An overview of the main Late Devensian glaciation of the Central Grampian Highlands

Jon W. Merritt*, Clive A. Auton*, Clare M. Boston, Jeremy D. Everest*, Jo E. Merritt*

The location of the Monadhliath Mountains in the middle of the Grampian Highlands places them in a central zone with respect to ice flow pathways during the maximum extent of the last British and Irish Ice Sheet (BIIS) in the Late Devensian. At the ice sheet maximum the Scottish mainland was probably entirely submerged beneath ice, which flowed north-westwards out to the continental shelf break, merging with Scandinavian ice occupying the North Sea basin (Bradwell *et al*., 2008). This period roughly equates with the global Last Glacial Maximum (LGM), 28,000-22,000 years ago (Mix *et al.* 2001). The most recent model of the BIIS (Clark *et al*., 2012) places the Monadhliath Mountains immediately to the east of the main north-south ice divide of the Scottish ice sheet, and north of a subsidiary west-east divide, centred over the East Grampian and Cairngorm mountains. Geomorphological evidence for ice streaming in the Great Glen and Spey Valley to the northeast and southwest of the Monadhliath massif indicates a general ice flow direction towards the northeast across the region, supporting this ice-divide positioning.

Previous research in the region has been focused on major trunk valleys, such as the Spey, Findhorn, Dulnain and Great Glen (see summaries below), but less is known about ice sheet dynamics over the Monadhliath massif. NEXTMap DEMs show a clear contrast between ice-moulded bedrock on the southern summits of the Monadhliath massif and the relatively unmodified interior of the central plateau (Boston et al., 2013, fig. 1). This suggests that slow-moving, possibly cold-based ice over the Monadhliath plateau was surrounded by zones of fast-flowing ice (ice streams), in the Great Glen and Strathspey. These ice streams both flowed northeastwards towards the Moray Firth (Hinxman and Anderson, 1915; Merritt *et al*., 1995). Detailed understanding of the early interactions between these different zones is currently unclear, especially whether or not the Monadhliath Mountains acted as an independent ice dispersal centre at any stage during the last glaciation.

A more detailed picture for the deglaciation of the Monadhliath Mountains is emerging, although a thorough assessment is hindered by the sparsity of dates and absence of a clear chronological framework. A chronology for deglacial events based on absolute dates has, however, been established to the east and southeast of the massif (e.g. Everest and Golledge, 2004; Everest and Kubik, 2006; Clark *et al*., 2012, Gheorghiu *et al*., 2012). These dates suggest that deglaciation in Strathspey was already well advanced by 16.2 ka (Ballantyne *et al*., 2009; Clark *et al*., 2012) and that Loch Etteridge, to the south of the Monadhliath Mountains, was ice free by ca. 15.8 to 15.5 ka BP, based on conventional ^{14}C dating (13 150 ± 350 ^{14}C yr BP) (Sissons and Walker, 1974; Walker, 1975) and AMS ^{14}C dating (12 930 ± 40 ^{14}C yr BP; 15.6 ± 0.5 cal ka BP) (Everest and Golledge, 2004). The AMS radiocarbon date has been independently corroborated from microtephra correlated with the main Borobol event at 14.4 ka BP (Lowe *et al*., 2008).

The nearest deglacial dates to the northeast of the Monadhliath Mountains were obtained around the inner Moray Firth in the vicinity of Inverness. In this area, there is evidence for two ice sheet oscillations. The first, rather poorly defined Elgin Oscillation, is believed to have occurred before 15 ka (Merritt *et al*., 1995, 2003a; Peacock, 1999), whilst the second, the Ardersier Readvance, shortly predated the beginning of the Lateglacial Interstadial (GI-1; 14.7 to 12.9 ka BP; Rasmussen *et al*., 2006; Lowe *et al*., 2008) (Smith, 1966; Peacock and Wilkinson, 1995; Merritt *et al*., 1995; Finlayson *et al*., 2007). These dates suggest that ice streams within the Great Glen and the Beauly Firth remained active longer than ice within Strathspey. The dates stated above are minima for ice-free conditions in the Beauly and Moray firths, but there are no dates to constrain the timing of the onset of deglaciation within the Great Glen itself.

The following sections provide details on evidence for glaciation and the timing of deglaciation in the southern, eastern and northern sectors of the Monadhliath Mountains.

The Quaternary geology and geomorphology of the Upper Spey Valley

The Upper Spey Valley (USV) is taken here to lie upstream of Grantown-on-Spey. This stretch of the valley lies between the Monadhliath Mountains, to the west, and the Cairngorm Mountains, to the east, and falls within the Cairngorm National Park. The lower reaches of the valley of the River Dulnain are included here, bounded to the north by ice-scoured mountains forming the watershed between the catchments of the Spey and Findhorn (Fig. 1). The USV contains exceptional assemblages of glacial, glaciofluvial and fluviatile landforms and deposits, in particular glacial drainage channels, eskers and ice-marginal features (Kirkbride and Gordon, 2010; Barron *et al*., 2011a, b).

The first systematic geological mapping of Strathspey between Grantown and Glentruim, on sheets 64 (Kingussie) and 74 (Aviemore), was described by Barrow *et al*. (1913) and Hinxman and Anderson (1915). The uppermost reaches of Strathspey falling on sheet 63E (Dalwhinnie) were surveyed in the 1980s (BGS, 2002) (Merritt, 1999). Sheet 64 was resurveyed in the 1990s, with Superficial editions published for 64W (Newtonmore) (BGS, 2008b) and 64E (Ben Macdhui) (BGS, 2008a) (Smith *et al*., 2013, in press). The Quaternary resurvey of the western half of sheet 74 (Tomatin), including Kingussie and the upper Dulnain and Findhorn valleys (BGS, 2004) has been described by Auton (1998). The Quaternary of sheet 74E (Aviemore) has been resurveyed recently (BGS, 2013), the bedrock geology being described by Highton (1999). All modern BGS mapping within the USV is available digitally or as paper maps at the 1:10,000 or 1:25,000 scales.

