Accepted Manuscript

Scottish Journal of Geology

Some geomorphological implications of recent archaeological investigations on river terraces of the River Dee, Aberdeenshire

Richard Tipping, Tim C. Kinnaird, Kirsty Dingwall & Irvine Ross

DOI: https://doi.org/10.1144/sjg2022-010

To access the most recent version of this article, please click the DOI URL in the line above. When citing this article please include the above DOI.

Received 23 June 2022
Revised 2 November 2022
Accepted 7 November 2022

Some geomorphological implications of recent archaeological investigations on river terraces of the River Dee, Aberdeenshire

Richard Tipping[1], Tim C. Kinnaird[2], Kirsty Dingwall[3] and Irvine Ross[4]

[1] *Biological & Environmental Sciences, School of Natural Sciences, University of Stirling, Scotland FK9 4LA (*rt1@stir.ac.uk*: ORCID FA: 0000-0002-6915-7095)*; [2] School of Earth and Environmental Sciences, University of St Andrews, Scotland (tk17@st-andrews.ac.uk); [3] Headland Archaeology Ltd, Edinburgh, Scotland; [4] 13 Barclay Park, Aboyne, Scotland (irvine@ordie.myzen.co.uk)* (*Correspondence: rt1@stir.ac.uk)

[abbreviated title] **River terraces of the River Dee, Aberdeenshire**

Abstract

Excavation and survey of archaeological sites have in recent years generated new data on the chronology of river terraces on the River Dee between Banchory and Peterculter in Aberdeenshire. Terrace fragments have been mapped and correlated on altitudinal grounds, for the first time. Five terrace surfaces are identified and named, refining the terminology of the British Geological Survey (Merritt *et al*. 2003). Three are distinct surfaces within the Lochton Sand and Gravel Formation. The relation between them, regional deglaciation and the formation of the Late Devensian Loch of Park, north of Crathes, suggests some time separated their development. Below these, a fourth terrace, the Camphill Terrace, is dated to before the Windermere Interstadial by finds of Late Upper Palaeolithic flints. The Camphill Terrace is argued to have been the active valley floor within the Younger Dryas also. Timing of incision from the Camphill Terrace is not understood: interpretations are different at three archaeological sites. The youngest terrace fill and surface, the Maryculter Terrace, began to form *c*. 5000 years ago.

Introduction

With a total length of 140 km and a catchment >2000 km^2, the River Dee in Aberdeenshire is one of Scotland's largest rivers (Fig. 1). The river is lined east of Braemar by a 'staircase' of river terrace fragments. These were mapped in the late 19th century (Geological Survey of Scotland 1897) and most recently in 1996 (British Geological Survey (BGS) 1996; Merritt *et al*. 2003). The Geological Survey of Scotland (1897) mapped three terrace surfaces, numbering terrace surfaces up from the present river, using terrace fill sediments as secondary correlatives, and assuming that, for example, the second terrace was always the same age wherever it was found. The BGS in 1996 also mapped three terrace surfaces (see below) but these are not necessarily the same three: there are differences in nomenclature, and therefore inferred relative age, of the same terrace fragments between 1897 and 1996. Maizels (1985) and McEwen (2000) both reported up to five major terrace surfaces, though details about them were not given. There has been, however, no attempt to correlate these terrace fragments from their altitudes, or to date them, despite their potential significance for unravelling the chronology of deglaciation (Brown 1993; Hall *et al*. 2016) and for understanding Holocene fluvial and environmental change (Macklin *et al*. 2010).

The BGS (1996) formally named only the highest and oldest terrace sediments as the Lochton Formation (Table 1). This is coarse to very coarse gravel with sand, understood to be of glaciofluvial origin, laid down as the Dee valley glacier retreated to the Cairn Gorm (Fig. 1a). Lower on the valley side and so younger is a distinct terrace fill and surface, called by the BGS (1996), informally and rather uninformatively, 'river terrace deposits'. These are also gravel rich but no inference as to their age or origin were made. The BGS (1996) also mapped younger sediments forming the floodplain as 'alluvium', "deposits of present river floodplains (mostly gravel)" … and … "stream floodplains (mainly pebbly sand)" (key to

Sheet 66E), notwithstanding the contrast in this description with the observation that floodplains on the River Dee are sandy (Maizels 1985), and the recognition that sediment fills underlying floodplains can have considerable antiquity (Lewin and Macklin 2003).

The work reported here had an archaeological focus. Spatially, the investigations are from lower Deeside, east of Banchory (Fig. 1b, c). Immediately east of Crathes (Fig. 1c), at Nethermills of Crathes, excavation and radiocarbon (^{14}C) dating of a small part of a dense and extensive Mesolithic (*c*. 11700–6000 cal BP) lithic assemblage also defines the underlying terrace surface, mapped as 'river terrace deposits' by the BGS (1996), as older than the Mesolithic (Wickham-Jones *et al*. 2017). Ewan (1981) showed from pollen analyses that the terrace surface is older than the Holocene Epoch. Re-examination of the lithic assemblage has now resulted in a few lithic pieces being typologically assigned to the Late Upper Palaeolithic period, within the Windermere or Lateglacial Interstadial (*c*. 14700–12900 cal BP), pushing further back the age of the terrace fill and surface. Renewed archaeological investigations included an analysis of the finer-grained fluvial sediments on the terrace surface at Nethermills, suggesting it formed prior to, and probably within the Younger Dryas stage (*c*. 12900–11700 cal BP) (Wickham-Jones *et al*. 2021; Tipping *et al*. 2022). Newly released LiDAR data allowed the mapping and correlation by altitude of the suite of terrace surfaces between Banchory and Drumoak (Fig. 2: Tipping and Ross in Wickham-Jones *et al*. 2021, 14-22).

Construction of the Aberdeen West Peripheral Route over the River Dee required archaeological mitigation and intervention (Dingwall *et al*. 2019). At Milltimber, near Peterculter (Fig. 1b), more Late Upper Palaeolithic flints were discovered, the age relations of archaeological features cut into the 'river terrace deposits' (BGS 1996) were used to suggest a date when incision from this terrace surface by the river occurred, and excavation allowed the absolute dating by optically stimulated luminescence (OSL) of the formation of the youngest terrace fill, mapped as 'alluvium' by the BGS (1996).

The purpose of this paper is to define the terrace surfaces mapped between Banchory and Peterculter and summarise and synthesise these new chrono-stratigraphic data. It is not a complete evaluation of the chronology of fluvial change on the lower River Dee but it is a start.

Methods

Field mapping of terrace surfaces between Crathes and Dalmaik was at a scale of 1:5000, onto enlarged 1:10 000 Ordnance Survey topographic maps and Google Earth printouts, drawing on BGS geological mapping (British Geological Survey *Geoindex*) and 0.5 m resolution LiDAR imagery (https://remotesensingdata.gov.scot/data#/map): COVID regulations meant that mapping west of Crathes was entirely from LiDAR imagery. The mean altitudes above Ordnance Datum (OD) of terrace surface fragments were defined using LiDAR imagery at 5.0 m intervals from 39 cross-valley transects along the 10.2 km reach between Banchory and Dalmaik, each terrace fragment included on at least two transects, which were approximately 0.25 km apart. Terrace surfaces were defined as >25 m wide, demonstrated from at least five points. A height-distance diagram of distances along the valley axis and altitudes OD was constructed.

The Nethermills lithic assemblage stretches some 1.75 km along the terrace surface on the left bank of the Dee. Most is known about two fields, NM3 and NM4, 0.4 ha in area. In these, techniques included geomorphological mapping, detailed analyses of aerial photographs and

LiDAR, auger surveys in sediment-stratigraphic transects across palaeochannels, archaeological fieldwalking with recording of finds with hand-held GPS to *c*. 3 m precision, test-pitting of 120 pits (2 x 2 m) across Field NM4 to the base of the soil profile (35–50 cm depth), machine excavation of 10 deeper trenches into natural sediment to around 130 cm depth, sampling down-profile in these last pits under blackout conditions for luminescence profiling (Sanderson and Murphy, 2010; Munyikwa, Sanderson and Kinnaird, 2021), at 5-10 cm intervals, and accelerator mass spectroscopic (AMS) ^{14}C dating of plant macrofossils (Tipping *et al*. 2022). Luminescence profiling was intended to understand the relative age and depositional characteristics of fine-grained fluvial sediments. Interpretation of each profile draws on the scheme for interpreting such signals in fluvial sediments of Muñoz-Salinas *et al*. (2011): (a) declining net signal intensities up-profile characterise sediments fully bleached during transport and exposed to radiation during redeposition, younger sediment being exposed for shorter times; (b) unchanging net signal intensities typify the same process, though greatly accelerated, so that the time difference between deposition of older and younger sediment is negligible; (c) increasing net signal intensities up-profile reflect deposition of partially or unbleached grains; (d) fluctuating profiles of net signal intensity have complex depositional histories or bioturbation; (e) abrupt changes in net signal intensity represent hiatuses in deposition. OSL net signal intensities (photon counts per 60 seconds measured in continuous wave mode: Munikywa *et al*. 2021) are used because they are 3.35 ± 1.21 times (n 102) ‘brighter’ than infra-red stimulated luminescence (IRSL).

At Milltimber, Peterculter, topsoil stripping along the line of the Aberdeen peripheral route exposed gravel across the Lochton Formation and the surfaces of two terraces, with complete excavation of very large areas. Archaeological features were AMS ^{14}C dated from charred short-lived single entity plant macrofossils. Around 1.75 m of stratified sand was exposed by excavation in the upper fill of the lower terrace and dated by nine OSL assays (Kinnaird, Sanderson and Tipping in Dingwall *et al*. 2019, digital appendices; Tipping and Kinnaird in Dingwall *et al*. 2019, 46–48).

Results and Interpretations

1. The terrace stratigraphy of the River Dee between Banchory and Drumoak

Fig. 2 depicts as four maps the terrace fragments defined by mapping and LiDAR imagery between Banchory and Drumoak (Fig. 1), showing the positions of the 39 cross-valley transects used to define this. The Lochton Formation as a deposit is far more extensive than the terrace fragments but commonly lacks a distinctive morphology. Fig. 3 is a height-distance diagram of the terrace surfaces downstream of Banchory (0 km on the x-axis). Five terrace surfaces have been defined (Table 1). All are parallel to the water surface with gradients around 2 m/km. They have been named: the Lochton, Maryfield, Toll House, Camphill and Maryculter terrace surfaces (Table 1: Tipping in Dingwall *et al*. 2019, 22, 30; Tipping and Ross in Wickham-Jones *et al*. 2021, 14-22).

The deposit of the Lochton Formation has at least two surfaces, the Lochton Terrace, and the Maryfield Terrace. The Lochton Terrace is the higher and older, represented throughout the reach, falling from 59 to 39 m OD at 2.0 m/km. There are sediments of the Lochton Formation mapped by the BGS (1996) much higher than this surface, notably at the Loch of Park (NO 770 985: Fig. 4a) at 70 m OD and under Drumoak where they are found to 65 m OD, but terrace surfaces at the latter could not be defined in this heavily disturbed area. Aerial photographs indicate two different morphologies to fragments of the Lochton Terrace in broad accord with BGS (1996) mapping although many fragments retain, through erosion, no clear morphology. Immediately east of the village of Crathes (transects 14 to 17: Fig. 2b;

Fig. 4) and north of Durris (transects 20 to 22; Fig. 2c) they have a kamiform topography, pitted with shallow kettle-holes and with common shallow channels falling eastward to the valley floor. One small patch of Lochton Formation gravel north of the A93 at Crathes was mapped as an ice-contact deposit by the BGS (1996) but these landforms are more extensive (Fig. 4). Seven metres of coarse gravel overlie till at borehole NO79NE1 (Fig. 2b: BGS *Geoindex*). At Milltimber, 6 km down-river, Lochton Formation gravels are found in terrace surfaces on the south side of the River Dee between 26 and 42m OD: terraces on the north side are indistinct because of natural and human disturbance.

