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Despite over a century of research, the record of events prior to deglaciation of the main Late Devensian ice sheet on land is less well understood than offshore. This is mainly because of the fragmentary nature of terrestrial deposits, the scarcity of organic material that is suitable for dating by radiocarbon methods and the relative unreliability of age determining methods beyond the range of radiocarbon dating, such as thermoluminescence (TL) techniques and amino-acid geochronology. Although more information is normally available at onshore sites compared to boreholes offshore, the absence of seismostratigraphy and palaeomagnetic chronology makes any correlation between those sites very difficult indeed. A summary of the important events is given in [P915341].

The hierarchy and description of named lithostratigraphical units are given in The groups, and correlations between these units and the Oxygen Isotope Stages are presented in P915347. Many correlations between units are based on a ‘count from the top’ basis, which means that any reinterpretation of the status of the uppermost unit has consequences for others lower in the sequence.
Early Quaternary (2.44 to 0.78 Ma)

No Early Quaternary deposits have been identified in north-east Scotland, but mollusc shell fragments in the Kippet Hills Sand and Gravel Formation of the Logie-Buchan Drift Group have most probably been derived from the Aberdeen Ground Formation lying offshore. The Early Pleistocene age assigned to the shells on faunal grounds by Jamieson (1882a) has been confirmed by amino-acid analysis (Kippet Hills).

Middle Quaternary (0.78 Ma to 130 ka)

Anglian glaciation (OIS 12) (=Elsterian)

The oldest known deposits in the district have been found at Kirkhill (Connell et al., 1982). The basal fluvial or glaciofluvial sands and gravels at this site contain erratics derived from the west, as does the basal till (Leys Till Formation) occurring nearby. The two units were originally assigned to the Anglian glaciation on the basis of minimum ages for the overlying glacial and interglacial deposits using a simple chronostratigraphical model (Connell and Hall, 1984a; Hall and Connell, 1991). However, they are now assigned tentatively to OIS 8 on the basis of new luminescence dates on the Corse Gelifluctate Bed higher in the sequence (P915347).

Glacial erratics of Norwegian origin are relatively common within glacigenic deposits in north-east Scotland (Read et al., 1923; Bremner, 1939; Hall and Connell, 1991). Although none of these clasts occurs in a till assigned to OIS 12, it is possible that they were transported to north-east Scotland during that stage (Ehlers, 1988).

Hoxnian interglacial (OIS 11) (=Holsteinian)

The oceanic climate record of the North Atlantic suggests that there have been only two periods in the last 600 ka that were as warm, or warmer, than the Holocene, namely the Hoxnian (OIS 11) and Ipswichian (OIS 5e) interglacials (Ruddiman and McIntyre, 1976). Other interglacials were temperate (e.g. OIS 9 and 7), but probably not as warm. The sands overlying the Kirkhill Palaeosol Bed (Lower Buried Soil) at Kirkhill contain detrital organic matter derived from the erosion of soil and vegetation formed in an interglacial climate, presumed from its stratigraphical position to be Hoxnian (Connell, 1984a; Lowe, 1984). The presence of pollen grains of pine, alder and lime appear to corroborate this presumption. However, while an OIS 11 age cannot be confirmed, the absence of significant unconformities within the Kirkhill sequence indicate that the soil and overlying organic sediment (Corse Gelifluctate Bed) may date from OIS 7, as indicated by luminescence dates reported by Duller et al. (1995). The Kirkhill Palaeosol Bed itself was originally thought to be of interglacial origin (Connell et al., 1982), but has also been compared to a cold-water gley soil formed in an interstadial climate (Connell and Romans, 1984). However, the strong development of the truncated Ea horizon, together with the presence of the mineral proto-imogite/allophane in the Bs horizon Kirkhill and Leys, suggests the interglacial interpretation is correct. The nearest other site with a possible Hoxnian record is Dalcharn, near Inverness, where the presence of significant quantities of holly pollen implies that the palaeosol there did form in a particularly warm interglacial (Walker et al., 1992). However, there too, subsequently obtained luminescence dates suggest a much younger age (Duller et al. (1995)).
Wolstonian glaciation(s) (OIS 6-10) (=Warthe/Saal/Drenthe/Fuhne)