The geomorphology of large parts of the USV has been mapped and described by Young (1974, 1975a, b, 1977a, b, 1978). These works are an invaluable record, although some interpretations are dated in that Young followed the prevailing paradigm that ice sheet deglaciation was mainly achieved through widespread stagnation and melting down *in situ*, rather than by active retreat. It follows, for example, that his ‘kame ridges’ might now be identified as recessional moraines and some of his eskers also. However, many of these features do merge with one another in complex ways. Similarly, Young interprets most glacial drainage channels as being of ‘subglacial’ origin, rather than strictly ‘ice-marginal’, whereas most formed at, or close to, receding ice margins. Young’s mapping is a unique record, for it was based mainly on 1960s aerial photographs and ground-truthed before the extensive forest regeneration that has taken place since then. Many of the delicate features that he mapped are now covered by dense woodland.

The findings of more recent geomorphological work (Gheorghiu *et al*., 2012; Trelea-Newton and Golledge, 2012; Boston, 2012a,b) undertaken in the USV, along the margins of the Monadhliath Mountains, is presented in Boston et al., (2013) (Boston and Trelea-Newton, 2013; Gheorghiu and Fabel, 2013; Auton, 2013). A site at Raitts Burn, near Kingussie, is also included as it has not been visited previously by the QRA (Phillips and Auton, 2000, 2013; Phillips *et al*., 2007).

Maximum extent of the last glaciation

During the LGM, the entire district was submerged beneath ice, based on evidence of lee-side joint-block removal, glacially transported tor blocks and stripping of blockfields at elevations of up to 1200 m in the Cairngorms (Hall and Glasser, 2003; Phillips *et al*., 2006). A powerful topographically-controlled ice stream (<u>Strathspey Ice Stream, SIS</u>) was centred on the USV (Hall and Sugden, 1987), as evidenced by severely ice-plucked rocks on the western valley flanks overlooking Newtonmore and Kingussie, extensive blankets of till on the valley-sides and mega-roche moutonnées such as Creagan a' Choin and Ordan Shios, 3 km south of Newtonmore (Fig. 2). These particular features, which are clearly visible from the A9 trunk road, have tails of sediment stretching south-westwards in the former up-ice direction and are commonly mistaken for crag-and-tails. Strathspey ice flowed against the Cairngorm massif, where it was fended off by local ice, but probably penetrated eastwards into the catchment of the River Dee via the valley of the Geldie (Barrow *et al*., 1913).

The SIS was mainly sourced in the western Grampian Highlands with a feeder draining ice from the Loch Ericht depression via the valley of the River Truim (Fig. 2). Most indicators suggest that ice flowed northeastwards along the axis of the Spey valley, at least as far as Grantown (Young, 1974, 1975a,b, 1977a, 1978). However, evidence for strong northward flow was identified in the lower Dulnain valley (Young, 1977b), where excellent large-scale crag and tail features may be seen to the east of the B9007 road leading northwards from Duthill towards Lochindorb (Fig. 3). These south to north-orientated streamlined features are particularly clear on NEXTMap hill-shaded models (Fig. 1), which indicate that the SIS flowed directly northwards towards the Moray Firth across the Spey - Findhorn catchment divide, through the Beum a' Chlaidheimh (NH 937 305). In contrast, the NEXTMap imagery reveals that the landscape to the east has experienced relatively little glacial modification, suggesting that local, sluggish, cold-based ice was centred over this part of the East Grampians, which includes the middle reaches of the Spey Valley downstream of Grantown.

Evidence of selective linear erosion (Sugden, 1968) in the Upper Spey Valley is clearly demonstrated at Aviemore, where the knobbly, mammillated, heavily ice-scoured rocks of Craigellachie (Fig. 3), an eastern spur of the Monadhliath Mountains, contrast starkly with the adjoining plateau some 4 km to the west, which is widely underlain by weathered, decomposed rock many metres in depth. Ice was deflected to the east of Craigellachie, where it eroded a deep 'moat' in the rockhead beneath the floodplain of the Spey. This hollow is filled with over 60 m of mostly granular, water-saturated sediments (BGS, 2013), from which groundwater is now abstracted for the local community.

The pattern of deglaciation

At a particular stage in deglaciation the ice sheet became too thin to flow over the Spey-Findhorn divide and a vast outlet glacier became established in the USV, upstream of the vicinity of Grantown. Lobes of this here-named Strathspey Outlet Glacier (SOG) penetrated into the Abernethy Forest, Loch Garten and Rothiemurchus/Glenmore depressions (Young, 1974, 1975b, 1977a) (Fig. 3). Recent surveying indicates that widespread ponding occurred following this decoupling on the northeastern side of the Spey-Findhorn divide, with the development of glaciofluvial fans and deltas (at elevations of 300-350 m OD) close to the former position of the boundary of the Strathspey Ice Stream, west of Lochindorb (Fig. 1). There is also converging evidence from the Cairngorms that locally sourced ice decoupled from ice flowing from the main ice sheet divide in the western Grampian Highlands via the SOG. An independent plateau ice cap supporting a radial pattern of outlet glaciers developed on the western Cairngorms (Everest, 2003; Everest and Kubik, 2006). Ice marginal lakes were impounded within the Lairig Ghru and Glenn Einich by the Rothiemurchus/Glenmore lobe during a stillstand, if not minor glacial re-advance, that lasted at least 1000 years (Brazier *et al*., 1998; Golledge, 2002). Cosmogenic dating suggests that the stillstand occurred between 16 and 14 ka BP (Everest and Golledge, 2004; Everest and Kubik, 2006). These dates have been questioned by Ballantyne *et al*. (2009), who present subsequent minimum cosmogenic ^{10}Be ages of 16.2 and 15.4 ka BP for rock glacier deposits in Strath Nethy and the Lairig Ghru respectively (Fig. 3). However, these features lie outwith the limits reconstructed by Everest and Kubik (2006), allowing the possibility of widespread early deglaciation in the Cairngorm Massif, and the subsequent late survival of the more restricted ice caps they propose. On present evidence the stillstand cannot be correlated with a specific northern hemispheric cooling event. It could have simply resulted from local glacial reorganisation brought about as topography increasingly affected local glaciodynamic conditions during ice-sheet thinning and retreat. As there is no reason to doubt that Strath Nethy and the Lairig Ghru were not glaciated during the LGM, the dates at least provide a minimum age for this major reorganisation.