The Maryfield Terrace (Figs 2, 3) surface is found throughout the reach, falling from 50 to 34m OD (Figs. 2, 3). It is named from its best development south east of Banchory where borehole NO79NW12 (Fig. 2a: BGS *Geoindex*) records 15 m of gravel over till. Immediately east of Crathes the Maryfield terrace surface is kamiform (Fig. 4). East of Crathes the terrace surface is >1 km long, set below the Lochton Terrace and Lochton Formation with no kamiform morphology. Fig. 5 shows the terraces and underlying deposits from boreholes along the line of the Durris Bridge at Crathes (Fig. 2b). The Maryfield Terrace surface may here be erosional, truncating Lochton Sands and Gravels: if aggradational, the river reworked Lochton Formation gravels.

The Toll House Terrace surface is of uncertain significance. It is identified only at Park Bridge, Drumoak (Transects 33, 34: Fig. 2c) and in one fragment only, where it borders the river, clearly separated in altitude from the Maryfield Terrace surface above by a break of slope and 1.5 m above adjacent fragments of the Camphill Terrace.

The Camphill Terrace surface is the equivalent of the BGS ‘river terrace deposits’ (Table 1). It is extensively developed at Knappach Toll (Fig. 2a: NO 72 96) and borders the Dee on both banks, forming a continuous surface on the left bank between Birkenbaud (NO 728 962) to the Mills of Drum (NO 761 968: Fig. 2b). It is rare east of this, eroded by the younger Maryculter Terrace. At Knappach Toll the surface is 5 m lower than the Maryfield Terrace (transects 39, 2 to 4: Fig. 2a) and cuts into this. Boreholes NO79NW12 and NO79NW13 (Fig. 2a: *Geoindex*) suggest that both surfaces may have formed in the same deposit, the Lochton Sand and Gravel Formation. At Crathes, Fig. 5 shows the Camphill Terrace surface at 37.5 m OD with a 10 m gravel fill. Downstream, borehole NO79NE5 (Fig. 2c: *Geoindex*) records >10m of coarse gravel under the Camphill Terrace surface, the top metre rich in sand. The Camphill Terrace is not mapped in the gorge-like reach between Drumoak and Peterculter. At Milltimber, closely spaced engineering boreholes along the road-line show it to be a 200 m wide surface on the north side of the valley at 16–17 m OD, underlain by some 18 m of coarse, often cobble sized, clast-supported imbricated gravel with a thin veneer of fine sediment (Dingwall *et al*. 2019, illus 2.04). The sediment of the Camphill Terrace fill is no different to those of the Lochton and Maryfield Terrace fills or the Lochton Formation. It may not be glaciofluvial, but it is derived from glaciofluvial sediment.

The Maryculter Terrace surface is the equivalent of the BGS ‘alluvium’ (Table 1). It is recorded in this reach only east of Crathes (Fig. 2b, c). Always bordering the river, at Durris Bridge (Fig. 5) the surface is at 36 m OD. It partly truncates the Lochton Sand and Gravels but is also incised into this. From engineering and hand sunk boreholes, it has a 1.5–3 m fill of sand in the Banchory-Drumoak reach. The closely spaced boreholes at Durris Bridge (Fig. 5) suggest there are three terrace surfaces cut into this fill, but this complexity is not seen elsewhere (e.g. transects 28 to 30: Fig. 2c). At Milltimber, Peterculter, the Maryculter Terrace surface is 400 m wide, at 12–13 m OD, 4m below the Camphill Terrace surface, its fill also 1.5–3 thick structureless sand fill (Dingwall *et al*. 2019, illus 2.04).

Recent sediment (Fig. 2) formed in the last several centuries is largely confined to within-channel locations where floods re-excavate abandoned channels (McEwen 2000), the winter 2015 Storm Frank little affecting terrace surfaces (Fieman, Attal and Addy 2020). In the Banchory-Drumoak reach, Roy's Military Survey (1747–1755) records large island bars and a braided channel system at Park (NO 783 975) in the middle of the reach, possibly from higher discharges or sediment waves pushed downstream in the 'little ice age'.

2. Relations between the Lochton and Maryfield Terrace surfaces and the Loch of Park

Brown (1993) described the significance for deglaciation of the kamiform mass of Lochton Formation glaciofluvial sand and gravel rising to around 50 m OD at Keith's Hill, south of Drumoak: Fig. 2d picks out the quarry in it. The ridge extends under Drumoak and forms a terrace surface at around 70 m OD to the south of a former ice-dammed lake, the Loch of Park (Brown 1993, 1994). Morainic deposits form an eastern edge of the lake (Merritt *et al*. (2003). These deposits were argued by Brown (1993, 1994) to represent a halt in deglaciation though Hall *et al*. (2016) have suggested they may represent an ice advance dated on Speyside between *c*. 17 000 and *c*. 14 700 BP. This ice margin is thought to have dammed the lake at Loch of Park, the basal organic sediments of this very large lake ^{14}C dated to 11900 ± 260 ^{14}C bp (HEL-417) (Vasari 1977), calibrated via Oxcal v4.4 and Intcal20 (Reimer *et al*. 2020) to 14836–13242 cal BP: this is a climato-stratigraphic boundary and very much a minimum date for the moraines and the lake.

The terrace stratigraphy and morphology of the Lochton Formation, and identification of a sequence of channels at Crathes (Figs 2b, 7) together suggest a slightly more nuanced account, albeit undated. The kamiform Lochton Formation at Crathes (Fig. 2b) is assumed to be contemporary with that at Keith's Hill. At Crathes, however, the younger Maryfield Terrace surface is also kamiform (Fig. 4). West of Mills of Drum, up to eight parallel, steep sided gullies are incised for around 400 m into Lochton Formation gravel (a to g: Fig. 4): two more cut this gravel east of Mills of Drum (h to i). They fall down a nearly vertical cliff, perhaps an ice-contact slope in a Lochton Formation kame and onto an 80 m wide east flowing channel (j) that was contemporary with or had cut into the kamiform Maryfield Terrace. Fig. 2c shows five transects (16 to 20) that cross this channel. Fig. 3 shows the surface of this channel falling steeply from the Maryfield Terrace towards the Camphill Terrace: it may grade to or fall below the Camphill Terrace surface. The steepness of channel j suggests a meltwater source. The channel can be traced north west to a shallow channel (k) that had also cut into the Lochton Terrace, and west to a channel (l) from the Burn of Coy west of Crathes.

The largest gullies (b to d; Fig. 4) end in small alluvial fans on the floor of channel j. The gullies were formed later than the Lochton Formation and the Maryfield Terrace. The gullies have no source but on the till surface north of the A93 there are three parallel N-S channels cut into the till of the watershed between the Burn of Coy and the Dee. The probable source of water to these channels was the Loch of Park, draining south and then south west along the Burn of Coy (Fig. 4a). Early in the deepening of this burn, water flowed south in these channels before splitting, probably on frozen ground, to cut the gullies. These relations suggest that initial drainage south from the Loch of Park was later than the deposition of Lochton Formation gravel and of the Maryfield Terrace. Whether this means that the Loch of

Park filled later than currently presumed (Brown 1993; Merritt *et al*. 2003), and whether these events were separated in time by weeks or centuries is unknown, but the River Dee incised several metres during these events.

3. The age of the Camphill Terrace surface

Ballin and Wickham-Jones (2017) reported one probable Late Upper Palaeolithic flint from the surface of the Camphill Terrace at Nethermills of Crathes (NO 758 961; Fig. 4b), a possible Havelte Phase tanged point, typologically dated to the Hamburgian/Ahrensburgian period *c*. 13500–11500 BC (Mortensen *et al*. 2014), within the Windermere Interstadial. From test-pitting on and around Kenworthy's excavation in 2019, Clarke (in Wickham-Jones *et al*. 2021, 103) reported a possible Hamburgian shouldered point. Lithics of this antiquity are rare in Scotland (Saville and Wickham-Jones 2012). Ballin (in Dingwall *et al.* 2019; 90, 95, 113–118) also identified an assemblage of 37 Late Upper Palaeolithic flints at Milltimber, centred on NO 3866 8010, at the base of a slope formed in Lochton Formation gravel, just above the surface of the Camphill Terrace, suggesting that the Camphill Terrace existed then, forming the valley floor (Tipping in Dingwall *et al*. 2019).

The Camphill Terrace surface, or rather the gravel underlying thin sands (below), is older than the Windermere Interstadial. In mid-Deeside to the west, Brown (1993) defined four surfaces formed in glaciofluvial gravel, the lowest three separated by less than 15 m height. He argued that these implied active ice retreat (cf. Clark *et al*. 2012) and a "continuous supply of debris" (p. 245) but this does not explain why there are distinct surfaces. In lower Deeside, the Dee formed three surfaces in glaciofluvial gravel as it incised some 20 m from Lochton Formation gravels to the Camphill Terrace surface at 30 m OD. The widespread extent of the Maryfield and Camphill Terraces indicate that the events creating these surfaces were of regional significance but it is difficult to understand the character of these events. The Lochton and Maryfield Terrace surfaces are both kamiform at Crathes. The Camphill Terrace is nowhere kamiform. All that can currently be said is that fluvial events, of higher discharge/stream power, remoulded the glaciofluvial gravel to form the Camphill Terrace (cf. Hall *et al*. 2016).

4. The age of fluvial activity on the Camphill Terrace surface at Nethermills of Crathes

There are sediments lying on the Camphill Terrace surface that are later than its coarse gravel fill. These were exposed in 2019 at the base of 120 2x2 m pits in Field NM4, the field originally excavated (Wickham-Jones *et al*. 2017) and mapped (Fig. 4b; Tipping *et al*. 2022). Two thin sand sheets are separated by a broad gravel ridge. The Late Upper Palaeolithic flints are thought to have been dropped on the gravel ridge, which may have been a bar in the river in the Windermere Interstadial (Tipping *et al*. 2022). On the gravel ridge and the northern sand sheet, six channels (A to F) are visible on aerial photographs (Fig. 4b). Channels B to E show a parallelism suggestive of a scroll bar (Nanson, 1980) prograding northward, a characteristic planform of meandering rivers. The channels contain peat. In Channel D, one of the younger channels, basal peat lying on sand was dated by pollen-stratigraphic correlation to the beginning of the Holocene Epoch *c*. 11700 cal BP (Ewan 1981).

Ten deeper pits (Fig. 7a) were machine-excavated to around 130 cm depth: most pits stopped short of coarse gravel. Relative ages of sediment are defined from sequences of samples with declining OSL net signal intensities up-profile (e.g. conformable stratigraphic sequences) in Table 2. The oldest conformable sediment is in TP42 (4.94×10^7 photon counts per 60 secs at 111 cm depth: this sample has 100 % OSL net signal intensity. Table 2 records two different periods of sedimentation, (a) an ‘older’ event (>82.6 %) in TPs 42 and 65 in the northern sand sheet and (b) a much 'younger' event <26.4 %. The oldest sediment in TP42, close to the earliest Holocene peat in Channel D, probably has an age within the Younger Dryas Stadial *c*. 12300 cal BP. Sediment with OSL net signal intensities >80% are very likely to date to the Greenlandian Stage of the Holocene, before *c*. 8300 cal BP (Walker *et al*. 2018). A very long hiatus in sediment deposition followed, sediment at 121 cm depth in TP28 having an OSL net signal intensity 26% that of the oldest sand, probably dating to the later Northgrippian or Meghalayan Stages of the Holocene, after *c*. 5000 cal BP. While the northern sand sheet (TPs 42, 43 and 65) has been starved of sediment in the Holocene, more than a metre of fluvial sediment has been deposited in the last *c*. 5000 years at TPs 201, 38 and 35 in the southern sand sheet and on parts of the gravel bar at TPs 28, 39 and 11 (Fig. 7). Yet an early Holocene anthropogenic feature, AMS ^{14}C dated from charred *Betula* (birch) and *Salix* (willow) fragments to 8775–8585 cal BP and 8951–8593 cal BP respectively (Wickham-Jones *et al*. 2021, 91-92, 99) was cut into surficial gravel on the crest of the bar at TP68 (Fig. 7), and early Neolithic pit complexes dating to *c*. 6000–5600 cal BP (Wickham-Jones *et al*. 2017) lay just below ploughed soil.

