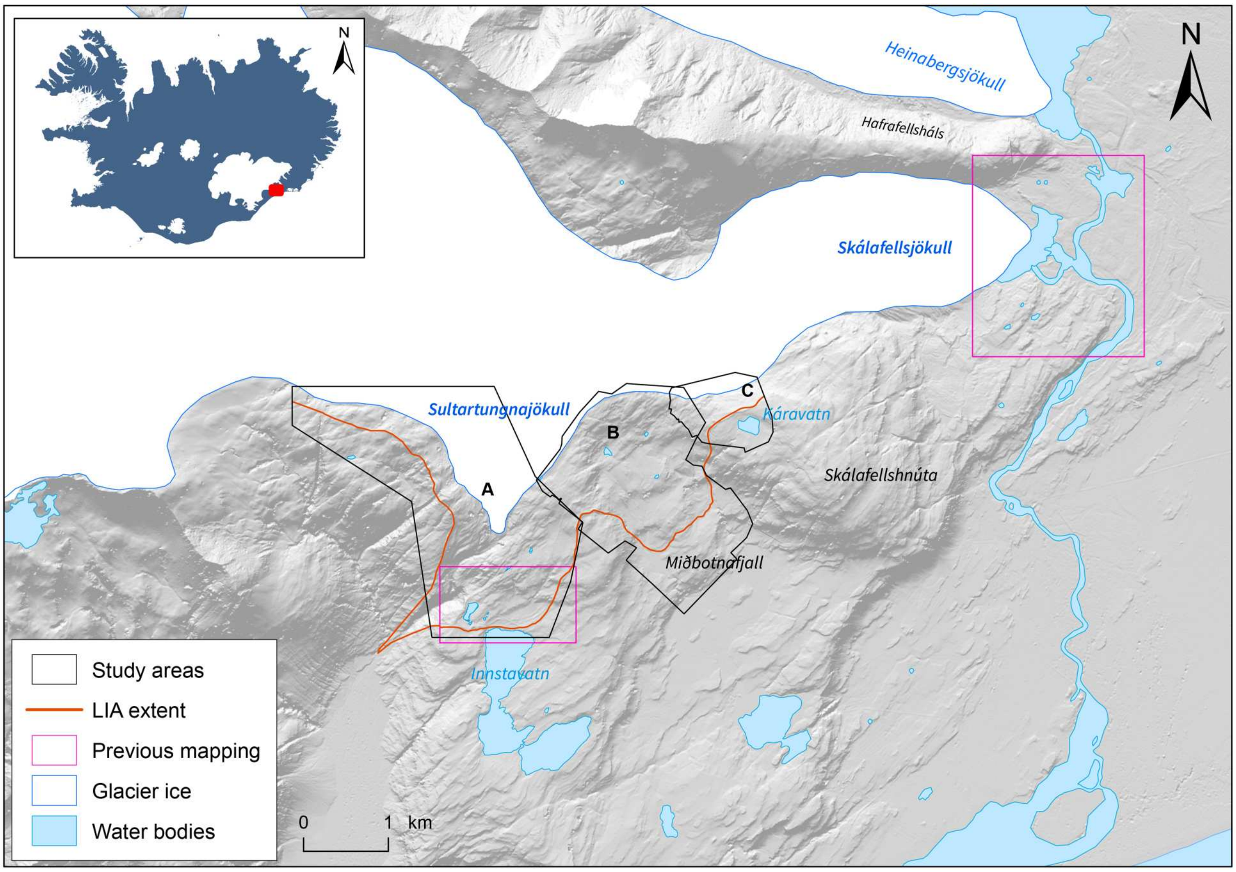

Figure 1. Map of Skálafellsjökull in southeast Iceland, displaying study areas, locations discussed in the text, Little Ice Age (LIA) extent and previous mapping at Sultartungnajökull (McKinzey et al., 2004) and Skálafellsjökull foreland (Chandler et al., 2016c). Hillshade from Arctic 2 m DEM (Porter et al., 2018). Map based on data from the National Land Survey of Iceland (IS 50V | National Land Survey of Iceland (lmi.is)).

Pro, DJI Phantom 4 Pro and DJI Phantom 3 quadcopters, which were used to produce a 6 cm resolution orthophoto and DEM. Ground control points were surveyed using an Emlid Reach RTK GNSS. Study area C was surveyed on the 9th September 2021 using a DJI Phantom 4 RTK to produce a 3.86 cm resolution orthophoto and 15.4 cm resolution DEM (Figures 2(A) and 2 (B)). The onboard RTK GNSS was used which produces accurately located images without ground control (Chudley et al., 2019). Mapping was mostly based on orthophotos, and hillshades were derived from the DEMs to aid mapping of the landforms, using an azimuth of 315° and sun altitude of 30°.

3.2. Image processing

The UAV-captured imagery was processed in *Agisoft Metashape Professional* version 1.5.3. using the following workflow and parameters. UAV images were aligned, and sparse point cloud and tie points were generated using the highest accuracy and with generic and reference preselection. High accuracy setting uses photos of the original size, while medium quality causes image downscaling by a factor of 4 (Agisoft Metashape, 2023). Depth maps and dense point clouds were generated using high-quality settings for study area B and medium quality for study area C. This processed imagery was used to produce orthophotos (e.g. Figure 2(B)) and DEMs (e.g. Figure 2(A)) for study areas B and C.

3.3. Map production

Detailed geomorphological mapping was completed using *Esri ArcMap 10.6.1.* following methods outlined in Chandler et al. (2018). Field investigations were conducted in May 2022 to ground truth the desk-based mapping. Geomorphological features were mapped primarily from orthophotos, with hillshades used to aid mapping, and digitised using polygon and line features. Moraines and flutes were mapped along the crestline. Contour lines were generated for the main map at 20 m intervals using the Arctic 2 m DEM and *Spatial Analyst* toolbox in *ArcMap*. *ArcScene* was used to view imagery in 3D. The maps were exported to *Adobe Illustrator 3.0.4* for editing and map design. The glacier surface is displayed on the main map in line with previously published glacial geomorphological maps of Icelandic glacier forelands (e.g. Chandler et al., 2016c; Evans & Orton, 2015), using 3 m resolution imagery from Planet (Planet Team, 2017).