Two distinct phases of ‘Saalian’ glaciation are thought to have affected continental north-west Europe during this period (Ehlers et al., 1991) and three regional glaciations affected the North Sea basin (Sejrup et al., 2000), but no equivalent terrestrial glacial deposits have been shown unequivocally to occur in Scotland. Several tills in north-east Scotland may date to this period, but arguments for their ‘Wolstonian’ age rely mainly on indirect evidence. This includes stratigraphical position, whether the tills are judged to have been weathered in an interglacial climate (as against incorporating materials weathered previously) and whether that weathering is judged to have occurred in the Ipswichian (OIS 5e). The Rottenhill Till (Kirkhill Lower Till) has been assigned to the ‘Wolstonian’ (Hall, 1984; Hall and Connell, 1991; Appendix 1) and luminescence dates from Leys Quarry nearby apparently confirm an OIS 6 age for the unit. Several other tills have been correlated with the Rottenhill Till (P915347), including the Red Burn Till at Teindland (Hall et al., 1995a), the Camp Fauld Till (Corse of Balloch Till) on the ‘Buchan Ridge’ (Whittington et al., 1993), the supposedly weathered ‘Kings Cross’ till at Aberdeen (Synge, 1963), the Craig of Boyne Till at Boyne Bay (Connell and Hall, 1984b; Peacock and Merritt, 2000), and the Bellscamphie Till near Ellon (Hall and Jarvis, 1995). Apart from the last two named tills, the others were laid down by ice that flowed out of the Moray Firth and south-eastwards across Buchan towards Aberdeen (see ice sheet models below). A ‘Wolstonian’ age is also likely for the Benholm Clay Formation occurring to the south of Inverbervie (Auton et al., 2000; Site 26 Burn of Benholm).

Late Quaternary (130 ka to the present day)

Ipswichian Interglacial (OIS 5e) (=Eemian)

Evidence from England and continental north-west Europe indicates that at least the early part of the last interglacial was a little warmer than the present day (Aalbersberg and Litt, 1998). Teindland and Kirkhill represent two of the four sites in Scotland at which organic deposits or palaeosols have been assigned to the Ipswichian (Sutherland and Gordon, 1993). Lowe (1984) disagreed with Fitz-Patrick (1965) and Edwards et al. (1976) that the Teindland Palaeosol Bed (Teindland Buried Soil) could not be attributed to the interglacial with any confidence, but more recent work there, and at Red Burn nearby, largely confirms the earlier conclusions (Hall et al., 1995a; Site 1 Teindland). For example, the soil contains pollen indicative of deposition towards the end of an interglacial with the progressive replacement of hazel-alder woodland, first by pine woodland, then by heathland and, ultimately, sparse grassland. Luminescence dating suggests an Ipswichian age.

The truncated Backfolds Palaeosol Bed (Kirkhill Upper Buried Soil) is now more confidently assigned to the Ipswichian, following the acquisition of new luminescence dates on sediments underlying it at Leys (Duller et al., 1995). Other supposed interglacial deposits at Tipperty and Balmedie (Bremner, 1938, 1943), north of Aberdeen, and at King’s Cross (Synge, 1963) in Aberdeen, have not been confirmed (Peacock, 1980; Edwards and Connell, 1981). Another site at Errollston, Cruden Bay (Site 17 Errollston Clay Pit), includes pre-Quaternary palynomorphs and clearly contains much reworked material (Peacock, 1984b; Connell et al., 1985). Reworked shell fragments of Ipswichian age are possibly present at Site 16 Kippet Hills.

Early Devensian (OIS 5a-d) (=Early Weichselian)
British and north-west European chronostratigraphy. P915253.

The ‘SPECMAP’ oxygen isotope curve for the last glacial-interglacial cycle. P915254.

The north-west European pollen and beetle record indicates that the last interglacial was followed by two short, cold stadials (the Herning 5d and Rederstall 5b) separated by cool and wet interstadials (the Brörup 5c and Odderade 5a) (Aalbersberg and Litt, 1998; P915253; P915254). Organic deposits of one or more of these interstadial periods appear to be more common in Scotland than those of the Ipswichian, possibly because the conditions were more conducive to the accumulation of peat. The most complete record in the region of an early Devensian interstadial, probably 5c, comes from the Allt Odhar site, near Inverness (Walker et al., 1992). Here, the pollen and beetle evidence indicates deteriorating climatic conditions towards the end of a cool interstadial as reflected in the replacement of birch woodland and willow scrub with grassland and heath, and then by open communities of grass and sedges. The record of the latter stages of this interstadial, followed by a colder phase of tundra environment, may be represented at both the Camp Fauld and Crossbrae sites in Buchan (Whittington et al., 1998; P915347; Sites 5 Crossbrae Farm, Turriff and 14 Moss of Cruden). The Burn of Benholm Peat Bed at the Benholm site, south of Inverbervie (Site 26 Burn of Benholm), is also now correlated tentatively on pollen evidence with OIS 5a or 5c (Auton et al., 2000).
Devensian–Weichselian events in Britain and south-west Fennoscandia. P915290.

