An introduction to the Quaternary geology and geomorphology of the area around Fort Augustus, Great Glen.

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Fort Augustus lies within the Great Glen at the south-western end of Loch Ness (Merritt *et al.*, 2013, fig.17). The settlement straddles the Caledonian Canal, which follows the valley of the River Oich south-westwards towards Loch Oich and, eventually, Fort William. The landforms and deposits in the vicinity of Fort Augustus include drift limits, kame-and-kettle topography and raised lake shorelines. They provide important information for interpreting events that occurred during late-glacial times, in particular, evidence for re-depression of the Earth's crust by the build-up of ice in the western Highlands during the Loch Lomond Stadial (LLS) (Firth, 1986, 1989), and for catastrophic drainage of the former ice-dammed lake in Glen Spean and Glen Roy, some 30 km to the south-west, towards the end of the Stadial (Sissons, 1979a, 1981). Three sites are described here; Borlum (NH 384 084), the 'north shore' of Loch Ness (NH 386 105) and Auchteraw (NH 364 082) (Fig. 1). A summary of each site is given below together with some new information obtained from a recent geological survey of the district (BGS, 2012). All modern BGS mapping around Fort Augustus is available digitally or as paper maps at the 1:10,000 scale.

The low ground at the southern end of Loch Ness and the surrounding slopes of the Great Glen are mantled by extensive glacial and glaciofluvial deposits (BGS, 2012). Both Charlesworth (1956) and Synge (1977) identified a lateral moraine on the eastern flank of the Great Glen in the vicinity of Fort Augustus, rising from the shore of Loch Ness southwards along the Allt an Dubhair to an altitude of about 100 m OD (Fig. 1). Drift limits also have been identified on the western side of the valley rising south-westwards from Jenkins Park (Fig. 1) (Synge, 1977; Sissons, 1979a, Firth, 1993a; BGS, 2012). Palaeoenvironmental evidence from cores taken from Loch Tarff (NH 425 100) and Loch Oich (NH 330 020) revealed that the typical late-glacial 'tripartite' sequence was absent from the latter loch whilst present in Loch Tarff, also in Loch Ness (Pennington *et al*., 1972). This indicates that the aforementioned moraines formed during the LLS and reveal the northernmost extent of the Loch Lomond Readvance (LLR) within the Great Glen.

Raised shorelines and deltas occur sporadically along both sides of Loch Ness, where they have been tilted north-eastwards away from the point of greatest glacio-isostatic uplift centred on Rannoch Moor (Firth, 1989). In general, the gradients of older shorelines are steeper than younger ones owing to the exponential decline of uplift since deglaciation. However, this would not be the case if the rate of uplift was slowed or halted by renewed ice sheet growth.

Borlum (NH 384 084)

The roadside site at Borlum provides a good vantage point overlooking the southern end of Loch Ness (Fig. 1, exposure A). It lies about 2 km within the LLR limit at Fort Augustus, where Firth (1984) mapped a glacial drainage channel descending through kame-and-kettle topography towards an outwash terrace. The terrace merges into a raised shoreline terrace at 32.4 m OD, capping a steep, erosional bluff adjacent to the road. Originally considered to be of marine origin (Synge, 1977; Smith, 1977), the shoreline is much more likely to be lacustrine (Sissons, 1979a,b; Firth, 1984, 1986). The bluff is fronted by a lower raised shoreline fragment at 22.4 m OD, which shelves towards a raised shingle ridge at 17.9-18.0

m OD, adjacent to the shore of Loch Ness (Sissons, 1979a; Firth, 1986, 1993a). The significance of the elevations of these shorelines is discussed below.

Degraded exposures in the roadside bluff (Fig. 1, exposure A) reveal that the high shoreline terrace is underlain by up to 0.5 m of subrounded to well rounded, clast-supported gravel including some cobbles. The gravel wraps around boulders in the underlying deposit, which it overlies unconformably (BGS registered photos P699063-4). The rest of the bluff is composed of up to 6 m of extremely poorly sorted, subangular to rounded boulder gravel, some clasts being over 1 m in diameter. The sequence is interpreted as a lake beach deposit resting on glaciofluvial outwash gravel.