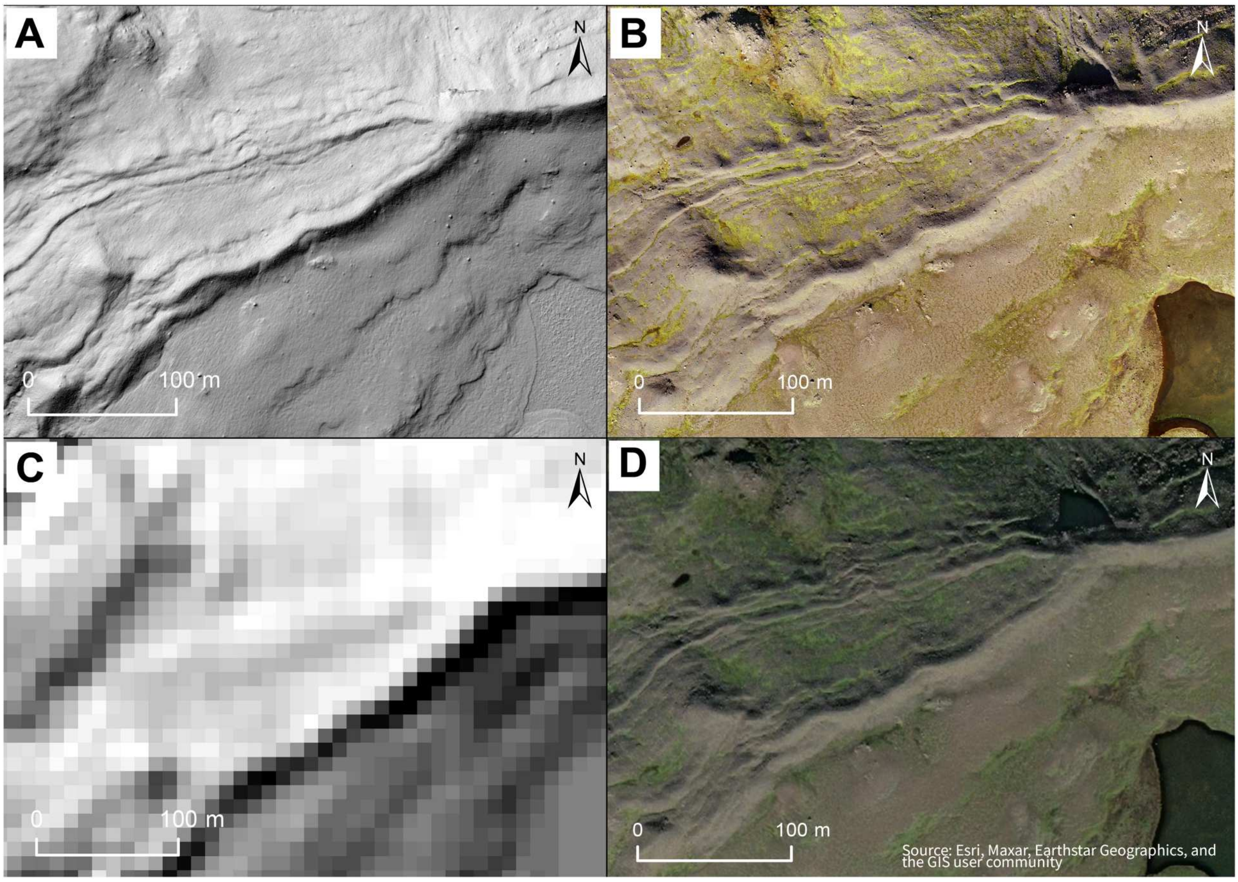

Figure 2. Extracts from data sets used for glacial geomorphological mapping (A) UAV captured DEM visualised as a hillshaded relief model (B) UAV captured orthophoto (C) Arctic 2 m DEM hillshade (Porter et al., 2018) (D) Esri World Imagery Base map (Source: Esri, Maxar, Earthstar Geographics, *and the GIS User Community). Extracts are showing the same extent and scale at study area C.*

4. Results

4.1. Topography

The southern margin of Skálafellsjökull contains three distinctly different topographic settings within the same glacier and climate system, making Skálafellsjökull a good location to observe the topographic influence on ice dynamics and glacier retreat, and landform production. The topography (Figure 3) at each study area of Skálafellsjökull outlet glacier is influenced by the underlying bedrock topography of the area, which largely consists of west-dipping basalt lavas (Sharp, 1984) and numerous dykes that are parallel with the strike of the lavas (Walker, 1964). The topography at study area A (Figure 3(A)) is steep, with a deeply incised ravine in the southwest created by a meltwater channel from Sultartungnajökull (Figure 4(A)), with a slope of ~55° at the steepest part of the ravine. To the southeast, at study area B (Figure 4(B)), three distinctive benches have formed due to NE-SW trending basaltic dykes (Figure 3(B) and Figure 4(B)). The benches are relatively flat, with an average slope of ~2°, changing to ~19° where the benches dip down. Study area C shows the Skálafellsjökull lateral margin (Figure 3(C)), which is a steep sided valley wall with an average slope of ~21°, dipping north towards the glacier margin, again displaying NE-SW trending dykes that lie beneath the glacial landforms.