There is abundant evidence from glacial drainage channels on the valley flanks for the retreat of the SOG, from the catchment divide in the north (Young, 1977b) (Fig. 1), progressing up-valley past Aviemore (Young, 1977a) and Glen Feshie (Young, 1975a) (Fig. 3), into uppermost Strathspey (Young, 1978) (Fig. 2). These channels are characteristically curved or crescentic in plan view, asymmetric in cross profile, and commonly occur in anastomosing flights across hillsides, where higher channels truncate, or feed into, lower ones, indicating that they formed progressively as the ice margin retreated. Some shallow gradient ice-marginal channels pass into steeper sub-marginal ‘chutes’ directed towards valley trunks. One-sided channels form benches on steeper slopes, and isolated flights of short channels commonly loop into the hillside. Some ice-marginal channels are intimately associated with lateral moraine ridges and are interpreted here to have been eroded by meltwater at, or closely within the margins of an actively receding, polythermal outlet glacier similar to those in contemporary sub-polar environments (Ó Cofaigh *et al*., 1999, 2003; Benn and Evans, 2010).

Good examples of ice-marginal drainage channels, benches, kame terraces and associated lateral moraines occur along the north-western side of the USV between Kincraig and Glen Banchor (Fig. 2). The features occurring in the vicinity of Loch Gynack, north of Kingussie, are particularly fine examples. Evidence from Raitts Burn, 4 km north-east of Kingussie (Phillips and Auton, 2000, 2013; Phillips *et al.*, 2007), indicate that the glacier remained active during its retreat. Similar suites of features were formed along the south-eastern margin of the SOG, particularly along the eastern flanks of the valley of the River Feshie downstream of Glenfeshie Lodge (Young, 1975a, Werritty and McEwen, 1993). Following its retreat from lower Glen Banchor, the snout of the SOG appears to have stabilised for a while in the vicinity of the Woods of Glentruim, 6 km east of Laggan, where an excellent assemblage of moraines, kame terraces, eskers and other ice-contact features are preserved (Fig. 2). The presence of Strathspey ice hereabout caused meltwaters emanating from a contemporaneous outlet glacier in Glen Truim to be diverted via stagnating ice at the site of Loch Etteridge (Young, 1978) (Fig. 2). Once the Strathspey glacier had retreated westwards towards Laggan, the Truim was able to take its present course, abandoning the Etteridge route, and in doing so preserving the glaciofluvial features there from subsequent fluvial erosion (Walker, 1993).

The Quaternary geology and geomorphology of the upper Findhorn and Dulnain valleys

The Findhorn and Dulnain valleys provide the two major drainage pathways from the heart of the Monadhliath Mountains north-eastwards, with the River Dulnain joining the River Spey immediately downstream of Dulnain Bridge. This section focuses on the upper reaches of these valleys lying to the west of the A9 trunk road (Fig. 4), although sites within the uppermost part of the Findhorn Valley are discussed in subsequent chapters of this field guide.

Maximum extent of the last glaciation.

Streamlined features associated with north-eastward flowing ice are clearly visible on NEXTMap imagery of the area, notably in the Dulnain catchment and along the north-western margin of the Monadhliath Mountains, in Strathnairn and Stratherrick. The contact between fast-flowing ice centred on the Great Glen and more stable portions of the ice sheet is seen clearly in the north-west corner of Fig. 4. Pronounced bedrock sculpturing is evident here (BGS, 1997), south-west of Daviot. Described as morainic features by Fletcher *et al*. (1996), these elongate ridges may now be interpreted to be megagrooves (cf. Benn and Evans, 2011). Associated northeastwardly-directed subglacial and englacial drainage hereabout is demonstrated by the Little Mill esker complex (Gordon, 1993). This northeastwardly-directed ice flow extended towards the inner Moray Firth, where it coalesced with ice from the uplands of Ross and Cromarty to flow eastwards across the coastal lowlands towards Elgin (Merritt *et al.*, 1995).

The contact between relatively stable ice centred over the Monadhliath Mountains and the SIS is less clearly defined, but it is evident on the lower hilltops around Carrbridge, where streamlining of bedrock is strongly directed northeastwards (Fig. 4). The more stable ice flowed in a similar direction, but fluting on the present interfluves between the Findhorn and Dulnain catchments is directed both towards the northeast and north-northeast. Subglacial drainage channels are more evident on the interfluves between the UFV and the Dulnain valley than farther north, but northwest-southeast directed major glacial drainage channels, which may have been initiated subglacially, are a feature on the interfluves northeast of the A9 trunk road. The broad upland basin blanketed in peat, visible on the NEXTMap imagery west of Tomatin (Fig. 4) is reminiscent of the little-modified interior of the central Monadhliath plateau and suggests that this may also have been an area of slow-moving, possibly cold-based ice.

The pattern of deglaciation

The limited chronology outlined in the introduction of this section suggests that the Findhorn and Dulnain valleys are likely to have been one of the first areas of the Monadhliath Mountains to deglaciate, potentially forming part of an unzipping corridor between ice retreating within the Upper Spey Valley and the Great Glen. However, the main Monadhliath plateau, directly to the west, could have provided a source for outlet glaciers in the upper Findhorn and Dulnain valleys, allowing local ice to remain following the retreat of regional ice. The role of such plateau ice in the Monadhliath Mountains is discussed further in Boston *et al.*, (2013) with respect to northern and southern areas, but it remains a somewhat unknown quantity in the east despite deliberation by previous authors (Bremner, 1939; Charlesworth, 1956).

