A Glacial Geomorphological Map of the Great Glen Region of Scotland

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Complete List of Authors:	Turner, Andrew; Northumbria University, Woodward, John; Northumbria University, Stokes, Chris; Durham University, Cofaigh, Colm; University of Durham, Geography Dunning, Stuart; Northumbria University,

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A Glacial Geomorphological Map of the Great Glen Region of Scotland

Andrew J. Turner[1, a], John Woodward[1], Chris R. Stokes[2], Colm Ó Cofaigh[2], Stuart Dunning[1]

[1] Faculty of Engineering and Environment, Department of Geography, Northumbria University, Ellison Place, Newcastle-Upon-Tyne, NE1 8ST, UK

[2] Department of Geography, Durham University, South Road, Durham, DH1 3LE, UK

[a] a.j.turner@northumbria.ac.uk

Abstract

This paper presents a detailed glacial geomorphological map of the Great Glen region of Scotland, UK, covering an area of over 6,800 km^2 extending from 56°34'7" to 57°41'1" N and from 3°44'2" to 5°33'24" W. This represents the first extensive mapping of the glacial geomorphology of the Great Glen and builds upon previous studies that conducted localised field mapping or ice-sheet wide mapping using remote sensing. Particular emphasis is placed on deriving medium-scale glacial retreat patterns from these data, and examining differences in landsystem assemblages across the region. Features were typically mapped at a scale of 1:8,000 to 1:10,000 and will be used to investigate the pattern and dynamics of the British-Irish Ice Sheet during deglaciation. Mapping was conducted using the NEXTMap digital terrain model. In total, 17,637 glacial landforms were mapped, with 58% identified as moraines, 23% as meltwater channels, 10% as bedrock controlled glacial lineations, 3% as eskers, 2% as cirques or arêtes, 2% as kame topography or kame terraces, and 1% as drumlins. Additionally, ten palaeo-lake shorelines were identified. Complex landform assemblages in the form of streamlined subglacial bedforms, moraines and glaciofluvial features exist across the region. Extensive subglacial meltwater networks are found over the Monadhliath Mountain Range. Transverse and longitudinal moraine ridges generally arc across valley floors or are located on valley slopes respectively. Hummocky moraines are found almost exclusively across Rannoch Moor. Finally, Eskers, meltwater channels and kame landforms form spatial relationships along the axis of Strathspey. These glacial landsystems reveal the dynamics and patterns of retreat of the British-Irish Ice Sheet during the last deglaciation.

Keywords: Great Glen, Geomorphology, British-Irish Ice Sheet, Deglaciation

1. Introduction

Glacial landforms are key ingredients for reconstructing the past extent and dynamics of the former British-Irish Ice Sheet (BIIS), which extended across much of Britain and Ireland, and reached the continental shelf edge during the last glaciation about 24,000 years ago (Bowen *et al*., 2002; Sejrup *et al*., 2005; 2009; Bradwell *et al*., 2008a; Chiverrell and Thomas, 2010; Clark *et al*., 2012). In Scotland, coastal and onshore geomorphology (e.g. Thorp, 1986; Firth, 1989a, b; Merritt *et al*., 1995; Finlayson, 2006; Finlayson *et al*., 2010) have been extensively employed to reconstruct flow paths and retreat patterns. The limits of the Younger Dryas (YD) readvance (12.9-11.7 ka BP) are also well known (e.g. Sissons, 1979a; Bennet and Boulton, 1993a; Clark *et al*., 2004). Terrestrial evidence suggests the configuration of the BIIS was complex and that the ice sheet was characterised by at least four areas of major ice streaming located at the Moray Firth, The Minch, along the eastern coast of England and within the Irish sea basin. These were zones of high flow velocity which drained large volumes of ice from the ice sheet's interior (e.g. Merritt et al., 1995; Bradwell *et al*., 2008b; Hughes *et al*., 2010; Clark *et al*., 2012). Less attention has been given to synthesising terrestrial limits and medium-scale retreat patterns between offshore/coastal and YD ice margin positions. Whilst there are a number of site specific studies of moraines, glaciofluvial landforms, and streamlined subglacial bedforms in Scotland (e.g. McCann, 1966; Peacock, 1971; Young, 1978; Firth, 1989a; Golledge, 2006; Livingstone *et al*., 2008), the glacial landforms across large sectors of the Scottish landscape have yet to be systematically mapped .

In the Great Glen (GG) and surrounding region a paucity of detailed mapping has precluded an accurate reconstruction of ice sheet retreat from the Scottish coast to the YD maximum extent positions mapped by Clark *et al*., 2004. However, recent research in the Monadhliath Mountain Range has suggested that ice cover between ~15 ka BP and 11.7 ka BP was more extensive than previously thought (Boston *et al*., 2013).

The accompanying geomorphological map covers a region of 6,828 km^2 centred on the Great Glen in Scotland. This builds upon previous mapping efforts (e.g. Clark *et al*., 2004; Hughes *et al*., 2010) and is part of ongoing research into the nature of deglaciation through the Great Glen sector of the BIIS including subaqueous geophysical surveys of the lochs in the region (e.g. Turner *et al*., 2012; 2013a, b).

2. Methods

2.1 Data Sources

The geomorphological map of the Great Glen region has been produced from high-resolution Intermap Technologies NEXTMap digital terrain data which has a horizontal resolution of 5 m and vertical resolution of 1 m. ESRI ArcGIS 9.3 software was used during mapping procedures. An orthogonally illuminated hillshade of the study area was produced (Smith and Clark, 2005). As lineations on the land surface have a predominant south-west/north-east trend, the digital elevation model was initially shaded from an azimuth perpendicular to their orientation (north-west: 315^{o}). To reduce the bias associated with hillshading from a single solar azimuth, a second relief map was produced with a perpendicular north-east (45^{o}) azimuth (e.g. Smith and Clark, 2005). A solar elevation angle of 45^{o} was selected for these images to reveal subtle topography within the study area. To further reduce azimuth biasing, a shaded relief image with an illumination angle of 90^{o} (vertical) was also produced, as suggested by Smith and Clark, (2005).

Additional contextual data from Ordnance Survey MasterMap, available from the Edina ShareGeo website (http://edina.ac.uk/projects/sharegeo/index.shtml), at a scale of 1:2,000 were also used. These data allowed roads, buildings, managed woodland, railway lines, rivers/streams, tree cover and landforms pertinent to this study to be identified. A base map for the remainder of Scotland is provided by NASA Shuttle Radar Topography Mission (SRTM) data, available at http://www2.jpl.nasa.gov/srtm/. This layer is not used in mapping procedures due to its low resolution (90 m - Farr *et al*., 2007) and vertical elevation errors (5 m - Rodriguez *et al*., 2005). All map layers were displayed using the British National Grid (OSGB 1936 datum) and projected to the Transverse Mercator, airy spheroid.

2.2 Mapping Procedure

The glacial geomorphological map was generated by visually identifying features of glacial origin from the relief shaded images described above. Across the area 17,637 individual glacial features were systematically located and classified according to common morphological descriptions (see section 3). Landforms were digitised within ArcGIS 9.3 software as colour coded polyline data at a scale of between 1:8,000 and 1:10,000. In cases where a landform was tentatively identified in the imagery, but lacked pronounced relief or was otherwise difficult to see, ESRI ArcScene 9.3 3D visualisation software was used to aid in scrutinising landforms. This helped classify the exact feature type, or allowed a feature to be rejected as unimportant to the study (e.g. roads, electrical pylons, buildings).

Whilst previous mapping has identified a wealth of glacial landforms such as bedrock controlled glacial features (e.g. Peacock *et al*., 1992; Hughes *et al*., 2010), drumlins (Hughes *et al*., 2010) meltwater channels (e.g. Gordon, 1993; Greenwood *et al*., 2007; Margold and Jansson, 2012), eskers (e.g. Young, 1978; Key, 1997), kame features (e.g. Young, 1978; May and Highton, 1998; Russell and Marren, 1998), moraines (e.g. Bennett and Boulton, 1993a, b; Benn and Lukas, 2006; Dunlop and Clark, 2006a, b; Smith *et al*., 2006) and ice dammed palaeo-lake shorelines (e.g. Sissons, 1977b; 1979a, c; Palmer *et al*., 2010); a new map was required that covers a regional area and synthesises these data at the medium-scale. The descriptions of landforms given in the above references have also provided criteria for identification of previously unmapped glacial landforms in the region. Where a landform was confirmed from visual identification of the relief imagery they were included on the final geomorphological map. The source references for such features were added to the attribute table entry during mapping. It is estimated that 80% of the landform record presented in the glacial geomorphological map has not been identified previously.

All features were further subdivided into 3 ‘certainty categories’ (cf. Greenwood, 2007). Category 1 (‘definite’) denotes a given landform possesses most of the characteristic attributes described in the literature for that landform type. Category 2 (‘probable’) refers to those landforms which are most likely of a particular feature type but some uncertainty remains as not all classic characteristics may be present. The final category 3 (‘possible’) landforms display only a few of the typical characteristics of its type or, alternatively, possess characteristics of two or more landform types and could potentially be misidentified. Category 3 landforms are omitted from the final geomorphological map. Statistical information for each landform type was drawn from examples classified as ‘definite’ or ‘probable’ (Table 1).

A short ground truthing field excursion was also conducted to verify several landform types. Locations included the northern and southern shores of Loch Ness, several locations within the Monadhliath Mountain Range and Glen Roy.