4.2. Glacial landforms

Moraines – The glacial geomorphological map of the Skálafellsjökull southeast margin and abandoned lobes is presented in the supplementary information (Main Map). Geomorphological mapping reveals a foreland and lateral margin that is typical of Icelandic temperate glaciers, with an abundance of till, moraines, and associated fluting (Evans et al., 2017; Evans & Twigg, 2002), though there appear to be no eskers or ice-cored landforms present at any of the study areas. Geomorphological mapping is shown in detail for each study area in Figures 5–7. A total of 1842 moraine ridges have been mapped across all three study areas, with 377 mapped at study area A, 1179 at study area B and 268 at study area C. Moraines at the Skálafellsjökull southern margin are mostly ~1 m in height and are typically fragmented, with a small number of longer moraine ridges.

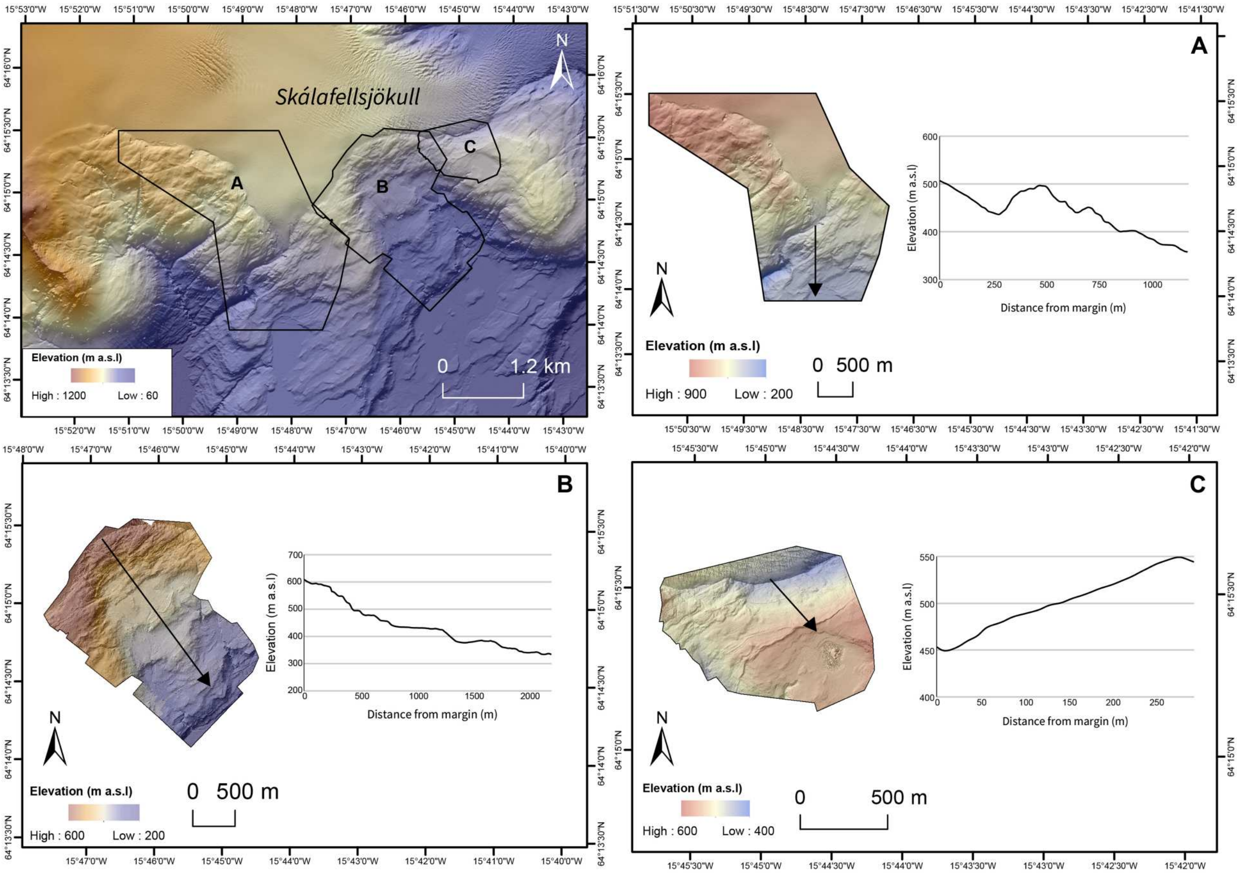

Figure 3. Location of study areas and elevation for Skálafellsjökull and topography of all three study areas, showing elevation change at (A) study area A, (B) study area B and (C) study area C. Using a hillshade relief model and elevation data from Arctic 2 m DEM tiles (Porter et al., 2018) for study area A and displayed using UAV-derived DEM overlaying the UAV-derived hillshade relief model for study areas B and C. Transverse topographical profiles are shown in graphs for each study area. The black arrow on each map indicates where the profile was developed from and the direction of the profile.

Some moraine fragments form longer chains reflecting ice margin positions, which is also observed at the main Skálafellsjökull foreland (Chandler et al., 2016c). Longer moraine ridges, ranging from 100–500 m in length, are primarily seen at study areas A and C, and are mostly linear and arcuate. Distinctive sawtooth moraines (Burki et al., 2009; Chandler et al., 2020a; Evans et al., 2017; Matthews et al., 1979; Sharp, 1984) have formed at study area B (<1 m in height) (Figure 4(C)), where squeezing and pushing at the ice margin forms sawtooth shaped moraine ridges that reflect the ice margin geometry (Chandler et al., 2016c; Price, 1970). The lateral moraines at study area C illustrate a long and mostly intact LIA moraine (~5 m in height and ~500 m in length) (Figure 4(F)), with a series of smaller (~1-2 m in height) and fragmented inset moraines formed close together (Figure 4(G)), appearing to be nested with double crests forming in some areas.