Evidence of major glaciation was formerly reported during OIS 5d and 5b in the north-west Fennoscandian record (Baumann et al., 1995; Mangerud et al., 1996), but it now seems that only limited glaciation occurred (Sejrup et al., 2000; P915290).

Early Devensian glaciation (OIS 4)

It has been suggested for some time (Sutherland, 1981) that much of Scotland was glaciated during this very cold stage, but no unequivocal evidence has been presented (Bowen et al., 1986; Worsley, 1991). Nevertheless, judging from the record of events in the North Sea basin and north-west Fennoscandia (P915290), a regional glaciation occurred during OIS 4 (Sejrup et al., 2000), and much of Scotland is likely to have been glaciated. Several sites in the district probably include a record of this period in the form of periglacial phenomena, for example Corsend Gelifluctate Bed (Gelifluctate IV) at Kirkhill. The Woodside Diamicton (Teindland Till) at Teindland was probably laid down during an Early Devensian glaciation (Hall et al., 1995a), but similar claims for the Hythie Till (Kirkhill Upper Till) (Hall and Jarvis, 1993a), and the Pitlurg Till near Ellon (Hall and Jarvis, 1995) are less secure; the units are assigned here tentatively to OIS 2 (P915347).

Sutherland (1984c) concluded that the clayey deposits containing beds of cold-water, interstadial-type marine molluscs beneath till at King Edward were in situ (Site 4 King Edward). The mid-Devensian amino-acid and radiocarbon ages obtained from the shells (Miller et al., 1987) therefore indicated mid-Devensian marine inundation. For this to have occurred during a period of low global sea level (Pirazzoli, 1993), there must have been substantial glacio-isostatic depression following an Early Devensian glaciation. However, the shelly deposits at King Edward almost certainly have been glacially reworked and form part of the Whitehills Glacigenic Formation (Peacock and Merritt, 1997). Sutherland (1981) used a similar argument in connection with the Clava Shelly Formation at Inverness (Fletcher et al., 1996). However, despite these shelly deposits also being glacial rafts, their derivation from Loch Ness, then a fjord, does seem to imply Early Devensian glaciation of at least the western Highlands (Merritt, 1992).

Middle Devensian (OIS 3)

Periglacial and glacial environments prevailed across much of continental north-west Europe during OIS 3 and glaciers probably existed in the western Highlands for most of the time. There were
relatively warm periods between 50 to 41 ka and 37 to 36 ka on the Continent (Huijzer and Vandenberghe, 1998), the former being correlated with the Upton Warren Interglacial of the British chronostratigraphy (P915253; P915254). There is also evidence of two interstadials at roughly equivalent times in the Scandinavian record (P915290). The younger of the two, the ‘Sourlie Interstadial’ is apparently represented by organic deposits beneath till in the lowlands around Glasgow, where reindeer, woolly rhinoceros and mammoth roamed in a tundra-like environment (Jardine et al., 1988; Sutherland and Gordon, 1993). Reindeer bones found in caves near Inchnadamph, Ross-shire, also date from the Middle Devensian (Lawson, 1984). However, there are no known representative organic deposits in north-east Scotland, although the district was probably free of ice. The Crossbrae Peat (Site 5) was originally thought to date from between 22 and 26.5 ka BP, but it is now correlated with OIS 5a or 5c (Whittington et al., 1998).

Sand within the glaciofluvial Byth Gravel at the Howe of Bythe Quarry (Site 6) has yielded luminescence ages of about 45 and about 37 ka, implying the presence of glacier ice in the vicinity (Hall et al., 1995b). This Middle Devensian glaciation would correlate with the Skjonghelleren glaciation of Norway (P915290), when ice probably crossed the North Sea basin (Carr, 1998; Sejrup et al., 2000).

