Site 18 Mill of Dyce Quarry

The sequence at Mill of Dyce, on Sheet 77 (Map 9), provides an insight into the sedimentary environments that were associated with ponding of glacial lakes in the major valleys during Late Devensian deglaciation. It indicates that retreat of a glacier in the Don valley was punctuated by a stillstand, during which an ice-contact delta accumulated in a proglacial lake downstream from the site. Radiocarbon dating of intercalated organic sediments towards the top of the sequence also controversially suggests that glacier ice remained buried within the delta sediments, until at least 11 550 ^{14}C years BP. It also implies that a later lake was impounded behind the delta, until at least the latter stages of the Windermere Interstadial.

Quarrying at the Mill of Dyce (formerly known as the St Fergus) sand and gravel pit has revealed an extensively deformed succession of diamicton, gravel and sand which pass laterally into less deformed sediments. The pit [NJ 871 152] is located in the valley of the River Don, 11 km north-west of Aberdeen. It was excavated into moundy topography principally underlain by sand and gravel. These glacial sediments infill the valley, although the river has cut a narrow channel through their northern margin

(Figure A1.22). Much of the moundy ground has been quarried away and the workings largely backfilled and landscaped, but in 1989 the unquarried portion reached an elevation of about 55 m above OD. The western margin of the moundy ground is an abrupt scarp (ice-contact) slope, whereas to the east the mounds merge into an undulating glaciofluvial terrace, which has been modified by excavations and landscaping associated with the expansion of industrial estates on the periphery of Dyce.

Exposures in the Mill of Dyce pit

Previous descriptions of the sediments at Mill of Dyce (Murdoch, 1975, 1977; Peacock *in* Harkness and Wilson, 1979; Auton and Crofts, 1986) have been reviewed by Aitken (1995). Murdoch (1977) recognised three sedimentary units at the pit. His basal unit, comprised up to 6 m of medium-grained sand typically showing very large-scale, planar cross-bedding, dipping at 28° towards the south-east. Murdoch's middle unit, comprised 6 to 8 m of poorly sorted bouldery gravel that was highly contorted (dips of 32° were common, and locally bedding was near vertical). Characteristically, the amount of deformation declined upwards within the exposures. Murdoch's top unit comprised bedded, fine-grained sand, which locally capped the succession and was best developed in swales between hummocks. He interpreted the basal unit as being of deltaic (possibly subglacial) origin, his middle unit as being a supraglacial deposit, deformed by the melting of underlying buried ice, and the uppermost unit as a later stage of subaerial fluvial deposition.

The coarsening-upward sequence exposed in the Mill of Dyce pit during 1984 was recorded as exceeding 16.2 m in thickness (Auton and Crofts, 1986). The succession included a lower unit of clayey sand, greater than 5.2 m thick, and cross-bedded in its upper 4 m. The sand was overlain by 10 m of poorly bedded gravel with boulders at the top. The gravel was overlain, in places, by up to 0.7 m of bouldery diamicton. Clasts within the gravel and the diamicton comprised a mixture of Dalradian metamorphic and Caledonian igneous rock types.

Exposures in the pit during 1988 and 1989 were logged in detail by Aitken (1995), who recognised five lithofacies associations (LFA). The main characteristics of each association are given in (Table A1.10); their relationships and interpreted palaeoenvironments are shown in (Figure A1.22).

LFA 1

LFA 1 occurred in the floor of the pit and was interpreted by Aitken (1995) as representing mainly deltaic bottomsets, with the cross-bedded upper parts of the association indicating a transition into foresets.

LFA 2

LFA 2 was exposed in the northern parts of the pit. It was interpreted as representing the cores of longitudinal or medial bars formed by proximal braided glaciofluvial drainage. The deformation structures were interpreted as indicating collapse following melting of buried glacial ice.

LFA 3

LFA 3 of Aitken, which probably equates with Murdoch's middle unit, graded laterally into LFA 2. It was interpreted as an ice-marginal deposit derived, in part, from basal debris carried upwards through the ice along shear planes to reach the snout of a glacier, which occupied the valley of the River Don to the west (upstream) of the Mill of Dyce. The debris was subsequently reworked by cohesionless debris flows and supraglacial and englacial meltwaters, to produce the better sorted sands and imbricated gravels.