Recent mapping has revealed that the high shoreline and related glaciofluvial terrace deposit at Borlum rests on till, which makes up most of the fan-shaped feature hereabout that has been deeply dissected by the River Tarff (BGS, 2012). At two river cliff exposures (Fig. 1, exposures B and C) glaciofluvial gravel underlies the till. Till was also observed in an excavation into a terrace of the River Tarff nearby (NH 3809 0842) (Fig. 1, exposure D) (BGS registered photos P699059-62). The exposure revealed about 0.8 m of very compact, stoney diamicton resting on extremely poorly-sorted boulder gravel several metres thick. These observations suggest that the snout of the LLR glacier may have oscillated, over-riding its outwash.

A delta-top terrace at Invermoriston (31.7 m OD), 9 km north-east of Fort Augustus, has been correlated with the highest shoreline at Borlum (Firth, 1984, 1986) (Fig. 2). A landslip scar (NH 4239 1621) cutting the terrace there in 2008 exposed at least 3 m of horizontally bedded, moderately well sorted, sandy gravel resting unconformably on over 2.5 m of fine-grained sand and silt, displaying ‘Type S’ and ‘lee-side preserved’ climbing ripple-drift lamination (cf. Evans and Benn, 2004) with a southwest-directed palaeocurrent (BGS registered photos P699080-3). Although the basal unit is consistent with deltaic deposition (BGS, 2012), the absence of large-scale planar cross-bedded sand and gravel between it and the upper unit suggests that much of any original coarsening-upwards deltaic sequence has been eroded away prior to the deposition of the upper, fluviatile unit. The elevation of the unconformity, which lies approximately 7 m above loch level, does not necessarily indicate former water level as in a classical Gilbert-style deltaic sequence.

Inchnacardoch Platform, north shore of Loch Ness (NH 386 105)

A prominent bench has been cut into the hillside above the northern shore of Loch Ness in the vicinity of the Inchnacardoch Hotel, north of Fort Augustus (Fig. 1). The bench, named here as the ‘Inchnacardoch Platform’, lies at 29.0-29.5 m OD, is up to 10 m wide, and backed locally by degraded cliffs cut in bedrock; an analogous, less well-developed feature occurs on the other side of the loch (Firth, 1984, 1989). Both features occur outside the likely LLR limit at Fort Augustus. Synge (1977) and Synge and Smith (1980) proposed that the shoreline was a marine feature formed during the decay of the main Late Devensian ice-sheet, when the sea penetrated into Loch Ness from the north-east. They considered that marine terraces occurred throughout the valley of the River Ness, near Inverness, revealing a former link between Loch Ness and the Moray Firth. However, subsequent mapping of the Ness Valley by Firth (1984, 1993b) revealed no evidence there to support a marine incursion into Loch Ness. As the Inchnacardoch Platform is mainly an erosional feature, and there is limited fetch on Loch Ness hereabout, the feature was most probably produced by periglacial shoreline processes during the LLS (Firth, 1986, 1989c: Mathews *et al*., 1986).

If the Inchnacardoch Platform is indeed of LLS age, its elevation and position just outwith the LLR limit at Fort Augustus demonstrates that a rise in loch level occurred from about 29 m to 32 m OD, when the highest shoreline terrace at Borlum was formed, which is within the LLR limit and therefore younger. Together with evidence from the gradients of tilted raised shorelines around Inverness and the Inner Moray Firth (Merritt *et al.*, 1995), this rise demonstrates that the Earth's crust was glacio-isostatically re-depressed regionally during the LLR (Firth 1986, 1989), as suggested by Sutherland (1984). Although shoreline fragments correlating with the Inchnacardoch Platform have been identified at Dores, Lochend and Glen Urquhart (Firth, 1984, 1993b), at the northern end of Loch Ness, some doubt exists about three well-documented raised shingle ridges at Dores. The age, origin and significance of these features has been debated in the literature (Firth, 1993b), whether marine or lacustrine, but they should now be reassessed in the light of the findings of geophysical surveys offshore (Turner *et al.*, 2012) that reveal a cluster of similarly orientated, cross-loch, De Geer moraine ridges lying closely offshore.