Fluting – Fluting is found across all three study areas, with 576 flutes mapped in total. There are notably fewer at study area A, with only 19 mapped, compared to 532 and 25 at study areas B and C, respectively. These features have been observed at many modern glacier forelands in Iceland, including Skálafellsjökull (e.g. Chandler et al., 2016c), Sandfellsjökull (e.g. Evans et al., 2010), Hoffellsjökull (e.g. Evans et al., 2019), Brúarjökull (e.g. Kjær et al., 2008), Eyjabakkajökull (e.g. Schomacker et al., 2014), Breiðamerkurjökull (e.g. Evans & Twigg, 2002; Guðmundsson & Evans, 2022) and Fjallsjökull (e.g. Evans & Twigg, 2002; Price, 1970). Fluting is found in clusters often associated with moraines (e.g. Chandler et al., 2016a; Evans et al., 2017), forming parallel to ice flow direction (Benn & Evans, 2014). Fluting at all three study areas are composed of till, with stoss side boulders present at most (Figure 4(D and 4(E)). The fluting is clearly observed in the orthophotos; however, most are not visible in the hillshade DEM, and field investigations at study area B revealed that the flutes have very low amplitude (<0.2 m) and width (~1–2 m). The fluting at study area B occurs in distinct areas on the proximal part of the topographic steps, with moraines forming on the distal part of the benches. Most recent fluting formed at the ice margin appear to be relatively short, ranging from ~5 m to 30 m and more densely spaced (~<3 m between flutes), compared with fluting on the benches which have ~20 m between flutes. Flutes at study area C appear to be superimposed over densely spaced recessional moraines that have formed on the steep lateral margin.

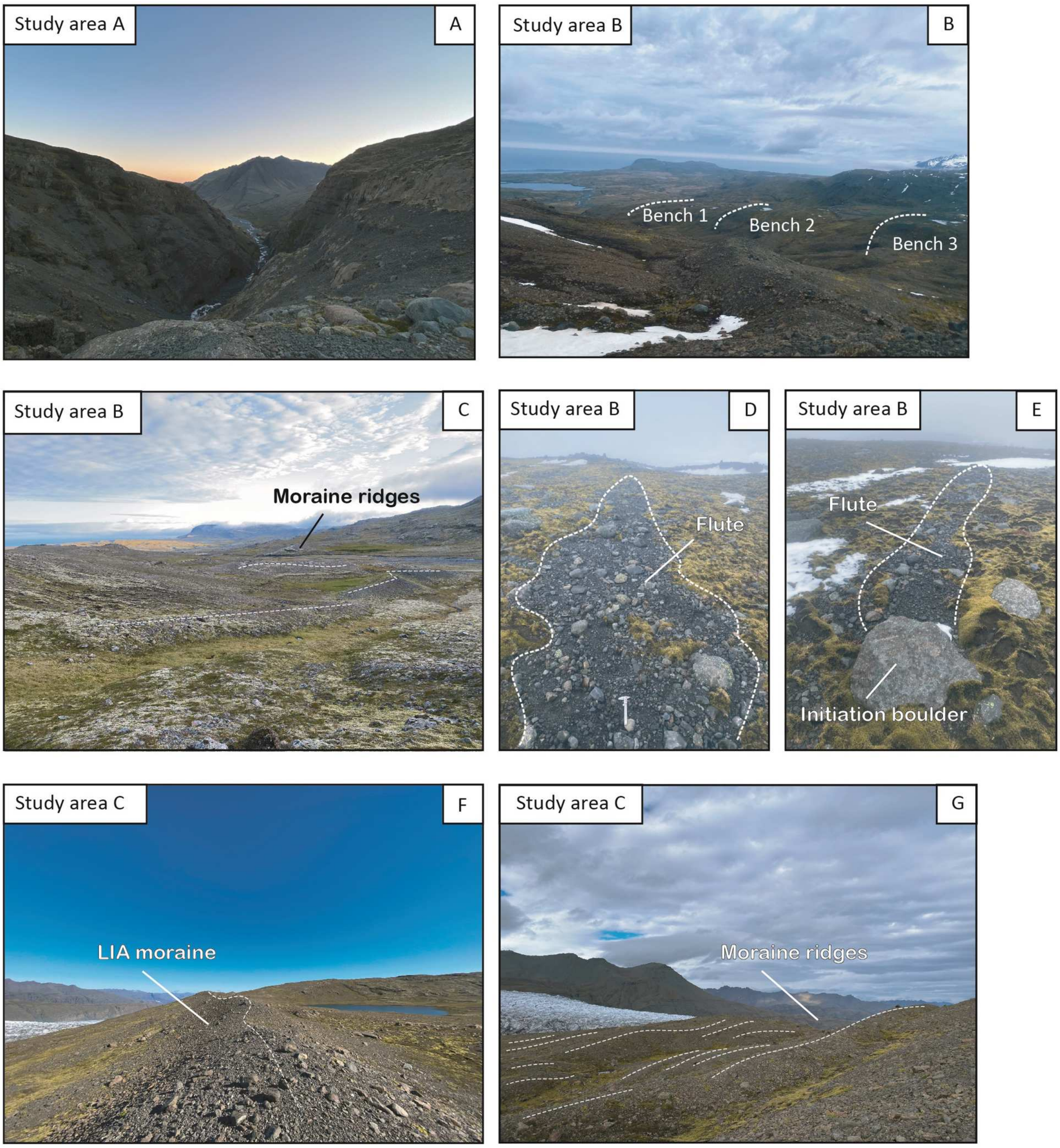

Figure 4. Photographs showing (A) deeply incised meltwater channel at study area A, (B) bench topography at study area B, (C) moraine ridges at study area B, (D) fluting at study area B, (E) flute with initiation boulder at study area B, (F) LIA moraine at study area C, and (G) moraine ridges at study area C.

