Quaternary of Scotland

Edited by

J. E. Gordon
Scottish Natural Heritage
Edinburgh, Scotland.

and

D. G. Sutherland
Edinburgh, Scotland.

GCR Editor: W. A. Wimbledon

JOINT NATURE CONSERVATION COMMITTEE

CHAPMAN & HALL
London · Glasgow · New York · Tokyo · Melbourne · Madras

Chapter 14

Eastern Highland Boundary

INTRODUCTION

D. G. Sutherland

The Eastern Highland Boundary region extends from west of Perth and the Tay Valley through Strathmore to Aberdeen (Figure 14.1). It incorporates the coastline from south of Montrose to Aberdeen. Glaciation of the area has been dominantly by ice originating in the western Highlands, with relatively little contribution from ice sources in the south-eastern Grampians. The eastern parts of the region are therefore located towards the periphery of the intensely glaciated zone and contain evidence of Pleistocene events pre-dating the Late Devensian; to the west the increasing intensity of glaciation has resulted in only deposits relating to the last phase of ice-sheet glaciation (the Late Devensian) being present. The region is important, too, for the development of vegetation during both the Lateglacial Interstadial and the Holocene as it is adjacent to the Highland Boundary Fault, one of the major topographical, geological and ecotonal boundaries in Scotland.

The eastern seaboard of the region contains a number of pre-Late Devensian landforms and deposits. The coast is flanked by two glaciated rock platforms, a higher one at around 23 m OD (Bremner, 1925b) and a lower one only slightly above present sea level (Synge, 1956). This latter platform is a clear feature at Milton Ness. The ages of the platforms are unknown. Evidence for glaciation prior to the Late Devensian is also preserved in the basal deposits at Nigg Bay (Bremner, 1934a; Synge, 1956, 1963; Chester, 1975) where the presence of erratics with a Norwegian origin points to an earlier glacial event with ice possibly moving onshore. This latter idea has also been suggested to explain shelly clays below till at Burn of Benholm and other neighbouring localities (Campbell, 1934).

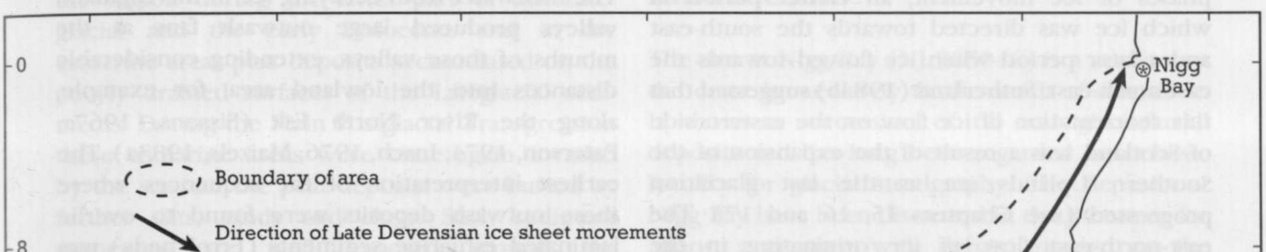


Figure 14.1 Location map of the Eastern Highland Boundary area.

An alternative explanation for these shelly deposits was advanced by Sutherland (1981a), who suggested that they may have formed from *in situ* marine clays deposited during the build-up of the last ice-sheet during the Early Devensian. More information is awaited on these deposits before their true nature is clear. Also at Burn of Benholm, lenses of peat have been found interbedded with the red till that overlies the shelly clays. Pollen analysis initially led Donner (1960) to hypothesize a Lateglacial age for the peat, and consequently that the enclosing till was soliflucted. However, radiocarbon dating indicated the age of the peat to be greater than 42,000 BP and Donner (1979) revised his interpretation, suggesting that the peat accumulated during a Middle or Early Devensian interstadial.

The great majority of the glacial deposits and landforms of the region have been interpreted as the product of the last ice-sheet. Armstrong *et al.* (1985) have provided evidence of two distinct phases of ice movement, an earlier period in which ice was directed towards the south-east and a later period when ice flowed towards the east-north-east. Sutherland (1984a) suggested that this reorientation of ice flow on the eastern side of Scotland was a result of the expansion of the Southern Uplands ice as the last glaciation progressed (see Chapters 15, 16 and 17). The east-north-east flow of ice originating in the south-west Highlands extended throughout the region and beyond the coast. It was sufficiently powerful to flow into the mouths of the Highland valleys such as Glen Clova and Glen Esk (Bremner, 1934b, 1936; Synge, 1956) and it left behind a characteristic red till. This till is well exposed at both Burn of Benholm and Nigg Bay and at the latter locality it overlies a grey till deposited by ice moving from the eastern Grampians, again indicating the relative timing and strengths of the two ice flows (cf. Chapter 8).

Deglaciation took place broadly from north-east to south-west, although large areas of 'dead' ice became isolated in the low ground of Strathmore and in the adjacent Highland valleys, giving rise to extensive areas of kames, kettle holes and eskers (Rice, 1959; Rose and McLellan, 1967; Paterson, 1974; Ellis, 1975; Insch, 1976; Armstrong *et al.*, 1985; Auton *et al.*, 1988; Auton *et al.*, 1990). Meltwater channels, both ice-directed and topographically controlled, occur extensively along the Highland margins (Bremner, 1925b, 1934b; Watson, 1945; Synge, 1956; Sissons, 1961a; Rose and McLellan, 1967; Ellis, 1975; Insch, 1976; Auton *et al.*, 1988; Auton *et al.*, 1990). The earliest area deglaciated was the eastern coast where a series of raised shorelines (Cullingford and Smith, 1980) was formed while ice decayed in the adjacent valleys. These shorelines are well exposed at Milton Ness and at Dryleys in the Montrose basin where their relationship to the fossiliferous Errol beds (Late Devensian estuarine sediments) has also been established. These shorelines are likely to have been formed between 17,000 BP and 14,000 BP (Sutherland, 1984a).

For some time after the deglaciation of the eastern coast the Tay estuary remained blocked by ice, and meltwater drainage was directed through the 'dead' ice in Strathmore. Eventually the ice in the Tay–Earn area receded and the sea flooded as far west as Crieff (Browne, 1980) and into the lower Tay valley to the north of Perth (Armstrong *et al.*, 1985). This is thought to have occurred at about or slightly before 13,000 BP. The meltwater from decaying ice in the Highland valleys produced large outwash fans at the mouths of those valleys, extending considerable distances into the lowland area; for example, along the River North Esk (Sissons, 1967a; Paterson, 1974; Insch, 1976; Maizels, 1983a). The earliest interpretation of the sequences where these outwash deposits were found to overlie laminated estuarine sediments (Errol beds) was that they were the product of a major readvance of the ice-sheet, the Perth Readvance (Simpson, 1933; Sissons, 1963a, 1964). The classic section in such a sequence is at Almondbank. However, Paterson (1974) has demonstrated that it is not necessary to invoke a readvance to explain the stratigraphic sequence in this area. The only section that may indicate at least a local readvance of the retreating ice-sheet is at Shochie Burn.

Kettle holes that developed in the outwash deposits and 'dead'-ice terrain have accumulated sediment since the time of deglaciation, and pollen analysis of these sediments has revealed the nature of the vegetational succession during the Lateglacial Interstadial once the region was ice-free and the climate had ameliorated. One particularly interesting sequence is that at Stormont Loch where, following an initial succession of open habitat taxa followed by birch, juniper and *Empetrum* heath, there was a notable return to more open vegetation suggestive of disturbed soils (Caseldine, 1980a). This distinct 'revertance' phase, which is not found in all Lateglacial pollen diagrams (Walker, 1984b; Tipping, 1991b), has been correlated with the Older Dryas 'chronozone' of the Scandinavian sequence. However, there is no radiocarbon evidence from Stormont Loch to support this correlation. Subsequent to this period, woody species again expanded, giving rise to a juniper-dominated heath with scattered copses of tree birches, the more typical vegetation of the Lateglacial Interstadial in this part of Scotland.

During the Loch Lomond Stadial there was a return to unstable soils, with a marked reduction in woody species and an increase in open-habitat species. There is an interesting trend in the values for pollen of *Artemisia* species during the stadial, from low values at the beginning to higher values in the latter part (Caseldine, 1980a). This has been interpreted as the result of a change from higher to lower precipitation as the stadial progressed.

Sea level was relatively low along the coasts of the region during the latter part of the Lateglacial and the early Holocene, and in the estuarine areas peat deposits accumulated on the poorly drained surfaces of the Lateglacial sediments. During the Main Postglacial Transgression these estuarine areas were once again invaded by the sea and the peat deposits were buried by further silts, sands and clays. Such sediment sequences are well exposed around the Montrose basin, for example at Maryton and Dryleys. The progress of the transgression has been studied using pollen and diatom analyses and radiocarbon dating (Smith *et al*., 1980), and the raised shorelines formed at the maximum of the transgression and subsequently have been mapped and surveyed by Smith and Cullingford (1985). Of particular note in the sediment sequence is a distinctive sand layer, exposed at Maryton, that was deposited slightly prior to the maximum of the transgression. A similar sand layer, dated to about 7000–6800 BP, has been found at a number of sites along the east coast of Scotland and it has been interpreted as the product of a major storm surge in the North Sea (Smith *et al*., 1985a) or a tsunami resulting from a large submarine slide (Dawson *et al*., 1988).

The Holocene forest history is of interest because this region lies close to the border of the mixed deciduous forest and the pine forest zones (Birks, 1977). Following an early Holocene succession of juniper scrub to birch–hazel woodland, mixed deciduous forest with oak, birch and elm became established throughout most of the region, although pine may have occurred during the middle Holocene in edaphically favourable locations. Man's impact on the forests was initially recorded by the decline in elm at around 5000 BP.

NIGG BAY

J. E. Gordon

Highlights

The deposits exposed in the coastal section at Nigg Bay comprise a sequence of tills and glaciofluvial sediments. These provide important evidence for establishing the sequence and patterns of glaciation, including the interactions of different ice masses, in eastern Scotland.

Introduction

The site at Nigg Bay (NJ 965046) is a section on the coast immediately to the south of Aberdeen. It shows a succession of till and glaciofluvial deposits and has long been regarded as a classic locality for glacial stratigraphy. The deposits at Nigg Bay have been discussed in the literature for almost a century, with debate focused on the number of separate ice advances and readvances that may be represented. The deposits have been described by Jamieson (1882b), Bremner (1928), Simpson (1948), Synge (1963), Chester (1975), McLean (1977) and Munro (1986), and also discussed in more general reviews by Charlesworth (1956), Synge (1956), Clapperton and Sugden (1972, 1977) Murdoch (1977) and Hall and Connell (1991).

Description

The section occurs on the south side of Nigg Bay in a suite of deposits infilling a former valley of the River Dee (Simpson, 1948; Law, 1962; Munro, 1986). Borehole evidence on the shore and seismic evidence from the bay show this channel to descend to below −40 m OD and extend at least 1 km offshore. Six distinctive beds have been recognized in the exposure (Jamieson, 1882b; Bremner, 1928; Simpson, 1948; Synge, 1963; Chester, 1975):

6.	Head	0.5–1.0 m
5.	Gravels	1–3 m
4.	Red sands with laminated silts and clays	1–2 m
3.	Red till	2–3 m
2.	Grey till	10 m
1.	Sands and gravels	3–6 m

The horizontally bedded sands and gravels (bed 1) are seen only at the southern end of the section and rest on a weathered granite–gneiss. Jamieson (1882b) described their thickness as 10–20 ft (3–6 m), but only part of this bed has been exposed in recent years. Diagnostic erratics include ultrabasic material which can be traced to the Belhelvie igneous complex 10 km to the north-north-west, larvikite and rhomb porphyry (see Bremner, 1922) inferred to be of Scandinavian origin, and andalusite schist (Read *et al.*, 1923; Bremner, 1928, 1934a, 1939b; Synge, 1963). Armoured till balls have also been found incorporated in the gravels (E. R. Connell, unpublished data). A 5 m thick layer of sands and gravels, underlying a till, was encountered at the base of a borehole at Nigg Bay, and this may correlate with the basal sands and gravels of the cliff section (Munro, 1986).