LFA 4

LFA 4 cropped out in the western face of quarry, adjacent to the ice-contact slope forming the western margin of the moundy deposits. It graded laterally into LFA 3. The sediments of LFA 4 were also interpreted as ice-contact deposits formed by in situ melt-out of debris-rich ice and resedimented by debris flows. Thus, much of the deformation was attributed to postdepositional loading or ice-push. Lenses of finer grained sediments, seen at the top of the association, were interpreted as kettlehole infills.

LFA 5

LFA 5 was restricted to swales in the upper surface of the moundy deposits and equates with Murdoch's upper unit. Aitken interpreted these sediments as lacustrine overspill deposits, laid down by high-energy unidirectional waterflows.

In one exposure [NJ 8713 1496] at 40 to 45 m above OD, visible in 1979, but since quarried away, Murdoch's middle and upper units (Aitken's LFAs 3 and 5) were separated by an organic layer (J D Peacock, personal. communication, in Aitken, 1995). A unit of fine- to coarse-grained sand greater than 1 m thick, with beds and masses of coarse-grained gravel, locally dipping at 80° (equivalent to Murdoch's middle unit), was overlain by an organic bed 3 m long and 32 cm thick. It consisted of grey, silty clay, thinly interbedded with organic sediment containing plant remains (including twigs) in beds 2 cm thick, dipping at 34°. The organic sediments were overlain by a 3 cm-thick yellow-brown clay that was, in turn, conformably overlain by 3 m of sand with interbedded cobble gravel. The gravel was disposed in a synclinal ice-collapse structure, truncated by 2 m of subhorizontally bedded coarse-grained sand with a thin gravel layer locally present at its base. The latter is taken to be equivalent to Murdoch's upper unit, and dipped at 54° locally.

Radiocarbon dating of the upper and basal 5 cm of the organic deposit gave ages of 11 550 ± 80 BP (SRR–762) and 11 640 ± 70 BP (SRR–763), respectively (Harkness and Wilson, 1979; (Table 8)). Peacock (*in* Harkness and Wilson, 1979) suggested that the organic material was deposited in a fluvial backwater and that disturbance of the bed was caused by the melting of buried ice. This implies that, if the radiocarbon ages are correct, the final melting of buried glacier ice at Mill of Dyce postdated 11 550 BP, a view accepted by Auton and Crofts (1986), Munro (1986) and Aitken (1995).

Borehole and mapping evidence

Several boreholes were sunk by BGS in the vicinity of the Mill of Dyce pit during 1984. Borehole NJ81SE/17 to the east of the pit, sited on top of a dissected mound at 44 m OD, proved laminated, micaceous, pale grey-brown silt and clayey sand with scattered pebbles between 10.2 and 12.2 m depth overlying more than 7.9 m of sandy gravel. The laminated sediment was overlain by a 6.9 m-thick coarsening-upward sequence of sandy gravel that was overlain in turn by 1.3 m of clayey sand. Boreholes sited on the floodplain to the west of the site clearly show that this part of the Don valley occupies a glacially overdeepened basin, infilled by sandy silts, which in Borehole NJ81NE/1 exceed 16.2 m in thickness. These silty deposits (Glen Dye Silts Formation) extend upstream from Mill of Dyce for a distance of at least 7.3 km (Aitken, 1991) and crop out in the frontal bluffs of terraces, on the north side of the valley, up to about 50 m above OD.

In many boreholes and trial pits, sited on the floodplain of the River Don near Kintore, the laminated silts are overlain by sands and gravels containing interbedded organic sediments (Auton and Crofts, 1986; Aitken, 1991). Palaeontological examination and radiocarbon dating indicate, however, that these organic sediments are of late Holocene rather than Windermere Interstadial age (see Site 20 Nether Daugh, Kintore).