Much of the Inchnacardoch Platform is now obscured by conifers, but is accessible from the Great Glen cycle track, for which there are several points of access from the A82 trunk road. Of additional interest is a section (Fig. 1, exposure E) (NH 3900 1067), situated behind a private house accessed from the main road. It lies a few metres down-slope from the eastern end of the platform, where it has been dissected by the Allt na Criche, a small stream that flows down the steep northern flank of the Great Glen into Loch Ness (BGS, 2012). In 2008 the exposure revealed over 3.5 m of large-scale planar cross-bedded gravel with beds dipping steeply towards the south-west, some beds revealing normal grading (BGS registered photos P699069-74). The mainly fine, angular to subangular gravel is loose, partly clast-supported and openwork. The deposit has the attributes of the foreset beds of a delta or subaqueous fan (cf. Benn and Evans, 2011) that probably formed contemporaneously with the Inchnacardoch Platform during the early LLS. The exposure was still in existence in 2012.

Auchteraw (NH 3642 0817)

Widespread glaciofluvial deposits lie beneath, and to the south-west of Fort Augustus in the valley of the River Oich, where they are locally heavily studded with kettle holes (Merritt *et al*., 2013, fig. 17, locality G). The whole spread has become loosely known as the ‘Auchteraw Terrace’, although it includes both moundy and younger terraced deposits (BGS, 2012). Sissons (1979a,b) argued that the main spread, which lies to the west of the River Oich, was associated with a recessional ice margin that lay about 4 km inside the LLR, to the south-west. He described sections (NH 355 073) (Fig. 1, locality G) in moundy deposits comprising poorly sorted materials ranging in size from sand to boulders. The apparent absence of major erosional contacts was consistent with high-energy fluvial deposition. Sissons (1979b) suggested that the spread is anomalous for several reasons, because it a) is much larger than any other outwash spread associated with the LLR in the interior of the Scottish mainland; b) occurs 4 km inside the LLR limit, rather than at, or closely associated with the limit; c) is chaotically and shallowly kettled rather than being deeply kettled close within a clearly defined ice-contact slope. The spread is therefore not a regular glacial outwash feature and was more likely to have been formed by a single catastrophic outburst. Sissons (1979b) presents a powerful argument that the event occurred during the initial drainage of the 260 m lake in Glen Spean. He also presented evidence for several subsequent events of lesser magnitude that apparently did not significantly affect the Fort Augustus area. Some of the evidence for these subsequent outbursts in Glen Spean has been questioned (Peacock and Cornish, 1979, p.66).

Sissons (1981) proposed that meltwaters associated with the main outburst descended in part towards the high shoreline described above at Borlum, concluding that the jökulhlaup temporarily raised the level of the loch by 8.5 m, from 22.5 to 31 m OD. However, Firth (1984) showed that the main terrace at Auchteraw descends towards the north-east, west of the River Oich, where it merges into a flattish raised shoreline/delta-top at 36.0-36.1 m OD (Fig. 2). As the highest shoreline at Borlum lies at 32 m OD, and it formed following the initial retreat and possible oscillation of the LLR glacier, it indicates that the jökulhlaup temporarily raised the loch level by only 4 m, from 32 m to 36 m OD, when the main terrace formed (Firth, 1984, 1993a).

Subsequent work by Russell and Marren (1998) concluded that both the sedimentology and morphology of the Auchteraw Terrace are indeed consistent with jökulhlaup deposition, although the general sandiness, fining-upwards trend and absence of large boulders was atypical for such deposits. This was explained to be a result of sediment supply and redistribution during waning phases of the jökulhlaup. However, the deposits in the vicinity of the sections (NH 363 082) described by these authors are now known to be at least 18 m thick (BGS, 2012) and to become more bouldery with depth. The exposed deposits are therefore probably not representative of the whole sequence.

The sections described by Russell and Marren (1998) were exposed in a gravel pit on the western bank of the River Oich (NH 3642 0817) (Fig. 1, exposure F) now disused. In 2008, up to 4 m of well stratified, moderately well sorted gravel was still exposed. The subrounded to well rounded gravel was mainly horizontally bedded with minor planar, cross stratification, typical of a conventional glaciofluvial outwash deposit (BGS registered photos P699027-9). The gravel pit may be accessed from the north-west by a track leading from the tarred road to Auchteraw: several tracks lead southwards through the moundy and kettled part of the spread described by Sissons (1981). Another part of this kettled spread has been utilized by the golf course at Fort Augustus (Fig. 1), where meltwaters flowed eastwards from the valley of the River Oich into the valley of the River Tarff (BGS, 2012).