There is no evidence at Nethermills of Crathes for the discrete Younger Dryas-age terrace surface Maizels and Aitken (1991) described at Aboyne in mid-Deeside (Fig. 1). They had no dating evidence, however, only the assumption that there should be a Younger Dryas terrace, but the braided planforms on the terrace surface in their study are probably older. Younger Dryas glaciers in the Dee Valley were confined to small areas in the Cairn Gorm (Everest and Kubik 2006), where incision at the Devensian-Holocene boundary occurred at Chest of Dee (Fig. 1: Wickham-Jones *et al*. 2020) but the sediment pulse of glaciofluvial sediment did not reach mid-Deeside, and thresholds governing incision (Vandenberghe, Cordier and Bridgland 2010) were not crossed here.

Sediment accumulation on the Camphill Terrace surface was significantly reduced early in the Holocene (above). Peat formation in channels in the earliest Holocene can be explained by increasing productivity of aquatic and marsh plants to rapid thermal amelioration (Brooks *et al*. 2012) or paludification through groundwater rise in response to increased effective precipitation (Bohncke, Vandenberghe and Wijmstra 1988; Bohncke 1993), but channels may have ceased to be active through reduced river discharge driven by evapotranspiration increases (Pastre *et al*. 2003) or channel abandonment (Gibbard and Lewin 2002; Turner *et al*. 2013). The evidence at Nethermills of Crathes is insufficient to discriminate. However, pollen assemblages from plants growing on the Camphill Terrace surface from *c*. 9500 cal BP are those of dryland woodland communities abundant in *Quercus* (oak) (Ewan 1981). These changes suggest that the Dee incised below the Camphill Terrace surface early in the Holocene. Paterson and Lacaille (1936) recorded much fluvial sand accumulating contemporary with deposition of Mesolithic lithic assemblages at Birkwood, near Banchory, 5 km upstream of Nethermills (Fig. 1) but the location of this excavation and its relation to the terrace sequence are vague. Renewed sediment accumulation in the latter half of the Holocene may be related to floods associated with aggradation of the Maryculter Terrace (below).

5. The date of fluvial incision from the Camphill Terrace surface at Milltimber

Sediment lying on the Camphill Terrace surface at Milltimber (Fig. 6) had been removed before it could be investigated. What was exposed was a coarse gravel surface with a few channels and several archaeological features. Tipping (in Dingwall *et al*. 2019, 48) used the chronology of these features to suggest a time that the Camphill Terrace surface had become dry enough to occupy, as an estimate for the date of fluvial incision. This was thought to have been in the early Neolithic *c*. 6000 cal BP or more probably by the mid-Neolithic *c*. 5200 cal BP.

6. The age of formation of the Maryculter Terrace fill at Milltimber

The 1.5–3 m thick structureless sand fill of the Maryculter Terrace lies south of and erosively against Lochton Formation gravels, some 4 m below the Camphill Terrace surface (Fig. 6). Soil-stripping exposed two *c*. 20 m wide sand-filled palaeochannels on the Maryculter Terrace, former courses of the River Dee. They in turn had ovens dug into them during brief Roman occupation, modelled by Bayesian techniques to 1960–1810 cal BP (Hamilton in Dingwall *et al*. 2019, 77). At one oven (NT 0875 0077: Fig. 6) the natural sand fill of the Maryculter Terrace was excavated, from 12.75 to 11.0 m OD, to the boundary with underlying Lochton Formation gravel (Fig. 8).

OSL dating of nine samples in three vertical profiles within three metres of each other (Fig. 8; Table 3) established the chronology of aggradation of the Maryculter Terrace (Tipping and Kinnaird in Dingwall *et al*. 2019, 46–48). Luminescence profiling (Fig. 8) demonstrated conformable sediment sequences except at profile 2 where sediment was probably disturbed in digging the oven (units 2B-2038 and -2039; Fig. 8): these cannot be related to the OSL profiles at Nethermills of Crathes because the measurements are from different, uncalibrated instruments. Unit A is a gritty coarse sand, dated at profile 2 to 5080 ± 380 yrs BP (before AD 2000: SUTL-2731; Table 3) and at profile 3 to 3480 ± 460 yrs BP (SUTL-2736), the latter not in stratigraphic order because the basal silty clay of unit B is dated at profile 1 to 4500 ± 500 yrs BP (SUTL-2728), the middle of unit B at profile 3 to 3310 ± 380 yrs BP (SUTL-2735) and its uppermost sediment at profile 1 to 2900 ± 200 yrs BP (SUTL-2727). Unit B was truncated in profile 2 by the Roman oven: assay SUTL-2733 (1840 ± 90 yrs BP) is on sand directly associated with the oven from which an AMS ^{14}C assay on *Alnus* charcoal gave a closely comparable age of 1929–1742 cal BP. Over this, assay SUTL-2730 dates the resumption of fluvial sedimentation (unit B) at profile 2 to 1190 ± 90 yrs BP. The earliest silt of Unit C is dated at profile 3 to 550 ± 40 yrs BP (SUTL-2734) and at profile 2 to 260 ± 40 yrs BP (SUTL-2729).

Accumulation of this fining up sediment stratigraphy was slow. It may not, at this location, have been continuous: Wilson and Tipping (in Dingwall *et al*. 2019, 56) reported soil development in unit A (Fig. 8). Unit A was also cut into by a shallow channel after *c*. 5080 yrs BP and before *c*. 4500 yrs BP. The paleochannel was dry enough for ovens to be cut in the 1st century AD; there is a probable hiatus between units B and C. Nevertheless, the assays date formation of the Maryculter Terrace to before *c*. 5080 yrs BP (*c*. 5000 cal BP). This suggests that incision of the river into the Camphil Terrace may well have been around 5200 cal BP (above). In the valley of the River Don to the north, at Kintore (Fig. 1), Aitken (1991) reported peat beneath 4.9 m of alluvium, the Maryculter Terrace fill, also fining up, with plant macro-remains ^{14}C dated to 3855 ± 50 ^{14}C bp and organic silt to 4120 ± 50 ^{14}C bp (SRR-3718), calibrated via Oxcal v4.4 and Intcal20 (Reimer *et al*. 2020) to 4416–4100 and 4829–4450 cal BP respectively. This is the only relevant age estimate in the region. It suggests a degree of synchroneity between the two river systems but much more work is needed to demonstrate this. The Maryculter Terrace surface continues to receive flood sediment. Recent landforms (Fig. 2) are gravel bars.

Conclusions

The river terrace sequence in mid-Deeside, east of Banchory, has been examined at different scales. Altitudinal correlation of terrace fragments between Banchory and Dalmaik has led to the first quantified terrace stratigraphy. Five terrace surfaces have been named. They are (a) the Lochton Terrace, (b) the Maryfield Terrace, (c) the Toll House Terrace (the reality of which is uncertain), (d) the Camphill Terrace and (e) the Maryculter Terrace (Table 1).

The Lochton, Maryfield and Camphill Terrace surfaces are over glaciofluvial gravel. The lowest, the Camphill Terrace, is dated by the typology of flint artefacts to before the Windermere Interstadial. The Maryfield and Camphill Terraces may be erosional rather than aggradational. The altitudinal relation between these terrace surfaces and probable drainage outlets from the Loch of Park at Crathes has led to an unpicking of the relative chronology for that Late Devensian lake, suggesting that the maximum depth of the lake was reached later than the earliest glaciofluvial gravels.

There are sands lying on the Camphill Terrace at Nethermills of Crathes that are earlier than the Holocene Epoch. They are argued to be of Devensian Lateglacial age, and to have formed by a meandering river system in this period. There appears not to be a terrace of Younger Dryas age in mid- and lower Deeside as sometimes presumed, because contemporary glaciers and meltwater pulses were distant, high in the Cairn Gorm.

Fluvial incision from the Camphill Terrace surface is inadequately understood. At Nethermills of Crathes it is inferred from palaeoecological data to have occurred before *c*. 9500 cal BP. Downstream at Milltimber it is inferred from archaeological data to have been later, 6000–5200 cal BP. It occurred at Milltimber before the earliest sediment of the Maryculter Terrace fill at *c*. 5000 cal BP. Aggradation of the thin Maryculter Terrace fill may have been interrupted by hiatuses.

Acknowledgements

We thank Caroline Wickham-Jones for inviting us (RT, TK, IR) to participate in the *Mesolithic Deeside* programme, all who have field-walked for flints over the years, Ali Cameron (Cameron Archaeology) for finding the LiDAR data, the volunteers of Mesolithic Deeside, Gordon Noble and students at the Department of Archaeology, University of Aberdeen for their work in the test-pitting at Nethermills of Crathes, Ann Clarke for her work on flint typology, Lisa Brown (Historic Environment Scotland) for supporting the ^{14}C dating programme at Nethermills of Crathes and staff at the Scottish Universities Environmental Research Centre for providing the ^{14}C dates.

References

Aitken, J. F. 1991. *Sedimentology and Palaeoenvironmental Significance of Late Devensian to mid-Holocene Deposits in the Don Valley, N. E. Scotland*. Unpublished Ph.D Thesis, University of Aberdeen.

Ballin, T. and Wickham-Jones, C. 2017. Searching for the Scottish late Upper Palaeolithic: a case study of early flints from Nethermills Farm, Aberdeenshire. *Journal of Lithic Studies* **4** (1) https://doi.org/10.2218/jls.v4i1.1907

Bohncke, S. J. P. 1993. Lateglacial environmental changes in the Netherlands: spatial and temporal patterns. *Quaternary Science Reviews* **12**, 707-717. https://doi.org/10.1016/0277-3791(93)90008-A

Bohncke, S., Vandenberghe, J. and Wijmstra, T. A. 1988. Lake level changes and fluvial activity in the Late Glacial lowland valleys. *In*: Lang, S. and Schluchter, C. (eds). *Lake, Mire & River Environments in the Past 15,000 Years*. Balkema, 115-121.

Institute of Geological Sciences. 1980. *Aberdeen: Sheet 77. Drift Edition. 1:50 000*. Institute of Geological Sciences.

British Geological Survey. 1996. *Banchory, Scotland Sheet 66E. Solid and Drift Geology. 1:50 000*. British Geological Survey.