5 . Discussion

5.1. Relationship between topography, glacial landforms, and glacier dynamics

5.1.1. Study area A (Sultartungnajökull)

At study area A (Figure 5), Sultartungnajökull is constricted by the steep V-shaped topography. There are fewer areas of fluting across study area A, as well as fewer densely spaced moraine ridges that have formed close to the glacier margin, indicating that these are not annually formed recessional push moraines like those observed at study areas B and C. Recessional annual push moraines (Krüger, 1995) are known to form at the margin of Icelandic glaciers due to the maritime, temperate climate causing late winter readvances, particularly in the southeast (Evans, 2005), and can also be formed sub-annually (Chandler et al., 2020a). There are several considerations for the lack of recessional push moraines and fluting at Sultartungnajökull, including steep topography and landform preservation (Barr & Lovell, 2014; Warren, 1991), sub-glacial drainage processes and meltwater. Recessional saw tooth moraines are mostly associated with poorly drained sub-marginal conditions (Evans et al., 2017). There is an abundance of meltwater channels at the glacier margin, and Hart et al. (2015)

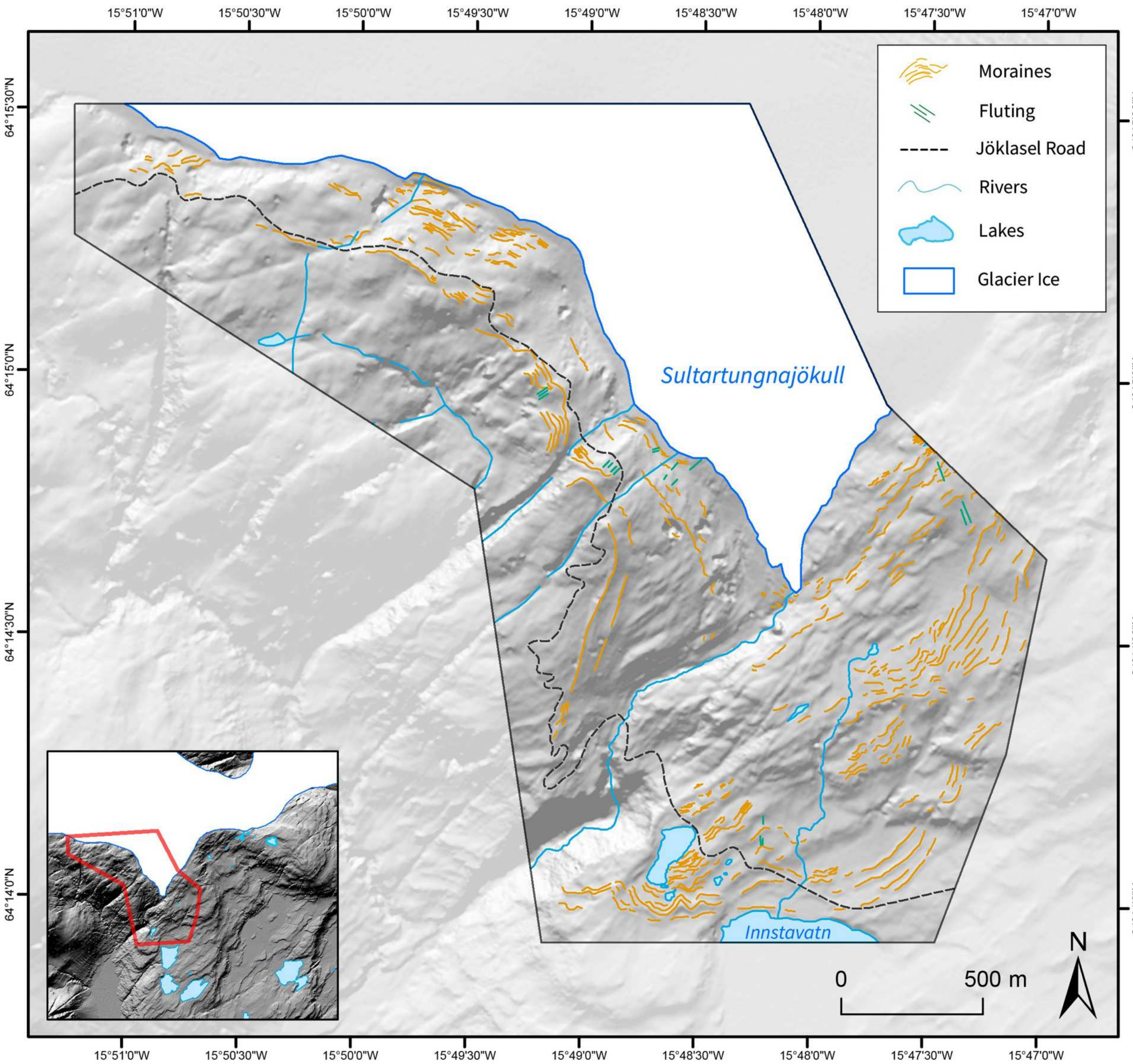

Figure 5. Glacial geomorphological map of study area A (Sultartungnajökull). Mapped using Arctic 2 m DEM (Porter et al., 2018) and Esri World Imagery Basemap (Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community). Background DEM source: ArcticDEM (Porter et al., 2018). Includes data from the National Land Survey of Iceland (IS 50V | National Land Survey of Iceland (lmi.is)). Map projection is WGS 1984 UTM Zone 28N (ESPG: 332628).

describe the low water storage capacity at Sultartungnajökull and the large sub-glacial river emerging from the glacier bed, which could be inhibiting the formation and preservation of recessional push moraines and fluting. The landforms present at Sultartungnajökull could also indicate a change in the glacier behaviour; undergoing downwasting and decay, rather than active retreat. This process has been observed at Virkisjökull-Falljökull, where annual push moraines ceased, indicating the glacier margin is no longer undergoing dynamic retreat and is now undergoing downwasting, decay, and collapse (Bradwell et al., 2013). The lower resolution of baseline data for Study area A (0.5 m image and 2 m DEM) compared to Study areas B and C (resolution greater than 0.15 m) might also have impacted the number of moraines and flutes detected and mapped.