The results of sub-bottom sonar and seismic surveys in Loch Ness have provided additional evidence supporting a single catastrophic outburst having occurred at Fort Augustus (Turner, et al., 2012). Some additional evidence supporting the source of the jökulhlaup being the ice-dammed lake in Glen Spean has been obtained from textural and mineral magnetic analysis of sediment sampled from Loch Ness and the Auchteraw Terrace (Cope and Cooper, 2004).

A conundrum that deserves further investigation concerns two 3 to 6 m long cores taken by Pennington *et al.* (1972) from Inchnacardoch Bay (NH 384 1030) consisting mainly of 'grey microlaminated glacial clay with laminae showing graded bedding from silt to clay with no organic content or microfossils'. The clay, described as 'plastic' and interpreted to be 'varved', cropped out on the lake floor and was not capped by any jökulhlaup-derived gravel. Similar laminated silt and clay has been augered onshore from Inchnacardoch Bay, near to where it is reported to have been worked by monks from the nearby monastery for making pots (JD Peacock personal communication, 2013) (BGS, 2012). The simplest explanation is that this clay, being coherent and protected behind the rocky peninsular to the south of the bay, was not ripped up by the jökulhlaup.

Summary

Field evidence at the south-western end of Loch Ness suggests that loch level stood at 29 m OD during the early part of the LLS, when the Inchnacardoch Platform and associated raised fan/deltas were formed (Fig. 2). On reaching its maximum extent the LLR glacier at Fort Augustus probably oscillated before retreating about 2 km, by which time loch level stood at

32 m OD, as recorded by the highest shoreline terrace at Borlum. The high-level delta at Invermoriston (31.7 m OD) formed contemporaneously. After the ice-front had retreated a further 4 km or so, the ice-dammed lake in Glen Spean drained catastrophically beneath ice occupying the Great Glen to produce the large outwash spread in the valley of the River Oich loosely known as the Auchteraw Terrace. The most extensive terraced part of this spread that lies to the west of the River Oich grades to a shoreline/delta at 36 m OD. This formed during a temporary high-stand following the jökulhlaup. Loch level then fell to 22.5 m OD, when the intermediate shoreline terrace at Borlum was formed (Fig. 1). This followed rapid, deep incision by the floodwaters at the north-eastern end of Loch Ness and in the vicinity of Inverness. The loch subsequently fell during the Holocene to its historical level (15 m OD) leaving abandoned shoreline features and deltas around its shores. Loch Ness was raised by 1 m following the construction of the Caledonian Canal at the northern end of the loch.

Some questions still remain concerning the precise series of events, evidence for lake levels, shoreline correlations and ice configurations within the Great Glen at the proposed time of the jökulhlaup, but on present evidence there is general consensus that it occurred and that it was a very significant outburst. Further research utilising modern technology on land and in Loch Ness is required to addresses these remaining issues.

References

Benn, D.I. and Evans, D.J.A. 2011. Glaciers and glaciations. Hodder Education, pp. 802.

British Geological Survey. 2012. 1:50 000 Sheet 73W (Invermoriston) of the Geological Map of Scotland. Bedrock and Superficial Deposits Edition.

Charlesworth, J.K. 1956. The late-glacial history of the Highlands and Islands of Scotland. Transactions of the Royal Society of Edinburgh, 62, 769-928.

Cope, M. and Cooper, M. 2004. Mineral magnetic evidence for the Lateglacial catastrophic lake drainage of Glen Roy/Glen Spean in and around Loch Ness, Scotland. Quaternary Newsletter, 103, 2-14.

Evans, D.J.A. and Benn, D.I. (eds) 2004. A practical guide to the study of glacial sediments. Arnold, London.

Firth, C.R. 1984. Raised shorelines and ice limits in the inner Moray Firth and Loch Ness areas, Scotland. Unpublished PhD thesis, Coventry (Lanchester) Polytechnic.

Firth, C.R. 1986. Isostatic depression during the Loch Lomond Stadial; preminary evidence from the Great Glen, northern Scotland. Quaternary Newsletter, 48, 1-9.