The active retreat of a valley glacier in the Lower Findhorn Valley (LFV), ponding glacial lakes following the decay of the regional ice cover, was proposed by Bremner (1939), and this model was subsequently adopted by Charlesworth (1956), to explain the deglaciation of both the Dulnain and Findhorn valleys. Glaciofluvial deltaic sequences on the present interfluves at elevations of up to 570 m OD, as well as laminated lake sediments with dropstone boulders, and staircases of outwash terraces and fans within the Middle Findhorn Valley (MFV) (Auton, 1990), all strongly support this interpretation. A similar suite of landforms and sediments have also been recognised during recently completed surveying of the LFV and its interfluves. Such widespread outwash terrace development and glaciodeltaic deposition is less pronounced in the Upper Findhorn Valley (UFV), where glacial lake sediments are generally restricted to sites within tributary valleys such as Glen Mazeran (Fig. 4). Within this glen, glaciofluvial gravels and sands that fine-downwards into rhythmically laminated clayey silts with dropstones, are overlain by at least 10 m of locally-derived till. The till is comparable in thickness and composition to that seen on the adjacent interfluves, suggesting that ponding in this tributary valley took place during build-up of the ice rather than during oscillations as it retreated.

The deglaciation of the regional ice on the interfluves of the UFV appears to have taken place by relatively slow, active retreat, as indicated by the widespread preservation of minor suites of recessional moraines, and associated networks of drainage channels. Ice-marginal processes appear to have been more intense and active during retreat within the valley itself, and more pronounced than in the MFV, with the widespread development of recessional moraines on the broad valley floor. This is particularly notable upstream of Coignafearn Lodge, where the valley sides are principally cliffs cut in bedrock, mantled by both active and relict talus (Auton, 1998). A complex of eskers, moraines and outwash terraces south of Daltomach, largely obscured by forestry, marks the only major still-stand position of the glacier downstream of the Dalbeg area.

In the middle and lower reaches of the Findhorn Valley meltwaters were firstly ponded behind temporary barriers of stagnant ice and glacial sediment, and then constrained to follow the present axis of the valley towards the coast. In contrast, much of the meltwater from decaying ice in the UFV drained northwestwards through the Moy Gap and into the Nairn valley, depositing broad spreads of kettled outwash around Moy (BGS, 1997). Meltwater also cut the glacial overflow channel northwest of Ruthven, in the MFV (Auton, 1990).

The Quaternary geology and geomorphology of the Great Glen

The primary survey of the Quaternary geology of the area around the southern end of Loch Ness has been published recently (Fig. 5) (Sheet 73W, BGS, 2012); primary survey of the ground on the south-eastern side of the loch (Sheet 73E), between Whitebridge and Loch Duntelchaig, and on the north-western side of the loch, around Drumnadrochit, is nearing completion The south-west/north-east orientated 'Caledonian' structural grain of these heavily ice-scoured districts is exemplified by the streamlined bedrock forms in Stratherrick and the trend of the Great Glen and Strathglass.

Maximum extent of last glaciation

During the LGM ice flow was less restricted by topography. Ice sourced within the western Highlands flowed north-eastwards 'across the grain', swinging to the east along Glen Moriston and Glen Urquhart, and then tangentially across the Great Glen towards the east (Merritt, 1992; Fletcher *et al.*, 1996). Some new evidence for flow during the LGM is a swathe of splendid glacially streamlined megagrooves, whalebacks and rock drumlins (cf. Benn and Evans, 2011) that have been identified in the upper valley of the River Endrick (BGS, 2012) (Fig. 5, locality A). These features are the legacy of a former topographically-unconstrained ice stream within the last ice sheet. Importantly, this former corridor of relatively fast-flowing ice, not one following the Great Glen (Turner et al., 2012; Clark *et al*., 2012), was a major direct tributary to the huge Moray Firth Ice Stream (Merritt *et al.*, 1995). Similar subglacially sculptured, elongate features occur within Balmacaan Forest (Fig. 5, locality B), to the south of Loch Tarff, in Glendoe Forest (Fig. 5, locality C) and between Foyers and Inverfarigaig.

The pattern of deglaciation

As the last ice sheet thinned following the LGM, ice became restricted to the lower ground in the form of valley glaciers, which left behind suites of hummocky morainic deposits, glaciofluvial sands and gravels, and till, notably within Glen Moriston and Strathglass (Fig. 5, locality D). These glaciers had probably retreated to the west of the district by the beginning of the Lateglacial Interstadial, about 14,500 years ago (Tipping *et al.*, 2003).

Following the model for deglaciation suggested by Clark *et al*. (2012) and evidence from around the inner Moray Firth (Merritt *et al.*, 1995), the Great Glen is likely to have become ice-free later than Strathspey. Charlesworth (1956) proposed that early ice retreat from the hills to the east of Stratherrick allowed the formation of a series of ice-dammed lakes within the eastern tributary catchments of the Allt Mòr (in square NH 62 24), the Allt Uisgan an t-Sidhein (NH 60 20), the Aberchalder Burn (NH 56

19), the River E (NH 52 16), the River Fechlin (NH 49 14), the Allt Breineag (NH 47 12), the Allt Doe (NH 41 07) and the River Tarff (NH 38 05). Charlesworth (1956) stated that drainage of these lakes was initially to the northeast into the Nairn valley and then later into the Ness Basin. More specifically, the author described the formation of a large lake within the Fechlin (or Killin) valley that was dammed by the advance of a lobe of the Ness Glacier. This ice lobe is said to have impounded a large lake that drained over a col at 642 m OD at the top of Glen Markie and into the valley of the River Eskin, at the head of the Findhorn Valley (Boston 2012a, Boston et al., 2013, fig. 37). Critically, in order for the lake drainage to occur at this location, the Findhorn Glacier would need to have already disappeared at a time when there was still a large ice lobe in the Great Glen. An alternative explanation put forward by recent BGS surveying is that the ponding in the Killin valley was less extensive, reaching an elevation of no more than c 500 m OD and that drainage occurred north-westwards. These competing interpretations require further examination as they are critical in resolving some of the uncertainty regarding the survival of local ice on the Monadhliath plateau.