The palaeo-shorelines of ice dammed lakes, which previously occupied glens, were produced by first identifying the palaeo-shoreline from the hillshaded NEXTMap data based on descriptions by

Sissons (1977b; 1979a, c) and Palmer *et al*. (2010). Where the surface elevation of a palaeo-shoreline was known, an isoline of the appropriate elevation above sea-level was generated in the GIS using a geoprocessing tool in order to keep elevation error to a minimum. The extent of the resulting palaeo-lake was therefore delineated primarily by topography, but also from associated moraine limits. A caveat to this is that the NEXTMap digital elevation model retains all natural and anthropogenic features in addition to the relief of the land surface; therefore where the lake shores disappear under tree cover, the mapping algorithm would map tree elevation instead of palaeo-shoreline elevation. Forested areas are therefore omitted from the elevation analysis. Glacio-isostatic adjustment is not accounted for, but given the relatively small size of the lakes, this is unlikely to be a problem.

3. Glacial Geomorphology

3.1 Cirques/Arêtes

Cirques are erosional hollows in mountainous terrain with concave slopes bounded upstream by a sharp arcuate headwall and sharp valley side ridges (arêtes) (Gordon, 2001; Evans, 2006) and are flat floored and open at the downstream end (Evans and Cox, 1974; Benn and Evans, 2010) (Fig. 2a, b). In the Great Glen region, clusters of cirques exist in the vicinities of Loch Ericht, Ben Nevis Mountain Range, Loch Arkaig, Loch Loyne and Loch Affric (Fig. 1). These locations lie within YD ice cap limits as defined by Clark *et al*. (2004). Three clusters of cirques occur outside the YD limit in proximity to Loch Laggan, Strathossian and Strathconnon (Fig. 1). It should be noted that the YD ice limits presented here are based on Clark *et al*. (2004). However, recent work in the Monadhliath Mountain Range suggests a more extensive ice limit during the YD cold event (Boston *et al*., 2013).

3.2 Streamlined bedrock

Streamlined bedrock features are highly elongate, (e.g. Table 1) ice flow parallel landforms (Bradwell *et al*., 2008b), possessing sharp crest lines in cross-profile and gentle long-profile morphology (Jansson *et al*., 2003). The highest concentration occurs over the mountainous areas surrounding Loch Ness (e.g. Fig. 2c, d); other concentrations are located on the western side of Strathspey and on peaks overlooking Glens Moriston, Roy and Spean. These fields of streamline bedrock ridges predominantly occur outside the YD ice limit. Within the YD limit, the streamlined features are located in the vicinities of Lochs Aber, Affric, Garry, Loyne (Fig. 1).

3.3 Crags and Tails

Crags and tails are ice moulded bedrock outcrops with indistinct or sharp crests and a leeward tail/ridge of unlithified material (usually till) tapering in the direction of ice flow (Smith *et al*., 2006; Greenwood and Clark, 2008; Hughes *et al*., 2010) (Fig. 2c, d). They are have a relatively high elongation ratio (Table 1) and are found outside the YD ice limits over elevated terrain, and surround the northern portion of Loch Ness. Other fields are found in proximity to Glen Affric, Strathconnon, the Clava river valley, and on peaks overlooking Strathspey (Fig. 1). Additionally, the northern Affric/Ness clusters surround the peripheries of drumlin fields discussed below.

3.4 Drumlins

Drumlins are streamlined, commonly described as asymmetric, ovoid hills aligned parallel to ice flow with gentle stoss and lee slopes which may also be spindle-like, parabolic or barchanoid in planview (Mitchell and Riley, 2006; Smith *et al*., 2006; Greenwood and Clark, 2008; Hughes *et al*., 2010). In this region, they are more elongate when compared to other types of glacial lineations (Table 1). They encircle the northern and eastern shores of Loch Ness, and they surround the northern and southern shorelines of Beauly Firth and west of Cromarty Firth.

3.5 Transverse moraines

Transverse moraines are ridges deposited perpendicular to ice flow which may be single ridges or broken into linear chains arcing across valley floors (Sissons, 1979c, Benn and Lukas, 2006; Golledge, 2006; Smith *et al*., 2006). The mean length of transverse moraines has been calculated to be ~128 m (Table 1). A characteristic cluster has been identified at the Blackwater Reservoir (Fig. 3a, b). Other fields occur in glens adjacent to Lochs Arkaig, Cluanie, Eil and Quioch with two further clusters located in Glen Spean and north-east of Loch Ness (Fig. 1).

3.6 Longitudinal (ice flow parallel) moraines

Longitudinal moraines occur laterally on valley slopes (lateral moraines) (Sissons, 1979c), on valley floors running parallel to the valley long axis and former ice flow (Benn and Evans, 2010), or extend from central ridges at the confluence of adjacent valleys, showing where two separate glacier systems have merged into one coherent ice mass flowing down-valley (medial moraines) (e.g. Spagnolo and Clark, 2009). They are frequently asymmetrically distributed across opposing valley slopes (Sissons, 1979c). They have also been calculated to possess a slightly longer mean length than transverse moraines, measured at ~149 m (Table 1). A large population is found at the northern end of Loch Ness and close to Foyers, with examples found at the YD limit in Glen Moriston. Further fields are found in proximity to Lochs Arkaig and Ossian, and across Rannoch Moor (Fig. 1).

3.7 Ribbed moraine

Ribbed moraine consist of curved, closely spaced ridges aligned transverse to ice flow with a characteristic anastomosing pattern or 'ribbing' (Lundqvist, 1989; Aylsworth and Shilts, 1989; Hättestrand and Kleman, 1999; Dunlop and Clark, 2006a, b) (Fig. 3e, f). They may have multiple sub-crests or singular flat apexes (Dunlop and Clark, 2006a, b; Hughes *et al*., 2010). Ribbed moraines are exclusively found surrounding the southern tip of the Cromarty Firth, deposited above a 40 m palaeo-sea level shoreline mapped by Firth (1989a) with few examples below this (Fig. 3e, f). They also possess the greatest mean length (measured perpendicular to ice flow direction), at ~243 m (Table 1).

3.8 Hummocky terrain

Hummocky terrain is defined as irregular mounded topography which exhibits varying degrees of order; ranging from unordered (chaotic) assemblages to suites of nested linear elements (Sissons, 1976; Smith *et al*., 2006). Hummocky terrain commonly occurs in localised depocentres in the form of broad and low ridges in the landscape, which may grade into till sheets (Key, 1997). The largest population was observed in the Rannoch Moor area with other concentrations located in western Strathspey, in the vicinities of Lochs Lochy, Eil and Quioch, and west of the YD ice limit in Glen Affric (Fig. 1).

3.9 Kame topography

Kame and kettle topography are assemblages of mounds and hollows generated through supraglacial or ice contact glaciofluvial deposition which may also represent zones of *in situ* ice stagnation, wastage, ice-block meltout or jökulhlaups (Sissons, 1976; 1979c; Young, 1978; Russell and Marren, 1998; Fay, 2002; Gordon and McEwen, 1993) (Fig. 4a, b). The largest field is located on the western slopes of Strathspey with another series of features found at the Auchteraw Terrace, close to Fort Augustus (Fig. 1). Another field exists at the head of Loch Treig (Fig. 1).

3.10 Kame terraces

Kame terraces are gently sloping depositional benches perched on valley sides, and are related to the lateral deposition of glaciofluvial outwash (Evans, 2005); or possibly outwash deposition in ice marginal ribbon lakes (Benn and Evans, 2010). They often occur in series and have differing gradients relating to former ice margin morphology (Fletcher *et al.*, 1996; Benn and Evans, 2010). The largest concentration occurs in Glen Moriston on the slopes on either side of the modern river within the YD ice limit. Also within the ice limit, kame terrace fragments are identified north of Loch Treig (Sissons, 1979c) (Fig. 1). Outside of the YD limit, in Strathspey, terrace fragments are observed north of Newtonmore (Young, 1978) and in the northern Findhorn river valley (Fletcher *et al.*, 1996).

3.11 Lateral meltwater channels

Lateral meltwater channels develop parallel to ice margin surfaces and erode distinct lateral or arcuate 'grooves' or benches into the topography during deglaciation (Dyke *et al.*, 1992; Kleman *et al.*, 1992; Dyke, 1993; Hättestrand, 1998; Hättestrand and Stroeven, 2002; Sollid and Sørbel, 1994; Smith *et al.*, 2006; Greenwood *et al.*, 2007). Outside the YD ice limit, channels are located at the peripheries of Loch Ness and valleys in the Monadhliath Mountain Range (Fig. 1). Within the ice limit, concentrations are found at Lochs Arkaig, Laggan and Ossian, and surround Leum Uilleim (Fig. 4e, f). Statistical information obtained from all meltwater channel types are presented in Table 1.

3.12 Sublateral meltwater channels

Sublateral channels typically have greater angles of dip on the land surface than lateral examples and often occur in series at elevations below major longitudinal moraine ridges and in some instances plunge through down slope chutes or fissures (Sissons, 1967; Greenwood *et al.*, 2007).

Concentrations exist in Glen Moriston, over Leum Uilleim, and at Urquhart Bay and Foyers, Loch Ness (Fig. 1).

3.13 Subglacial meltwater channels

Subglacial channels can form in an upslope flow direction and may overtop mountainous peaks/ridges and erode directly into bedrock, due to controls imparted by ice flow direction and hydrostatic pressures (Sissons, 1967; Nye, 1973; Young, 1978; Sharpe and Shaw, 1989; Sugden *et al*., 1991; Kleman and Borgström, 1996; Kleman *et al*., 1997; Hättestrand and Stroeven, 2002). They may also preferentially erode into faults in bedrock surfaces and display anastomosing or braided patterns (Margold and Jansson, 2012). The highest density is found over the Monadhliath Mountain Range and on the elevated terrain between Loch Ness and Glen Affric (Fig. 1). These areas are located outside of the YD ice limit. Within the ice limit small clusters are located on the flanks of Leum Uilleim, Loch Treig and Loch Eil (Fig. 1).