British Geological Survey. *Geoindex* http://mapapps2.bgs.ac.uk/geoindex/home.html (accessed 26/05/2021)

Brooks, S. J., Matthews, I. P., Birks, H. H. and Birks, H. J. B. 2012. High resolution Lateglacial and early-Holocene summer air temperature records from Scotland inferred from chironomid assemblages. *Quaternary Science Reviews* **41**, 67-82. https://doi.org/10.1016/j.quascirev.2012.03.007

Brown, I. M. 1993. Pattern of deglaciation of the last (Late Devensian) Scottish ice sheet: evidence from ice-marginal deposits in the Dee valley, northeast Scotland. *Journal of Quaternary Science* **8**, 235-250. https://doi.org/10.1002/jqs.3390080305

Brown, I. M. 1994. Former glacial lakes in the Dee valley: origin, drainage and significance. *Scottish Journal of Geology* **30**, 147–158. https://doi.org/10.1144/sjg30020147

Clark, C. D., Hughes, A. L. C., Greenwood, S. L., Jordan, C. and Sejrup, H. P. 2012. Pattern and timing of retreat of the last British–Irish Ice Sheet. *Quaternary Science Reviews* **44**, 112–146. https://doi.org/10.1016/j.quascirev.2010.07.019

Dingwall, K., Ginnever, M., Tipping, R., van Wessel, J. and Wilson, D. 2019. *The Land was Forever. 15,000 years in north-east Scotland*. Oxbow.

Dingwall, K., Tipping, R. and Wilson, D. 2019. A landscape through time: Milltimber and the River Dee. *In*: Dingwall, K. *et al*. (eds) *The Land was Forever: 15,000 years in North-east Scotland*. Oxford, Oxbow, 20-139.

Everest, J. and Kubik, P. 2006. The deglaciation of eastern Scotland: cosmogenic ^{10}Be evidence for a Lateglacial stillstand. *Journal of Quaternary Science* **21**, 95-104. https://doi.org/10.1002/jqs.961

Ewan, L. A. 1981. *A Palynological Investigation of a Peat Deposit near Banchory: Some local and regional environmental implications*. Department of Geography, Aberdeen.

Fieman, D. M., Attal, M. and Addy, S. 2020. Geomorphic response of a mountain gravel-bed river to an extreme flood in Aberdeenshire, Scotland. *Scottish Journal of Geology* **56**, 101-116. https://doi.org/10.1144/sjg2019-005.

Geological Survey of Scotland 1897. *Banchory*. *Sheet 66*. Edinburgh: HMSO. http://www.largeimages.bgs.ac.uk/iip/mapsportal.html?id=1001323 (accessed 24/05/2021)

Gibbard, P. L. and Lewin, J. 2002. Climate and related controls on interglacial fluvial sedimentation in lowland Britain. *Sedimentary Geology* **151**, 187-210. https://doi.org/10.1016/S0037-0738(01)00253-6

Hall, A. M., Binnie, S. A., Sugden, D. E. and Dunai, Y. J. 2016. Late readvance and rapid deglaciation of the last ice sheet in the Grampian Mountains, Scotland. *Journal of Quaternary Science* **31**, 869-878. https://doi.org/10.1002/jqs.2911

Kenney, J. 1993 *The beginnings of agriculture in Britain: A critical assessment*. Unpublished Ph.D Thesis, University of Edinburgh.

Kinnaird, T., Sanderson, D. C. W. and Tipping, R. 2017. Using OSL to reconstruct the historic landscape of the River Dee at Milltimber. *In*: Dingwall *et al*. (2019) *Aberdeen Western Peripheral Route / Balmedie to Tipperty*. *Digital Appendices* [data-set]. York: Archaeology Data Service [distributor] https://doi.org/10.5284/1050093

Maizels, J. 1985. The physical background of the River Dee. *In*: Jenkins, D. (ed.) *The biology and management of the River Dee*. Swindon, 7-22.

Lewin, J. and Macklin, M. G. 2003. Preservation potential for Late Quaternary river alluvium. *Journal of Quaternary Science* **18**, 107-120. https://doi.org/10.1002/jqs.738

Macklin, M.G., Jones, A.F. and Lewin, J. 2010. River response to rapid Holocene environmental change: evidence and explanation in British catchments. *Quaternary Science Reviews* **29**, 1555-1576. https://doi.org/10.1016/j.quascirev.2009.06.010

Maizels, J. and Aitken, J. 1991. Palaeohydrological change during deglaciation in upland Britain: a case study from northeast Scotland. *In*: Starkel, L., Gregory. K. J. and Thornes, J. B. (eds) *Temperate Palaeohydrology: fluvial processes in the temperate zone during the last 15,000 years*. Wiley, 105-145.

McEwen, L. J. 2000. *The Geomorphological Character of The River Dee*. Scottish Natural Heritage Report no. F99LF05.

Merritt, J. W., Auton, C. A., Connell, E. R., Hall, A. M. and Peacock, J. D. 2003. *Cainozoic geology and landscape evolution of north-east Scotland. Memoir of the British Geological Survey, sheets 66E, 67, 76E, 77, 86E, 87W, 87E, 95, 96W, 96E and 97 (Scotland)*. Earthwise. http://earthwise.bgs.ac.uk/index.php/Cainozoic_geology_and_landscape_evolution_of_north-east_Scotland._Memoir_of_the_British_Geological_Survey,_sheets_66E,_67,_76E,_77,_86E,_87W,_87E,_95,_96W,_96E_and_97_(Scotland)

Mortensen, M. F., Olsen, J., Holm, J. and Christensen, C. 2014. Right time, right place – dating the Havelte phase in Slotseng, Denmark. *In*: Riede, F. and Tallaavaara, M. (eds) *Lateglacial and Postglacial Pioneers in Northern Europe*. BAR International Series 2599, 11-22.

Muñoz-Salinas, E., Bishop, P., Sanderson, D. C. W., Kinnaird, T. and Zamorano, J. J. 2011. Interpreting luminescence data from a portable OSL reader: three case studies in fluvial settings. *Earth Surface Processes and Landforms* **36**, 651-660. https://doi.org/10.1002/esp.2084

Munyikwa, K., Kinnaird, T. C. and Sanderson, D. C. W. 2021. The potential of portable luminescence readers in geomorphological investigations: a review. *Earth Surface Processes and Landforms* **46**, 131-150. https://doi.org/10.1002/esp.4975

Nanson, G. 1980. Point bar and floodplain formation of the meandering Beatton River, northeastern British Columbia, Canada. *Sedimentology* **27**, 3–29. https://doi.org/10.1111/j.1365-3091.1980.tb01155.x

Pastre, J-F., Limondin-Louzouet, N., Leroyer, C., Ponel, P. and Fontugne, M. 2003. River system evolution and environmental changes during the Lateglacial in the Paris Basin (France). *Quaternary Science Reviews* **22**, 2177–2188. https://doi.org/10.1016/S0277-3791(03)00147-1

Paterson, H. M. L. and Lacaille, A. D. 1936. Banchory microliths. *Proceedings of the Society of Antiquaries of Scotland* **70**, 419-434.

Rasmussen, S. O., Seierstad, I. K., Andersen, K. K., Bigler, M., Dahl-Jensen, D. and Johnsen, S. J. 2008. Synchronization of the NGRIP, GRIP and GISP2 cores across MIS2 and palaeoclimatic implications. *Quaternary Science Reviews* **27**, 18-28. https://doi.org/10.1016/j.quascirev.2007.01.016

Reimer, P., Austin, W., Bard, E., Bayliss, A., Blackwell, P., Bronk Ramsey, C., . . . Talamo, S. 2020. The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon* **62**, 725-757. https://doi:10.1017/RDC.2020.41

Sanderson, D. C. W. and Murphy, S. 2010. Using simple portable OSL measurements and laboratory characterisation to help understand complex and heterogeneous sediment sequences for luminescence dating. *Quaternary Geochronology* **5**, 299-305. https://doi.org/10.1016/j.quageo.2009.02.001

Saville, A. and Wickham-Jones, C. 2012. Palaeolithic & Mesolithic. Scottish Archaeological Research Framework. https://scarf.scot/national/palaeolithic-mesolithic-panel-report. (accessed 05/2021).

Tipping, R., Bates, R., Cameron, A., Clarke, A., Duthie, S., Ewan, L., Kinnaird, T., Mann, B., Noble, G., Ross, I., Sabnis, H. and Wickham-Jones, C. 2022. Environmental reconstruction and formation processes in a large Mesolithic lithic scatter at Nethermills of Crathes, Aberdeenshire, Scotland. *Journal of Archaeological Science: Reports* 103065. https://doi.org/10.1016/j.jasrep.2022.103605

Turner, F., Tolksdorf, J. F., Viehberg, F., Schwalb, A., Kaiser, K., Bittmann, F., … Veil, S. 2013. Lateglacial/early Holocene fluvial reactions of the Jeetzel river (Elbe valley, northern Germany) to abrupt climatic and environmental changes. *Quaternary Science Reviews* **60**, 91–109. https://doi.org/10.1016/j.quascirev.2012.10.037

Vandenberghe, J. 2015. River terraces as a response to climatic forcing: formation processes, sedimentary characteristics and sites for human occupation. *Quaternary International* **370**, 3–11. https://doi.org/10.1016/j.quaint.2014.05.046

Vandenberghe, J., Cordier, S. and Bridgland, D. 2010. Extrinsic and intrinsic forcing of fluvial development: understanding natural and anthropogenic influences. *Proceedings of the Geologists' Association* **121**, 107-112. https://doi.org/10.1016/j.pgeola.2010.05.002

Vasari, Y. N. 1977. Radiocarbon dating of the Late-Glacial and early Flandrian vegetational succession in the Scottish Highlands and the Isle of Skye. *In*: Gray, J. M. and Lowe, J. J. (eds) *Studies in the Scottish Lateglacial Environment*. Pergamon Press, 143-162.

Walker, M., Head, M. J., Berkelhammer, M., Björck, S., Cheng, H., Cwynar, L., … Weiss, H. 2018. Formal ratification of the subdivision of the Holocene Series/ Epoch (Quaternary System/Period): two new Global Boundary Stratotype Sections and Points (GSSPs) and three new stages/ subseries. *Episodes* **41**, 213-223. https://doi.org/10.18814/epiiugs/2018/018016

Wickham-Jones, C. R., Kenworthy, J. B., Gould, A., MacGregor, G. and Noble, G. 2017. Archaeological excavations at Nethermills Farm, Deeside, 1978–81. *Proceedings of the Society of Antiquaries of Scotland* **146**, 7-55.

Wickham-Jones, C. R., Noble, G., Fraser, S. M., Warren, G., Tipping, R., Paterson, D., … Clarke, A. 2020. New evidence for upland occupation in the Mesolithic of Scotland. *Proceedings of the Prehistoric Society* **86**, 13-42. https://doi:10.1017/ppr.2020.8

Wickham-Jones, C., Bates, R., Cameron, A., Clarke, A., Collinson, D., Duthie, S., Kinnaird, T., Noble, G., Ross, I., Sabnis, H. and Tipping, R. 2021. *Prehistoric Communities of the River: Mesolithic and other lithic scatter sites along the middle reaches of the River Dee, Aberdeenshire*. Scottish Archaeological Internet Reports. http://journals.socantscot.org/index.php/sair/article/view/10482/10562

Figure and Table Captions

Fig. 1. (a) a map of Scotland outlining Fig. 1b; (b) relief map of the catchment of the River Dee, Aberdeenshire, showing localities mentioned in the text and outlining Fig. 1c; (c) the location between Banchory and Drumoak of the four detailed maps in Fig. 2. Figs. 1b and 1c are licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license: contains Ordnance Survey data © Crown copyright and database right.

Fig. 2. River terrace fragments defined by mapping and LiDAR imagery between Banchory and Dalmaik showing the positions of the 39 cross-valley transects used to define these: (a) Banchory to Crathes Castle; (b) Crathes Castle to West Park; (c) Crathes to Nether Park; (d) Nether Park to Dalmaik.

Fig. 3. Height-distance diagram of the terrace surfaces mapped in Fig. 2. B = Banchory; C = Crathes; D = Drumoak. Altitudes on the surface of channel j at Crathes (Figs. 4, 7) are also marked.