Geophysical surveys by Turner *et al.* (2012) provide the first investigation of the glaciolacustrine record within Loch Ness. These authors propose that the margin of the Ness Glacier terminated in water throughout retreat within the Ness Basin due to raised sea levels prior to glacio-isostatic uplift. In the northern part of the glen they suggested that the Ness Glacier formed a lightly grounded or potentially floating ice shelf, but subsequently retreated to a more grounded position by Foyers, where a major moraine was deposited. Turner *et al.* (2012) interpreted this moraine as evidence for a major stillstand. Furthermore, the authors suggested that subsequent retreat of the ice lobe was dynamic and also punctuated by stillstands and oscillations, which deposited the smaller hummocky moraines. At present the relationship between this record of deglaciation in the Ness Basin and ice-dammed lake formation at the southern margin of this ice lobe has not been established, however.

Summary

During the maximum extent of the last glaciation (28-22 ka BP) ice sourced over the Monadhliath Mountains flowed northeastwards towards the Moray Firth, constrained between corridors of relatively faster flowing ice (ice streams) centred on the Ness Basin and the Upper Spey Valley. At a particular stage in deglaciation (before 16 ka BP) ice became too thin to flow over the Spey-Findhorn divide and a vast outlet glacier became established in Strathspey, upstream of Grantown. Proglacial lakes formed around the margins of the glacier and high on the Spey-Findhorn divide, ponded behind ice flowing towards the Moray Firth from the Ness Basin. Lakes and extensive spreads of glaciofluvial outwash formed at successively lower elevations in the Middle Findhorn and Nairn valleys as the southern margin of the Ness/Moray Firth ice stream shrank northwards towards the inner Moray Firth. The Spey Outlet Glacier retreated contemporaneously and had vacated the site of Loch Etteridge by 15.6 ka BP. Extensive ponding subsequently occurred high on the eastern flanks of the Great Glen, draining into the Nairn (and possibly Findhorn) valleys at declining elevations, whilst the Ness outlet glacier shrank towards its sources in the north-western Highlands. The glacier terminated in water throughout its retreat within the Ness Basin, with a major stillstand occurring at Foyers. Ice had vacated the Ness Basin before the beginning of the Younger Dryas.

Figure captions

1. NEXTMap hill-shaded digital elevation model of the area around Grantown-on-Spey, revealing the imprint of the Strathspey Ice Stream across the Spey-Findhorn catchment divide (after McMillan and Merritt, 2012). The streamlined landforms and widespread sheets of till of the Central Grampian Glacigenic Subgroup that formed beneath the Strathspey ice contrast with the relatively minimal glacial modification of the landscape to the east, which was covered by more sluggish, cold-based, local ice during the LGM. BC, Beum a' Chlaidheimh. (NEXTMap Britain^{TM} elevation data from Intermap Technologies).

2 NEXTMap hill-shaded digital elevation model of lower Glen Truim and Strathspey with a reconstruction of ice flow at the LGM, based on large-scale features, and inferred recessional stages (after Smith *et al.*, 2013). CC, Creagan a' Choin; OS, Ordan Shios. (NEXTMap Britain^{TM} elevation data from Intermap Technologies).

3. NEXTMap hill-shaded digital elevation model of the Aviemore district (after BGS, 2013). The northern corries of the Cairngorms are in the bottom right, together with the northern ends of Gleann Einich (GE) and the Lairig Ghru (LG). Glacial meltwaters generally flowed north-eastwards around the retreating Strathspey Outlet Glacier, carving numerous deep, steep-sided channels sequentially at lower elevations, notably to the north of Carrbridge (CB), Duthil (D) and Dulnain Bridge (DB). Other ice-marginal landforms formed around retreating glacier lobes in the Rothiemurchus (R), Loch Garten (LG) and Abernethy Forest (AF) depressions. Major channels dissecting topographical divides include Beum a' Chlaidheimh (BC), the Pass of Ryvoan (PR) and north-east of Nethy Bridge (NB). Huge glaciofluvial fans and deltas were created in Strath Nethy (SN). Esker complexes may be observed in the vicinity of Tullochgribban (T) and Grantown (G). The River Spey flows through moundy topography mainly created during glacial retreat, with terraces and meander belts of relatively restricted extent for a river of its capacity. The rocky promontory of Craigellachie (C) formed a major obstacle to ice flow down the Spey Valley. (NEXTMap Britain^{TM} elevation data from Intermap Technologies).

4. NEXTMap hill-shaded digital elevation model of the northern portion of the Monadhliath Mountains and the Findhorn and Dulnain valleys, showing features associated with the maximum extent of the last glaciation and subsequent deglaciation. Dulnain Valley (DV), Middle Findhorn Valley (MVF), Upper Findhorn Valley (UFV), Little Mill (LM), Glen Mazeran (GM), Daltomach (D), Moy Gap (MG). (NEXTMap Britain^{TM} elevation data from Intermap Technologies).

5. NEXTMap hill-shaded digital elevation model of the area around the southern end of Loch Ness covered by BGS Sheet 73 W (Invermoriston) (BGS, 2012). Refer to the text for localities A to G. The box shows the location of the figure accompanying the

Fort Augustus site description (Merritt and Firth, 2013). (NEXTMap Britain^{TM} elevation data from Intermap Technologies).