3.14 Proglacial meltwater channels

Proglacial channels are formed at the termini of glaciers and ice sheets which can form braided and branching channel networks in the proglacial zone (Benn and Evans, 2010). They often rapidly erode pre-existing channels or down-cut into bedrock surfaces and may be difficult to distinguish from modern drainage channels, or, if channels are of low relief, they may have a very weak signature on the land surface (Benn and Evans, 2010; Margold *et al*., 2011). Only three features have been confirmed as proglacial channels. These are located in the Glen Roy area, eroded through a series of transverse moraines and into the top of a proglacial fan complex known as the Glen Turret Fan (Chen and Rose, 2008).

3.15 Over-col spillway channels

Over-col spillways (Fig. 4f) are deep channels or gorges incised into bedrock which are often found in association with former ice dammed lakes (Margold and Jansson, 2012). Four of the spillways are associated with the former ice dammed lakes in Glens Spean, Roy and Gloy, with further spillways located near Beinn a'Bha'ach Ard and Sgurr na Ruaidhe between Strathconnon and Strathfarrar and at Leum Uilleim (Fig. 1).

3.16 Eskers

Eskers are well-defined, sub-linear to sinuous ridges which may have smooth or sharp crests and are often associated with lakes, kame and kettle topography. They typically trend in the direction of former meltwater flow which may not necessarily be the same as the regional ice flow direction (Smith *et al*., 2006; Margold and Jansson, 2012). They can form supraglacially, englacially or subglacially (Banerjee and McDonald, 1975) via sustained deposition over long timescales or via single high-magnitude events (jökulhlaups) (Burke *et al*., 2008; 2010). Eskers are observed in proximity to Glens Moriston and Spean, Strathossian, and on slopes overlooking Lochs Ericht, Lochy, Oich, and Treig. Elsewhere, eskers are found in the vicinities of Strathspey, Loch Laggan and the Clava and Findhorn river valleys. A small number of eskers located at the northern end of Loch Ness are larger in scale.

3.17 Paleo-lake shorelines

Palaeo-lake shorelines are laterally continuous valley side terraces, notches or benches that are the result of wave erosion and beach deposition at a former long-lived palaeo-water-level which also often occur in series (Darwin, 1839; Sissons, 1977a; 1978; Sissons and Cornish, 1982; Chen and Rose, 2008; Margold and Jansson, 2012). Six shorelines are identified in Glen Doe at 510 m, 406 m, 359 m, 334 m, 324 m and 305 m above sea-level (a.s.l.) (Fig. 5a-f). A 355 m a.s.l. shoreline is identified in Glen Gloy and crosses two sets of transverse moraine deposited within the valley bottom, resulting in possible minimum and maximum extents (Fig. 5g, h). Three are traced in Glen Roy where they are laterally extensive and occur at 350 m, 325 m and 260 m a.s.l. (Fig. 5i-k). The 260 m a.s.l. shoreline is also traced in Glen Spean (Fig. 5j, k).

4. Conclusions

The map accompanying this article is the first detailed map of the glacial geomorphology of the Great Glen region of Scotland. This map builds upon and extends previous work by both field researchers, cartographers and the BRITICE data set by synthesising small-scale mapping efforts at the medium-scale, including previously unmapped landform assemblages, to produce a detailed regional pattern of glacial landforms which can be used to reconstruct the dynamics and retreat patterns of the former BIIS in this sector of Scotland. Complex landform assemblages exist across the study area especially on the eastern side of the Great Glen, where a larger number of landforms appear to have been preserved. In total 17,637 individual features were mapped in the 6828 km^2 study area; 58% of these are moraine, 23% are meltwater channels, 10% are bedrock lineations, 3% are eskers, 2% are cirques or arêtes, 2% are kame and kettles or kame terraces and 1% are drumlins.

Where mountainous areas are present, glacial erosion has produced cirques, marking initial accumulation areas and final deglacial enclaves of the former ice cover in Scotland. Over elevated ground, streamlined bedforms dominate, with drumlins occupying lower ground to the north-east. Extensive subglacial meltwater networks are found over the Monadhliath Mountain Range. Across low elevation terrain in the southern extremity of the study area, in western Rannoch Moor, moraine ridges are the prevailing landforms. Transverse and longitudinal moraine ridges are generally located across valley floors or deposited on valley slopes respectively dispersed across the study area. Longitudinal moraines additionally share a spatial relationship with lateral meltwater channels along the axis of the Great Glen. Eskers, meltwater channels and kame landforms also form spatial relationships along the axis of Strathspey.

The glacial geomorphological map accompanying this paper synthesises morphological data in order to examine the nature of glaciation in the Great Glen region and the potential evidence of fast flow (ice streaming). Particular emphasis is placed on deriving regional glacial retreat patterns, and finally, examining any differences in morphology or landsystem assemblages occurring within the Younger Dryas ice cap limits.

5. Software

Relief shaded visualisations of the NEXTMap dataset and onscreen digitisation of landforms were done using ESRI ArcGIS 9.3 software. The 3D visualisation tool of ArcScene 9.3 was used to aid assessment of landform features where this was difficult in the planview of ArcGIS 9.3. The final geomorphological map was produced in ArcGIS 9.3 and exported as a PDF document.

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7. Map Design

All glacial landforms were mapped as a series of polyline data, colour coded to feature type for expedient mapping. For meltwater channels, kame features and moraines different colours were also used to differentiate between sub-types (e.g. dark blue for subglacial meltwater channels and lighter blues for lateral and sublateral types). Mapped landforms were overlaid on various hillshaded renditions of the NEXTMap data and coloured white to emphasise the topography of the area and to aid clarity of individual features. Place names were kept to an absolute minimum on the final geomorphological map to avoid cluttering the map and obscuring geomorphological features. This accompanying paper contains a figure with all relevant place names mentioned in the text.

8. References

AYLSWORTH, J. & SHILTS, W. (1989), 'Bedforms of the Keewatin Ice Sheet, Canada.', *Sedimentary Geology* **62**, 407-428.

BANERJEE, I. & MCDONALD, B. (1975), Nature of Esker Sedimentation, In: JOPLING, A. & MCDONALD, B., ed., *Glaciofluvial and Glacio-lacustrine Sedimentation, Special Publication 23*, Society of Economic Palaeontologists and Mineralogists, pp. 132-154.

BENETTI, S., DUNLOP, P. & Ó COFAIGH, C. (2010), 'Glacial and glacially-related features on the continental margin of northwest Ireland mapped from marine geophysical data', *Journal of Maps* **v2010**, 14-29.

BENN, D. & EVANS, D. (2010), *Glaciers and Glaciation (2nd Edition)*, Hodder, London.

BENN, D. & LUKAS, S. (2006), 'Younger Dryas glacial landsystems in North West Scotland: an assessment of modern analogues and palaeoclimatic implications', *Quaternary Science Reviews* **25**, 2390-2408.

BENNETT, M. & BOULTON, G. (1993a), 'Deglaciation of the Younger Dryas or Loch Lomond Stadial icefield in the northern Highlands, Scotland', *Journal of Quaternary Science* **8**, 133-145.

BENNETT, M. & BOULTON, G. (1993b), 'A reinterpretation of Scottish ' hummocky moraine' and its significance for the deglaciation of the Scottish Highlands during the Younger Dryas or Loch Lomond Stadial', *Geological Magazine* **130**, 301-318.

BOSTON, C.M., LUKAS, S., MERRITT, J.W. (eds.) (2013). *The Quaternary of the Monadhliath Mountains and Great Glen, Field Guide*. Quaternary Research Association, London.

BOWEN, D., PHILLIPS, F., MCCABE, A., KNUTZ, P. & SYKES, G. (2002), 'New data for the Last Glacial Maximum in Great Britain and Ireland', *Quaternary Science Reviews* **21**, 89-101.

BRADWELL, T., STOKER, M. & KRABBENDAM, M. (2008b), 'Megagrooves and streamlined bedrock in NW Scotland: The role of ice streams in landscape evolution', *Geomorphology* **97**, 135-156.

BRADWELL, T., STOKER, M., GOLLEDGE, N., WILSON, C., MERRITT, J., LONG, D., EVEREST, J., HESTVIK, O., STEVENSON, A., HUBBARD, A., FINLAYSON, A. & MATHERS, H. (2008a), 'The northern sector of the last British Ice Sheet: maximum extent and demise', *Earth Science Reviews* **88**, 207-226.

BRITISH GEOLOGICAL SURVEY (1995), Glen Roy, Scotland Sheet 63W, British Geological Survey, Keyworth, Nottingham.

BRITISH GEOLOGICAL SURVEY (1997), Fortrose, Scotland Sheet 84W, British Geological Survey, Keyworth, Nottingham.

BRITISH GEOLOGICAL SURVEY (2000), Dalwhinnie, Scotland Sheet 63E, British Geological Survey, Keyworth, Nottingham.

BURKE, M., WOODWARD, J., RUSSELL, A., FLEISHER, P. & BAILEY, P. (2010), 'The sedimentary architecture of outburst flood eskers: A comparison of ground-penetrating radar data from Bering Glacier, Alaska and Skeiðarárjökull, Iceland', *Geological Society of America Bulletin* **122**, 1637-1645.