Fig. 4. (a) Topography, present drainage, probable maximal extent of Devensian Lateglacial Loch of Park (Merritt *et al*. 2003) and suggested routes of overflows to the River Dee in relation to the terrace stratigraphy of the Dee east of Crathes; (b) Google Earth image (6/2018) of the terraces east of Crathes showing the kamiform morphologies of the Lochton and Maryfield Terrace surfaces: localities referred to in the text are lettered.

Fig. 5. Terrace surfaces and underlying fills from borehole data (BGS *Geoindex*) along a north-south transect along the A957 at Durris Bridge, Crathes.

Fig. 6. River terrace surfaces and Lochton Formation gravels along the line of the Aberdeen West Peripheral Route at Milltimber showing in red the outline of the road scheme and areas excavated in detail.

Fig. 7. (a) map of surficial sediments in Field NM4 beneath ploughed soil in archaeological test-pits (numbered) with the locations of deeper test-pits (TP: triangles) sampled for OSL profiling. The area excavated by Kenworthy is hachured. Each grid is 40.0m on a side. Gravel at the surface is in orange; sand at the surface is in yellow; pebbly sand is in darker yellow; gravel over sand is in brown; (b) Google Earth image (6/2018) of Fields NM3, 4 and 5 showing the dark peat filled channels A to F and locations where the absolute chronology of sediments has been sought from ^{14}C, OSL or pollen stratigraphy (see text).

Fig. 8. The sediment stratigraphy of the Maryculter Terrace at Milltimber related to altitude (m OD) showing the three sediment units A to C, the position of the Roman-age oven (units 2B-2038 and -2039), the three vertical profiles sampled for luminescence profiling and associated OSL profiles and the nine OSL assays (cal BP).

Table 1. The nomenclature of the terrace surface sequence in this paper related to that of the BGS (1996; Merritt *et al*. 2003), mean height of the surfaces above the present water surface of the River Dee, the slope of the surface, number of fragments of that surface identified and the strength of linear correlation, and composition of the fill beneath the surface.

Table 2. Sequences of conformable pOSL samples in the 10 geological test-pits in Field NM4, ordered with increasing distance from the present Dee channel (Fig. 7a), showing the

depth below ground surface of a sample, sediment type analysed (gravel or sand) and proportion of OSL net signal intensities relative to the oldest sediment (100%), in TP42. TP37 had no conformable sediment.

Table 3. Details of the OSL assays on the fill of the Maryculter Terrace at Milltimber.

Figure 1

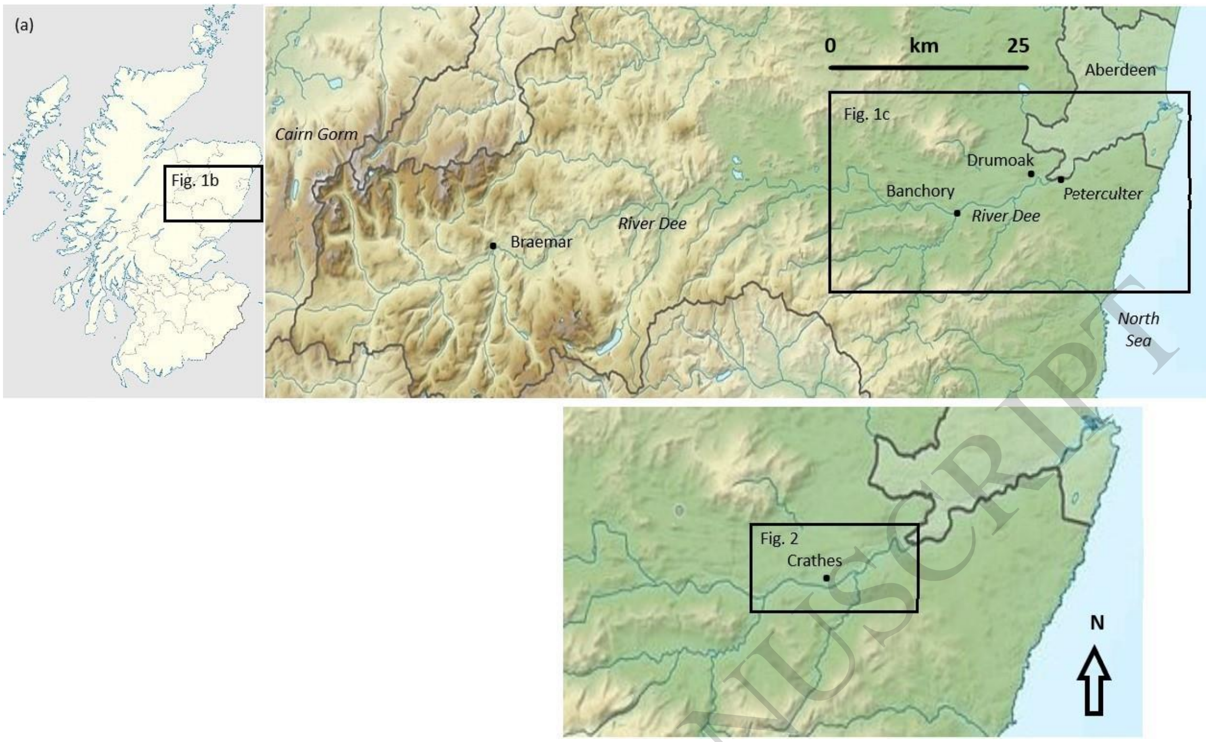

(a)
Fig. 1b
Cairn Gorm
Braemar
River Dee
0 km 25
Aberdeen
Fig. 1c
Drumoak
Banchory
Peterculter
River Dee
North Sea
Fig. 2
Crathes
N

Figure 2a

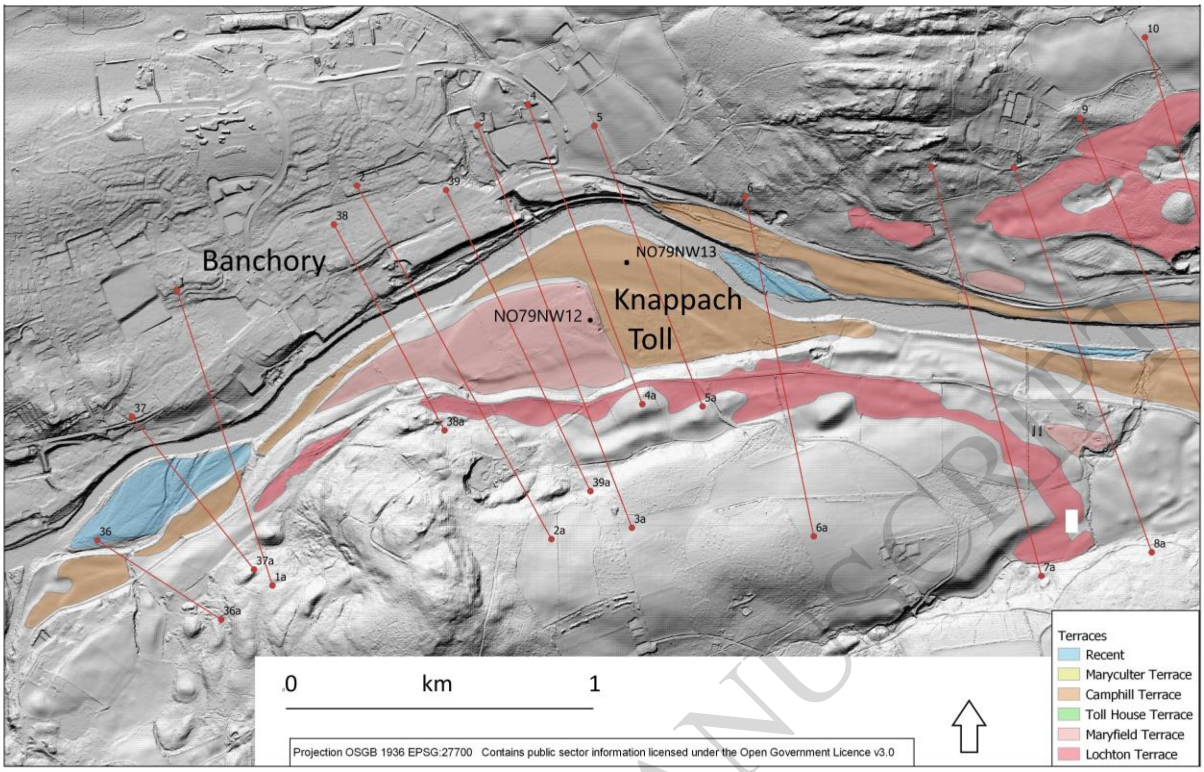

Banchory
Knappach
Toll
NO79NW13
NO79NW12
0
km
1
Projection OSGB 1936 EPSG:27700 Contains public sector information licensed under the Open Government Licence v3.0
Terraces
Recent
Maryculter Terrace
Camphill Terrace
Toll House Terrace
Maryfield Terrace
Lochton Terrace

Figure 2b

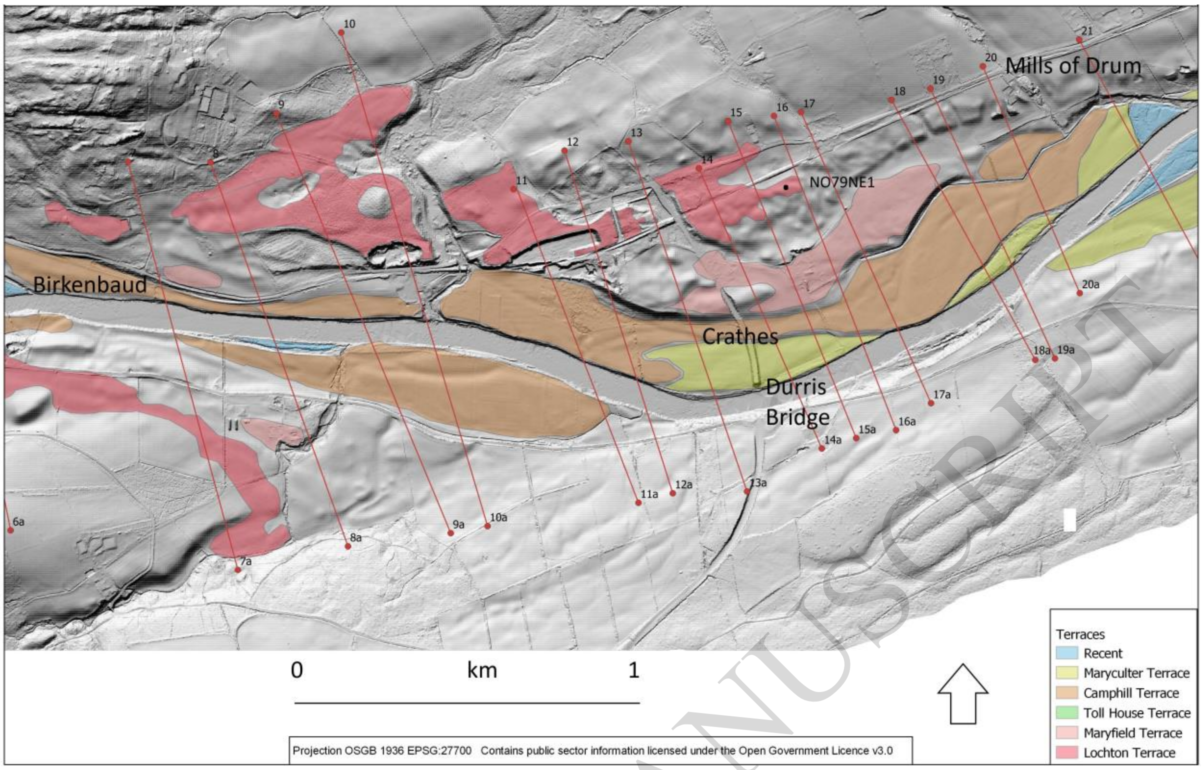

Mills of Drum
Birkenbaud
NO79NE1
Crathes
Durris
Bridge
0
km
1
Terraces
Recent
Maryculter Terrace
Camphill Terrace
Toll House Terrace
Maryfield Terrace
Lochton Terrace
Projection OSGB 1936 EPSG:27700 Contains public sector information licensed under the Open Government Licence v3.0