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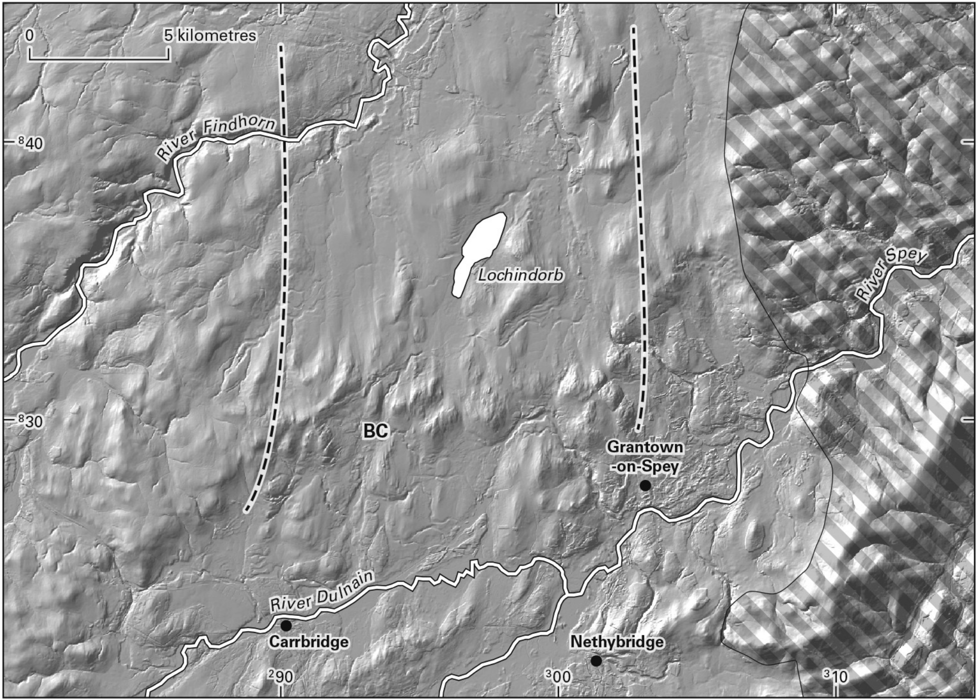

Central Grampian Glacigenic Subgroup

East Grampian Glacigenic Subgroup

Aproximate boundaries of Strathspey Ice Stream

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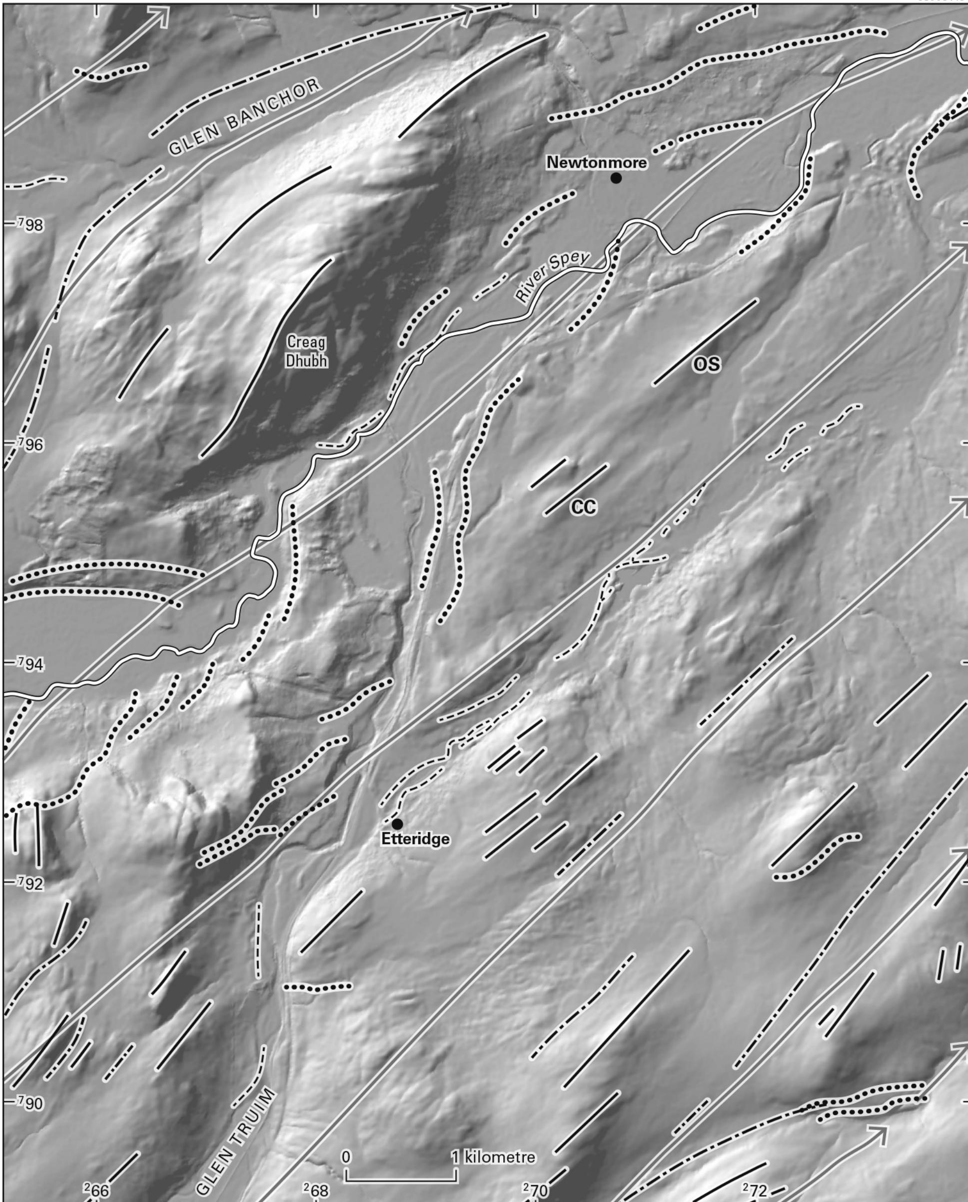