Sedimentological interpretation of the Mill of Dyce sequence

All of the laminated silty deposits in the vicinity of the Mill of Dyce have been interpreted as glaciolacustrine deposits (Auton and Crofts, 1986; Aitken, 1995) and their presence has important implications for interpretation of the lithofacies that were seen in the pit. This interpretation agrees in most aspects with the model presented by Aitken (1995), which differs from that of Murdoch (1977), who suggested that much of the sequence in the Mill of Dyce pit was deposited as a subglacial delta. Subsequent investigations (Auton and Crofts, 1986; Aitken, 1995) indicate that much of the pit sequence represents an ice-marginal delta which prograded into a lake ponded by ice downstream (Figure A1.21). The lake level, which at its maximum probably stood at about 50 m above OD, varied as a result of periodic outflow, either subglacially or englacially, through the ice dam.

Deposition at Mill of Dyce commenced by the laying down of coarse ice-proximal gravels by high-discharge, sediment-laden streams and debris flows near the mouths of meltwater conduits at an ice margin. It occured during a stillstand in the active retreat of a glacier in the Don valley. The debris flow deposits, which have been extensively deformed, pass down dip into less deformed gravels that were deposited by sediment-laden meltwater streams. Deformation of the proximal gravels resulted from a combination of collapse, owing to the melting both of buried and buttressing ice, and ice push resulting from minor fluctuations of the ice margin. Both gravel deposits directly overlie sandy foresets in parts of the pit. The foresets represent progradation of the delta into the lake during periods of stable lake level. In places, foresets pass gradationally into bottomsets that were deposited by a combination of small-scale turbidity flows and sedimentation from suspension. The absence of dropstones in the bottomset beds may indicate that the ice margin had little direct contact with the ponded water body while the bottomsets were being deposited.

In the northern parts of the pit, the bottomset beds were overlain, with an erosive contact, by proximal braided outwash gravels. The latter were laid down during periods of delta incision and consequent erosion of any pre-existing foresets. Incision occurred as a result of the periodic falls in the level of the proglacial lake. Localised deformation of these gravels resulted from collapse owing to meltout of buried blocks of ice.

If Aitken's interpretation of the sediments of LFA 1 at Mill of Dyce as lacustrine overspill deposits is correct, the youngest deposits were laid down after glacier ice had retreated from the Don valley. This retreat left a lake, upstream of Mill of Dyce, ponded by the debris flow and deltaic deposits, and the ice buried within them. In this model, lake overspill eventually incised the upper part of the deltaic sequence and deposited relatively thin, coarse-grained sands on top of the Late-glacial organic sediments at low points on the abandoned delta surface. If the radiocarbon dates on the organic material and the palaoenvironmental interpretation of LFA 1 are accepted, they imply that a deep lake survived, upstream of Mill of Dyce, through at least most of the relatively warm Windermere Interstadial; final drainage occurred some time after 11 550 BP.

Pattern of deglaciation in the adjacent area

The sequence recorded from the Mill of Dyce forms part of a complex suite of Late Devensian glaciofluvial deposits, laid down in the Don valley by meltwaters derived from the East Grampian ice sheet as it retreated westwards. Much of the sediment that was exposed at Mill of Dyce accumulated at a relatively late stage in this deglaciation. At an earlier stage, East Grampian ice and its associated meltwater drainage flowed directly eastwards, across the northern interfluve of the present river, towards the coastal ice stream responsible for laying down deposits of the Logie-Buchan Drift Group. The glaciofluvial sands and gravels deposited by the inland meltwaters, form flat-topped mounds and hummocky ridges, orientated east to west, extending between Mill of Dyce and Corby Loch [NJ 924 145] (Auton and Crofts, 1986). The sediments are well exposed in Lochhills pit [NJ 912 147], where the sequence is similar in many respects to that formerly exposed at Mill of Dyce.