Figure 2c

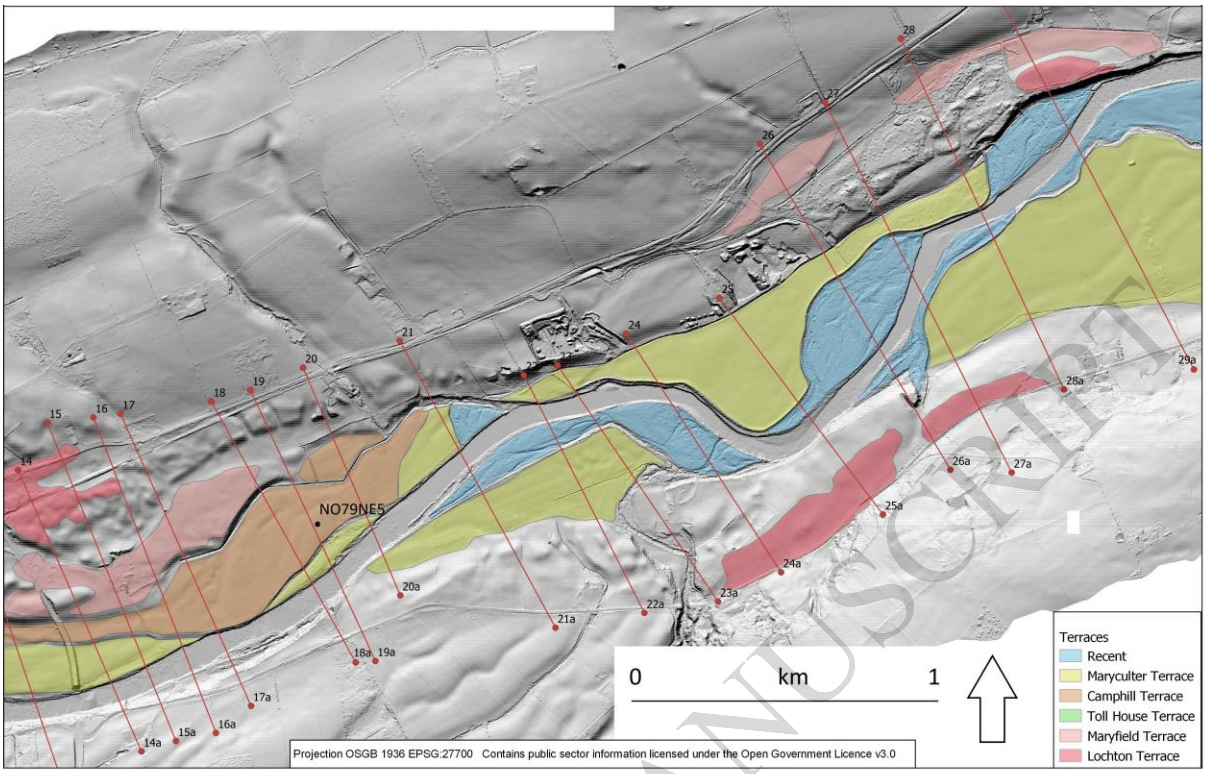

NO79NE5
0
km
1
Terraces
Recent
Maryculter Terrace
Camphill Terrace
Toll House Terrace
Maryfield Terrace
Lochton Terrace
Projection OSGB 1936 EPSG:27700 Contains public sector information licensed under the Open Government Licence v3.0

Figure 2d

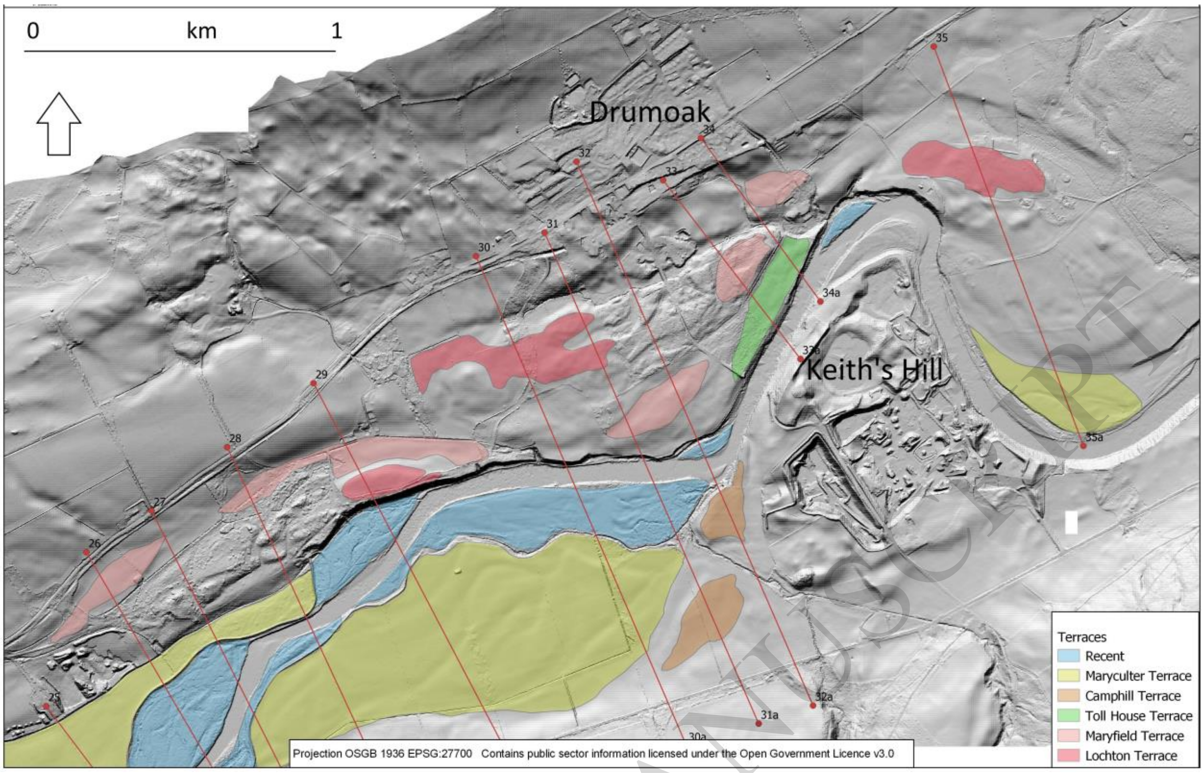

0
km
1
Drumoak
Keith's Hill
25
26
27
28
29
30
31
32
33
34
35
30a
31a
32a
34a
35a
Projection OSGB 1936 EPSG:27700 Contains public sector information licensed under the Open Government Licence v3.0
Terraces
Recent
Maryculter Terrace
Camphill Terrace
Toll House Terrace
Maryfield Terrace
Lochton Terrace

Figure 3

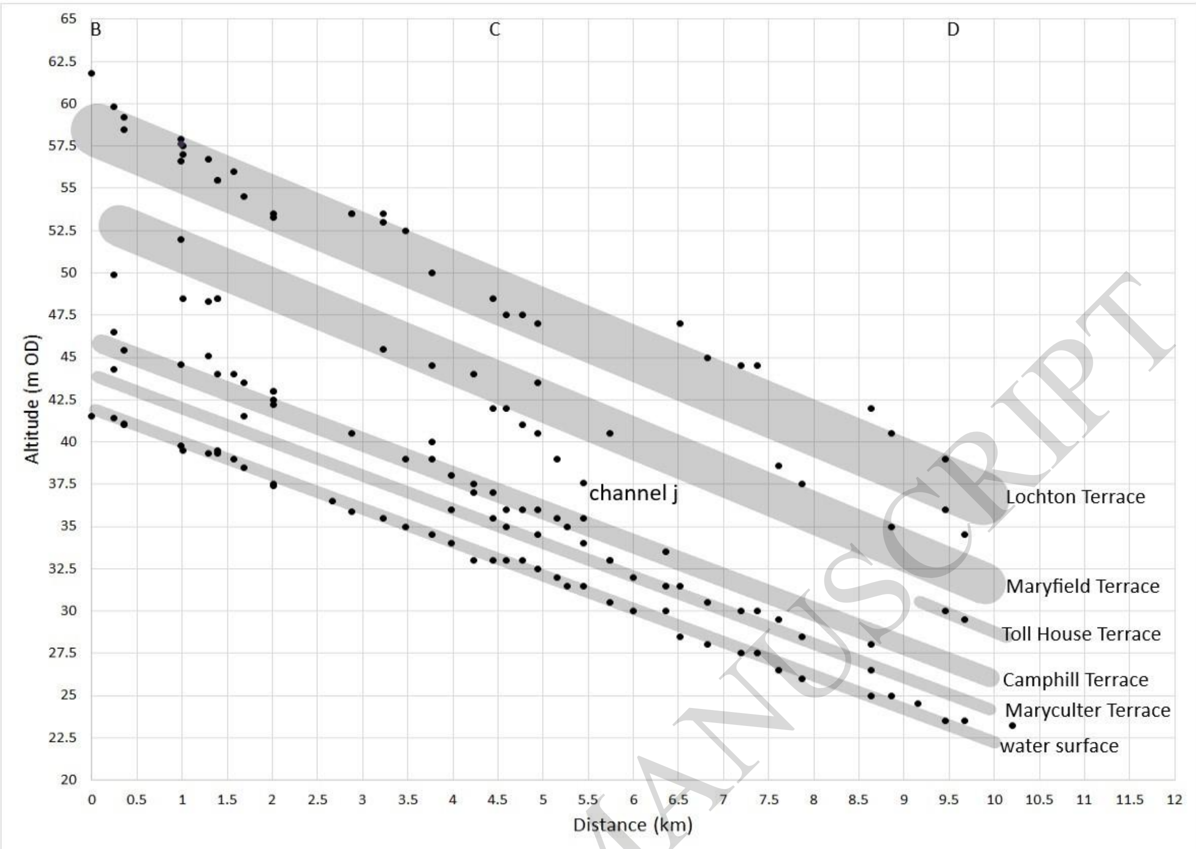
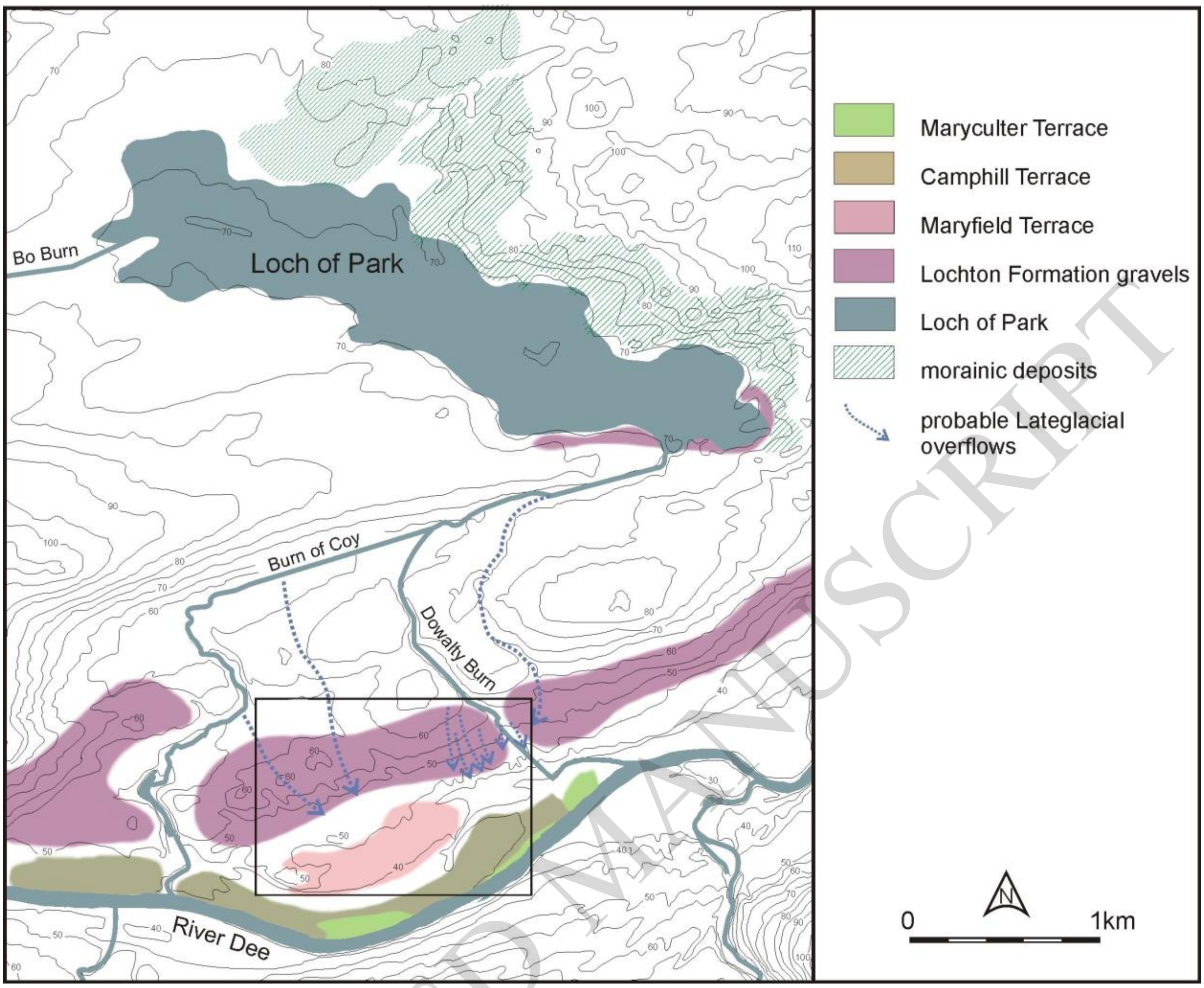