Ice recessional stages

Inferred strong line of flow at LGM

Esker

Megagouge

Megaflute

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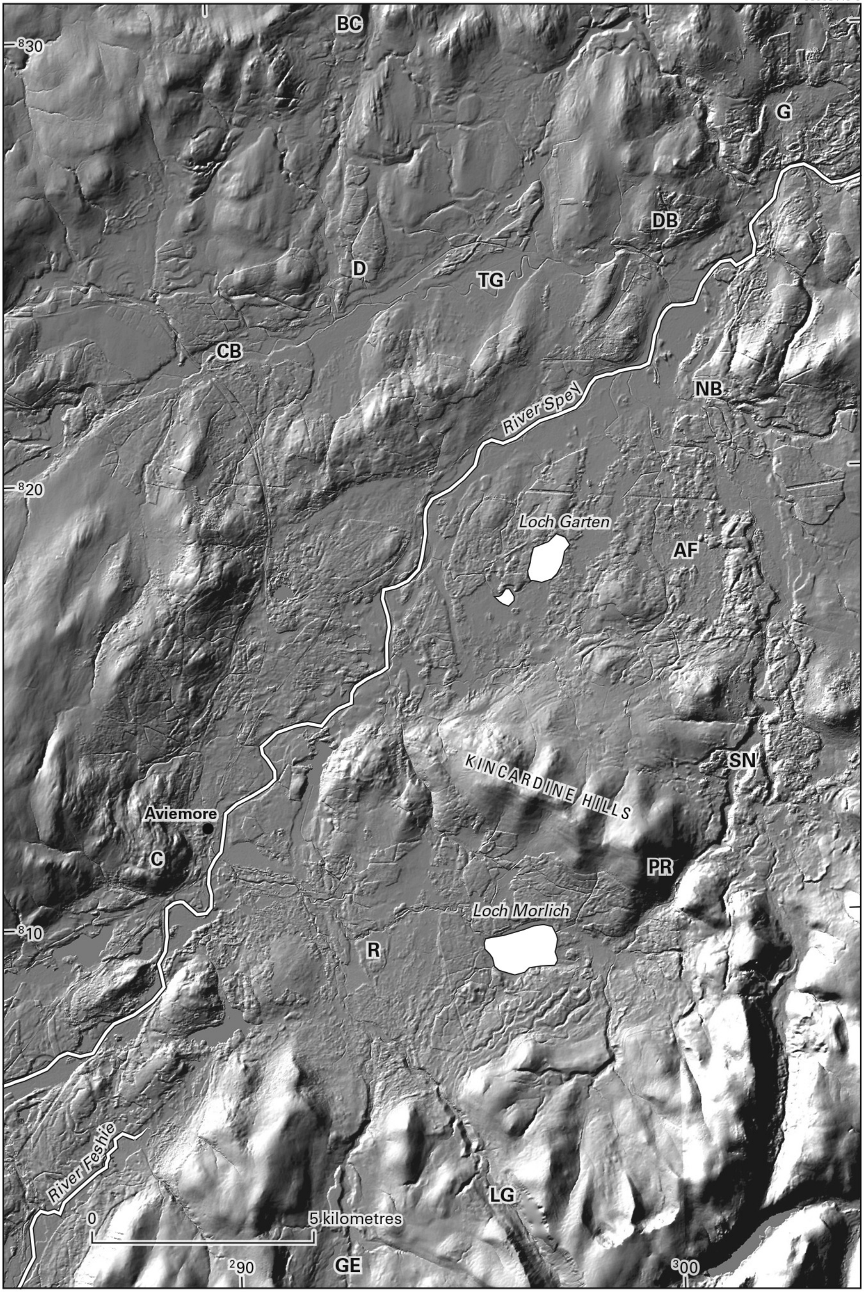
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River Spey
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0
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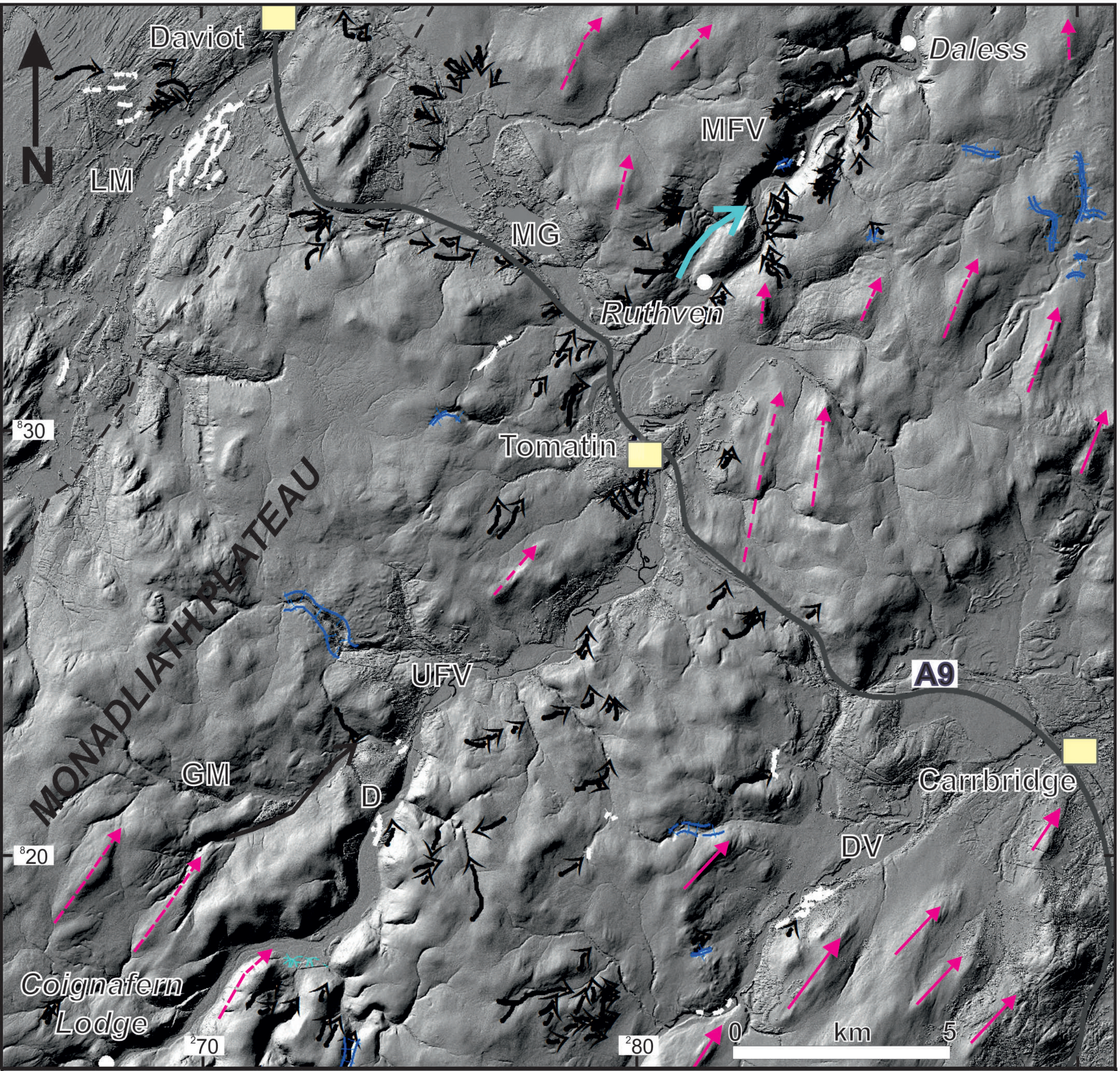
290
GE
300