Unconformably overlying the lower sands and gravels is a tough, compact, grey till up to 10 m thick (bed 2). It contains local erratics predominantly of granite and gneiss and in its lower part the clasts have a south-south-west to north-north-east preferred orientation (Synge, 1963). This unit correlates with a widely occurring local till in the Aberdeen area (McLean, 1977; Murdoch, 1977). There is a transition upwards from the grey till to the red till (bed 3). Elsewhere, in pipeline trench exposures near Aberdeen, these two tills have been seen interbedded (Chester, 1974, 1975; Murdoch, 1975, 1977; Munro, 1986). Apart from its colour the red till is distinguished by the presence of Old Red Sandstone conglomerate and volcanic erratics and by a more northerly preferred stone orientation than the grey till (Jamieson, 1882b, 1906; Synge, 1963). The source of this material was traditionally held to be the Old Red Sandstone rocks of Strathmore and the volcanic rocks between Lunan Bay and Montrose (Jamieson, 1906; Munro, 1986). However, heavy-mineral studies by Glentworth *et al.* (1964) point to the floor of the North Sea as an additional source, a possibility in fact admitted by Jamieson (1882b). The red till forms part of a suite of red deposits extending along the north-east coast of Scotland from south of Stonehaven to north of Peterhead (Jamieson, 1882b; Bremner, 1916b; Synge, 1956; McLean, 1977; Murdoch, 1975, 1977; Hall, 1984b; Auton and Crofts, 1986; Munro, 1986).

The sands (bed 4) above are reddish brown in colour and contain thin bands of laminated red clays. Southwards these sands merge into and are succeeded by gravels (bed 5) containing the same erratics as the red till. There is no sharp junction between the sands and gravels, implying that they are probably contemporaneous (Simpson, 1948). The gravels are coarse and poorly bedded with lenticles of sand, and in their upper part (bed 6) are highly shattered and cracked (Jamieson, 1882b), typical of a head deposit. Simpson (1948) suggested that sorted coarse and fine fractions in this deposit represented stone stripes and polygons seen in section. The gravels have a hummocky surface expression (termed 'morainic' by Simpson (1948)), and continue inland and to the south of Nigg Bay where they are associated with kettle holes in the Loirston area (NJ 940010).

Interpretation

The erratic content of the lower sands and gravels led most workers to postulate early glaciation from the north or north-west contemporaneous with the presence of Scandinavian ice in the North Sea Basin. Bremner (1928) suggested that the lower sands and gravels consisted in part of deposits from his first glaciation from the north that were subsequently reworked by meltwater. Simpson (1948) also thought that they were derived from the earliest glacial deposits of the area, which might be associated with Bremner's first ice-sheet (Bremner, 1928, 1934a, 1938). From the distribution of erratics in north-east Scotland, Bremner inferred ice movement during this glaciation from north-west to south-east across this area; for example, near Aberdeen he recorded boulders thought to be from the northern Highlands and the Elgin area, and, near Inverbervie, boulders from Huntly. At the same time Scandinavian ice in the North Sea Basin blocked the escape of Scottish ice to the east and, as the former approached from the north-east, it impinged on the coast at Aberdeen and in Kincardineshire. It was possible, he argued, that the shelly indigo-coloured till in the Ellon area (see Bellscamphie) reported by Jamieson (1906) and thought by him to have been transported from the north during the first glaciation was in fact related to the Scandinavian ice moving onshore (Bremner, 1928, 1934a). Clapperton and Sugden (1977), however, have advocated the need for caution in interpreting igneous and metamorphic 'erratics' since more recent work on bedrock geology in north-east Scotland has shown greater diversity of rock types and more widespread distribution of the sources of indicator types. Moreover, in the light of evidence from the North Sea (Stoker *et al.*, 1985), Hall and Connell (1991) considered it unlikely that Scandinavian ice ever reached the coast of Scotland, and that the erratics of presumed Scandinavian origin were ice-rafted and subsequently entrained by Scottish ice.

Synge (1956, 1963) also proposed early glaciation from the north-east (Scandinavian glaciation) followed by an expansion of Scottish ice (Greater Highland Glaciation) moving south-south-east along the Aberdeenshire coastal area, but he thought the lower sands and gravels at Nigg Bay were beach deposits derived from the earliest till rather than glaciofluvial deposits, as implied by Bremner (1928) and stated by Read *et al.* (1923). Possibly the armoured till balls in the lower sands and gravels at Nigg Bay are the reworked remnants of an early till. Further evidence for an early north-west to south-east ice movement was provided by Murdoch (1975, 1977) from clast-fabric studies of an argillaceous lodgement till found locally in the Aberdeen area but not seen at Nigg Bay. This till was considered (Murdoch, 1975; Munro, 1986) to be of Late Devensian age, but Sutherland (1984a), on the basis of evidence for ice-free conditions to the north-west of Aberdeen (Hall, 1984b), suggested that the north-west to south-east glaciation that deposited this till must have pre-dated the Late Devensian.

There is general agreement among all workers that the red and grey tills were broadly contemporaneous and reflect the interaction of two distinctive ice masses (Jamieson, 1882b, 1906; Bremner, 1928, 1934a, 1938; Simpson, 1948, 1955; Synge, 1956, 1963; Clapperton and Sugden, 1972, 1977; Murdoch, 1975, 1977; McLean, 1977; Auton and Crofts, 1986; Munro 1986; Hall and Connell, 1991). The grey till with its local erratics was deposited by ice moving down the Dee Valley; the red till, with its Old Red Sandstone erratics, was deposited by Strathmore ice moving north-east along the coast. Both Jamieson and Bremner related the two tills to their respective second ice-sheets and suggested that the local Dee ice had receded before the red till was deposited. Most workers now agree, however, that the two ice streams coalesced, although the initial influx of ice from the west weakened and was succeeded by the Strathmore ice (Hall and Connell, 1991). Synge interpreted the deposits as being the product of his Moray Firth–Strathmore Glaciation of Devensian age; Simpson, Clapperton and Sugden, McLean and Murdoch assigned them to the Late Devensian ice-sheet.

The presence of Scandinavian ice in the North Sea Basin has often been cited as the reason for deflection of the Strathmore ice along the east coast of Scotland. Recent studies of offshore sediments, however, indicate that the Scottish and Scandinavian ice-sheets did not meet or coalesce during the Late Devensian (Jansen, 1976; Cameron *et al.*, 1987; Sejrup *et al.*, 1987; Hall and Bent, 1990). Alternative explanations for the flow pattern must therefore be sought. Following the suggestion of Hall and Bent (1990) for the Moray Firth area, one possibility is that a change in flow pattern developed where ice from sources in the south-west Highlands emerged from valleys with rigid rock beds on to the potentially mobile beds formed by the thick sediments of the lowlands and nearshore coastal zone. That such changes can theoretically occur has been demonstrated for the Late Weichselian Laurentide ice-sheet (Fisher *et al.*, 1985).

Influenced by the presence of red clay deposits at Tullos and to the north of Aberdeen, Jamieson envisaged a marine or lacustrine depositional environment for the Nigg Bay tills. However, their undoubted glacial nature was established by later investigators. Recent ideas suggest they may have been formed by melt-out and flow processes (McLean, 1977; Murdoch, 1977).

The origin of the upper gravels (bed 5) has been more contentious. Agassiz (see Jamieson, 1874, p. 323) suggested that the gravel mounds were moraines, a view endorsed by Buckland (1841a). According to Jamieson (Jamieson, 1865, 1874, 1882b, 1906) they were the ice-marginal moraines of his third and last glaciation during which ice advanced down the Dee Valley and extended just offshore, forming an 8 km wide ice-front between Nigg Bay and Belhelvie to the north of Aberdeen where another suite of gravel mounds occurs. He also argued that there had been a longer and possibly warmer time interval between his second and third ice-sheets than between the first two. Bremner (1928, 1934a, 1938) proposed a similar interpretation, but placed the northern limit of the ice near the Ythan. He also related the gravels to his third ice-sheet, the existence of which he had established elsewhere largely on the basis of supposedly marginal meltwater channels.

Charlesworth (1956) included the upper morainic gravels as part of his Highland Glaciation, which he recognized as a separate readvance after the last ice maximum, with a local ice limit near Belhelvie. Synge (1956, 1963), too, thought the gravels were ice-marginal deposits, part of what he called a 'kame moraine' marking the limit of a separate glacial event of pre-Loch Lomond Stadial age, the Aberdeen Readvance. Synge correlated this glacial event with the Perth Readvance (Simpson, 1933), but Sissons (1965, 1967a) later linked it with features in the south of Scotland to mark another event known as the Aberdeen–Lammermuir Readvance. However, subsequent re-examination of the evidence has failed to substantiate the existence of these readvances (Sissons, 1974c).

In important contributions, Simpson (1948, 1955) was first to perceive that the upper 'morainic' gravels did not represent a separate ice readvance but were contemporaneous with the last ice-sheet to cover the area. The gravels contained the same erratics as the red till and were not derived by ice readvance from the west. Moreover, he suggested that the gravels were not moraines, but were glaciofluvial kames which formed a continuous suite of deposits extending from south of Nigg Bay to the River Ythan. In places the kames were overlain by till and he proposed that many were of englacial origin. Subsequent work by Clapperton and Sugden (1972, 1975, 1977) and Murdoch (1975, 1977) has substantiated Simpson's interpretation. These authors argued that the continuity of glaciofluvial landforms across the supposed limit of the Aberdeen Readvance reflected the integrated subglacial hydrological system of a single ice-sheet. Moreover, the continuity of the landforms and the undisturbed nature of the red and grey tills implied contemporaneous deposition and ice decay during a single glaciation. Furthermore, ice-wedge casts occur both within and outside the supposed Aberdeen Readvance ice limit (Sissons, 1974c; Gemmell and Ralston, 1984), and therefore their distribution cannot be used to support the readvance concept, as was suggested by Synge (1963).

The Nigg Bay section is a key reference locality for the interpretation of the glacial history of the eastern Highland boundary area. At least two distinct glaciations can be inferred from the sequence of deposits: a pre-Devensian glaciation represented by the lower sands and gravels, and a Late Devensian glaciation by the overlying succession of tills, sands and gravels. The succession of Late Devensian deposits illustrates particularly well the complexity of depositional environments that may be associated with a single glacial episode. Nigg Bay also has significant potential for further research, for example on the sedimentology of the deposits. In addition, further study of Nigg Bay and other multiple till sections will provide useful field evidence of changing ice-sheet flow patterns that can be used to test and refine theoretical models of ice-sheet growth. For example, Nigg Bay clearly illustrates that early expansion of inland ice from the mountains and valleys to the west was succeeded by a dominant flow of ice from sources in the south-west Highlands.

Conclusion

The deposits at Nigg Bay are important for interpreting the glacial history of the Eastern Highland Boundary area. They have a long history of research and illustrate the interaction of ice masses from different source areas. Although it has been proposed that the deposits were formed by different ice-sheets in a series of separate glaciations, current interpretations ascribe most of the sequence to the Late Devensian glaciation (approximately 18,000 years ago).

BURN OF BENHOLM

J. E. Gordon

Highlights

Stream sections at Burn of Benholm have revealed a sequence of deposits including a pre-Late Devensian shelly clay with marine molluscs and an interstadial peat of Early or Middle Devensian origin. These deposits provide important evidence for interpreting the Quaternary history of eastern Scotland.

Introduction

This site (NO 795691) comprises a series of stream sections at *c.* 45 m OD along the Burn of Benholm, 14 km north of Montrose. It is notable for a dark shelly deposit interpreted as a till, and for peat lenses incorporated near the base of an overlying red till. These deposits have played an important role in reconstructing the glacial history and environmental changes in the area (Campbell, 1934; Donner, 1960, 1979). More recently, Sutherland (1981a) has proposed an alternative explanation that the shelly sediment is an *in situ* marine deposit. He described its possible wider correlations with other sites in Scotland and how it might relate to a model of glacio-isostatic sea-level changes associated with the inception of the last ice-sheet during the Early Devensian.

Description

The deposits at Burn of Benholm were first described by Campbell (1934). He recorded the following sequence in several sections:

4.	Coarse gravel	0.3–0.8 m
3.	Red till derived from the Old Red Sandstone rocks of Strathmore and typical of the tills of this part of eastern Scotland	0.3–1.2 m
2.	Greyish-black till containing abundant 'arctic' shells, the commonest being *Arctica islandica* (L.), and relatively few clasts, but of lithologies quite distinct from those in the overlying red till (Lower Old Red Sandstone, basalt, gneiss, troctolite, limestone (including chalk), shale, flint and jet)	0.6–1.8 m
1.	Andesite bedrock	

In the sections described by Campbell the shelly till (bed 2), which extended almost continuously for a distance of over 550 m, was locally underlain by sands and gravels (0.2–0.3 m thick) and, in places, it was mixed with the red till (bed 3). At one locality, finely laminated silts and a band of peat (total thickness 0.3 m) were incorporated at the base of the red till (bed 3).