B
C
D
channel j
Lochton Terrace
Maryfield Terrace
Toll House Terrace
Camphill Terrace
Maryculter Terrace
water surface
Altitude (m OD)
Distance (km)

Figure 4a



Loch of Park
Bo Burn
Burn of Coy
Dowalty Burn
River Dee
Maryculter Terrace
Camphill Terrace
Maryfield Terrace
Lochton Formation gravels
Loch of Park
morainic deposits
probable Lateglacial overflows
0
1km
N

Figure 4b

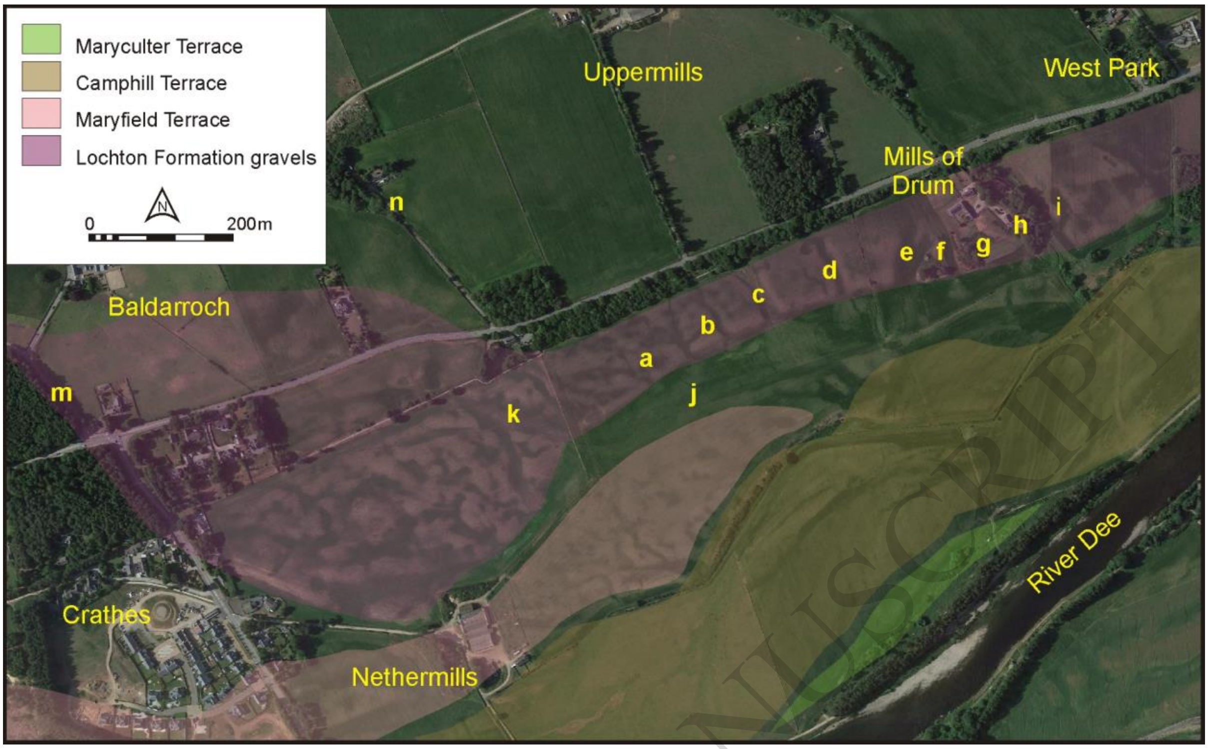

Maryculter Terrace
Camphill Terrace
Maryfield Terrace
Lochton Formation gravels
N
0
200m
Uppermills
West Park
Mills of Drum
n
Baldarroch
m
a
b
c
d
e
f
g
h
i
j
k
Crathes
Nethermills
River Dee

Figure 5

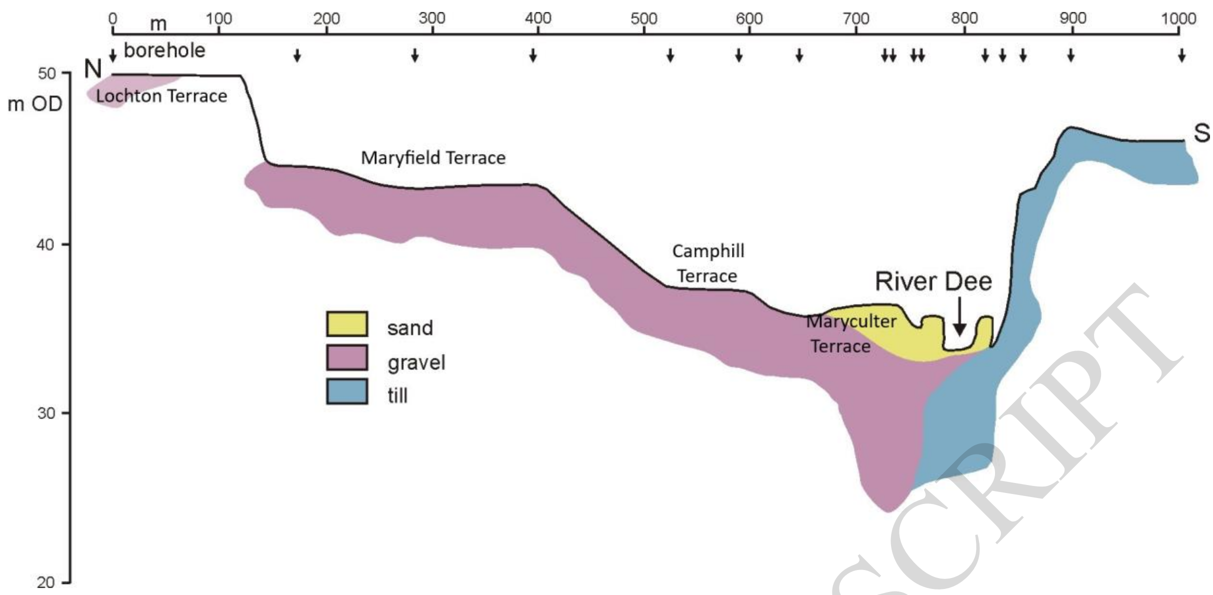

0
m
100
200
300
400
500
600
700
800
900
1000
borehole
N
S
50
m OD
40
30
20
Lochton Terrace
Maryfield Terrace
Camphill Terrace
Maryculter Terrace
River Dee
sand
gravel
till

Figure 6

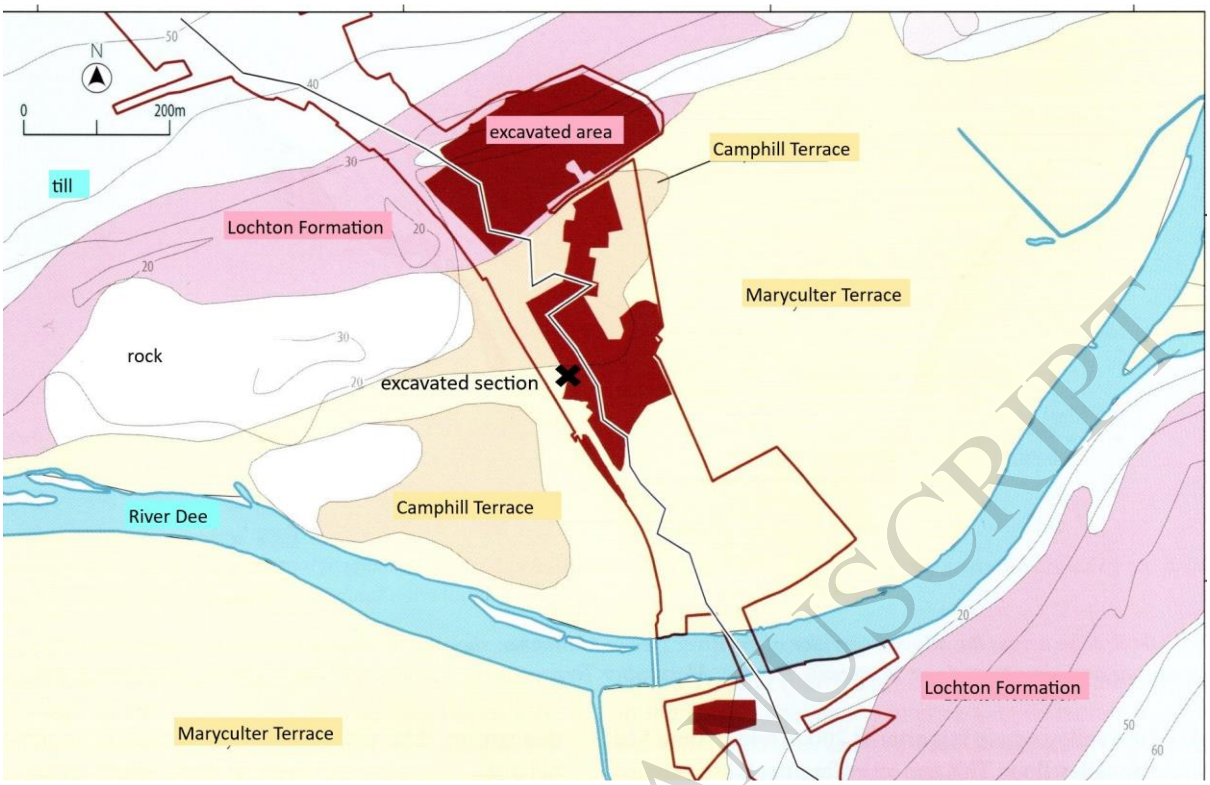

N
0
200m
till
Lochton Formation
excavated area
Camphill Terrace
Maryculter Terrace
rock
excavated section
Camphill Terrace
River Dee
Lochton Formation
Maryculter Terrace