5.1.2. Study area B (Miðbotnafjall)

Study area B (Figure 6) contains clear saw tooth moraines (Figure 8) that are typical for Icelandic piedmont glaciers (Matthews et al., 1979; Sharp, 1984). Sawtooth moraines have been documented at several sites in Iceland, including the Skálafellsjökull main outlet (Chandler et al., 2016c; Evans & Orton, 2015) and other southeast Vatnajökull outlets such as Fláajökull (Evans et al., 2016; Jónsson et al., 2016), Hoffellsjökull (Evans et al., 2019), Fjallsjökull (Chandler et al., 2020a), and Lambatungnajökull (Bradwell, 2004), which all terminate on broad outwash plains. These moraines have sawtooth planform geometries, are linked to longitudinal crevassing in lobate snouts and are related to poorly drained sub-marginal conditions (Evans et al., 2017). The sawtooth moraines formed in study area B (Figure 8) are densely spaced and

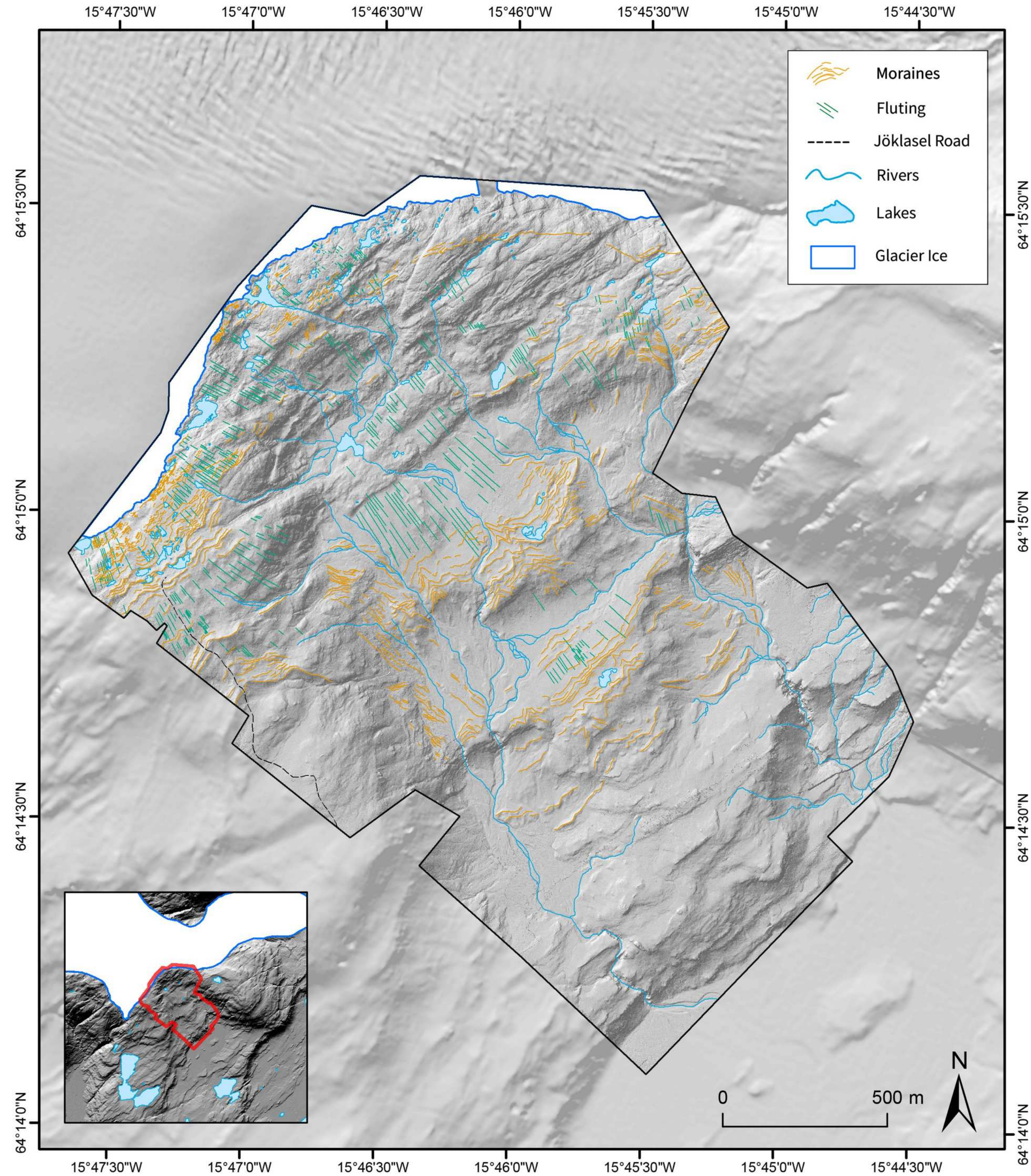

Figure 6. Glacial geomorphological map of study area B (Miðbotnafjall). Mapped using 2018 UAV-captured orthophoto and DEM. Background DEM source: ArcticDEM (Porter et al., 2018). Includes data from the National Land Survey of Iceland (IS 50V | National Land Survey of Iceland (lmi.is)). Map projection is WGS 1984 UTM Zone 28N (ESPG: 332628).

found in the distal parts of the topographic benches, likely formed in response to longitudinal crevassing of the ice front as the ice spread out on the latter benches after descending the steep slopes. Evans et al. (2017) identified a similar spatial and temporal change in glacier margin conditions and topography which impact landform development at Skaftafellsjökull, demonstrating a change from straight crested moraines to sawtooth moraines created by strong longitudinal crevassing during its recession. Fluting is abundant on the proximal part of the benches but is absent on the distal part. This pattern of moraine and flute formation appears to be related to the topographic benches.