BURKE, M., WOODWARD, J., RUSSELL, A., FLEISHER, P. & BAILEY, P. (2008), 'Controls on the sedimentary architecture of a single event englacial esker: Skeiðarárjökull, Iceland', *Quaternary Science Reviews* **27**, 1829-1847.

CHEN, C.-Y. & ROSE, J. (2008), Assessment of remote sensed imagery on the analysis of landforms in Glen Roy, In: PALMER, A., LOWE, J. & ROSE, J., ed., *The Quaternary of Glen Roy and Vicinity, Field Guide*, Quaternary Research Association, London, pp. 36-45.

CHIVERRELL, R. & THOMAS, G. (2010), 'Extent and timing of the Last Glacial Maximum (LGM) in Britain and Ireland: a review', *Journal of Quaternary Science* **25**, 535-549.

CLARK, C., EVANS, D., KHATWA, A., BRADWELL, T., JORDAN, C., MARSH, S., MITCHELL, W. & BATEMAN, M. (2004), 'Map and GIS database of landforms and features related to the last British Ice Sheet', *Boreas* **33**, 359-375.

CLARK, C., HUGHES, A., GREENWOOD, S., JORDAN, C. & SEJRUP, H. (2012), 'Pattern and timing of retreat of the last British-Irish Ice Sheet', *Quaternary Science Reviews* **44**, 112-146.

DARWIN, C. (1839), 'Observations on the parallel roads of Glen Roy, and of other parts of Lochaber in Scotland, with an attempt to prove that they are of marine origin', *Philosophical Transactions of the Royal Society* **129**, 39-81.

DUNLOP, P. & CLARK, C. (2006a), 'Morphological characteristics of ribbed moraine', *Quaternary Science Reviews* **25**, 1668-1691.

DUNLOP, P. & CLARK, C. (2006b), 'Distribution of ribbed moraine in Lac Naococane region, central Quebec, Canada', *Journal of Maps* **v2006**, 59-70.

DYKE, A. (1993), 'Landscapes of cold-centred Late Wisconsinan ice caps, Arctic Canada', *Progress in Physical Geography* **17**, 223-247.

DYKE, A., MORRIS, T., GREEN, D. & ENGLAND, J. (1992), *Quaternary geology of Prince of Wales Island, Arctic Canada, Geological Survey of Canada Memoir 433*, Geological Survey of Canada.

EVANS, D., (2005), Ice-marginal Terrestrial Landsystems: Active Temperate Glacier Margins, In: EVANS, D., ed., *Glacial Landsystems*, Hodder, London, pp. 12-43.

EVANS, I. & COX, N. (1974), 'Geomorphometry and the operational definition of cirques', *Area* **6**, 150-153.

EVANS, I. (2006), 'Allometric development of glacial cirque form: geological, relief and regional effects on the cirques of Wales', *Geomorphology* **80**, 245-266.

EYLES, N., BOYCE, J. & BARENDREGT, R. (1999), 'Hummocky moraine: sedimentary record of stagnant Laurentide Ice Sheet lobe resting on soft sediment', *Sedimentary Geology* **123**, 163-174.

FARR, T., ROSEN, P., CARO, E., CRIPPEN, R., DUREN, R., HENSLEY, S., KOBRICK, M., PALLER, M., RODRIGUEZ, E., ROTH, L., SEAL, D., SHAFFER, S., SHIMADA, J., UMLAND, J.,

WERNER, M., OSKIN, M., BURBANK, D. & ALSDORF, D. (2007), 'The Shuttle Radar Topography Mission', *Reviews of Geophysics* **45**, RG2004.

FAY, H. (2002), Formation of kettle holes following a glacial-outburst flood (jökulhlaup), Skeiðarársandur, southern Iceland, In: SNORRASSON, A., FINNSDOTTIR, H. & MOSS, M., ed., *The Extremes of the Extremes: Extraordinary Floods, IAHS Publication, 271*, IAHS Press, Oxford, pp. 205-210.

FINLAYSON, A. (2006), 'Glacial geomorphology of the Creag Maegaidh Massif, western Grampian Highlands: implications for local glaciation and palaeoclimate during the Loch Lomond Stadial', *Scottish Geographical Journal* **122**, 239-307.

FINLAYSON, A., MERRITT, J., BROWNE, M., MERRITT, J., MCMILLAN, A. & WHITBREAD, K. (2010), 'Ice sheet advance, dynamics, and decay configurations: evidence from west central Scotland', *Quaternary Science Reviews* **29**, 969-998.

FIRTH, C. (1989a), 'Late Devensian raised shorelines and ice limits in the inner Moray Firth area, northern Scotland', *Boreas* **18**, 5-21.

FIRTH, C. (1989b), 'A reappraisal of the supposed Ardersier Readvance, inner Moray Firth', *Scottish Journal of Geology* **25**, 249-261.

FLETCHER, T., AUTON, C., HIGHTON, A., MERRITT, J., ROBERTSON, S. & ROLLIN, K. (1996), *Geology of Fortrose and eastern Inverness District*: *Memoir for 1:50 000 Geological Sheet 84W (Scotland)*, British Geological Survey, Keyworth, Nottingham, pp. 64-100.

GLASSER, N. & JANSSON, K. (2008), 'The Glacial Map of southern South America', *Journal of Maps* **v2008**, 175-196.

GOLLEDGE, N. (2006), 'The Loch Lomond Stadial glaciation south of Rannoch Moor: New evidence and palaeoglaciological insights, Scottish', *Geographical Journal* **122**, 326-343.

GORDON, J. & MCEWEN, L. (1993), North Esk and West Water glaciofluvial landforms, In: GORDON, J. & SUTHERLAND, D., ed., *Quaternary of Scotland*, Joint Nature Conservation Committee, Chapman and Hall, London, pp. 499-501.

GORDON, J. (1993), Carstairs kames, In: GORDON, J. & SUTHERLAND, D., ed., *Quaternary of Scotland*, Chapman and Hall, London, pp. 544-549.

GORDON, J. (2001), 'The corries of the Cairngorm Mountains', *Scottish Geographical Journal* **117**, 49-62.

GREENWOOD, S. & CLARK, C. (2008), 'Subglacial bedforms of the Irish Ice Sheet', *Journal of Maps* **v2008**, 332-357.

GREENWOOD, S., CLARK, C. & HUGHES, A. (2007), 'Formalising an inversion methodology for reconstructing ice-sheet retreat patterns from meltwater channels: application to the British Ice Sheet', *Journal of Quaternary Science* **22**, 637-645.

HÄTTESTRAND, C. & KLEMAN, J. (1999), 'Ribbed moraine formation', *Quaternary Science Reviews* **18**, 43-61.

HÄTTESTRAND, C. & STROEVEN, A. (2002), 'A relict landscape in the centre of Fennoscandian glaciation: Geomorphological evidence of minimal Quaternary glacial erosion', *Geomorphology* **44**, 127-143.

HÄTTESTRAND, C. (1998), 'The glacial geomorphology of central and northern Sweden', *Sveriges Geologiska Undersökning Ca* **85**, 1-47.

HUGHES, A., CLARK, C. & JORDAN, C. (2010), 'Subglacial bedforms of the last British Ice Sheet', *Journal of Maps* **v2010**, 543-563.

JANSSON, K., STOEVEN, A. & KLEMAN, J. (2003), 'Configuration and timing of Ungava Bay ice streams, Labrador-Ungava, Canada', *Boreas* **32**, 256-263.

KEY, R. (1997), *Geology of the Glen Roy district*: *Memoir for 1:50 000 geological sheet 63W (Scotland)*, British Geological Survey, Keyworth, Nottingham, pp. 96-104.

KLEMAN, J. & BORGSTRÖM, I. (1996), 'Reconstruction of Palaeo-ice sheets: The use of geomorphological data', *Earth Surface Processes and Landforms* **21**, 893-909.

KLEMAN, J., BORGSTRÖM, I., ROBERTSSON, A.-M. & LILLIESKÖLD, M. (1992), 'Morphology and stratigraphy from several deglaciations in the Transtrand Mountains, western Sweden', *Journal of Quaternary Science* **7**, 1-17.

KLEMAN, J., HÄTTESTRAND, C., BORGSTRÖM, I. & STROEVEN, A. (1997), 'Fennoscandian palaeoglaciology reconstructed using a glacial geological inversion model', *Journal of Glaciology* **43**, 283–299.

KNIGHT, J. & MCCABE, M. (1997), 'Identification and significance of ice-flow-transverse subglacial ridges (Rogen moraines) in northern central Ireland', *Journal of Quaternary Science* **12**, 519-524.

LIVINGSTONE, S., Ó COFAIGH, C. & EVANS, D. (2008), 'Glacial geomorphology of the central sector of the last British-Irish Ice Sheet', *Journal of Maps* **v2008**, 358-377.

LUNDQVIST, J. (1989), 'Rogen (ribbed) moraine: identification and possible origin', *Sedimentary Geology* **62**, 281-292.

MARGOLD, M. & JANSSON, K. (2012), 'Evaluation of data sources for mapping glacial meltwater features', *International Journal of Remote Sensing* **33**, 2355-2377.

MARGOLD, M., JANSSON, K., KLEMAN, J. & STROEVEN, A. (2011), 'Glacial meltwater landforms of central British Colombia', *Journal of Maps* **v2011**, 486-506.

MAY, R. & HIGHTON, A. (1998), *Memoir for 1:50 000 geological sheet 73W (Scotland)*, British Geological Survey, Keyworth, Nottingham, chapter Geology of the Invermoriston district, pp. 59-62.