Amino-acid ratios and radiocarbon dates on shells within rafts and tills in the Whitehills Glaciogenic Formation suggest that the deposits are derived from cold-water marine muds of Middle Devensian age. More specifically, the ratios correlate with the Bö Interstadial of Norway (P915290), for which ages from 40 to 80 ka have been proposed by Miller et al. (1983) and the higher estimates are favoured by Sejrup et al. (2000). The rafts of the Clava Shelly Clay near Inverness are also thought to have been originally deposited during that interstadial (Merritt, 1992b). Oddly, there appear to be no correlatives of the younger Ålesund Interstadial of the Norwegian sequence in north-east Scotland (Peacock and Merritt, 1997).

**Dimlington Stadial of the Late Devensian (28 ka to 13 ka BP) (OIS 2)**
ice sheet at its maximum extent. P915250.

Reconstruction of the maximum extent of the Main Late Devensian–Weichselian ice sheets. P915288.

Although most of the drift deposits in the district were laid down during this period, the sequence of events that occurred is not fully understood. Several conflicting models have been published (P915250), and the controversy is discussed more fully below, where a more detailed history is given. It is the view of the authors that the district was overwhelmed entirely by ice in the Late Devensian, approximately coeval with the mainland ice sheet reaching the continental shelf break to the north-west of Scotland (P915288). There is growing evidence from Scandinavia, the North Sea and elsewhere that the ice reached its maximum extent early in the Late Devensian, between about 28 ka and 22 ka BP, not at about 18 ka BP, as was widely believed until recently (e.g. Bowen et al., 1986). The Scottish and Scandinavian ice sheets coalesced during this early phase (Carr, 1999; Sejrup et al., 2000). It was probably also at this time that ice of the Moray Firth ice stream was forced to flow south-eastwards across Buchan to lay down at least part of the Whitehills Glacigenic Formation and its correlatives (P915347). There probably followed a period of glacial retreat that lasted from about 21 to 18 ka BP, roughly equivalent to the Hamnsund Interstadial of Norway (Valen et al., 1995; P915290). A major re-advance then probably occurred between 18 and 15 ka BP equivalent to the Tampen Re-advance of Norway (Sejrup et al., 1994; P915290). This would have mostly involved the coastal ice streams. The Moray Firth ice stream had retreated from the north-east coast of Buchan by about 15 ka BP, and the whole district would have been ice-free by the beginning of the Windermere Interstadial at 13 ka BP.

Throughout this memoir, the Scottish ice sheet that formed between 28 and 13 ka is referred to as the ‘Main Late Devensian’ in order to to distinguish it from that of the Loch Lomond Stadial, also part of the Late Devensian. The term ‘Dimlington Stadial ice sheet’ is not used because there are now strong arguments for redefining the time span of the Dimlington Stadial to 18–13 ka BP (Sejrup et al., 1994).

**Windermere (‘Lateglacial’) Interstadial (13 ka to 11 ka BP) (OIS 2)**

A sudden amelioration of the climate occurred at about 13 ka BP when the oceanic polar front in the North Atlantic migrated northwards (Ruddiman and McIntyre, 1973, 1981; Ruddiman et al., 1976) and temperate waters returned off the western coasts of the British Isles (Peacock and Harkness, 1990). Atmospheric temperatures rose within decades to close to present values (Bishop and Coope, 1977; Atkinson et al., 1987). It is almost certain that no ice survived the interstadial in north-east
Scotland, although glaciers might not have disappeared completely in the central and western Highlands (Sissons, 1974a; Sutherland, 1984a; Sutherland and Gordon, 1993; Clapperton, 1997). Masses of ice buried within sediments from all phases of the Main Late Devensian glaciation (if not before) commonly melted out relatively slowly resulting in kettleholes (Peacock in Harkness and Wilson, 1979).