5.1.3. Study a rea C (Skálafellshnúta)

The steep sided valley wall at study area C (Figure 7) displays the LIA moraine (Figure 4(D)) which formed between ~1880-1890 AD (Hannesdóttir et al., 2015b), with several small, annual recessional push moraines formed since (Figure 4(C)). These moraines are close together (~4 m apart) where the topography is steep,

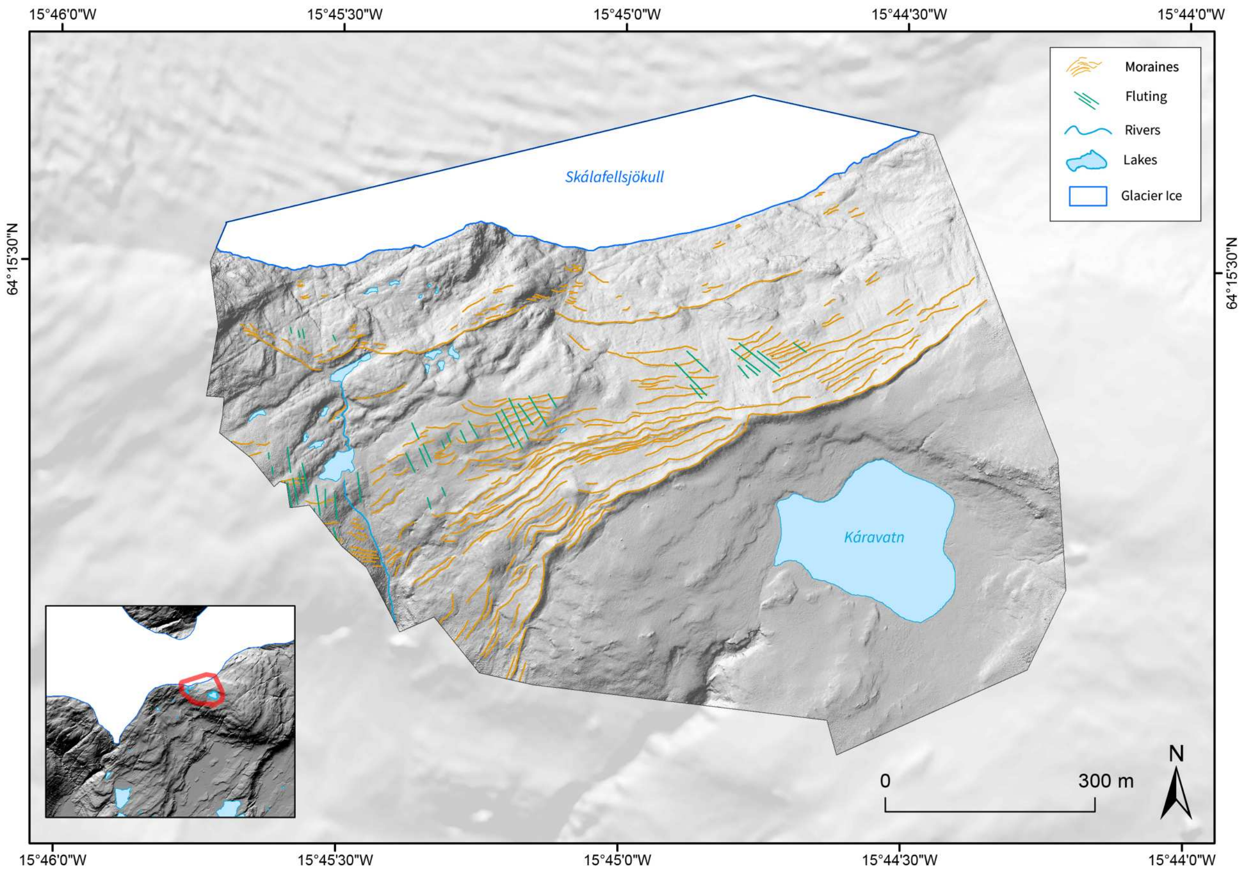

Figure 7. Glacial geomorphology at Study Area C (Skálafellshnúta). Mapped using 2021 UAV-captured orthophoto and DEM. Background DEM source: ArcticDEM (Porter et al., 2018). Includes data from the National Land Survey of Iceland (IS 50V | National Land Survey of Iceland (lmi.is)). Map projection is WGS 1984 UTM Zone 28N (ESPG: 332628).