The present exposures clearly demonstrate (1) red till overlying grey, shelly clay with a low stone content, as described by Campbell (1934); (2) in some sections a sharp, undulating contact between the grey clay and the red till, varying from subhorizontal to steeply dipping; (3) in other sections, a zone of mixing up to 0.4 m thick of red till and grey clay; (4) deformation of the upper surface of the grey clay and interfingering with the red till; (5) stringers and bands of grey clay incorporated into the red till; (6) a layer of reddish sand (0.01–0.02 m thick) 0.03–0.04 m below the contact of the red till and the grey clay; (7) deformation of the grey clay and underlying bands of sand and gravel against a bedrock knoll. Hall and Connell (1991) have reported that the grey clay contains reworked Upper Cretaceous and Tertiary dinoflagellate cysts which they considered were derived from the North Sea Basin to the south-east.

Bremner (1943a) recorded that analysis of the peat (base of bed 3) by I. M. Robertson had revealed pollen of oak, pine, alder and elm. Donner (1960) noted that the peat, which is no longer exposed, occurred in thin lenses. The pollen content, however, was dominated by non-arboreal types, notably Gramineae and Cyperaceae, representing herb communities (Donner, 1979). Radiocarbon dating of the peat gave an age of >42,000 BP (Hel–1098) (Donner, 1979).

Interpretation

The dark shelly deposit at Burn of Benholm is one of several such occurrences in Kincardineshire described by Campbell (1934), but it is the only one presently exposed. It is also the only locality where peat deposits have been recorded in the sequence. Campbell (1934) concluded that the shelly deposit was a till emplaced by ice moving across the floor of the North Sea when Scottish and Scandinavian ice-sheets coalesced (but see Nigg Bay). The peat represented interglacial conditions, being formed after retreat of the North Sea ice and before the advance of the Strathmore ice-sheet.

Donner (1960) reinterpreted the sequence inferring that the red till was not *in situ*, but had been transported by solifluction or a small landslide during the Loch Lomond Stadial. In support he cited the results of pollen analysis on the peat which showed similarities with Lateglacial Interstadial deposits elsewhere in Scotland, and he concluded that the peat had also been displaced by solifluction during the stadial. Subsequently, however, from the radiocarbon date and a re-evaluation of the pollen data, Donner (1979) revised his conclusions. He considered that the peat represented the remains of an organic deposit formed in a tundra environment of predominantly grassland communities, probably during the Early or Middle Devensian. It was then incorporated into the base of the red till during the Late Devensian glaciation in Strathmore. As noted by Edwards and Connell (1981), the discrepancy between the pollen records of Bremner (1943a) and Donner (1960, 1979) either casts doubts on the earlier identifications or suggests that peat of more than one age or environment was present.

Sutherland (1981a) presented a radically different interpretation of the shelly deposit at Burn of Benholm. He inferred that it was an *in situ* marine bed on the basis that it formed part of a suite of high-level marine shell beds buried by till and that its altitude conformed with a model that involved a marine transgression associated with depression of the Earth's crust as the last ice-sheet began to accumulate. Sutherland argued that this occurred during the Early Devensian rather than during the Late Devensian, as in more conventional interpretations (Sissons, 1976b).

The Burn of Benholm deposits therefore have a significant bearing on the interpretation of the Late Pleistocene history of eastern Scotland. In the conventional view the shelly deposit is a till and provides support for the onshore movement of ice, possibly deflected by the presence of Scandinavian ice in the North Sea during a glacial episode pre-dating the last ice-sheet. Although the presence of Scandinavian ice has also been held responsible for the movement of Strathmore ice north-eastwards along the east coast during the last glaciation (see Nigg Bay), recent evidence from the central North Sea (Sutherland, 1984a; Stoker *et al*., 1985; Sejrup *et al*., 1987) suggests this to have been unlikely. Hall and Connell (1991) have maintained the interpretation of the shelly deposit as a till, and proposed deposition by ice flowing from the east or south-east. This, they suggested, may have occurred during the 'Wolstonian' glaciation.

In the model of Sutherland (1981a), the shelly deposit at Burn of Benholm forms part of a network of *in situ*, high-level shell beds in Scotland (see Afton Lodge, Clava and Tangy Glen). Together these were considered to reflect ice-sheet growth and high relative sea level during the Early Devensian. However, correlations with other high-level shell beds are, at present, conjectural; before either interpretation can be tested, several key questions remain to be answered. These concern first, the origin of the shelly deposit and whether it is a till, an *in situ* marine deposit, or possibly a glaciomarine deposit or an ice-rafted marine deposit; second, the age of the shelly deposit; and third, whether the shelly deposit and the overlying red till are broadly contemporaneous or separated by a significant time interval, possibly represented by the deposition of the peat. The deposits therefore have significant potential for detailed sedimentary and faunal studies. In addition, amino acid analyses of the shells should help to clarify the age of the shelly deposit and provide a firmer basis for any wider correlations. Reported results indicate isoleucine ratios of 0.36 from *Arctica* shells (Bowen, 1991). Therefore, according to Bowen (1991), if the shelly clay is glaciomarine in origin, then it dates from the time of deglaciation of the Anglian ice-sheet (Oxygen Isotope Stage 12). However, if the deposit is a till, then it is younger than Stage 11.

The peat at Burn of Benholm, although no longer exposed, is also significant in having provided a rare pollen record of interstadial environmental conditions during Early or Middle Devensian times. Middle Devensian pollen profiles are also recorded from Tolsta Head, Crossbrae, St Kilda, and possibly Teindland (see Lowe, 1984), but as yet the record of this time period in Scotland is highly fragmentary. The available radiocarbon dates suggest that the Burn of Benholm peat represents an earlier phase than the organic deposits at the other sites.

Conclusion

Burn of Benholm is notable for a sequence of deposits that provide important evidence for interpreting the glacial history of eastern Scotland. Of particular interest is a clay deposit, the origin and age of which are controversial. It contains shells of marine molluscs and may be an *in situ* marine deposit representing a high sea-level stand pre-dating the Late Devensian, possibly as old as 450,000 years, or it may be a deposit transported by ice from offshore, that is by the last or earlier ice-sheets. In either case it is a deposit of great interest for Quaternary studies. Also of note is an interstadial peat bed formerly exposed at the site. This provided a rare pollen record of environmental conditions during Early or Mid-Devensian times.

ALMONDBANK

J. E. Gordon and D. G. Sutherland

Highlights

The sequence of deposits exposed in the river bank section at Almondbank has provided important evidence for interpreting the pattern of deglaciation of the Late Devensian ice-sheet. Historically, this evidence was used to support a major readvance of the ice, but current understanding indicates progressive ice decay and deposition of the sediments in a prograding marine delta.

Introduction

This site (NO 084262) comprises a section on the north bank of the River Almond, located 1.75 km west of its junction with the River Tay and *c.* 1 km west of the outskirts of Perth. The sequence of deposits has provided important evidence for interpreting the pattern of decay of the Late Devensian ice-sheet. In particular, it was first described and used by Simpson (1933) as evidence for a readvance, the Perth Readvance, which interrupted wastage of the ice-sheet. The concept of this readvance was supported by Sissons (1963a, 1964, 1967a) as well as by Cullingford (1972), but the investigations of Paterson (1974), Browne (1980), Paterson *et al.* (1981) and Armstrong *et al.* (1985) have led to a rejection of the concept. The section at Almondbank, however, retains its importance in the interpretation of the deglaciation of this part of eastern Scotland.

Description

The sediments exposed in the Almondbank section comprise the following sequence, described by Simpson (1933) and Paterson (1974):

3.	Sands and gravels	4.6 m
2.	Laminated silts and clays	7.2 m
1.	Red-brown till	at least 3.7 m

Although Simpson (1933) described bed 3 as 'morainic deposits', he recognized that the deposits were outwash, a view since confirmed by Sissons (1963a) and Paterson (1974). The sands and gravels (bed 3) occur as terraces on both sides of the River Almond and contain large kettle holes immediately to the north of the section (Figure 14.2).

Paterson (1974) reported that the laminated sediments contained the mollusc *Portlandia arctica* (Gray), Foraminifera and ostracods. Further details were provided by Browne (1980) who reported a restricted microfauna with the Foraminifera mainly being *Elphidium clavatum* (Cushman). Browne also established that the laminated silts and clays extended as far west as Crieff and that they had not been disturbed subsequent to deposition.

Interpretation

Simpson (1933) considered that the red-brown till (bed 1) was deposited by the last ice-sheet to cover the area and that the laminated silts and clays (bed 2) were laid down immediately upon retreat of that ice-sheet. Although he had found no fossils in the immediate vicinity, Simpson argued that the silts and clays correlated with the extensive fossiliferous marine clays (Errol beds, Peacock, 1975c) farther east in the Tay estuary (Jamieson, 1865; Brown, 1867; Davidson, 1932). They could be traced as far west as Templemill (NN 875187), near Crieff, and Simpson inferred ice retreat to at least this locality during their deposition. In addition, Simpson interpreted the rhythmic bedding of these sediments as evidence of annual deposition (that is, they were varves) and estimated that the whole 12.2 m thickness at Almondbank took 640 years to accumulate. It is of note that measurements on a similar sequence of laminated sediments at Dunning in the Earn valley were matched by De Geer (1935) with a Swedish varve sequence from which he inferred a date of deglaciation for that area of 13,013 to 13,071 BP.

The sands and gravels (bed 3) that overlie the laminated sediments are in a similar stratigraphic position to other, frequently poorly sorted, gravels which Simpson mapped in the Earn valley as far west as Crieff. Simpson considered that these were the product of a readvance of the ice-sheet. This conclusion was apparently confirmed by the occurrence of kettle holes in the sands and gravels, which implied the presence of ice at the

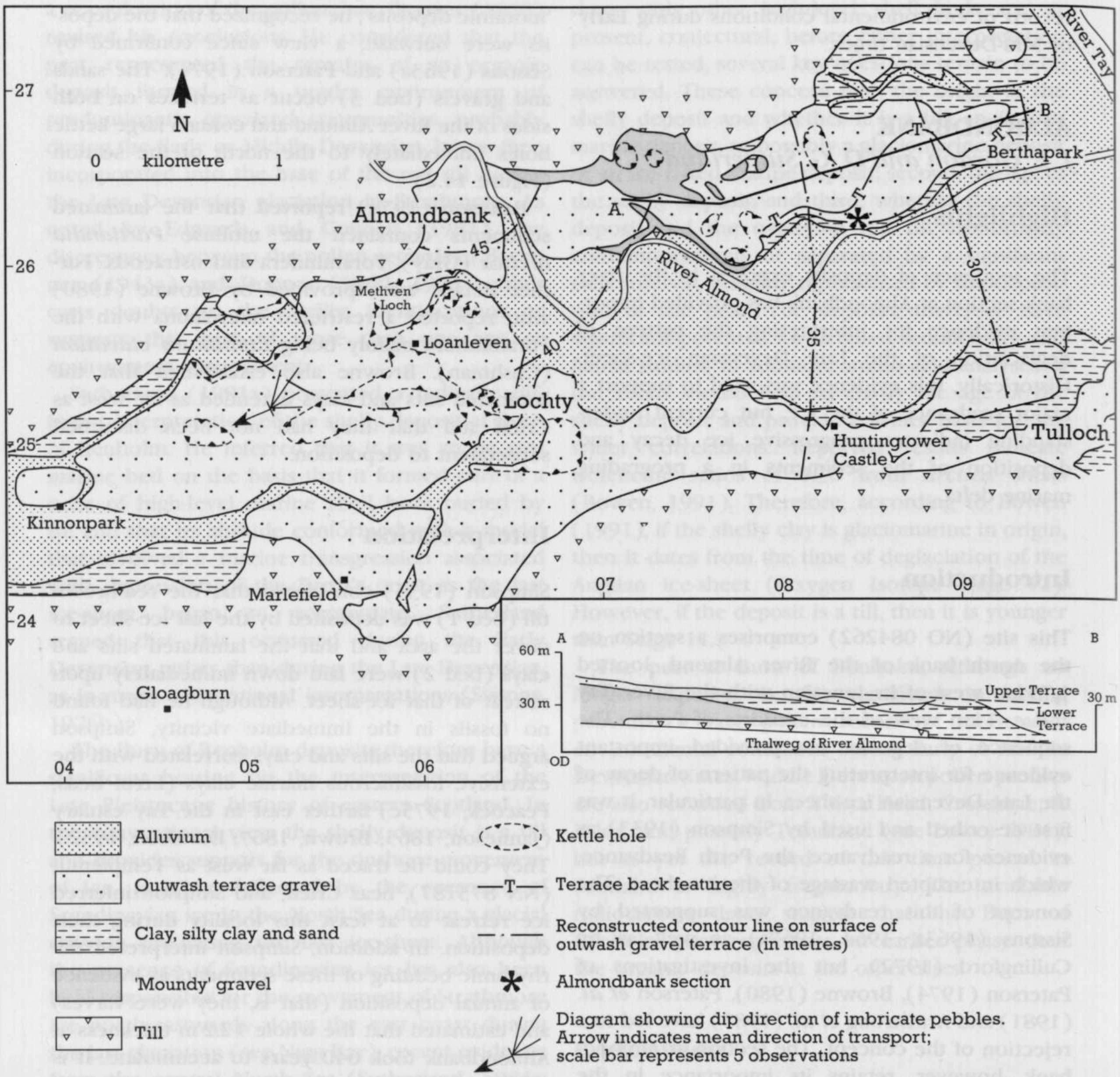


Figure 14.2 Map and section of Late glacial deposits in the Almond Valley (from Paterson, 1974).

time of their deposition.