MCCANN, S. (1966), 'The limits of the Late-glacial Highland, or Loch Lomond, Readvance along the West Highland seaboard from Oban to Mallaig', *Scottish Journal of Geology* **2**, 84-95.

MERRITT, J., AUTON, C. & CALLUM, R. (1995), 'Ice-proximal glaciomarine sedimentation and sea-level change in the Inverness area, Scotland: a review of the deglaciation of a major ice stream of the British Late Devensian ice sheet', *Quaternary Science Reviews* **14**, 289-329.

MITCHELL, W. & RILEY, J. (2006), 'Drumlin map of the Western Pennines and southern Vale of Eden, Northern England, UK', *Journal of Maps* **v2006**, 10-16.

NYE, J. (1973), 'Water at the bed of a glacier', *IASH Publication (Symposium at Cambridge 1969 – Hydrology of Glaciers)* **95**, 189-194.

PALMER, A., ROSE, J., LOWE, J. & MACLEOD, A. (2010), 'Annually resolved events of the Younger Dryas glaciation in Lochaber (Glen Roy and Glen Spean), Western Scottish Highlands', *Journal of Quaternary Science* **25**, 581-596.

PEACOCK, J. (1971), 'Terminal features of the Creran Glacier of Loch Lomond Readvance age in western Benderloch, Argyll, and their significance in the late-glacial history of the Loch Linnhe area', *Scottish Journal of Geology* **7**, 349-356.

PEACOCK, J., MENDUM, J. & FETTES, D. (1992), *Geology of the Glen Affric district*: *Memoir for 1:50,000 geological sheet 72E (Scotland)*, British Geological Survey, Keyworth, Nottingham, pp. 69-77.

RODRIGUEZ, E., MORRIS, C., BELZ, J., CHAPIN, E., MARTIN, J., DAFFER, W. & HENSLEY, S. (2005), 'An assessment of the SRTM topographic products, Technical Report JPL D-31639', Technical report, Jet Propulsion Laboratory, Pasedina, California.

RUSSELL, A. & MARREN, P. (1998), 'A Younger Dryas (Loch Lomond Stadial) jökulhlaup deposit, Fort Augustus, Scotland', *Boreas* **27**, 231-242.

SEJRUP, H., HJELSTUEN, B., DAHGREN, K., HAFLIDASON, H., KUIJPERS, A., NYGÅRD, A., PRAEG, D., STOKER, M. & VORREN, T. (2005), 'Pleistocene glacial history of the NW European continental margin', *Marine and Petroleum Geology* **22**, 1111-1129.

SEJRUP, H., NYGÅRD, A., HALL, A. & HAFLIDASON, H. (2009), 'Middle and Late Weichselian (Devensian) glaciation history of south-western Norway, North Sea and eastern UK', *Quaternary Science Reviews* **28**, 370-380.

SHARPE, D. & SHAW, J. (1989), 'Erosion of bedrock by subglacial meltwater, Cantley, Quebec', *Geological Society of America Bulletin* **101**, 1011-1020.

SISSONS, J. & Cornish, R. (1982), 'Differential glacio-isostatic uplift of crustal blocks at Glen Roy, Scotland', *Quaternary Research* **18**, 268-288.

SISSONS, J. (1967), *The Evolution of Scotland's Scenery*, Oliver and Boyd, Edinburgh.

SISSONS, J. (1976), *The Geomorphology of the British Isles: Scotland*, Methuen and Co. Ltd., London.

SISSONS, J. (1977a), 'Former ice-dammed lakes in Glen Moriston, Inverness-shire, and their significance in upland Britain', *Transactions of the Institute of British Geographers New Series* **2**, 224-242.

SISSONS, J. (1977b), *The parallel roads of Glen Roy*, Nature Conservancy Council, London.

SISSONS, J. (1978), 'The parallel roads of Glen Roy and adjacent glens, Scotland', *Boreas* **7**, 229-244.

SISSONS, J. (1979a), 'The Loch Lomond Stadial in the British Isles', *Nature* **280**, 199-203.

SISSONS, J. (1979b), 'Catastrophic lake drainage in Glen Spean and the Great Glen, Scotland', *Journal of the Geological Society of London* **139**, 215-224.

SISSONS, J. (1979c), 'The limit of the Loch Lomond Advance in Glen Roy and vicinity', *Scottish Journal of Geology* **15**, 31-42.

SMITH, M. & CLARK, C. (2005), 'Methods for the visualization of digital elevation models for landform mapping', *Earth Surface Processes and Landforms* **30**, 885-900.

SMITH, M., ROSE, J. & BOOTH, S. (2006), 'Geomorphological mapping of glacial landforms from remotely sensed data: An evaluation of the principal data sources and an assessment of their quality', *Geomorphology* **76**, 148-165.

SOLLID, J. & SØRBEL, L. (1994), 'Distribution of glacial landforms in Southern Norway in relation to the thermal regime of the last continental ice sheet', *Geografiska Annaler* **76 A**, 25-35.

SPAGNOLO, M. & CLARK, C. (2009), 'A geomorphological overview of glacial landforms on the Icelandic continental shelf', *Journal of Maps* **v2009**, 37-52.

SUGDEN, D., DENTON, G. & MARCHANT, D. (1991), 'Subglacial Meltwater Channel Systems and Ice Sheet Overriding, Asgard Range, Antarctica', *Geografiska Annaler* **73 A**, 109-121.

THORP, P. (1986), 'A mountain ice field of Loch Lomond Stadial age, western Grampians, Scotland', *Boreas* **15**, 83-97.

TURNER, A., WOODWARD, J., DUNNING, S., SHINE, A., STOKES, C. & Ó COFAIGH, C. (2012), 'Geophysical surveys of the sediments of Loch Ness, Scotland: implications for the deglaciation of the Moray Firth Ice Stream, British–Irish Ice Sheet', *Journal of Quaternary Science* **27**, 221-232.

TURNER, A., WOODWARD, J., DUNNING, S., SHINE, A., STOKES, C. & Ó COFAIGH, C. (2013a). 'The deglaciation of the Great Glen based on the results of geophysical surveys within Loch Ness'. In: Boston, C.M., Lukas, S. and Merritt, J.W. (eds.). *The Quaternary of the Monadhliath Mountains and Great Glen, Field Guide*. Quaternary Research Association, London, pp. 83-88.

TURNER, A., WOODWARD, J., DUNNING, S., SHINE, A., STOKES, C. & Ó COFAIGH, C. (2013b). 'Evidence from geophysical surveys for Younger Dryas (jökulhlaup) sedimentation within Loch Ness'. In: Boston, C.M., Lukas, S. and Merritt, J.W. (eds.). *The Quaternary of the Monadhliath Mountains and Great Glen, Field Guide*. Quaternary Research Association, London, pp. 89-92.

YOUNG, J. (1978), 'The landforms of the upper Strathspey, Scottish Geographical Magazine', *Scottish Geographical Magazine* **94**, 76-94.

9. Tables

Table 1 – Statistical properties calculated for glacial landforms.[1]

Glacial Landform	*N*	Mean Length (m)	Mean Width (m)	L/W Ratio	Mean Orientation (°)	Mean Area (km²)
Cirques	277	1155 ± 811	1038 ± 553	1.4:1	89.2 ± 50.98	1.42 ± 1.78
Arêtes	77	1804 ± 1462	-	-	-	-
Eskers	553	222 ± 202	-	-	65.2 ± 45.0	-
Glacial Lineations	1977	290 ± 377	158 ± 132	4.2:1	47.9 ± 23.9	0.13 ± 0.26
Crag & Tail	314	482 ± 400	111 ± 82	4.4:1	49.1 ± 37.5	0.5 ± 0.09
Drumlins	181	778 ± 750	189 ± 154	3.9:1	46.4 ± 22.2	0.18 ± 0.33
Streamlined Bedrock	1482	268 ± 260	55 ± 35	5.0:1	47.4 ± 18.2	0.01 ± 0.07
Kames	387	-	-	-	-	-
Kame & Kettle	337	-	-	-	-	-
Kame Terraces	50	355 ± 252	-	-	76.6 ± 34.5	-
Meltwater Channels	4117	413 ± 347	-	-	74.7 ± 46.2	-
Lateral	2468	310 ± 293	-	-	76.8 ± 46.3	-
Sublateral	221	377 ± 323	-	-	94.2 ± 49.4	-
Subglacial	1418	560 ± 413	-	-	68.0 ± 44.3	-
Proglacial	3	229 ± 68	-	-	112.9 ± 7.8	-
Over-col	7	858 ± 449	-	-	58.6 ± 50.1	-
Moraines	10227	116 ± 114	-	-	90.0 ± 52.3	-
Transverse	3397	128 ± 107	-	-	98.8 ± 55.6	-
Longitudinal	3478	149 ± 143	-	-	77.8 ± 46.5	-
Hummocky	3077	62 ± 45	-	-	-	-
Ribbed	275	243 ± 180	-	-	105.9 ± 64.3	-

[1] Standard deviations (±) are derived from the square root of the variance within each landform population.