<table>
<thead>
<tr>
<th>Site</th>
<th>Grid reference</th>
<th>Laboratory number</th>
<th>Age (year BP)</th>
<th>Dated material and setting</th>
<th>Reference</th>
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<td>Rothes cutting</td>
<td>NJ 277 498</td>
<td>Beta 8653</td>
<td>11 110 ± 70</td>
<td>peat under remobilised till</td>
<td>Appendix 1</td>
</tr>
<tr>
<td>Garral Hill, Keith</td>
<td>NJ 444 551</td>
<td>Q-104</td>
<td>10 808 ± 230</td>
<td>peat under remobilised till</td>
<td>Godwin and Willis (1959)</td>
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<tr>
<td>Garral Hill, Keith</td>
<td>NJ 444 551</td>
<td>Q-103</td>
<td>11 098 ± 235</td>
<td>peat under remobilised till</td>
<td>Godwin and Willis (1959)</td>
</tr>
<tr>
<td>Garral Hill, Keith</td>
<td>NJ 444 551</td>
<td>Q-102</td>
<td>11 308 ± 245</td>
<td>peat under remobilised till</td>
<td>Godwin and Willis (1959)</td>
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<tr>
<td>Garral Hill, Keith</td>
<td>NJ 444 551</td>
<td>Q-101</td>
<td>11 888 ± 225</td>
<td>peat under remobilised till</td>
<td>Godwin and Willis (1959)</td>
</tr>
<tr>
<td>Garral Hill, Keith</td>
<td>NJ 444 551</td>
<td>Q-100</td>
<td>11 358 ± 300</td>
<td>peat under remobilised till</td>
<td>Godwin and Willis (1959)</td>
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<tr>
<td>Woodhead, Fyvie</td>
<td>NJ 788 384</td>
<td>SRR-1723</td>
<td>10 780 ± 50</td>
<td>peat under remobilised till</td>
<td>Connell and Hall (1987)</td>
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<tr>
<td>Howe of Byth</td>
<td>NJ 822 571</td>
<td>SRR-4830</td>
<td>11 320</td>
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<td>Hall et al. (1995)</td>
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<td>Moss-side, Tarves</td>
<td>NJ 833 318</td>
<td>I-6969</td>
<td>12 200 ± 170</td>
<td>peat under remobilised till</td>
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<td>Loch of Park</td>
<td>NO 772 988</td>
<td>HEL-416</td>
<td>10 280 ± 220</td>
<td>kettlehole infill</td>
<td>Vasari and Vasari (1968)</td>
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<td>Loch of Park</td>
<td></td>
<td>HEL-417</td>
<td>11 900 ± 260</td>
<td>kettlehole infill</td>
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<td>Mill of Dyce</td>
<td>NJ 8713 1496</td>
<td>SRR-763</td>
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<td>kettlehole infill</td>
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<td>Glenbervie</td>
<td>NO 767 801</td>
<td>GX-14723</td>
<td>12 460 ± 130</td>
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<td>Glenbervie</td>
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<td>SRR-3687a. (humic)</td>
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<td>Appendix 1</td>
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<td>Glenbervie</td>
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<td>Brinzieshill Farm</td>
<td>NO 7936 7918</td>
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<td>12 390 ± 100</td>
<td>peat under remobilised till</td>
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<td>Appendix 1</td>
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</table>

Organic sequences preserved in some kettleholes in the region provide a record of environmental
change during the Late-glacial period (Donner, 1957; Vasari and Vasari, 1968; Vasari, 1977; Gordon, 1993; Mill of Dyce, Rothens, Loch of Park). Elsewhere, beds of peat preserved beneath solifluction deposits and landslips provide important evidence (Godwin and Willis, 1959; Clapperton and Sugden, 1977; Hall, 1984; Connell and Hall, 1987; Aitken, 1991; Site 25 Glenbervie). Radiocarbon dates are given in the table above. The freshly deglaciated ground was first colonised by a pioneer vegetation of open habitat species followed by the immigration of crowberry heath, juniper and dwarf varieties of birch and willow. Eventually open birch woodland developed with juniper and isolated stands of Scots pine locally. A stepwise climatic deterioration occurred throughout the Windermere Interstadial (Lowe et al., 1999; Mayle et al., 1999) and it is likely that glaciers had already started to build up in the Western Highlands before more sustained cooling began at about 11.2 ka BP.

Relative sea level in north-east Scotland probably had fallen to below its present level by the beginning of the interstadial and it continued to fall, especially in the west of the district, where glacio-isostatic rebound was greater.

**Loch Lomond Stadial (11 ka to 10 ka BP) (OIS 2)**

The North Atlantic Polar Front migrated rapidly southwards to the latitude of northern Portugal at about 11 ka BP (Bard et al., 1987), and the climate of the British Isles reverted temporarily to arctic conditions.