This interpretation of the Almondbank sequence was accepted by Sissons (1963a), although he suggested a modification to Simpson's readvance limit, placing it approximately 5 km north-west of Perth, where outwash graded into ice-contact glaciofluvial deposits. This latter limit was accepted by Cullingford (1972) who correlated the maximum of the readvance with a pronounced raised shoreline (the Main Perth Shoreline) which had been traced widely along the coasts of south-east Scotland; this shoreline also apparently correlated with a corresponding ice margin in the Forth Valley (Sissons and Smith, 1965a; Sissons *et al.*, 1966; Cullingford, 1977).

Subsequent work by the Geological Survey in the Earn–Tay area (summarized in Paterson *et al.*, 1981; Armstrong *et al.*, 1985) has confirmed Simpson's (1933) stratigraphic sequence, but effectively demonstrated that it is not necessary to invoke a readvance to explain it. Paterson (1974) found evidence that could be interpreted as indicating a readvance at only two localities; Almondbank, where the kettled outwash overlay laminated sediments, and Shochie Burn (see below), where two tills were separated by a layer of sand and gravel. However, Paterson argued that the general absence in the area of an overlying second till together with the lack of disturbance of the laminated sediments precluded a readvance. The contained fossils confirmed the marine origin of the silts and clays, but Paterson argued that, if they were varves, then their period of formation would have been considerably greater than that estimated by Simpson since their thickness was proven to be much greater in boreholes down-valley from the Almondbank section. Alternatively, Paterson contended that these sediments were not varves, but that they accumulated by repeated discharge of material, possibly several times annually, in a marine delta advancing down the lower Almond valley where there were still areas of stagnant ice (Figure 14.2). With the final decay of the 'dead' ice, outwash containing kettle holes was left on top of the deltaic sediments.

According to Browne (1980), the altitudinal distribution of the laminated sediments implies that the sea at the time of the formation of the Main Perth Shoreline had penetrated much farther to the west than Cullingford (1972, 1977) had suggested and that hence the Main Perth Shoreline was not associated with an ice margin immediately north-west of Perth. The overall picture to emerge from the work of the Geological Survey was one of continuous ice retreat with deltaic sedimentation by the major rivers such as the Tay, Earn and Almond into a marine embayment stretching as far west as Crieff and occupying, at its maximum extent, the Methven depression between there and Almondbank.

The Almondbank section is one of considerable historical significance in the development of understanding of the glacial history of Scotland. The original interpretation of the sequence as resulting from a major readvance of the last ice-sheet at approximately 13,000 BP has now been rejected in favour of an origin as the product of deltaic progradation following earlier uninterrupted deglaciation of the area. The sediments retain their interest, however, as one of the few accessible exposures of the marine laminated deposits (equivalent to the Errol beds) in east-central Scotland.

Conclusion

The sequence of deposits at Almondbank is important for interpreting the mode of deglaciation of the Late Devensian ice-sheet (approximately 14,000–13,000 years ago). Historically, it was the key reference site used to substantiate a major ice readvance, the Perth Readvance. Although the deposits have now been reinterpreted in terms of a delta that built seawards during uninterrupted decay of the ice-sheet, the site retains both its historical significance and its high value for sedimentological studies.

SHOCHIE BURN
J. E. Gordon

Highlights

The sequence of deposits exposed in the stream section at Shochie Burn shows glaciotectonically disturbed sands and gravels overlain by till. It shows that a local readvance of ice interrupted the decay of the Late Devensian ice-sheet.

Introduction

The site (NO 071292) is a stream section located on the south bank of the Shochie Burn near Moneydie, 5 km north of Perth. The deposits comprise a succession of two tills separated by sands and gravels, which are important in interpreting the pattern of recession of the Late Devensian ice-sheet margin. The site occurs within the area of the formerly recognized Perth Readvance, and although the succession represents a readvance of the ice margin, this was probably only a minor oscillation. The only description of the site is by Paterson (1974).

Description

The section at Shochie Burn was described by Paterson (1974). It shows a sequence of:

4. Coarse gravel
3. Reddish-brown, sandy till
2. Silt and sand with clay laminae and gravel lenses
1. Reddish-brown, clayey till

The geometry of the deposits is illustrated in Figure 14.3. The lower till (bed 1) is separated from the overlying silt and fine sand (bed 2) by what appears to be a shear plane (Paterson, 1974). The sediments of bed 2 are compacted and deformed: clay laminae are folded, streaked out and displaced by many small faults. The lamination dips generally at 15–20° to the west, but towards the western end of the section it is vertical where the deposit abuts a mass of reddish-brown, clayey till. Overlying bed 2 is a reddish-brown, sandy till (bed 3) which has the form of a wedge. The uppermost deposit (bed 4) is a coarse gravel 4–5 m thick.

Interpretation

Although historical arguments that tripartite sequences, comprising sand and gravel between two tills, imply ice readvance have been shown to be unfounded by work in modern glacier environments (Boulton, 1972b), Paterson (1974) considered that additional evidence from the Shochie Burn deposits supported a minor readvance or brief surge of the Late Devensian ice-sheet. The compacted nature of bed 2, interpreted as fluvial in origin, and the deformation of the sediments, suggested that it had been overridden and glaciotectonized by the ice that deposited the upper till (bed 3); at the same time blocks of till detached from bed 1 were emplaced into the silts and fine sands of bed 2. The gravels of bed 4 form part of an extensive deposit, probably an outwash fan produced as the ice subsequently retreated westwards.

Shochie Burn lies within the limits of the formerly hypothesized Perth Readvance (Simpson, 1933; Sissons, 1963a, 1964). However, the evidence for this event has been reinterpreted, and the readvance is no longer recognized (Paterson, 1974; Sissons, 1974c). The succession at Shochie Burn, the only locality in the Perth area where two tills are known to occur (Paterson, 1974), therefore provides a valuable record of a localized oscillation of the Late Devensian ice-sheet margin and the accompanying sedimentary processes. In particular, the glaciotectonic features are potentially of considerable interest although they have not been studied in any detail.

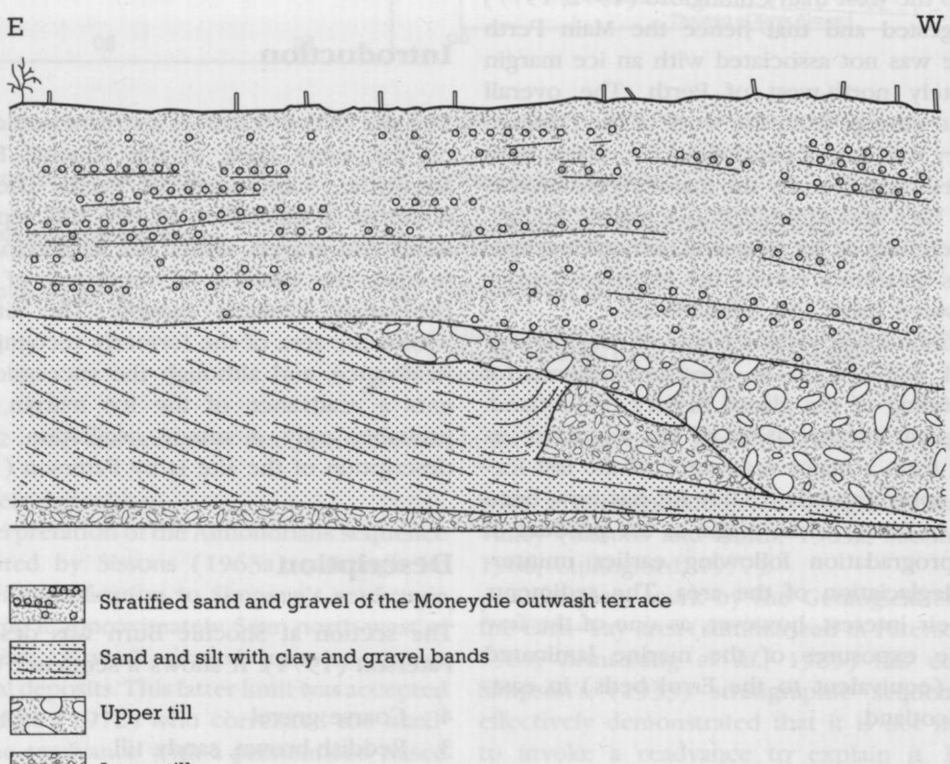


Figure 14.3 Sketch section of glacial deposits at Shochie Burn (unscaled) (from Paterson, 1974).

Conclusion

The deposits at Shochie Burn provide evidence for interpreting the pattern of decay of the last ice-sheet during Late Devensian times (approximately 14,000–13,000 years ago). They show that there was a local readvance of the icefront which overrode and disturbed previously deposited sands and gravels. Although there is no evidence for a widespread readvance, the site is important in demonstrating aspects of the complexity of depositional environments at an ice margin.

DRYLEYS

D. E. Smith

Highlights

The sequence of estuarine sediments in the former clay pit at Dryleys has yielded an important fossil fauna which, in conjunction with geomorphological and sedimentary evidence from the adjacent area, provides a detailed picture of sea-level changes and conditions in the marine environment during the Lateglacial.

Introduction

The Dryleys site (NO 709604) is a former claypit in Late Devensian and Holocene estuarine sediments near Dryleys Farm, north of Montrose. During the latter part of the 19th century, the pit yielded the shells of a largely marine, cold-climate fauna, collected by J. C. Howden. A partial list of the fauna is contained in his account (Howden, 1868) of the sequence of glacial events and relative sea-level changes in the Montrose area. Recent studies by Smith *et al.* (1977), Cullingford and Smith (1980) and Smith and Cullingford (1985) have further contributed to knowledge of Late Devensian and Holocene relative sea-level change in the area, and they enable the Dryleys fauna and deposits to be placed in a more detailed palaeoenvironmental context.

Description

The hillslopes on the northern side of the Montrose Basin are marked by a large number of terraces between Langleypark and Hillside (Figure 14.4). These terraces have been mapped and surveyed by Cullingford and Smith (1980) and Smith and Cullingford (1985). Above 25 m OD, the terraces are glaciofluvial in origin, declining rapidly in altitude eastwards and, from available exposures, are largely composed of poorly sorted sands and gravels. Below 25 m OD, the terraces are marine in origin. Between 10 m and 25 m OD, they are composed of generally fine-grained deposits, largely fine sands and silts, becoming increasingly clayey with depth. These terraces decline only gently eastwards, and at least one appears as the continuation of a higher glaciofluvial terrace, where glacial outwash reached standing water. The marine terraces are, however, fragmentary, being deeply dissected by gullies, most of which formed during the Late Devensian and are now dry. The lower reaches of these gullies are infilled by grey silty clay, reaching a maximum altitude of 6 m to 7 m OD. These sediments underlie a large flat area along the Tayock Burn, reaching the edge of the Montrose Basin. The grey silty clay is similar to the estuarine (carse) clay found in similar areas of central Scotland, and is considered to be the local equivalent of the carse clay. The surface which it forms, here as elsewhere, is distinguished by its uniformity and consistent altitude.

The Dryleys claypit lies on the eastern side of a gully at the eastern margin of this area (Figure 14.4). On the slopes around the gully, terraces formed at approximately 23 m, 19 m, 18 m, 15 m and 13 m OD as relative sea level fell. The claypit is excavated into the 13 m surface which is the main surface in the area, and several exposures, one over 4 m high, occur in the southern face of the pit. This shows laminated sandy silts becoming coarser with depth. These marine sediments are older than the carse clay that occupies the floor of the gully here, although it is not exposed.

During the 19th century, J. C. Howden made a collection of fossil remains from excavations in the Montrose area. This collection was given to the Montrose Museum, where it is still held (1990). Much of the collection was obtained from the carse clay, but from the older terrace deposits above the carselands Howden also obtained a largely arctic fauna, most of which appears to have come from claypits at Dryleys and Puggieston (Figure 14.4). This fauna is listed in Howden's (1868) paper, differing slightly from the museum collection in Table 14.1.