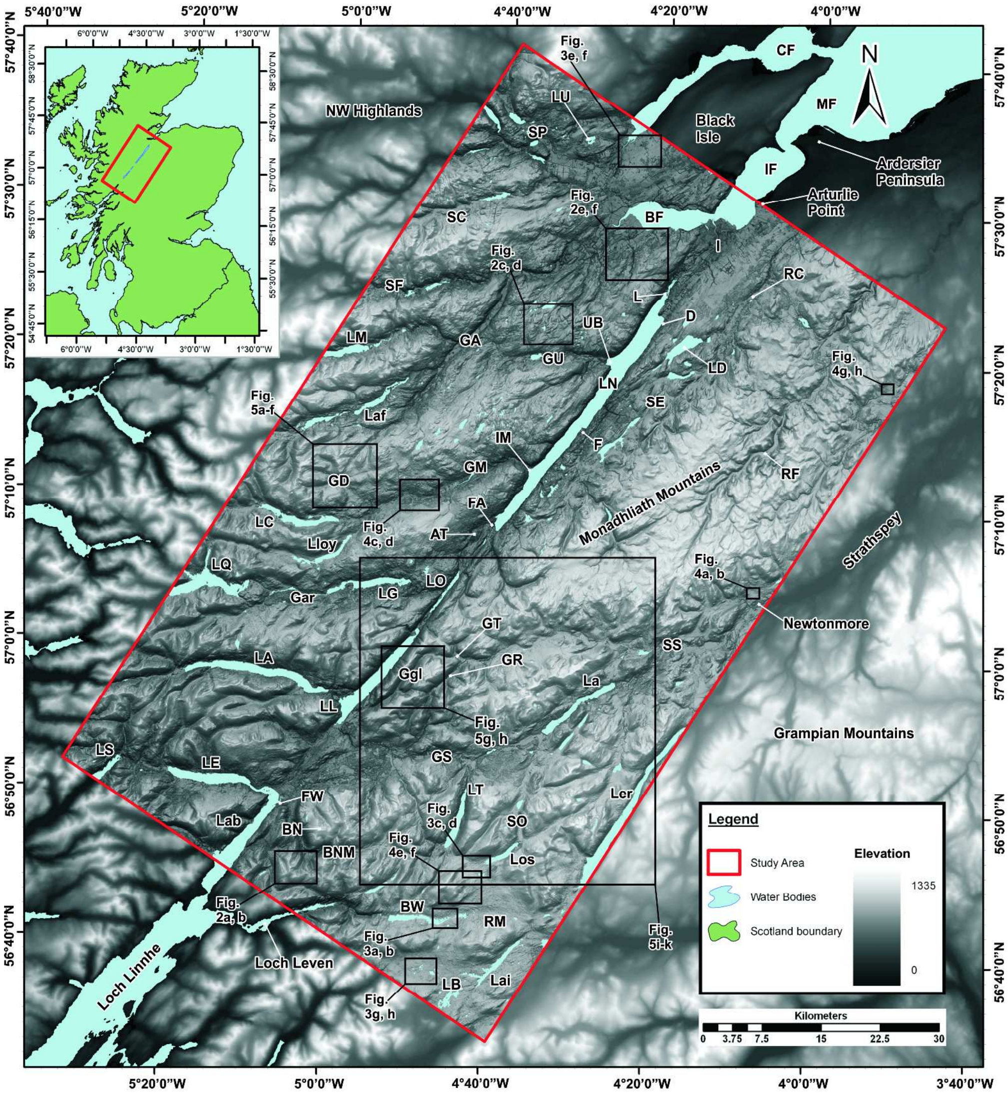


Figure 1 – Map to show locations described in the text with figure extents. CF = Cromarty Firth; MF = Moray Firth; LU = Loch Ussie; SP = Strathpeffer; IF = Inverness Firth; SC = Strathconnon; BF = Beauly Firth; I = Inverness; L = Lochend; D = Dores; LD = Loch Duntelchaig; RC = River Clava; UB = Urquhart Bay; SF = Strathfarrar; LM = Loch Mullardoch; GA = Glen Affric; GU = Glen Urquhart; LN = Loch Ness; SE = Stratherrick; RF = River Findhorn; Laf = Loch Affric; GD = Glen Doe; GM = Glen Moriston; FA = Fort Augustus; AT = Auchteraw Terrace; LC = Loch Cluanie; LQ = Loch Quioch; Lloy = Loch Loyne; Gar = Glen Garry; LG = Loch Garry; LO = Loch Oich; GT = Glen Turret; GR = Glen Roy; Ggl = Glen Gloy; LA = Loch Arkaig; LL = Loch Lochy; La = Loch Laggan; SS = Strathspey; LS = Loch Shiel; LE = Loch Eil; Lab = Loch Aber; FW = Fort William; BN = Ben Nevis; BNM = Ben Nevis Mountain Range; LT = Loch Treig; SO = Strathossian; Los = Loch Ossian; Ler = Loch Ericht; BW = Blackwater Reservoir; RM = Rannoch Moor; Lai = Loch Laidon; LB = Loch Ba.

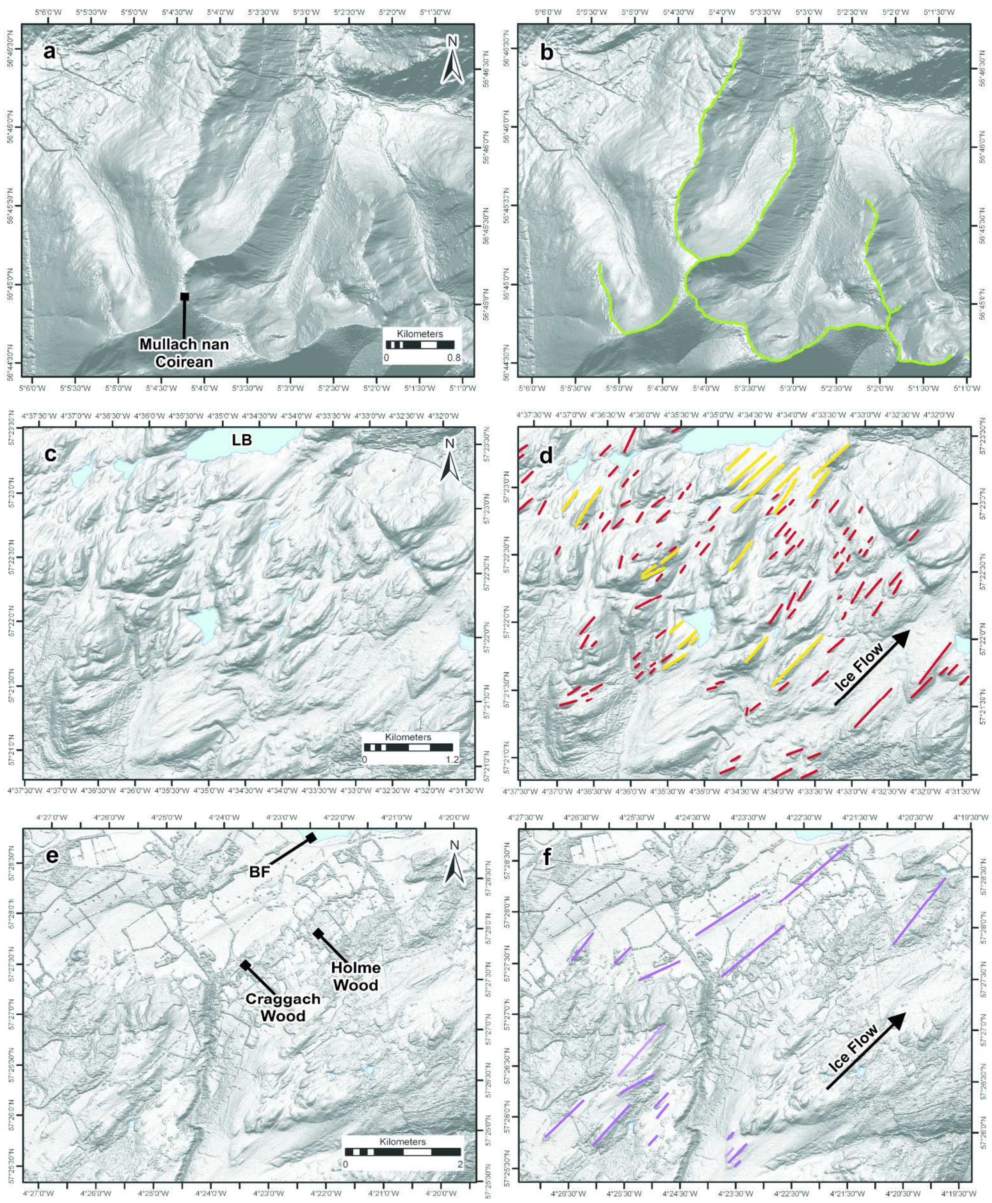


Figure 2 – a) Map data showing glacial valleys surrounding the peak of Mullach nan Coirean, Ben Nevis Mountains. b) Interpreted image with cirque and arête features identified in green. c) Streamlined landforms found on the high ground to the west of Loch Ness. d) Interpreted image with crag and tails (yellow) and streamlined bedrock (red) identified. e) Extract from south of the Beauly Firth (BF). f) Interpreted image with drumlins identified in purple. LB = Loch Bruicheach.