Figure 7

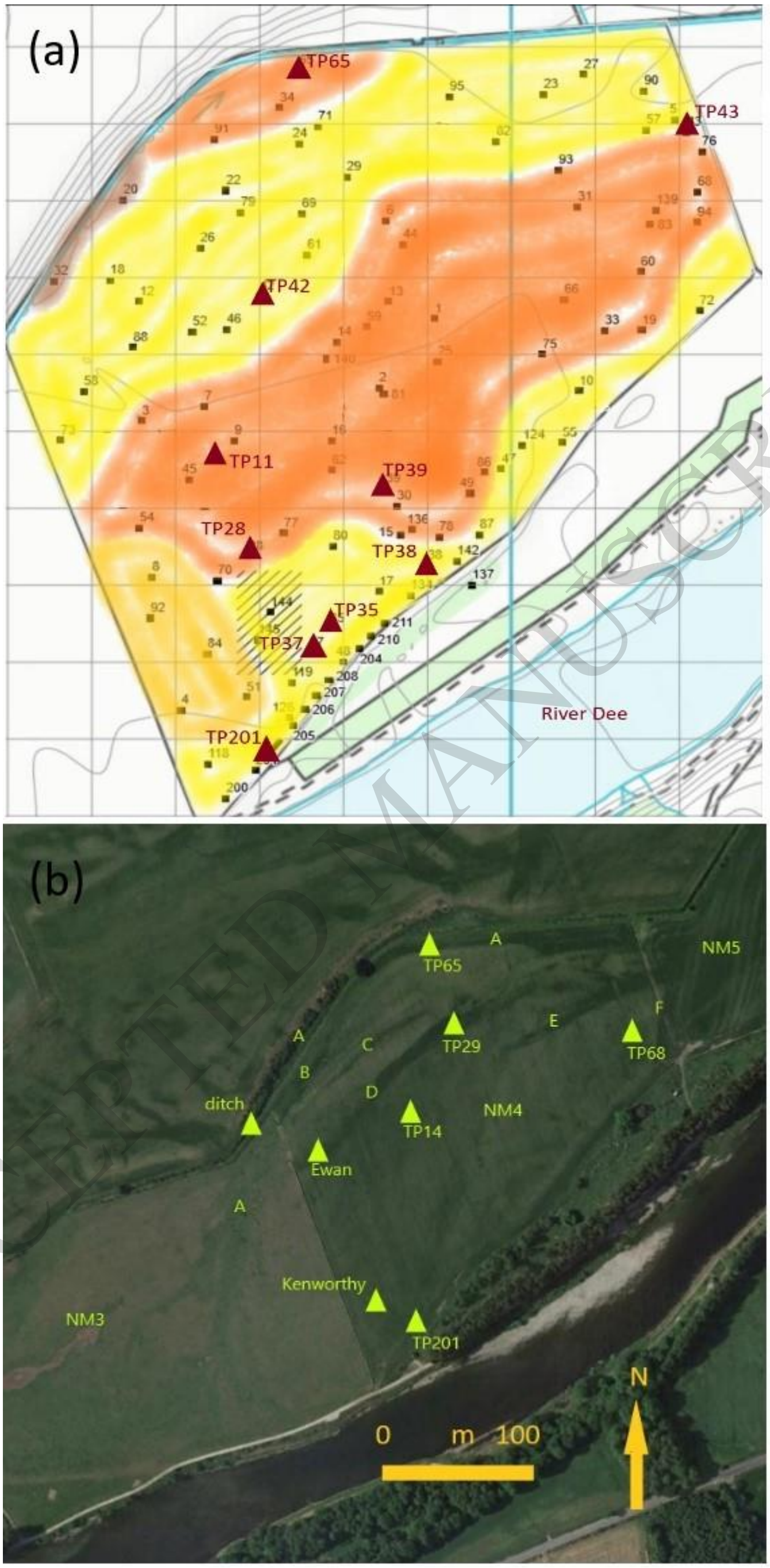
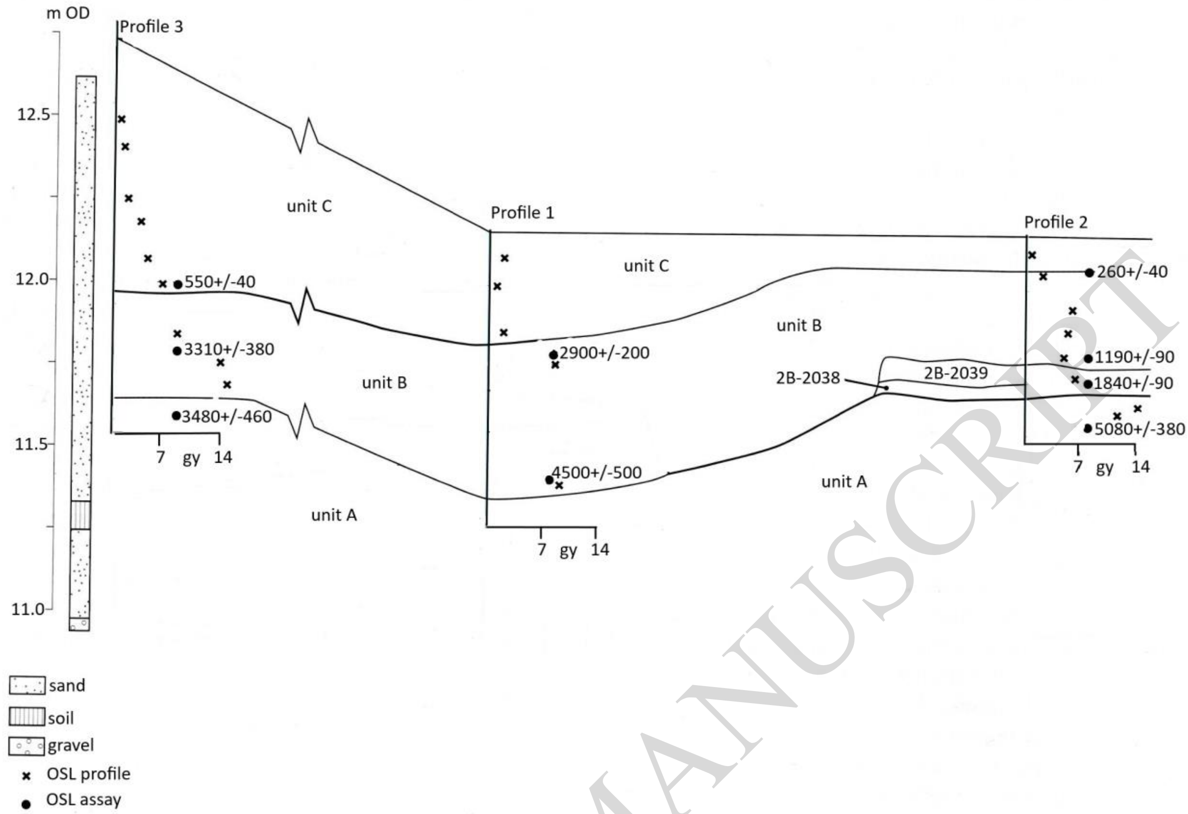

(a)
TP65
TP43
TP42
TP11
TP39
TP28
TP38
TP35
TP37
TP201
River Dee
(b)
TP65
A
NM5
TP29
E
F
TP68
A
B
C
D
ditch
TP14
NM4
Ewan
A
Kenworthy
TP201
NM3
0 m 100
N

Figure 8


m OD
12.5
12.0
11.5
11.0
Profile 3
Profile 1
Profile 2
unit C
unit B
unit A
550+/-40
3310+/-380
3480+/-460
2900+/-200
4500+/-500
260+/-40
1190+/-90
1840+/-90
5080+/-380
2B-2038
2B-2039
7 gy 14
sand
soil
gravel
OSL profile
OSL assay

Terrace (this study)	*BGS nomenclature*	*Height above the water surface and slope*	*Fragments and linear correlation*	*Composition*
Lochton	Lochton Sand & Gravel Formation	15.5–17.0 m (2.0 m/km)	23 (r^2 0.969)	gravel
Maryfield	Lochton Sand & Gravel Formation	9.5–11.0 m (1.7 m/km)	12 (r^2 0.988)	gravel
Toll House	?	*c.* 6 m		?
Camphill	river terrace deposits (undifferentiated) gravel, sand and silt	4–5 m (1.9 m/km)	20 (r^2 0.980)	sand over gravel
Maryculter	alluvium	2–3 m (2.0 m/km)	17 (r^2 0.992)	sand

TP201		TP38		TP35		TP39		TP28		TP11		TP43		TP42		TP65	
Depth	%	Depth	%	Depth	%	Depth	%	Depth	%	Depth	%	Depth	%	Depth	%	Depth	%
												36	0.3				
35	0.4											45	0.4				
43	0.6																
												55	1.2				
						67	1.5										
48	1.6																
						78	1.8			44	1.8						
										52	2.6						
								32	2.7								
								47	3.0								
										103	3.2						
						85	4.0										
														58	4.7		
		100	5.4														
		107	5.4														
		123	5.4														
		143	5.4														
										110	5.5						
								56	5.8								
								68	6.3								
						120	7.6										
55	7.9																
				84.0	8.4												
				91.0	8.4												
				96.0	8.4												
				103.0	8.4												
62	9.9																
										123	10.6						
100	10.8																
								89	10.9								
												64	11.9				
113	16.8																
								105	18.0								
						91	19.1										
														75	19.5		
								113	19.9								
								121	26.4								
														90	82.6		
														100	82.8		
																110	91.9
														111	100.0		
sand	gravel																

SUTL	Profile	Unit	Dose rate /mGy a^{-1}	Equivalent dose /Gy	Years / ka	Years 2bK
2727	1	base of unit C	3.20 ± 0.21	9.3 ± 0.6 (0.2)	2.91 ± 0.20	3900 ±200
2728	1	base of unit B	3.23 ± 0.17	14.6 ± 1.5 (0.3)	4.52 ± 0.26	4500 ±500
2729	2	Base of unit C	3.59 ± 0.26	1.0 ± 0.1 (0.02)	0.28 ± 0.02	260 ± 40
2730	2	within unit C	3.53 ± 0.24	4.3 ± 0.3 (0.07)	1.20 ± 0.08	1190 ± 90
2731	2	top of unit A	3.96 ± 0.12	20.2 ± 1.4 (0.4)	5.10 ± 0.19	5080 ±380
2733	2	2B-2038	3.09 ± 0.14	5.9 ± 0.1 (0.07)	1.83 ± 0.08	1820 ± 90
2734	3	base of unit C	3.74 ± 0.19	2.1 ± 0.3 (0.06)	0.57 ± 0.03	550 ± 40
2735	3	Within unit B	3.63 ± 0.16	12.1 ± 1.2 (0.4)	3.33 ± 0.19	3310 ±360
2736	3	Top of unit A	3.40 ± 0.15	11.9 ± 1.5 (0.5)	3.49 ± 0.22	3480 ±460