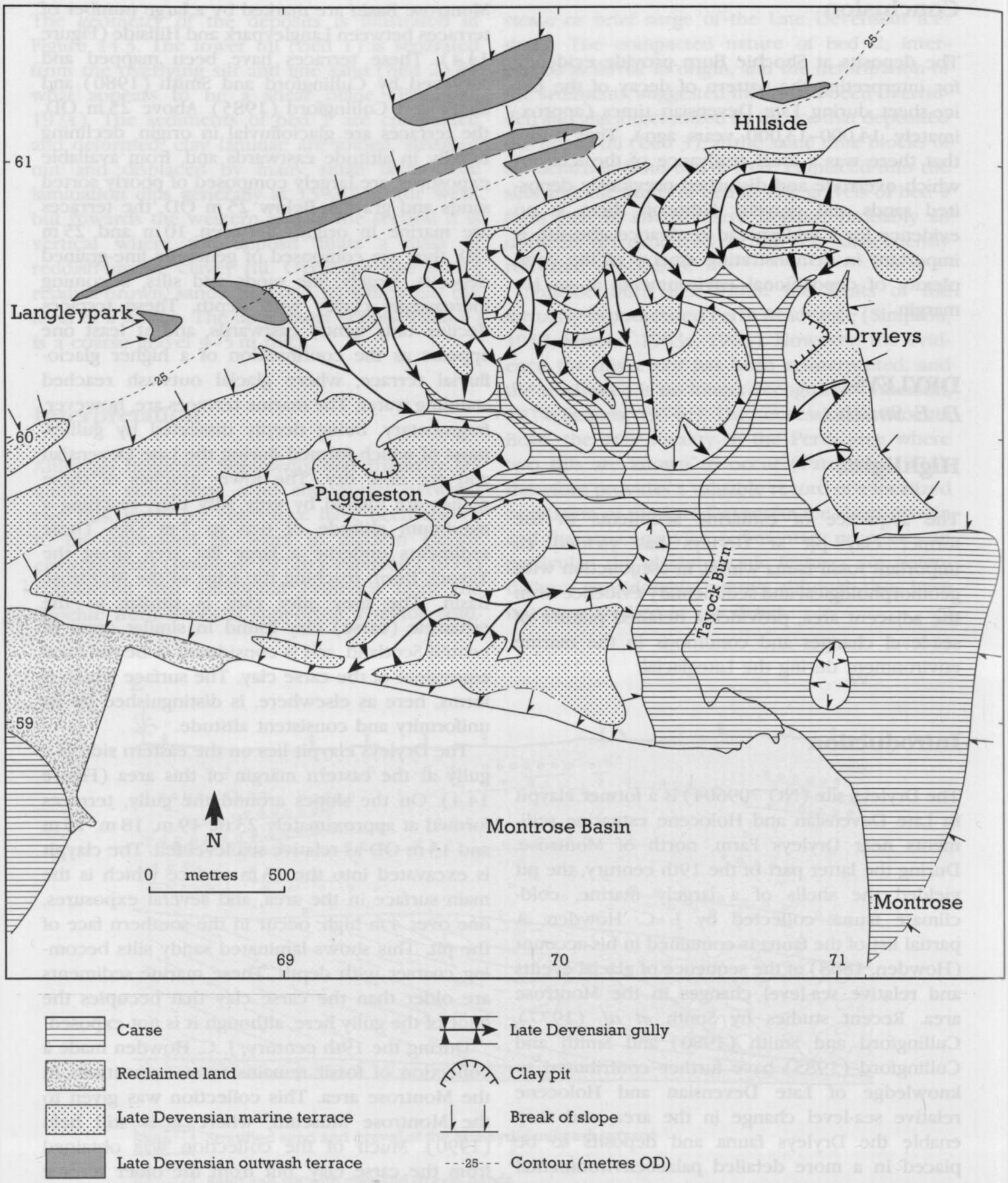


Figure 14.4 Lateglacial and Holocene raised marine deposits in the Dryleys area.

The following details are also provided by J. D. Peacock (unpublished data). The preservation of the specimens of *Arctica islandica* is good, ranging from slightly weathered to fresh and unweathered, whereas that of the other fossils is poor. This contrast suggests that the *Arctica*

Table 14.1 Faunal remains (collected by J. C. Howden) in the Montrose area and attributed to a cold-climate environment

Museum specimen	Location	Modern name
Cyprina islandica	Dryleys	*Arctica islandica* (L.)
Leda arctica	Not given	*Portlandia arctica* (Gray)
Nucula tenuis	Not given	*Nuculoma tenuis* (Montagu)
Pecten greenlandicus	Dryleys	*Arctinula greenlandica* (Sowerby)
Saxicava sulcata	Dryleys	*Hiatella arctica* (L.)
Yoldia arctica	Dryleys	*Portlandia arctica* (Gray)
Somateria sp.	Puggieston	
Cythere sp.	Not given	
Ophiolepis gracilis	Dryleys	
Phoca vitellinus	Balwyllo	*Phoca vitulina* L.

An investigation of the Howden Collection in the Montrose Museum showed the following molluscan fauna to be present (J.D. Peacock, unpublished data).

Dryleys: *Arctinula greenlandica* (Sowerby), *Hiatella arctica* (L.), *Mya truncata* (L.) *Nuculoma belloti* (Adams), *Portlandia arctica* (Gray) and *Yoldiella* cf. *lenticula* (Müller).

Puggieston: *Arctica islandica* (L.), *Hiatella arctica* (L.), *Nuculoma* cf. *belloti* (Adams), *Yoldiella solidula* Warén and *Y. lenticula* (Müller).

Ballwyllo: *Arctinula greenlandica* (Sowerby).

Unplaced specimens: *Arctica islandica* (L.), *Arctinula greenlandica* (Sowerby), *Hiatella arctica* (L.) and *Portlandia arctica* (Gray).

Table 14.2 Radiocarbon dates from faunal remains in the Montrose area

Sample	Location	Age (14C years BP)	Laboratory number
[1]*Somateria mollissima*	Puggieston	10,610 ± 220	Birm–660
[1]*Somateria* sp. or *Melanitta* sp.	Puggieston	11,110 ± 210	Birm–661
[2]*Arctica islandica*	Dryleys		
Outer fraction		3830 ± 140	Birm–737(1)
First middle fraction		4180 ± 120	Birm–737(2)
Second middle fraction		4170 ± 160	Birm–737(3)
Inner fraction		4020 ± 200	Birm–737(4)

[1]Smith *et al.* (1977); Williams and Johnson (1976).
[2]Smith (1986).

specimens are an intrusion into the high-arctic, fully marine fauna, a conclusion that accords with radiocarbon dating (see above). The specimens of *Yoldiella solidula* and *Y. lenticula* from Puggieston presumably came (as *Leda pygmaea*) from the tympanic bones of the seal *Phoca vitulina* L. (see Howden, 1868, p. 141). The list of ostracods from Dryleys given by Brady *et al.* (1874) supports the high-arctic affinities of the fauna.

The principal difference between the faunal list contained in the 1868 paper and the specimens preserved in the museum is the presence of duck bones in the museum, identified as those of Eider (*Somateria* sp.). These bones, collected in 1891 from the claypit at Puggieston, were re-examined by D. Bramwell in 1976 and are believed to belong to two individuals, identified as Eider (*Somateria mollissima* (L.)) and either Eider, or Scoter (*Melanitta* sp.) (Smith *et al.*, 1977).

Smith *et al.* (1977) sought to determine the age and environment of the fauna. They examined pollen from the clay in which the Eider bones were embedded, finding evidence of an open habitat, with Gramineae, Cyperaceae, *Empetrum*, *Artemisia* and Rosaceae pollen grains present. Table 14.2 gives the radiocarbon dates from the duck bones and a specimen of *Arctica islandica*.

Smith and Cullingford (1985) identified a buried peat beneath the grey silty clay, and, in addition, found a layer of grey, micaceous, silty fine sand within the deposits in several of the gullies, including that at Dryleys. From peat above and below this layer, in the nearby gully at Puggieston, they obtained radiocarbon dates (Table 14.3).

Table 14.3 Radiocarbon dates on a possible storm surge layer at Puggieston, after Smith and Cullingford (1985)

Sample	Date (14C years BP)	Laboratory number
0.02 m thick slice of peat above layer	6850 ± 75	SRR–2119
0.02 m thick slice of peat below layer	7120 ± 75	SRR–2120

Interpretation

The morphology of the area surrounding Dryleys indicates that the pit was excavated in deposits belonging to one of a series of eight Late Devensian shorelines in the region, formed as ice withdrew from the Montrose Basin area. The five terraces surrounding the gully at Dryleys are correlated with shorelines DS3 to DS7 of Cullingford and Smith (1980), with the pit having been excavated in the deposits of DS7. Cullingford and Smith identified the nearby deposit at Puggieston as belonging to the same sequence, but related to the lowest shoreline, DS8, one below that at Dryleys. The largely cold-climate faunal remains recovered from the pit during the 19th century are in accord with this interpretation, as is the limited pollen evidence from the deposit. The radiocarbon dates obtained from faunal remains from Dryleys and Puggieston are of limited value. The dates for the *Arctica islandica* shell specimen, although internally consistent, are far too young for a Late Devensian deposit, and since this bivalve has a wide environmental range, the possibility of incorrect labelling in the museum collection must be considered. The dates for the duck bones are older, but apparently also too young, and museum conservation practices may have produced contamination. Thus, in view of the uncertainty of the radiocarbon evidence all that can be said at present is that the deposits are of Late Devensian age.

The gully system at Dryleys is largely dry, and in view of the extensive Holocene estuarine deposits in the floor of the gullies, it seems likely that, by analogy with similar features elsewhere in Scotland (see Sissons *et al.*, 1965), the gully system was largely excavated under periglacial conditions during the Late Devensian.

Smith and Cullingford (1985) confirmed that the grey silty clay infilling the floors of the gullies was a Holocene estuarine deposit accumulated during the Main Postglacial Transgression, and that the surface on the deposit was formed at the maximum of that event in the area, correlating with the Main Postglacial Shoreline. A layer of grey, micaceous, silty fine sand was formed in the course of the transgression and then buried by later deposits. This layer has been identified at a number of estuarine sites in eastern Scotland (see Maryton, Silver Moss and Western Forth Valley), and must have been a widespread event (Smith *et al.*, 1985a). It has been interpreted as a storm surge event (Smith and Cullingford, 1985; Smith *et al.*, 1985a; Haggart, 1988b), or more probably as a tsunami associated with a submarine slide on the Norwegian continental slope (Dawson *et al.*, 1988; Long *et al.*, 1989a).

The Dryleys claypit is of great importance for studies of the Late Devensian environment in Scotland. Excavated into a terrace which forms part of a suite of Late Devensian marine shorelines in the area, it yielded during the 19th century a largely cold-climate fauna which is still preserved and available for study; present-day exposures provide the potential for further sedimentological and palaeoecological investigation. In addition, the site lies in an area rich in Late Devensian and Holocene landforms and deposits. The evidence it contains can thus be set in a wider context, in which the relationships between morphology and stratigraphy are clearly demonstrated. There are few other Late Devensian sites in eastern Scotland where such an extensive and varied faunal record has been identified.

Conclusion

Dryleys is important for studies of Late Devensian sea levels in eastern Scotland. The deposits form part of a series of marine terraces that formed during and following the deglaciation of the area (possibly between 16,000 and 14,000 years ago) and were first studied last century. They have yielded a range of fossils which have been used to interpret a cold-climate marine environment at their time of deposition. Adjacent deposits include later Holocene marine sediments. Dryleys is a valuable reference site in an area of long-standing interest for sea-level studies.

MARYTON

J. E. Gordon

Highlights

Deposits in the coastal section at Maryton include a sequence of estuarine sediments and buried peat. These deposits provide a record of the changes that occurred in sea level and coastal environmental conditions during the Holocene. The site is particularly notable for the evidence it displays for a major coastal flood in eastern Scotland during the middle Holocene.

Introduction

The site at Maryton (NO 683565) is a cliff section in raised estuarine deposits on the west side of the Montrose Basin. It is important for demonstrating Holocene sea-level fluctuations in eastern Scotland and provides one of the best exposures showing the stratigraphic relationships of the estuarine (carse) deposits of the Main Postglacial Shoreline. It is also the only site known where a possible storm-surge or tsunami deposit dating to slightly prior to the maximum of the Main Postglacial Transgression is currently exposed. The site has been described by Smith *et al.* (1980) and discussed in a wider context by Smith *et al.* (1985a); it has also been illustrated in Smith *et al.* (1985a), Long *et al.* (1989b) and Smith and Dawson (1990).