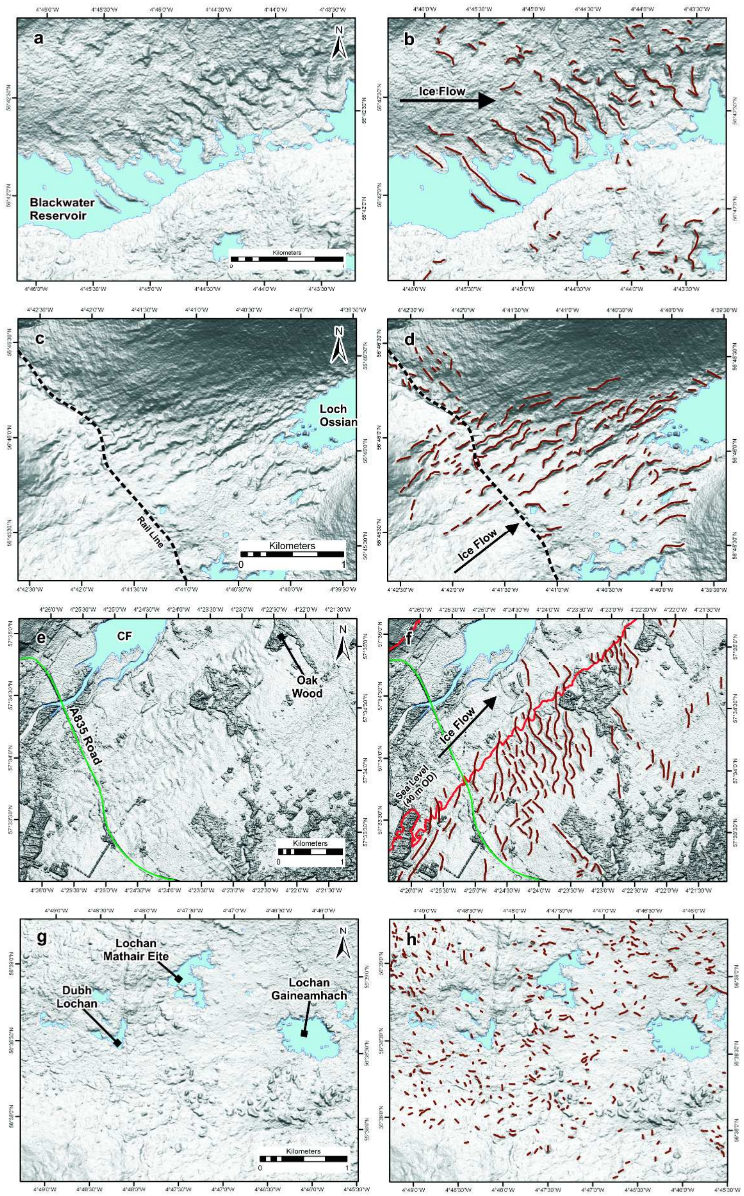


Figure 3 – a) NextMap data showing a field of ridges perpendicular to the long axis of Blackwater Reservoir. b) Interpreted image with transverse moraines identified. c) NextMap data showing ridges aligned parallel to the valley long axis in proximity to Loch Ossian, cross-cut by a modern railway line and coming into contact with valley slopes. d) Interpreted image with longitudinal moraines identified. e) NextMap image showing ridges with an anastomosing pattern from Cromarty Firth. f) Interpreted image with ribbed moraine identified and associated with a palaeo-shoreline mapped by Firth (1989a). g) NextMap data from Rannoch Moor showing a field of chaotically distributed mounds. h) Interpreted image with hummocky moraine identified; no clear linear trends exist. Ice flow directions are indicated. See figure 1 for locations.

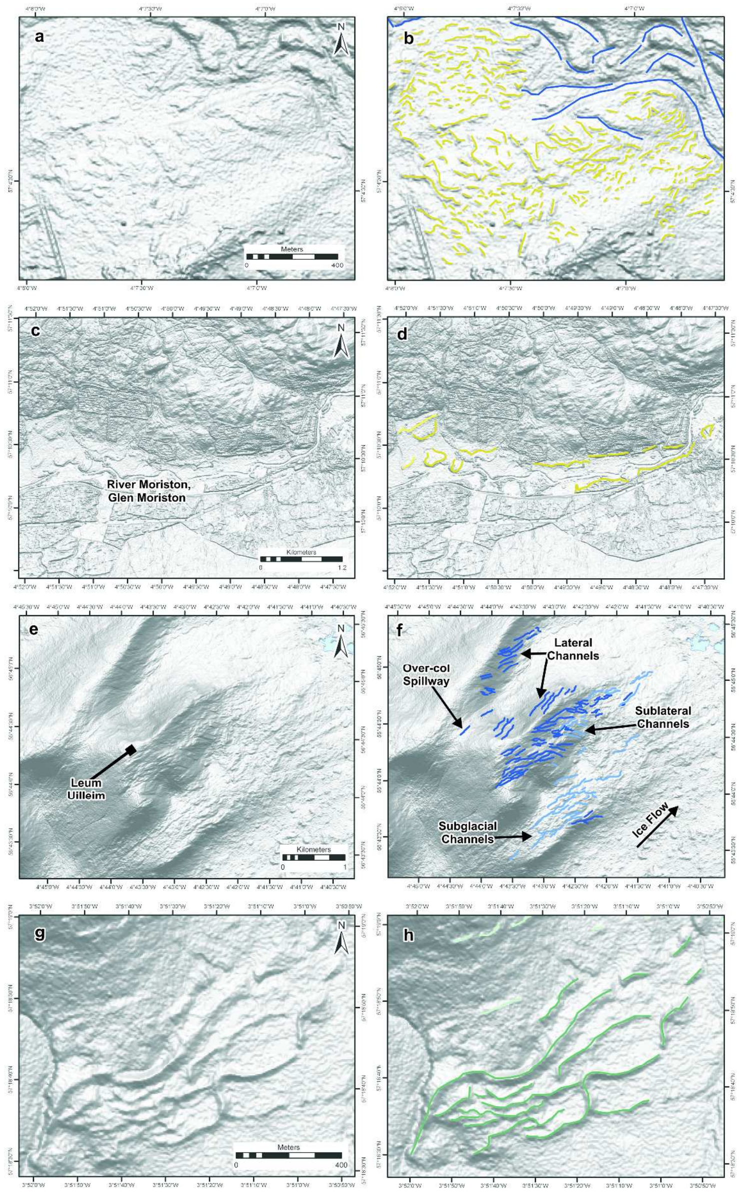


Figure 4 – a) NextMap data showing chaotic surface morphology north of Newtonmore. b) Interpreted image with kame and kettle topography identified. c) NextMap data showing linear terraces aligned parallel to the valley axis in Glen Moriston. d) Interpreted image with kame terraces identified. e) NextMap image showing numerous channelised features around Leum Uilleim, Rannoch Moor. f) Interpreted image with lateral, sublateral, subglacial and over-col spillways identified. g) NextMap data from western Strathspey showing a field of sinuous, sharp crested ridges. h) Interpreted image with eskers identified. See figure 1 for locations.

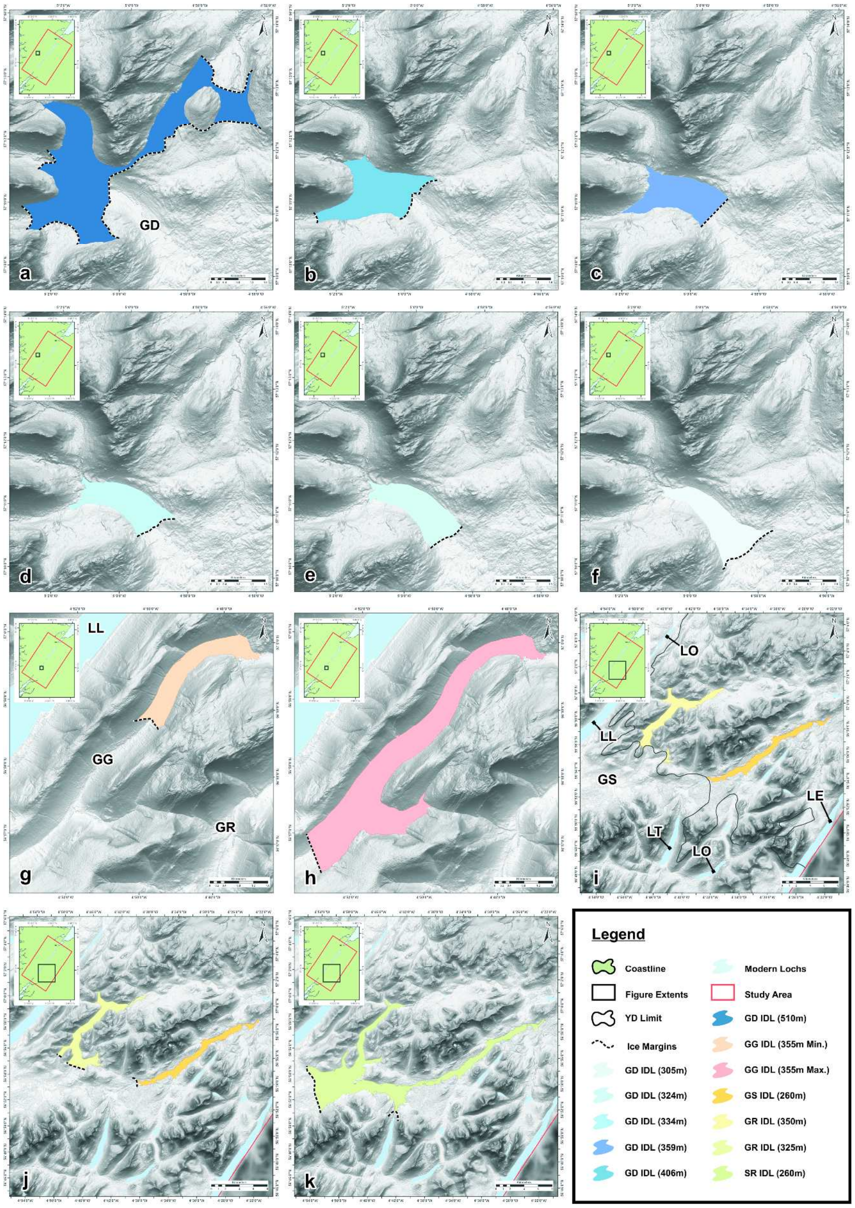


Figure 5 – Reconstruction of the waning stages of ice dammed lake development based on shorelines mapped in this study and before complete drainage. a) Glen Doe 510 m; b) Glen Doe 406 m; c) Glen Doe 359 m; d) Glen Doe 334 m; e) Glen Doe 324 m; f) Glen Doe 305 m; g) Glen Gloy 355 m maximum extent; h) Glen Gloy 355 m minimum extent; i) Glen Roy 350 m and Glen Spean 260 m; j) Glen Roy 325 m and Glen Spean 260 m; k) Spean/Roy 260 m. Drainage has been interpreted to be via a series of outburst floods (jökulhlaups) (Sissons, 1977a; 1979b). Dashed lines indicate ice margins.