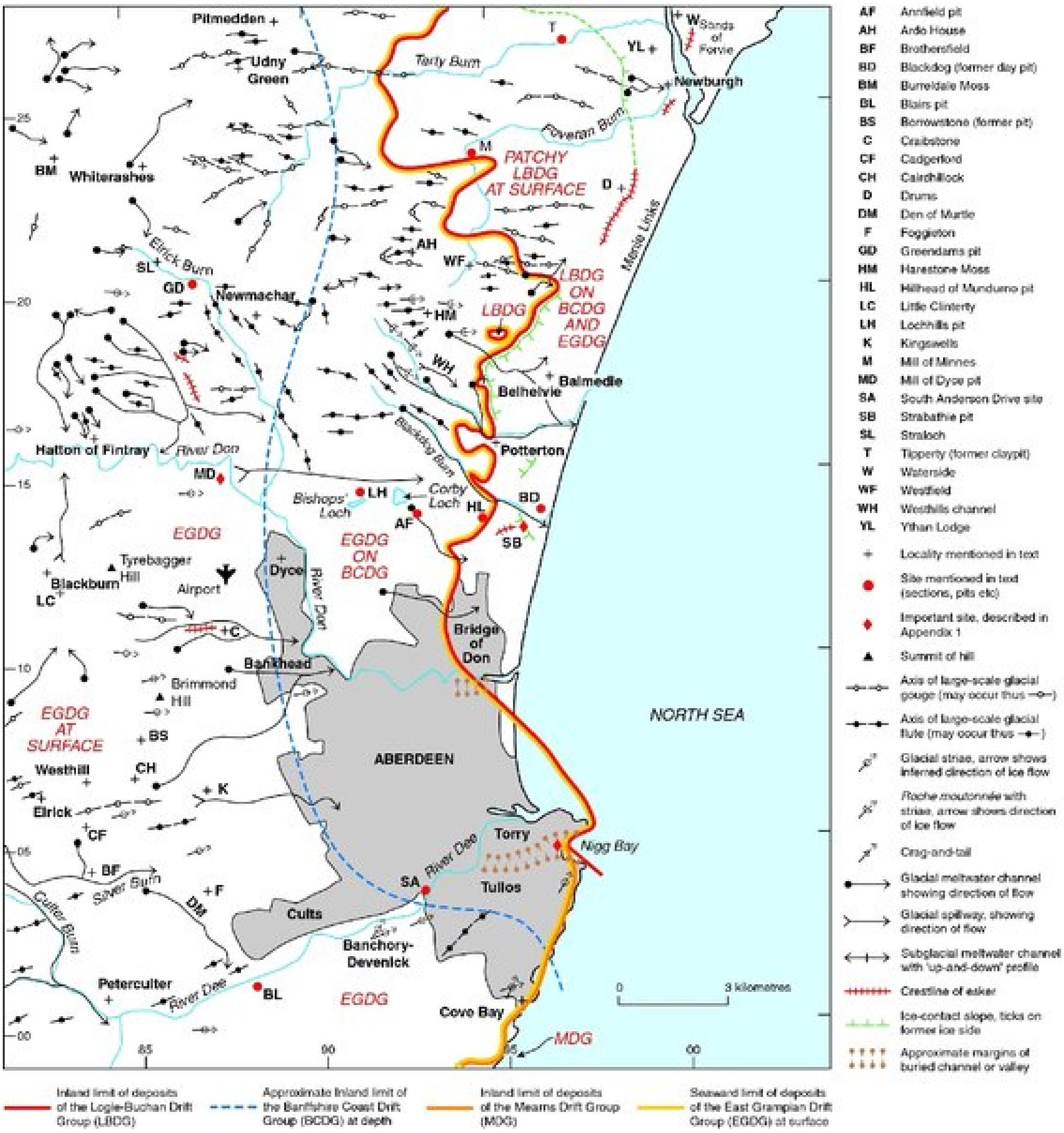
Foreset bedding at Lochhills pit, and in several former workings around Corby Loch, indicates that many of the sequences were laid down as ice-contact fans and deltas (Aitken, 1998). The tops of the deltas indicate that water levels reached heights of up to 91 m above OD, probably ponded between coastal ice and retreating East Grampian ice. Further evidence of the confluence of the ice masses comes from the complex assemblage of northerly and easterly trending moundy outwash deposits occurring between Corby Loch and Potterton (Murdoch, 1975; Munro, 1986). The orientations of these features indicate the contrasting patterns of meltwater drainage that were associated with retreat of the East Grampian and coastal ice sheets.