Description

The superficial deposits of the Montrose area were first described in detail by Howden (1868) and later summarized by him (Howden, 1886) in the following general succession:

6. Blown sand
5. Estuarine (carse) clay and sand
4. Peat
3. Glaciofluvial sands and gravels
2. Laminated marine clay
1. Till

The basal unit of till was overlain by laminated marine clay extending up the South Esk Valley to an altitude of 40 ft (12.2 m). Although the contact between the two was nowhere exposed, Howden was in no doubt of their stratigraphic sequence. The clay (bed 2) contained abundant fossil remains of arctic molluscs which Howden (1868) listed (see Dryleys). Jamieson (1865) gave additional details, and Brady *et al.* (1874) listed the ostracods.

Howden described sands and gravels (bed 3) overlying the marine clay and the till, which extended as far inland as the mouths of the Highland glens. These gravels were part of the sequence first described by Buckland (1841a), and in mineralogical composition were identical to the moraines of the Highland glens. Howden suggested that the sands and gravels were formed by meltwaters at the end of the great ice-sheet glaciation and subsequently while valley glaciers remained in the glens. Cullingford and Smith (1980) have mapped these deposits to the west of the Montrose Basin and noted that four separate outwash terraces can be related to distinct shorelines at altitudes of between 15 m and 25 m OD around the Montrose Basin.

In a number of stream courses tributary to the South Esk, Howden observed peat (bed 4) resting on the marine clays and extending on to the gravels. At one locality the peat was overlain by carse clays. Generally, however, the latter deposits rested on the lower marine clay and reached an altitude of 15 ft (4.6 m). Shells similar to those found in the present-day estuary were locally abundant in the carse clay. Details were given by Jamieson (1865) and Howden (1868). More recently, the pattern of Holocene sea-level changes in the Montrose area has been investigated in detail by Crofts (1971, 1972, 1974) and Smith and Cullingford (1985). In particular, Maryton has been described in detail by Smith *et al.*

(1980). A sequence of marine and non-marine organic deposits infills a number of gullies dissecting Late Devensian marine and glaciofluvial terraces at the western end of the Montrose Basin (Cullingford and Smith, 1980; Smith *et al.*, 1980). A section in a terrace bluff at Maryton shows (Figure 14.5):

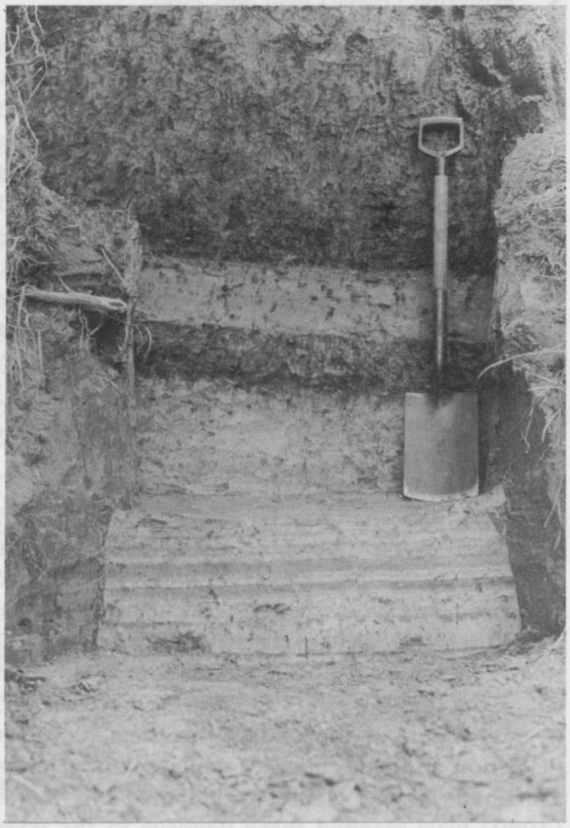


Figure 14.5 Section at Maryton. Laminated Late Devensian marine clays are overlain by peat then a layer of grey, micaceous, silty, fine sand interpreted as a tsunami deposit. Above the latter is silty peat then carse clay. (Photo: D. E. Smith.)

5.	Grey silty clay (carse)	0.85 m
4.	Peat	0.10 m
3.	Grey, micaceous, silty fine sand	0.18 m
2.	Peat	0.15 m
1.	Laminated, pink silty clay	0.20 m

The sequence in the section is broadly similar to that revealed in boreholes in the Fullerton area 0.5 km to the west (Smith *et al.*, 1980). Samples for pollen analysis were taken from the Maryton section and two coring sites at Fullerton by Smith *et al.* (1980). They recognized three pollen assemblage zones at Maryton (Figure 14.6). Zone M–1 includes poorly preserved pollen from most of the laminated, pink silty clay (bed 1). Although the pollen frequencies are low and the range of taxa restricted, open habitat conditions are indicated. Zone M–2 includes pollen from the horizons between the upper layers of the pink silty clay (bed 1) and the lowest part of the carse clay (bed 5). Contrasts in pollen frequency and assemblage suggest a break in deposition between zones M–1 and M–2. The main characteristics of zone M–2 are the consistent representation of *Betula* and *Pinus sylvestris*, variable amounts of *Corylus*-type and *Salix*-type pollen and the presence of *Ulmus* and *Quercus*. Several taxa also suggest the proximity of damp conditions (Gramineae, Cyperaceae, Chenopodiaceae, Nymphaceae and *Filipendula*). Zone M–3 includes the greater part of the carse clay. The main representatives of M–3 are *Pinus sylvestris*, *Corylus* type, *Betula*, *Ulmus* and *Quercus*. Other taxa (Nymphaceae and Cyperaceae) again indicate local damp conditions.

Smith *et al.* (1980) correlated pollen zone M–1 with an equivalent zone from a similar, basal, laminated clay layer in one of the Fullerton boreholes. It was thought to reflect an open-habitat, Late Devensian environment. Zones M–2 and M–3 also have equivalents with similar tree and herbaceous pollen in both the Fullerton boreholes. These assemblages indicate a boreal environment, corresponding with Holocene 'chronozone' Fl I of West (1970). An additional zone, corresponding with 'chronozone' Fl II, is represented in one of the Fullerton profiles.

Smith *et al.* (1980) obtained radiocarbon dates for several horizons at Maryton and Fullerton (Table 14.4).

Interpretation

Sequences similar to those described by Howden (1868, 1886) from the Montrose area have long been recognized elsewhere in the Tay, Forth and Ythan estuaries. Together with the evidence from these other sites, the Montrose deposits have formed an important part of the wider interpretation of Lateglacial and Holocene sea-level changes in eastern Scotland (Jamieson, 1865; J. Geikie, 1874; Wright, 1937; Sissons, 1967a; Cullingford *et al.*, 1986, 1991). A full sequence of Lateglacial and Holocene deposits is nowhere exposed, but the section at Maryton demonstrates a key part of the succession spanning the period of the

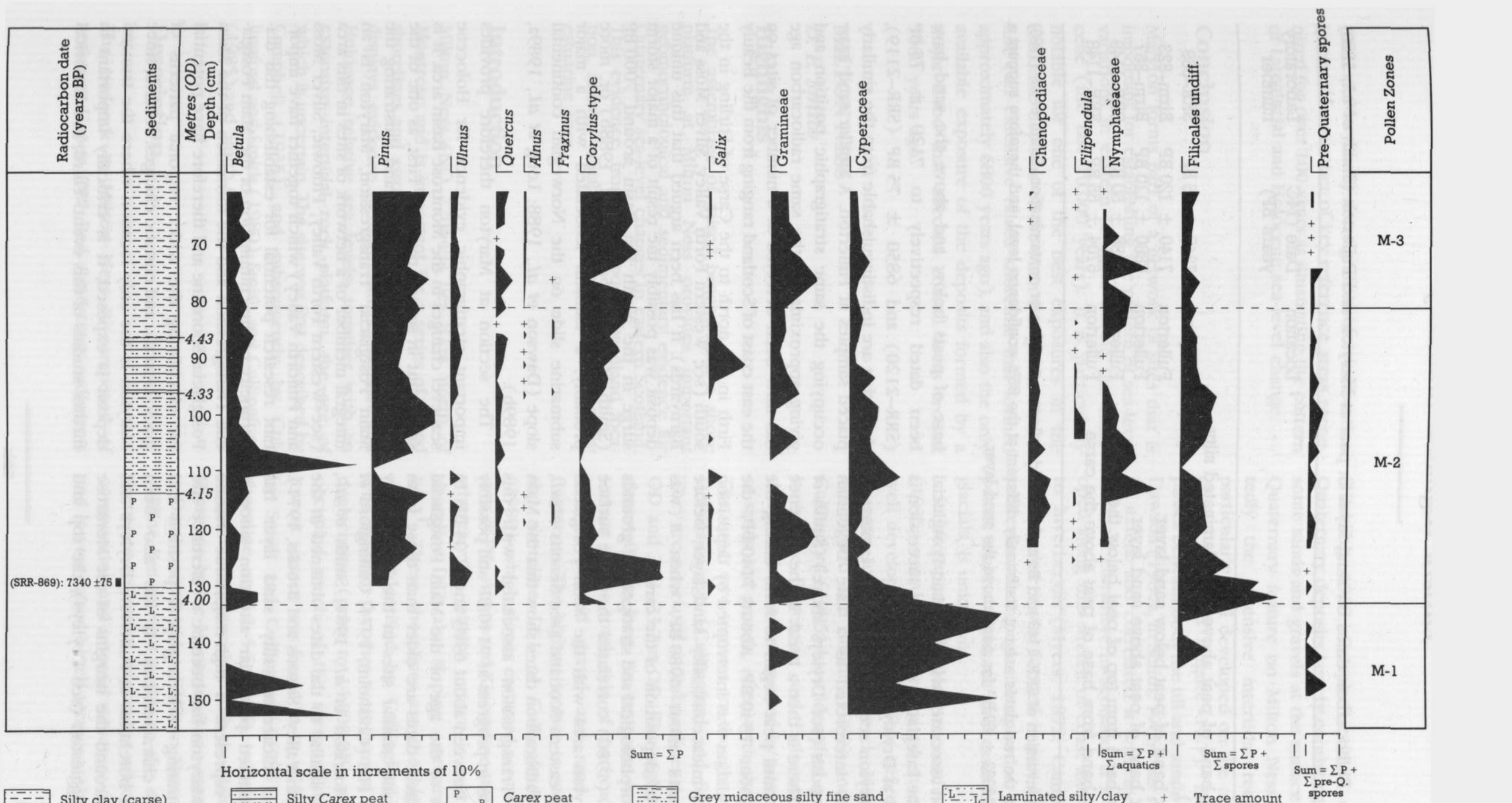


Figure 14.6 Maryton: relative pollen diagram showing selected taxa as percentages of total pollen (from Smith *et al.*, 1980).

Table 14.4 Radiocarbon dates on sand layer in peat at Maryton and Fullerton (Smith *et al.*, 1980)

Sample	Location	Date (14C years BP)	Laboratory number
0.02 m thick band of peat above basal laminated silty clay (bed 1)	Maryton	7340 ± 75 BP	SRR–869
0.02 m thick band of peat below sand layer	Fullerton	7140 ± 120 BP	Birm–823
0.02 m thick band of peat above sand layer	Fullerton	6880 ± 110 BP	Birm–867
0.02 m thick band from top of peat below the carse	Fullerton	7086 ± 50 BP	SRR–1149
0.02 m thick band from base of peat above the carse	Fullerton	6704 ± 55 BP	SRR–1148

Although the inversion of SRR–1149 and Birm–867 could reflect reworking or contamination, Smith *et al.* (1980) point out that the two dates are not statistically different at the 95% confidence level, and therefore suggest a mean age of 6983 ± 60 BP for peat above the sand layer.

transgression associated with the Main Postglacial Shoreline; the Lateglacial part of the succession is represented at Dryleys (see above).

In the Maryton sequence the basal, laminated, silty clay is interpreted as a Late Devensian estuarine deposit (see Dryleys above) (Smith *et al.*, 1980). There is then a break in the sequence of deposits until peat began to form during the Holocene about 7340 BP. About 7140 BP, the peat accumulation was interrupted by deposition of the grey, micaceous, silty sand layer, before resuming until about 6980 BP, when it was terminated by deposition of the carse.

On geomorphological and stratigraphic grounds Smith *et al.* (1980) correlated the carse surface in the Maryton area with the Main Postglacial Shoreline of eastern Scotland (see Sissons *et al.*, 1966). The radiocarbon dates show that the Main Postglacial Transgression associated with this shoreline was in progress at 7140 BP and possibly culminated between about 6983 and 6704 BP. In the context of the age of the Main Postglacial Shoreline, these dates are older than those from stratigraphically similar sites in the Tay estuary and eastern Fife (Chisholm, 1971; Cullingford *et al.*, 1980; Morrison *et al.*, 1981; Smith *et al.*, 1985b), but similar to the dates obtained in the Western Forth Valley (Sissons and Brooks, 1971).