A Glacial Geomorphological Map of the Great Glen Region, Scotland, UK

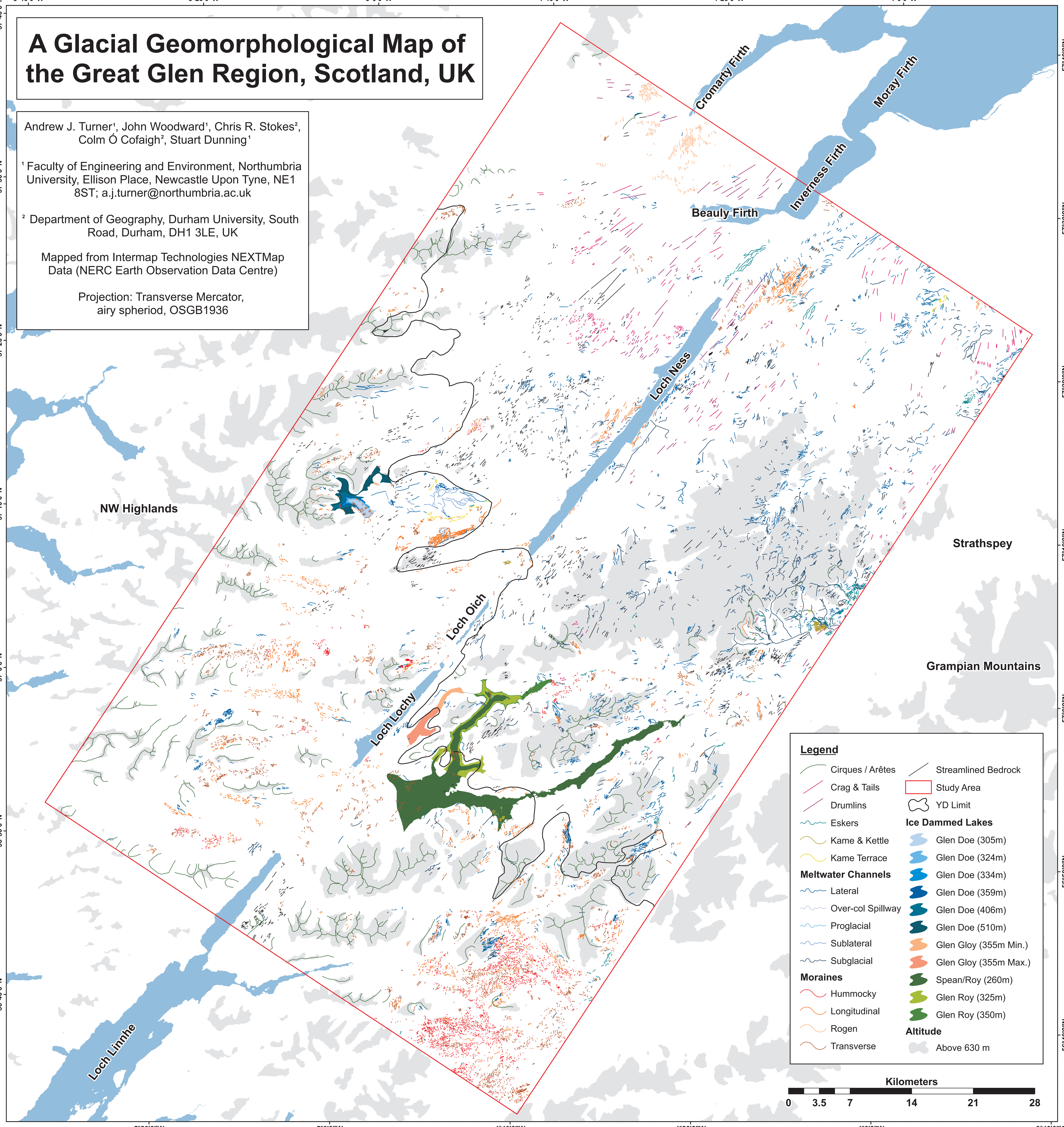
Andrew J. Turner[1], John Woodward[1], Chris R. Stokes[2], Colm Ó Cofaigh[2], Stuart Dunning[1]

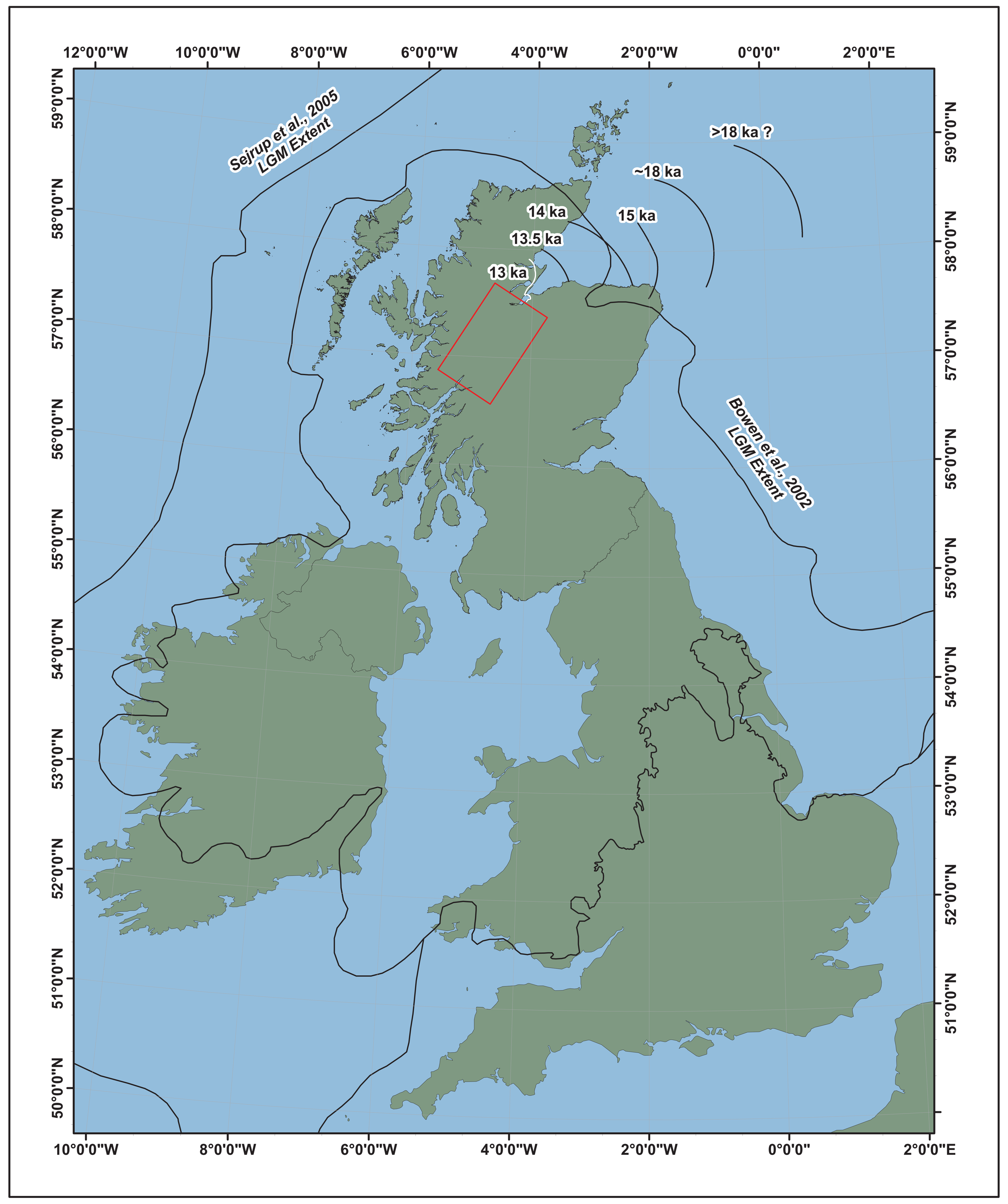
[1] Faculty of Engineering and Environment, Northumbria University, Ellison Place, Newcastle Upon Tyne, NE1 8ST; a.j.turner@northumbria.ac.uk

[2] Department of Geography, Durham University, South Road, Durham, DH1 3LE, UK

Mapped from Intermap Technologies NEXTMap Data (NERC Earth Observation Data Centre)

Projection: Transverse Mercator, airy spheriod, OSGB1936





Above: Inset showing major retreat configurations of the former British-Irish Ice Sheet with the current study area in context. Numbered retreats are interpreted from Merritt et al. (1995).

Below: Inset showing Shuttle Radar Topography Mission (SRTM) 90 m resolution DEM of the Great Glen and surrounding regions.