It is likely that the ice emanating from the Dee valley caused the initial ponding in the Don valley immediately downstream of Mill of Dyce, diverting meltwaters towards Corby Loch. It is also likely that any sediments blocking the valley hereabouts would not have been dissected by drainage until the regional water table had lowered following the decay of the coastal ice stream and/or of sea level, possibly from a height of about 30 m OD.

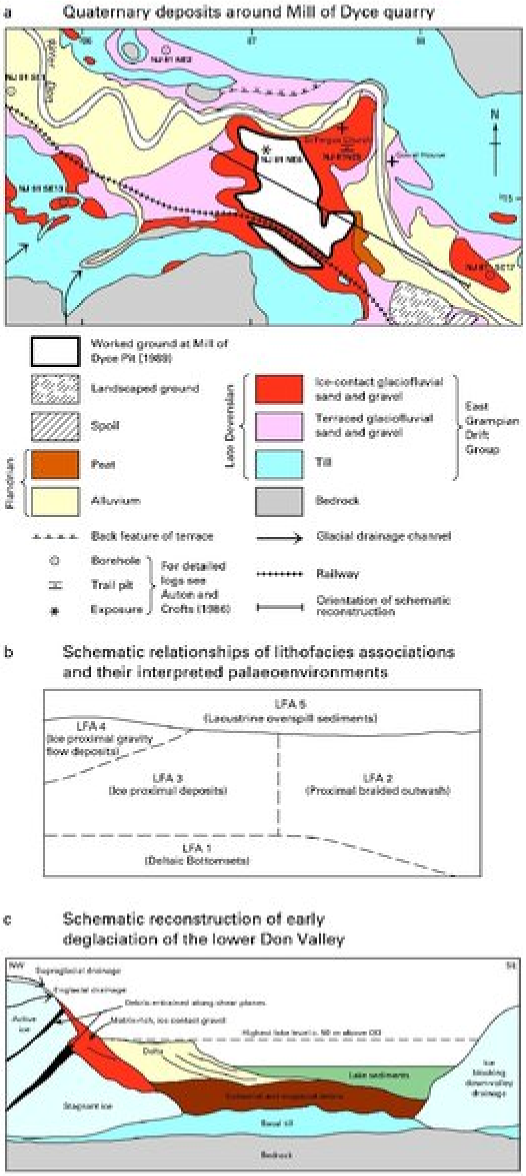
(Table A1.10) Lithofacies associations at Mill of Dyce Pit.

Lithofacies Association (LFA)	Main sediment types	Stratification	Palaeocurrent directions	Other structures
5	Medium- to coarse-grained sand with scattered pebbles	Small-scale planar cross-bedding		
4	Mixture of diamicton, boulders, gravel, sand and silt	Crude bedding in cliamicton and boulder gravel, ripples and cross-bedding in sand, pebble and cobble stringers		Chaotic upright open folds, slumps and normal faults
3	Poorly sorted matrix-rich boulder gravel, pods of open-work gravel, minor sand lenses	Crude, discontinuous bedding with cobble and pebble lags, minor planar, ripple and trough cross-bedding in sandy units	Towards 066° (imbrication in open-work gravel)	Vestigial folds
2	Poorly sorted matrix-rich gravel; subordinate interbeds and lenses of sand, open-work gravel	Crude, some horizontal bedding, erosional bases in matrix-rich gravel; imbrication in open-work gravel	Towards 119° (gravel imbrication)	Possible frost-wedges; steep, tight to open folds in gravel (dips up to 80°)
1	Fine- to medium-grained sand; minor silt	Planar cross-bedding, climbing ripples, horizontal bedding, large-scale trough cross-bedding; horizontal lamination in silt	Towards 090° and 100° (climbing ripples); towardsl 52° (planar cross-bedding); towards 040° (trough cross-bedding)	–

References



(Map 9) Glacial and glaciofluvial features and the distribution of glacigenic deposits on Sheet 77 Aberdeen.