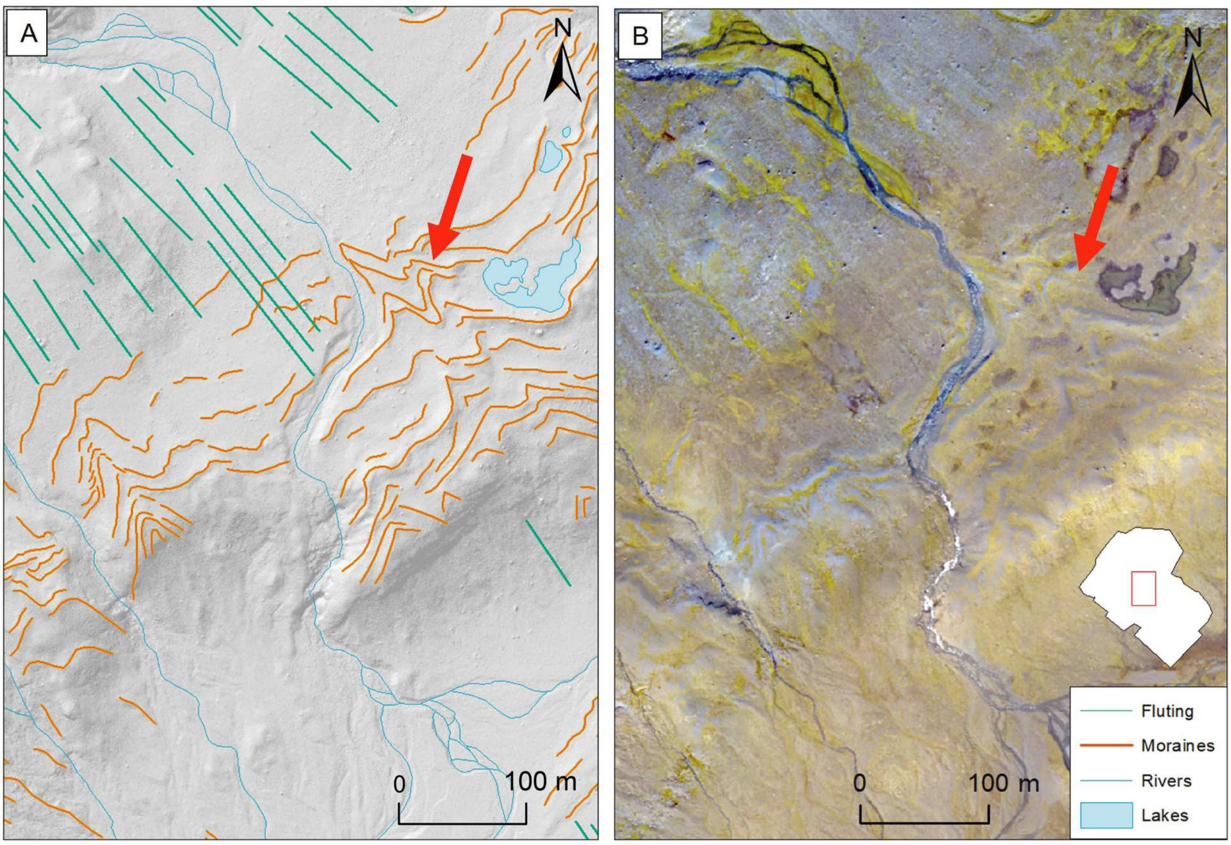

Figure 8. Map displaying clear sawtooth moraine ridges at study area B (red arrows), also highlighting the differences between the (A) orthophoto and (B) hillshade DEM. Study area location indicated by white outline and brown box.

reflecting subtle changes in the glacier surface elevation, and start to spread out to the west where the glacier once extended towards Miðbotnafjall. These densely spaced moraines could indicate a more dynamic ice margin, or their formation was impacted by the steep slope, meaning the spacing between moraines is denser when the glacier rests on a slope, similar to observations at Fjallsjökull (e.g. Chandler et al., 2020a).

The fluting observed here appears to be sloped uphill and superimposed over recessional moraines, with no evidence of an initiation boulder from the UAV-imagery, which could have been removed or displaced during glacier retreat (Ely et al., 2017), or formed without the initiation boulder (Boulton, 1976; Ewertowski et al., 2016). Ploughing and grooving processes from boulders protruding from the base of the ice could have resulted in the formation of these flutes, as observed at Hoffellsjökull (Evans et al., 2019).

5.2. Directions for future research

Our high resolution glacial geomorphological mapping at the southern margin of Skálafellsjökull, provides a framework for further understanding the influence of topography on glacier retreat in southeast Iceland. This study will be useful for (1) demonstrating the relationship between climate, topography, and ice dynamics, (2) illustrating how the topography impacts glacial landform production, (3) examining the timing and nature of glacier retreat across Iceland and the southeast, and (4) constraining numerical modelling of glacier retreat.

Annual recessional push moraines have been used as a proxy for ice front retreat (e.g. Bradwell et al., 2013; Krüger, 1995) which can be compared with other glaciers and climate records from nearby meteorological stations or longer climatic records, such as lake or marine sediment records. Annual push moraines have been measured at the main Skálafellsjökull foreland to understand ice margin retreat rates and compared with climate data from summer air temperature, sea surface temperature and NAO (e.g. Chandler et al., 2016a). Applying this to the mapped moraines at all three study areas would provide a comparison of retreat rates and response to climate in southeast Iceland.

There is a notable lack of ice cored landforms (e.g. ice-cored moraines and eskers, buried snouts), that are reported at other sites (e.g. Bennett and Evans, 2012; Chandler et al., 2020b; Evans et al., 2023; Schomacker et al., 2006; Schomacker and Kjær, 2008; Storrar et al., 2015), meaning that Skálafellsjökull is almost entirely devoid of supraglacial cover. Further studies at this location are required to explore the links between topography, glacier transport pathways, and landform production and degradation rates.

6. Conclusion

Glacial geomorphological mapping of the southern Skálafellsjökull margin displays a topographically diverse glacier margin with landforms that are typical of temperate southeast Icelandic glaciers, including moraines, sawtooth moraines, and fluting, but lacking ice-cored landforms. Detailed, high resolution mapping using UAV-captured imagery shows three different topographic settings each having a distinctive geomorphological signature that can be used to evaluate the influence of topography on glacier behaviour, deglaciation, and landform formation. The high-resolution imagery presented in this study further demonstrates the potential application of UAVs in high-resolution mapping of glacial geomorphological features, which can be used to understand landscape evolution and ice-frontal fluctuations from glaciers that are actively retreating, such as those in southeast Iceland.

Software

Image processing was carried out in *Agisoft Metashape Professional 1.5.3*. Geomorphological mapping was conducted using *ESRI ArcGIS ArcMap 10.6.1*. *ArcScene* was used to view imagery. Final map production was carried out using *Adobe Illustrator 3.0.4.*

Acknowledgements

Thank you to the Vatnajökull National Park and the landowners at Skálafell Guesthouse for permission to undertake fieldwork at Skálafellsjökull and Skálafellshnúta. Thanks are due to Haukur Ingi Einarsson for logistical support when undertaking fieldwork. Thank you to the reviewers for their valuble comments. ArcticDEM dems were provided by the Polar Geospatial Center under NSF-OPP awards 1043681, 1559691, 1542736, 1810976, and 2129685.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

RDS received an Early Career Researcher Grant from the British Society for Geomorphology (BSG). SW received a Postgraduate Research Grant from the BSG under grant reference number BSG-2022-07. This work was also supported by the Department of the Natural and Built Environment at Sheffield Hallam University.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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