The grey, micaceous, silty sand layer has recently attracted particular attention since it appears to represent a high-magnitude marine event, and Maryton has become a reference site for demonstrating its stratigraphic position and sedimentary characteristics. It has also been identified in boreholes at Fullerton, Dryleys and other sites around the margins of the Montrose Basin. At Puggieston (see Dryleys), the top and base of peats below and above the sand have been dated respectively to 7120 ± 75 BP (SRR–2120) and 6850 ± 75 BP (SRR–2119), dates that are indistinguishable from the similarly placed samples at Fullerton. A similar sand layer occupying the same stratigraphic position and giving approximately the same radiocarbon age has now been detected at a number of sites on the east coast of Scotland ranging from the Beauly Firth in the north to the Carse of Stirling in the south (see Western Forth Valley, Silver Moss and Barnyards). It has been argued that this unique deposit was possibly the result of a major storm surge in the North Sea Basin around 7000 BP (Smith *et al.*, 1985a; Haggart, 1988b) or, more probably, a tsunami associated with a major submarine slide on the Norwegian continental slope (Dawson *et al.*, 1988; Long *et al.*, 1989a, 1989b).

The section at Maryton therefore provides important stratigraphic evidence for Holocene sea-level changes in the Montrose Basin area. It is significant in several respects. First, as one of the best sections in eastern Scotland illustrating the Main Postglacial Transgression, Maryton is an integral member of a network of sites in this area (see Western Forth Valley, Pitlowie, Silver Moss and Philorth Valley) which together have important research potential for establishing the diachroneity of the culmination of the Main Postglacial Transgression and the formation of the Main Postglacial Shoreline and therefore have potential for elucidating the wider regional patterns of glacio-isostatic and eustatic changes. Second, since Maryton is the only location where the tsunami deposit is exposed, it is critically important in further studies of this event. Third, in a historical context, Maryton is also significant for its location in one of a number of key reference areas recognized for over 100 years as illustrating the pattern of Lateglacial and Holocene sea-level change.

Conclusion

Maryton forms part of a network of sites that is important for establishing the pattern of sea-level variations in eastern Scotland during the Holocene (the last 10,000 years). It is particularly notable for one of the best exposures in the estuarine deposits of the Main Postglacial Shoreline (an extensive raised shoreline that formed approximately 6800 years ago), and also the only available exposure of the deposits formed by a major flood that affected coastal areas around 7000 years ago.

MILTON NESS

D. E. Smith

Highlights

The assemblage of raised beaches and a shore platform at Milton Ness provides important geomorphological and sedimentary evidence for Quaternary sea-level changes in eastern Scotland. This evidence, from an exposed headland location, allows valuable comparisons with nearby estuarine sites.

Introduction

Milton Ness (NO 770649) lies 8 km north of Montrose and is important for a series of raised shorelines and associated deposits. The headland displays evidence of both Late Devensian and Holocene relative sea levels, together with an extensive intertidal rock platform, the age of which is uncertain. The site was first described by Campbell (1935), and subsequently by Cullingford and Smith (1980), Smith and Cullingford (1985) and Smith (1986).

Description

The bedrock at Milton Ness is composed of resistant Upper Old Red Sandstone sediments (Hickling, 1908; Campbell, 1913) overlain by Quaternary deposits largely consisting of till, with some sands and gravels at the surface. The oldest Quaternary feature on Milton Ness is undoubtedly the extensive intertidal rock platform, particularly well developed on the northern side of the headland (Figure 14.7). This platform passes beneath both the till and sands and gravels. Dawson (1980a, in Smith, 1986) has remarked on its extent and correlated it with the Low Rock Platform elsewhere in Scotland. It is well developed along this stretch of coast and northwards to Inverbervie (Myers, 1872; Campbell, 1935) but whether it was formed in part by periglacial processes during glacial episodes, or by temperate marine erosional processes during interglacials, is unknown.

In his paper on the Mearns coastline, Campbell (1935) noted that three raised shorelines were well developed at Milton Ness, reflecting former changes in relative sea level. More recently, Cullingford and Smith (1980) and Smith and Cullingford (1985) have identified a sequence of both Late Devensian and Holocene shorelines there, each shoreline marked by a terrace formed of sands and gravels, often with shell fragments. The upper two terraces are thought to be of Late Devensian age (Cullingford and Smith, 1980). They are associated with shorelines at 20.1–20.7 m OD and 21.1–23.7 m OD. The highest terrace is almost 0.5 km long. An exposure in the middle terrace on the south side of the headland shows 5 m of bedded gravel and sand with shell fragments. The highest terrace is correlated with the shoreline DS1 of Cullingford and Smith (1980), which slopes eastward across the general area of Fife, Angus and Kincardine at 0.85 m km^{-1}, whereas the middle terrace is correlated with shoreline DS2, also sloping eastward, at 0.73 m km^{-1}. These shorelines are the highest in the sequence identified by Cullingford and Smith, who maintain that they were formed very early in deglaciation (prior to 14,000 BP), when ice still occupied much of the surrounding area. The lowest terrace was found to be of Holocene age by Smith and Cullingford (1985). It forms a shoreline at 5.2–5.5 m OD, which they have suggested may correlate with the Main Postglacial Shoreline in the Montrose Basin carselands.

On the south side of Milton Ness, the present cliffline lies at right angles to the shoreline and there are extensive exposures which reveal the composition and internal structure of the middle and lowest raised beach terraces. Although these

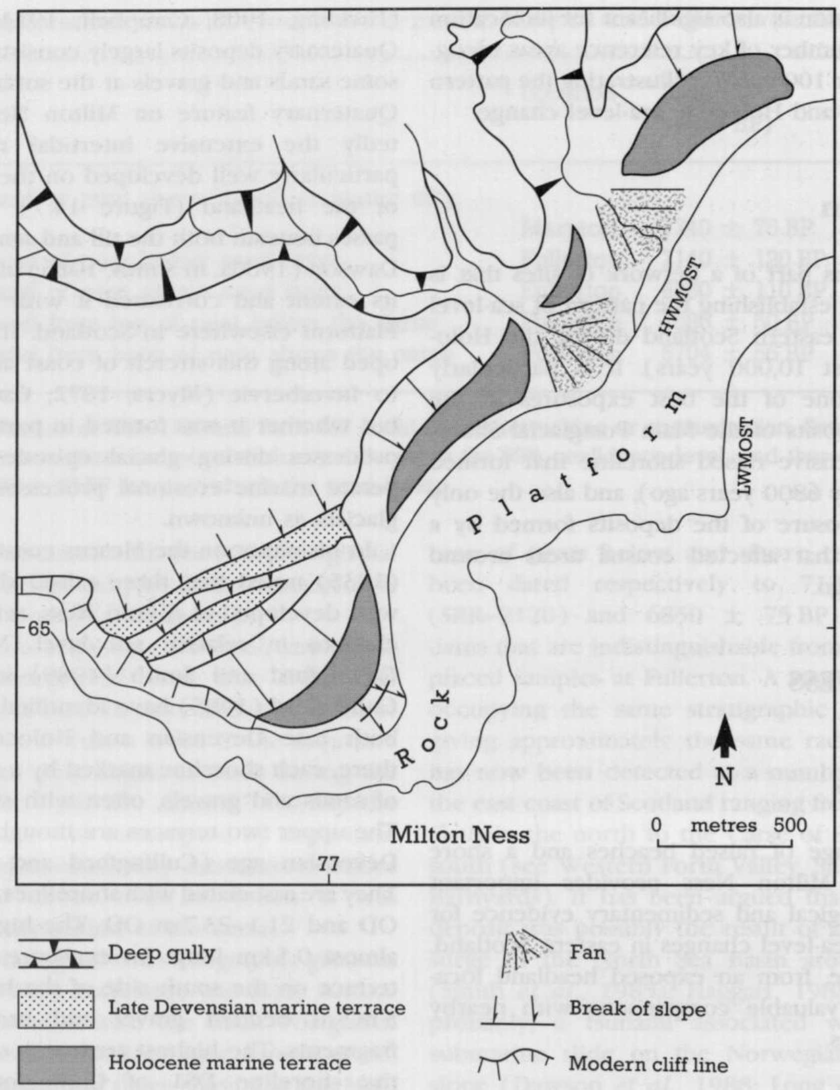


Figure 14.7 Raised shorelines and intertidal shore platform at Milton Ness.

have not been studied in detail, they provide a potential opportunity to relate raised beach morphology and sediments.

Interpretation

Milton Ness demonstrates an assemblage of several important features associated with relative sea-level changes in eastern Scotland. The interest includes first, an intertidal shore platform of uncertain age but pre-dating, at least in part, the last glaciation; second, two Lateglacial raised beaches, which are part of the earliest shorelines to form in the general area following deglaciation; and third, a prominent Holocene raised beach terrace possibly related to the Main Postglacial Shoreline. Each feature is clearly identifiable and extensive exposures illustrate the structure and composition of the raised beach terraces. Elsewhere in eastern Scotland, comparable sequences of raised beaches occur in East Fife (Cullingford and Smith, 1966), and between Dundee and Arbroath and north of Johnshaven (Cullingford and Smith, 1980), but they lack comparable exposures to those at Milton Ness. This rare combination of both morphological and sedimentary evidence is important in the study of coastal evolution in eastern Scotland. The morphological and sedimentary evidence from the exposed headland at Milton Ness complements the stratigraphic evidence for sea-level change represented nearby at Maryton and Dryleys in the more sheltered estuary of the South Esk. Milton Ness, together with Dunbar and Kincraig Point, provides good examples of the range of coastal landforms and sediments developed on the exposed (as opposed to estuarine) coasts of the east of Scotland. They can be compared directly with the similarly exposed coastal sites in the west (Glenacardoch Point, Northern Islay and West Coast of Jura) to illustrate the differing histories of coastal evolution during the Late Quaternary.

Conclusion

Milton Ness is important for the study of coastal changes in eastern Scotland during pre-Late Devensian times and during the Late Devensian and Holocene (approximately the last 16,000 years). The features of interest include a shore platform and raised beaches with good exposures in the deposits. The particular value of Milton Ness lies in this combination of geomorphological and sedimentary evidence and its location on an exposed headland, which contrasts with sedimentary evidence in the estuarine situation of Dryleys and Maryton.

NORTH ESK AND WEST WATER GLACIOFLUVIAL LANDFORMS

J. E. Gordon and L. J. McEwen

Highlights

The assemblage of outwash and river terraces at this site illustrates the range of geomorphological processes that accompanied the decay of the Late Devensian ice-sheet in the Eastern Highland Boundary area. The site is particularly noted for its palaeochannels which have allowed changing discharge patterns to be reconstructed since the time of deglaciation.

Introduction

This site comprises two areas in Strathmore located at the Highland edge near Edzell. The larger ($c.$2.5 km^2) lies to the west of the village between NO 565695 and NO 597679; the smaller ($c.$ 0.6 km^2) to the south-east between NO 614686 and NO 620673. Together these areas are important for an assemblage of glaciofluvial landforms and deposits. These comprise an extensive spread of outwash (palaeosandur) deposits built out eastwards across Strathmore during the wastage of Late Devensian glaciers in the adjacent glens of the West Water and River North Esk (Synge, 1956; Sissons, 1967a; Maizels, 1976). In the former case the sandur deposits are associated with an ice-marginal position marked by a distinctive area of kame and kettle topography and meltwater channels.

The palaeosandur deposits associated with the North Esk and its tributary, the West Water, extend for 10 km downstream from the Highland Boundary Fault zone. They provide an excellent example of Late Devensian outwash deposits which have been dissected to form four main terrace systems. The terraces display systems of palaeochannels which have been mapped in detail by Maizels (1976, 1983a, 1983b), and used in palaeohydrological reconstructions and modelling (Maizels, 1983a, 1983b, 1983c, 1986; Maizels and Aitken, 1991).

Description

In the valley of the West Water, 3 km west of Edzell, an area of hummocky kame and kettle topography and ice-contact slopes marks the position of a former glacier margin. A section at NO 567688 shows that, at least in part, the landforms are developed in sand and gravel. Although formerly ascribed to readvances of the last ice-sheet (Synge, 1956; Sissons, 1967a), these deposits probably reflect either a local halt, or change in glacier dynamics and sedimentation as the Late Devensian ice wasted back from Strathmore into the confined Angus glens, probably between 14,000 and 13,000 BP (Sutherland, 1984a). The former ice margin is not marked by an end moraine in the classic sense, but rather by a landform assemblage typical of modern glacier environments dominated by glaciofluvial activity and the formation of kame and kettle topography (Price, 1973; Boulton and Paul, 1976).