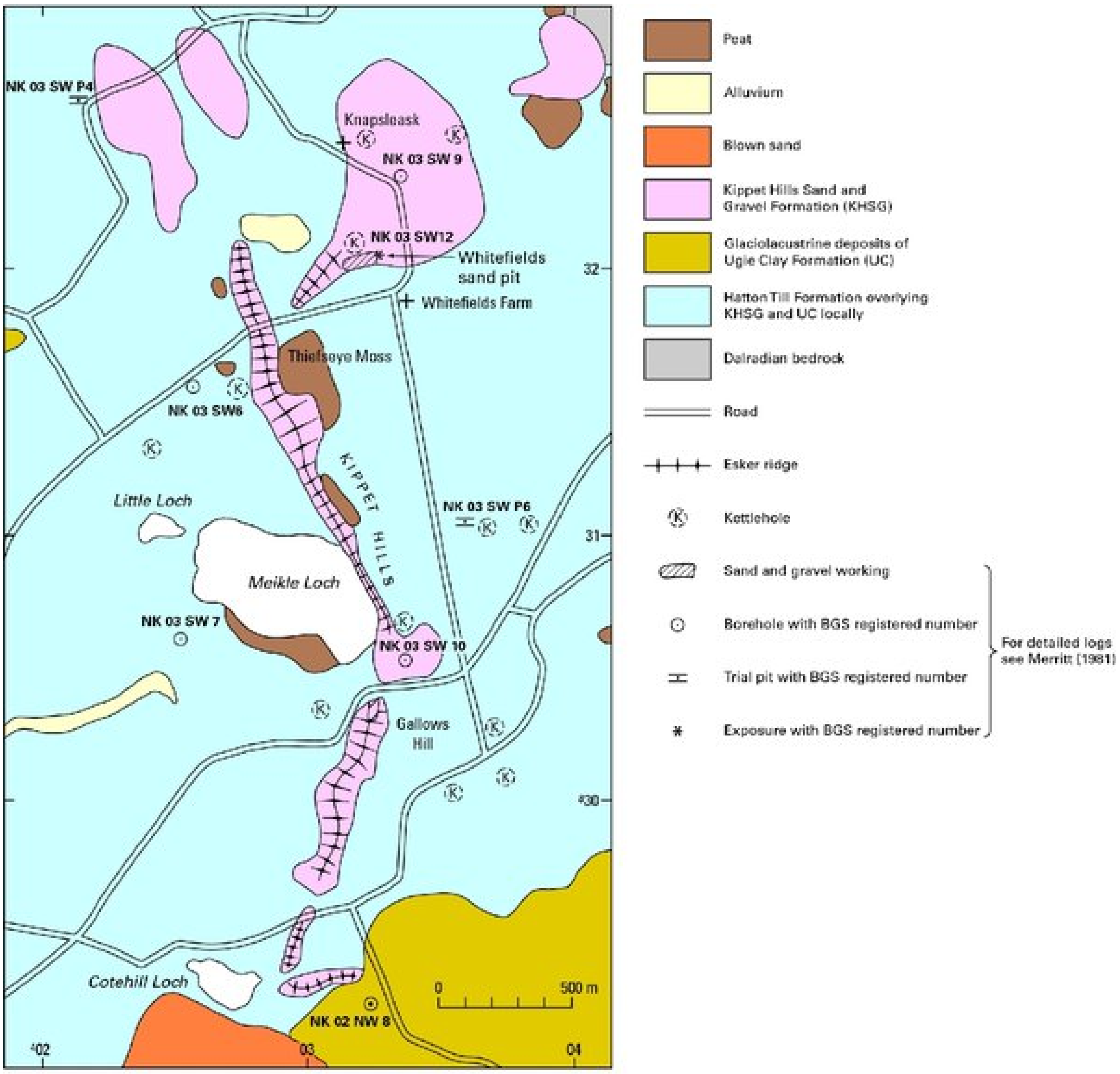
(Figure A1.22) Mill of Dyce sand and gravel quarry and the deglaciation of the lower Don valley.