Firth, C.R. 1989. Isostatic depression during the Loch Lomond Stadial (Younger Dryas): evidence from the inner Moray Firth, Scotland. Geologiska Föreningens i Stockholm Förhandlingar, 111, 296-298.

Firth, C.R. 1993a. Fort Augustus. In: Gordon, J.E. and Sutherland, D. G. (eds). The Quaternary of Scotland: Geological Conservation Review Series. London: Chapman and Hall. 192-196.

Firth, C.R. 1993b. Dores. In: Gordon, J.E. and Sutherland, D. G. (eds). The Quaternary of Scotland: Geological Conservation Review Series. London: Chapman and Hall. 196-199.

Mathews, J.A., Dawson, A.G. and Shakesby, R.A. 1986. Lake shoreline development, frost weathering and rock platform erosion in an alpine periglacial environment, Jotenheimen, southern Norway. Boreas, 15, 33-50.

Merritt, J.W., Auton, C.A. and Firth, C.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. Vol. 14, pp 289-329.

Merritt, J.W., Auton, C.A., Boston, C.M., Everest, J.D. and Merritt, J.E. 2013. An overview of main Late Devensian glaciation of the Central Grampian Highlands. 25-40 *in:* Boston, C.M., Lukas, S. and Merritt, J.W. (eds.) *The Quaternary of the Monadhliath Mountains and the Great Glen: Field Guide*. Quaternary Research Association, London.

Peacock, J.D. and Cornish, R. 1979. Glen Roy Area - Field Guide. Quaternary Research Association, Cambridge, 69 pp.

Pennington, W., Haworth, E.Y., Bonny, A.P. and Lishman, J.P. 1972. Lake sediments in northern Scotland. Philosophical Transactions of the Royal Society of London, B264, 191-294.

Russell, A.J. and Marren, P.M. 1998. A Younger Dryas (Loch Lomond Stadial) jökulhlaup deposit, Fort Augustus, Scotland. Boreas, 27, 231-242.

Sissons, J.B. 1979a. The limit of the Loch Lomond Advance in Glen Roy and vicinity. Scottish Journal of Geology, 15, 31-42.

Sissons, J.B. 1979b. Catastrophic lake drainage in Glen Spean and the Great Glen, Scotland. Journal of the Geological Society of London, 136, 215-24.

Sissons, J.B. 1981. Lateglacial marine erosion and a jökulhlaup deposit in the Beauly Firth. Scottish Journal of Geology, 17, 7-19.

Smith, J.S. 1977. The last glacial epoch around the Moray Firth. In: The Moray Firth Area Geological Studies (ed. G.Gill). Inverness Field Club, Inverness, 72-82.

Sutherland, D.G. 1984. The Quaternary deposits and landforms of Scotland and the neighbouring shelves: a review. Quaternary Science Reviews, 3, 157-254.

Synge, F.M. 1977. Land and sea level change during the waning of the last regional ice sheet in the vicinity of Inverness. In: The Moray Firth Area Geological Studies (ed. G.Gill). Inverness Field Club, Inverness, 83-102.

Synge, F.M. and Smith, J.S. 1980. A Field Guide to the Inverness area. Quaternary Research Association, Aberdeen, 24 pp.

Turner, A.J., Woodward, J., Dunning, S.A., Shine, A.J., Stokes, C.R. and ò 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 Research, 27, 221-232.

Figures

1. Geomorphology of the Fort Augustus area (after Firth, 1993).

2. a) Diagram to explain the presence and significance of raised shorelines and deltaic deposits around the southern end of Loch Ness. b) Changes in lake level at the southern end of Loch Ness during the past 16,000 years. (after BGS, 2012).