Streamlined features from Strathspey Ice Stream

Ice-moulded features from Central Highlands Ice

Margin of fast-flowing Great Glen Ice Stream

Margins of major transverse drainage channels

Glacial overflow channel

Glacial drainage channels

Eskers

NEXTMap Britain™ elevation data from Intermap Technologies

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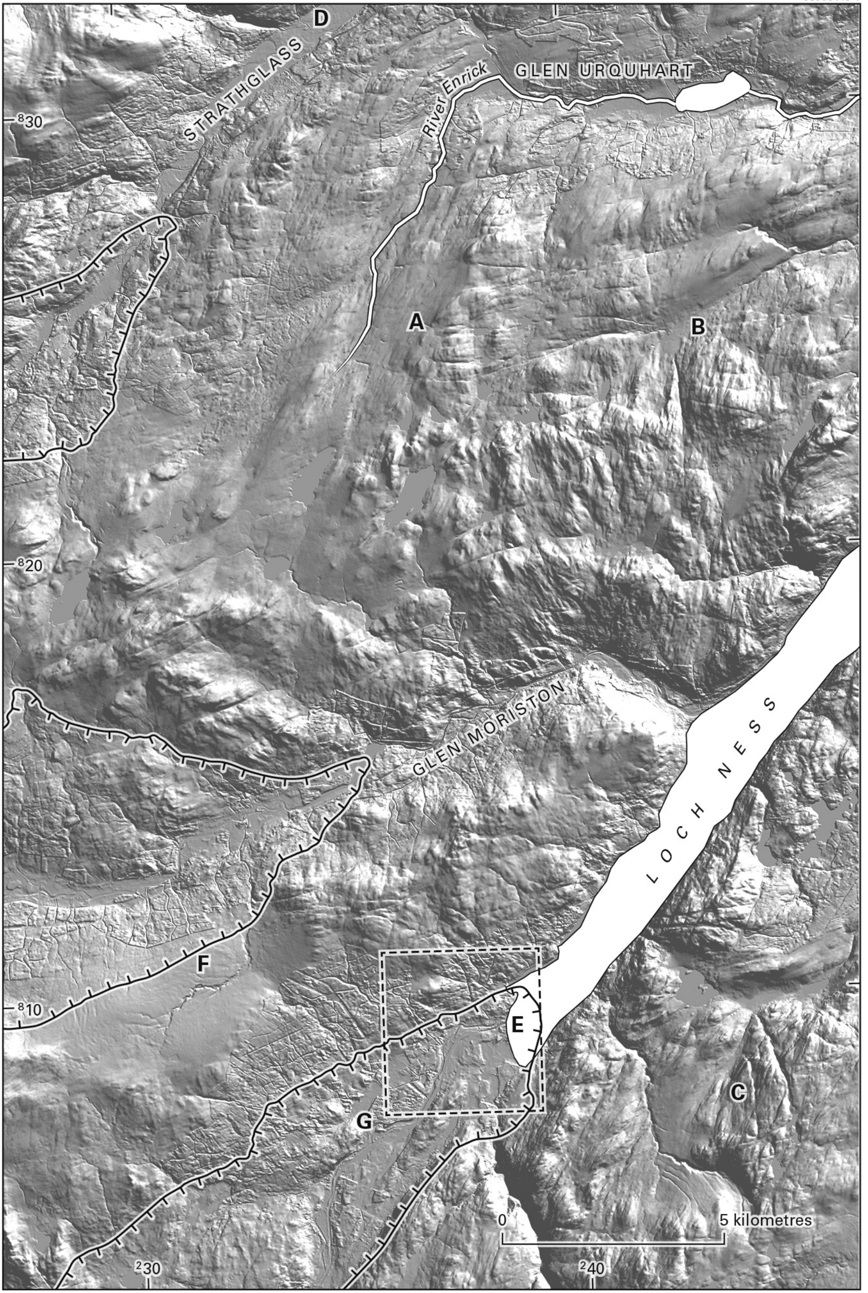
D
STRATHGLASS
River Enrick
GLEN URQUHART
830
A
B
820
GLEN MORISTON
LOCH NESS
F
810
E
G
C
0
5 kilometres
230
240