Lithofacies Association (LFA)	Main sediment types	Stratification	Palaeocurrent directions	Other structures
5	Medium- to coarse-grained sand with scattered pebbles	Small-scale planar cross-bedding	~	~
4	Mixture of diamicton, boulders, gravel, sand and silt	Crude bedding in diamicton and boulder gravel, ripples and cross-bedding in sand, pebble and cobble stringers	~	Chaotic upright open folds, slumps and normal faults
3	Poorly sorted matrix-rich boulder gravel, pods of open-work gravel, minor sand lenses	Crude, discontinuous bedding with cobble and pebble lags, minor planar, ripple and trough cross-bedding in sandy units	Towards 066° (imbrication in open-work gravel)	Vestigial folds
2	Poorly sorted matrix-rich gravel; subordinate interbeds and lenses of sand, open-work gravel	Crude, some horizontal bedding, erosional bases in matrix-rich gravel; imbrication in open-work gravel	Towards 119° (gravel imbrication)	Possible frost-wedges; steep, tight to open folds in gravel (dips up to 80°)
1	Fine- to medium-grained sand; minor silt	Planar cross-bedding, climbing ripples, horizontal bedding, large-scale trough cross-bedding; horizontal lamination in silt	Towards 090° and 100° (climbing ripples); towards152° (planar cross-bedding); towards 040° (trough cross-bedding)	~

(Table A1.10) Lithofacies associations at Mill of Dyce Pit.

Site	Grid reference	Laboratory number	Age (years BP)	Dated material and setting	Reference
Rothes cutting	NJ 277 498	Beta-86532	11 110 ± 70	peat under remobilised till	Appendix 1
Garral Hill, Keith	NJ 444 551	Q-104	10 808 ± 230	peat under remobilised till	Godwin and Willis (1959)
Garral Hill, Keith	NJ 444 551	Q-103	11 098 ± 235	peat under remobilised till	Godwin and Willis (1959)
Garral Hill, Keith	NJ 444 551	Q-102	11 308 ± 245	peat under remobilised till	Godwin and Willis (1959)
Garral Hill, Keith	NJ 444 551	Q-101	11 888 ± 225	peat under remobilised till	Godwin and Willis (1959)
Garral Hill, Keith	NJ 444 551	Q-100	11 358 ± 300	peat under remobilised till	Godwin and Willis (1959)
Woodhead, Fyvie	NJ 788 384	SRR-1723	10 780 ± 50	peat under remobilised till	Connell and Hall (1987)
Howe of Byth	NJ 822 571	SRR-4830	11320	peat beneath gravel	Hall et al. (1995)
Moss side, Tarves	NJ 833 318	I 6969	12 200 ± 170	peat under remobilised till	Clapperton and Sugden (1977)
Loch of Park	NO 772 988	HEL-416	10 280 ± 220	kettlehole infill	Vasari and Vasari (1968)
Loch of Park		HEL-417	11 900 ± 260	kettlehole infill	Vasari and Vasari (1968)
Mill of Dyce	NJ 8713 1496	SRR 762	11 550 ± 80	kettlehole infill	Harkness and Wilson (1979)
Mill of Dyce	NJ 8713 1496	SRR-763	11 640 ± 70	kettlehole infill	Harkness and Wilson (1979)
Glenbervie	NO 767 801	GX-14723	12 460 ± 130	peat under remobilised till	Appendix 1
Glenbervie	NO 767 801	SRR-3687a (humic)	12 305 ± 50	peat under remobilised till	Appendix 1
Glenbervie	NO 767 801	SRR-3687b (humin)	12 340 ± 50	peat under remobilised till	Appendix 1
Brinzieshill Farm	NO 7930 7918	SRR-387	12 390 ± 100	peat under remobilised till	Auton et al. (2000)
Rothens	NJ 688 171	SRR-3803	10 680 ± 100	kettlehole infill	Appendix 1
Rothens	NJ 688 171	SRR-3804	11 640 ± 160	kettlehole infill	Appendix 1
Rothens	NJ 688 171	SRR-3805	11 760 ± 140	kettlehole infill	Appendix 1

(Table 8) Radiocarbon dates from Late-glacial sites in the district.



(Figure A1.21) Quaternary deposits and landforms of the Kippet Hills area.