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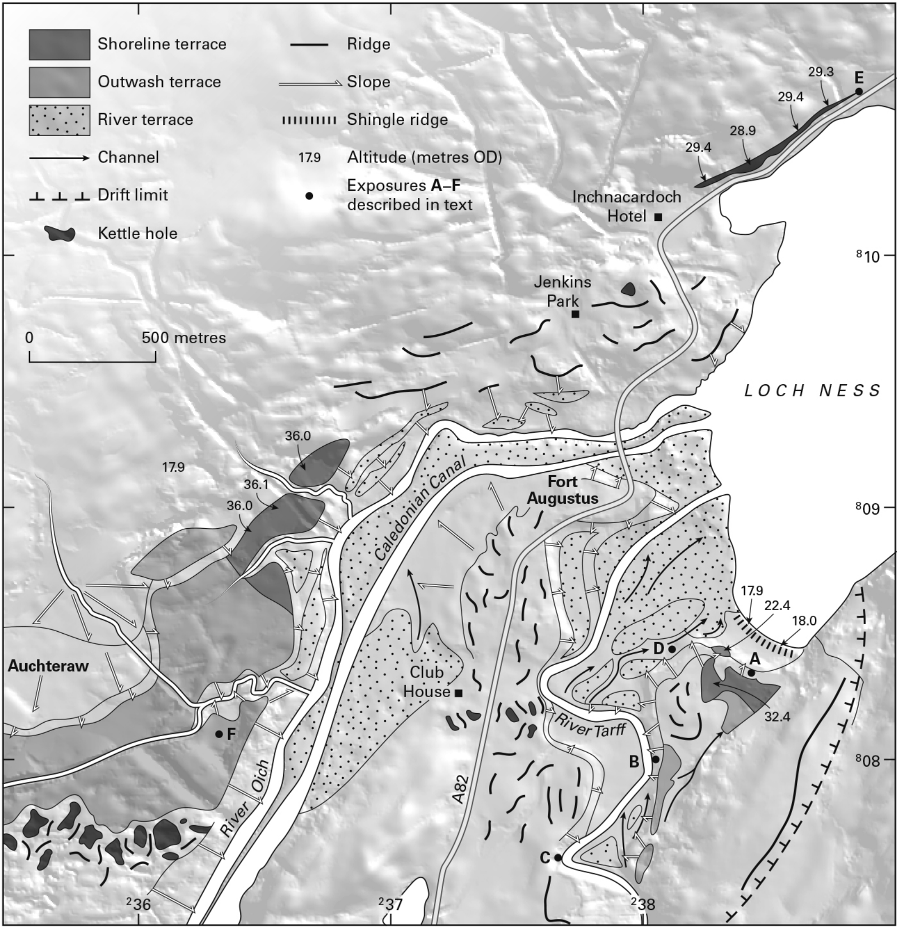
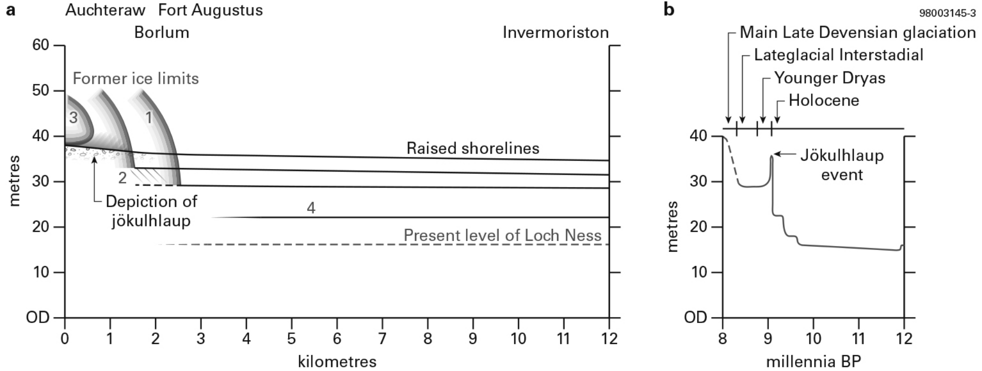


Shoreline terrace
Outwash terrace
River terrace
Channel
Drift limit
Kettle hole
Ridge
Slope
Shingle ridge
17.9
Altitude (metres OD)
Exposures **A–F** described in text
0
500 metres
Inchnacardoch Hotel
Jenkins Park
LOCH NESS
Fort Augustus
Caledonian Canal
Club House
Auchteraw
River Oich
River Tarff
A82
29.3
29.4
28.9
29.4
36.0
36.1
36.0
17.9
17.9
22.4
18.0
32.4
A
B
C
D
E
F
8 10
8 09
8 08
2 36
2 37
2 38



1 Maximum limit of Loch Lomond Readvance at Fort Augustus
2 Deposition of raised deltas at Borlum and Invermoriston
3 Position of ice front during jökulhlaup event
4 Post-jökulhlaup shoreline