Although no glaciers are thought to have developed in the district they did so in the corries of the Cairngorms and the Mounth, and substantial ice caps formed over Rannoch Moor and in the North-west Highlands (Sutherland and Gordon, 1993). A tundra environment existed in north-east Scotland during the stadial. Soils that had developed during the Windermere Interstadial were largely destroyed by periglacial processes such as solifluction and frost churning (geliturbation) (FitzPatrick, 1956, 1958, 1969, 1972, 1976, 1987; Galloway, 1961a–c, Connell and Hall, 1987). Vegetation was quickly replaced by open-habitat plant communities tolerant of the Arctic conditions and unstable soil (Gunson, 1975). Some fossil frost polygon networks observed in the district might have been formed during the stadial (Clapperton and Sugden, 1977), but most probably formed earlier during the retreat of the Main Late Devensian ice sheet (Gemmell and Ralston, 1984, 1985; Armstrong and Paterson, 1985; Connell and Hall, 1987; Ugie valley). Fluvial and debris-flow activity would have been enhanced during the stadial, especially during springtime snow-melts (Ballantyne and Harris, 1994; Maizels and Aitken, 1991). Slopes would have been particularly prone to land-slipping (Glenbervie) and head deposits formed widely across the district. Much of the coarse-grained alluvium in minor valleys across the district would also have been laid down then.

**Holocene (10 ka BP to the present day) (OIS 1)**

At about 10 ka BP the global climate changed rapidly, possibly within an average human lifetime, to its present interglacial mode, marking the beginning of the Holocene epoch. The oceanic polar front in the North Atlantic rapidly shifted northwards and the warm Gulf Stream current became established, providing an ameliorating influence on the climate of Scotland. At first the glaciers in the western Highlands might have re-advanced locally as a result of increased snowfall (Benn et al., 1992), but rapid disintegration soon followed. The widespread occurrence of bare, unstable soils at the beginning of the Holocene apparently led to a period of intense fluvial erosion and deposition with enhanced debris flow activity on mountain sides and extensive formation of landslips as the ground thawed (McEwen, 1997). Soils gradually became more stable following the establishment of vegetation: firstly shrubs and scrub communities were established during the early part of the
Windermere Interstadial, and was replaced later by woodland (Durno, 1956, 1957; Vasari and Vasari, 1968; Edwards, 1978). A distinct phase of juniper dominance was replaced by birch woodland, followed by the arrival of hazel, elm and shortly after, by oak (Loch of Park, Nether Daugh). Pine forest became established in the East Grampians by the mid-Holocene whereas birch-hazel forest was predominant in the east and across the coastal lowlands (Vasari and Vasari, 1968; Gunson, 1975; Birks, 1977).

Climatic deterioration may have begun soon after the beginning of the Holocene and it has continued in a stepwise fashion. Distinct layers of pine stumps preserved quite widely in upland blanket peat deposits in the East Grampians indicate that pine forest locally succumbed to the spread of Sphagnum moss between 6.7 ka and 5 ka BP (Pears, 1968, 1970). Colder and wetter climatic conditions caused this change, rather than the influence of people, but human impact is apparent in the pollen and sediment records before 5 ka BP (Edwards, 1978, 1979b; Edwards and Rowntree, 1980). It can also be seen in the late Holocene pollen and Coleopteran record obtained from a silted-up ox-bow lake on the floodplain of the River Don at Nether Daugh, near Kintore.

Although the imprint of glaciation remains dominant, postglacial processes have superimposed subtle, but distinctive, modifications on the landscape. Steep hillsides have been modified by landslips, soil-creep and debris flows, whereas valley floors have been sculptured by rivers forming spreads of alluvium and river-terrace deposits. In general, braided rivers with gravelly beds would have been replaced by the single-thread, and locally meandering, rivers of the present day by the mid-Holocene (McEwen, 1997). The Spey is an exception in that it still maintains a braided, gravelly floodplain in its lower reaches (Lewin and Weir, 1977).

Inferred sea-level change over the past 15 000 years, based on height-age relationships of raised shorelines. P915295.

Sea level was below that of the present day during the early Holocene, but the Main Postglacial Transgression resulted in the formation of raised beaches and marine inundation of the lower reaches of valleys. The latter led to the deposition of estuarine silts, fine-grained sands and clays, locally on terrestrial peats, tree stumps and fluvial muds. The transgression reached its maximum after 6.1 ka BP in the Ythan valley (Smith et al., 1999; P915295) and between 6.3 ka and 5.7 ka BP in the Philorth valley, between Fraserburgh and Peterhead (Smith et al., 1982; Site 9). The subsequent regression, which has been attributed to a general lowering of global sea level following expansion of the Antarctic ice cap (Goodwin, 1998), was accompanied by renewed terrestrial sedimentation in the valley mouths. Horizons of fine-grained sand identified in both estuarine and near-shore terrestrial deposits of the lower Ythan and Philorth valleys were laid down at about 7200 BP by a tsunami caused by a major submarine slide on the Norwegian continental slope (Dawson et al., 1988; Long et al., 1989; Philorth).

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Full reference list

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