Meltwater channels are associated with the ice-front deposits and they also occur in a proglacial location, for example, at Edzell Castle (NO 585692). Outwash terraces lead away from the former ice-front and extend out across Strathmore, and also from adjacent glens (Buckland, 1841a; Lyell, 1841a; Howden, 1868; Bremner, 1939a; Synge, 1956; Sissons, 1967a, 1976b;

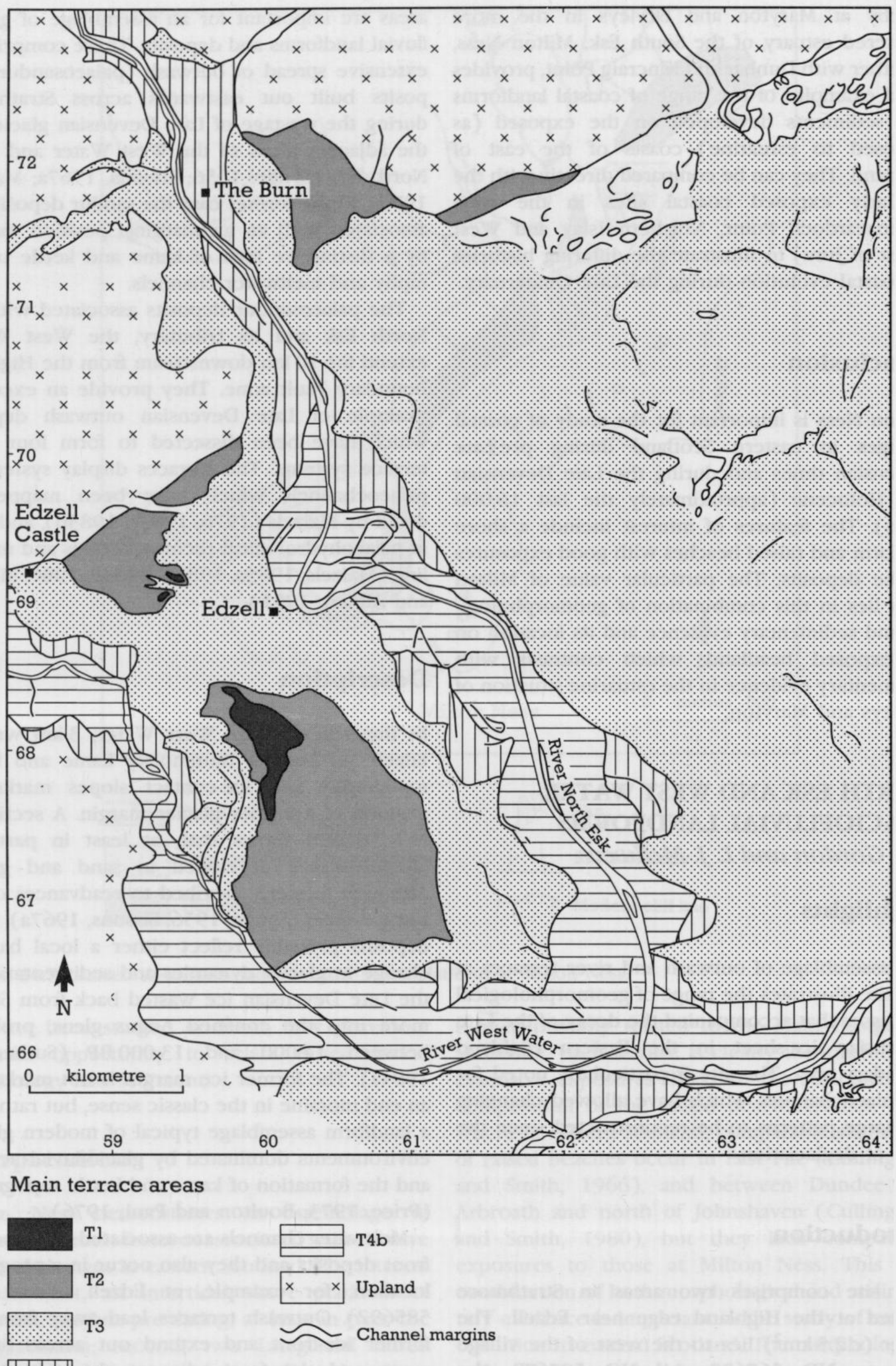


Figure 14.8 Terraces of the River North Esk and West Water in the Edzell area (from Maizels, 1983a).

Crofts, 1974). In Glen Esk, outwash terraces extend from north-west of The Burn (Sissons, 1967a). As deglaciation progressed, the outwash deposits and stream channels would have continued to adjust to changes in water discharge and sediment supply. During and following deglaciation, the area also underwent isostatic uplift, with consequent changes in base level.

The sandur deposits are up to 6 m in depth and are characterized as 'massive, coarse, poorly-sorted, imbricated gravels and cobbles, with isolated lenses of cross-bedded and plane-bedded coarse and medium sands, characteristic of Miall's (1978) 'Gm' gravel lithofacies type, and similar to Scott outwash sediments (facies assemblage GII of Rust, 1978) comprising over 90% gravel content' (Maizels, 1983b, p. 256). The sedimentary characteristics of the sediments indicate deposition in an aggrading, proglacial, braided river environment (Maizels, 1983a).

The four main terraces, associated with both the North Esk and the West Water, have been mapped by Maizels (1983a, 1983b) (Figure 14.8). The upper two terraces (T1 and T2) are evident only as isolated fragments; the lower two (T3 and T4) are much more extensive (Figure 14.8). Study has focused on the nature, direction and magnitude of change within this terrace sequence (Maizels, 1983a, 1983b, 1983c, 1986; Maizels and Aitken, 1991). For example, large-scale changes in channel pattern and morphology have been identified between terrace fragments and attributed to a decline in the amounts of meltwater discharge and sediment supplied during and after deglaciation. The resulting palaeoforms thus reflect channel adjustment from a proglacial environment to present-day fluvial controls. They also demonstrate a south-eastward migration of the North Esk/West Water confluence by 2.8 km; a shift that was clearly accompanied by periods of aggradation and incision.

As well as macro-scale change, more intricate localized channel incision and minor terrace fragments have been mapped. Three different types of palaeochannel have been identified, each type associated with different rates of discharge and sediment availability (Maizels, 1983a). These include complex braided systems (Type A), deeper wider channels (Type B) and deeply incised and relatively localized meander scars (Type C). In terms of inter-terrace variation in palaeochannel type, the two upper terraces have been identified as having more braided (Type A) and periglacial (Type B) channel systems, whereas the lower terraces have more sinuous (Type C) channels, although all terraces exhibit complex braided palaeochannels to a certain degree. The lower terraces (T3 and T4) are characterized by multiple channel networks, longitudinal bars, high width-to-depth ratios and low sinuosities. The lower terrace surfaces are also locally incised by relatively well-defined, deep, low-gradient, sinuous channels and many of the adjacent terrace bluffs possess major meander scars. The number of sinuous channels increases from the highest terrace (T1) to the lowest (T4), whereas the degree of braiding declines. Mean width-to-depth ratios decline from about 108 to about 40 between T1 and T4 (Maizels, 1983a).

Interpretation

Maizels (1983a, 1983b) concluded that the deep, sinuous channels (Type C) were responsible for terrace formation and that each phase of terrace formation involved a change from straight, multiple channels to single-thread channels in response to threshold changes in meltwater and sediment discharges, which could relate to glacier fluctuations or episodic flood events. Base-level variations appear to have had only a minor effect on the channel adjustments.

As well as inter-terrace variation in palaeochannel type, both lateral and downstream intra-terrace changes have been identified. It is important to note, however, that many of the palaeochannel features are of low amplitude; the palaeochannel patterns are better viewed from the air, and are especially highlighted on infra-red aerial photographs. This site, with its extensive suite of palaeochannels in the terrace surfaces, thus provides a marked contrast to the well-defined suite of terraces with steep 'risers' along the River Findhorn (see above).

The present channel discharges are small compared with estimated palaeodischarges, and Maizels (1983a, 1983b, 1986; Maizels and Aitken, 1991) estimated order-of-magnitude velocities and discharges for particular palaeochannels, using empirical formulae (cf. Church, 1978; Ryder and Church, 1986). Peak flows calculated for the terrace sequence decreased from a maximum of *c.* 18,000 m^3s^{-1} on the highest terrace to *c.* 1,300 m^3s^{-1} on the lowest. The decline in peak discharge to the present day value of *c.* 330 m^3s^{-1} is thus as much as fifty times. At best, these values provide only order-of-magnitude estimates (cf. Maizels and Aitken, 1991)

The River North Esk and West Water site is significant in several respects. First, it provides a good illustration of a suite of glaciofluvial landforms which are characteristic of the Highland margin in Strathmore, where extensive spreads of outwash have built out from the mouths of the Highland glens (Sissons, 1967a, 1976b; Paterson, 1974; Insch, 1976). Second, it provides a good illustration of a former glacier-margin landform assemblage dominated by glaciofluvial activity and the close association of ice-contact and proglacial meltwater features. In this respect the site bears comparison with, for example, Muir of Dinnet, Glen Feshie and Almondbank, and with the Loch Lomond Readvance features at Moss of Achnacree and the Western Forth Valley. Third, the River North Esk and West Water site demonstrates the effects of topographic controls on deglaciation. As the Late Devensian ice receded from the open, piedmont area of Strathmore, the tributary glacier fronts in the narrow Highland glens may have become temporarily stabilized in the lower reaches of the valleys as their ablation areas changed configuration. Fourth, the site is significant for the development of palaeochannels on the terrace surfaces. These features are among the best preserved of their type studied in Scotland and have allowed significant insights into the controls and thresholds governing channel change during and since deglaciation, particularly in relation to discharge and sediment supply. It is an important research site for assessing the extent of adjustments within the fluvial system since the Late Devensian in a lowland area with upland headwaters. Although Late Devensian palaeochannels are known to exist on terrace surfaces at other locations in Scotland; for example, along the River Dee (Maizels, 1985) and River Don (Maizels and Aitken, 1991), in Glen Feshie (Robertson-Rintoul, 1986a) and in the area south of Fraserburgh (British Geological Survey 1:50,000 Sheet 97) these are generally less extensive and have not been studied in comparable detail to the North Esk and West Water features.

Conclusion

This site is important for understanding the geomorphological changes that occurred in the landscape during and following deglaciation of the Late Devensian ice-sheet (approximately 14,000–13,000 years ago) when large volumes of meltwaters were released from the decaying ice. It shows an excellent assemblage of landforms characteristic of the eastern Highland boundary area. These include outwash and river terraces that were formed as the ice melted and wasted back into the Highland glens. The higher terraces contain kettle holes indicating the former presence of the glacier, whereas the lower terraces are most notable for particularly good examples of fossil river channels. The latter provide valuable evidence for reconstructing the changes that occurred in river characteristics and behaviour during and following the period of ice melting.

STORMONT LOCH

C. J. Caseldine

Highlights

The sediments which infill the floor of Stormont Loch provide an important pollen record, supported by radiocarbon dating, of the vegetational history and environmental changes in eastern Scotland during the Lateglacial.

Introduction

Stormont Loch (NO 190423) is a partially infilled, shallow (less than 3 m) lake which occupies part of a large kettle hole complex in the outwash fan that spreads across Strathmore from the Ericht valley, draining both Glenshee and Strathardle (Paterson, 1974; Insch, 1976). The site lies at an altitude of 61 m OD within freely drained iron podsols (Corby Association; Laing, 1976), where they closely abut brown earths (Balrownie Association) which comprise the fertile, till-derived soils of much of Strathmore. Stormont Loch is one of the few lowland sites in Strathmore which retains a complete Lateglacial and Holocene sedimentary sequence, having escaped drainage and marl extraction during the 18th and 19th centuries, which either removed or disturbed deposits on a wide scale throughout the agricultural lowlands of eastern Scotland. Limited stratigraphical investigations and detailed pollen analysis of one part of the loch basin have been undertaken by Caseldine (1980a, 1980b).

Description

Borings in the western fringe of the basin have shown relatively rapid thickening of the sediment infill to over 6 m within 50 m of the edge; beyond this, surface water conditions prevented further boring. The Lateglacial sediments comprise a straightforward sequence of a basal, dark grey clay which becomes increasingly coarse with depth, followed by a brown organic mud incorporating occasional lenses of both gyttja and sedge peat, overlain in turn by a very fine grey clay (Figure 14.9). Overlying the Lateglacial deposits there are over 4 m of Holocene sediments, largely telmatic peats and dystrophic gel muds.

Pollen diagrams have been prepared for the Lateglacial and Holocene sediments from the basin by Caseldine (1980a, 1980b). Of particular interest is the record for the Lateglacial derived from two parallel cores and comprising both relative pollen (Figure 14.9) and pollen concentration diagrams supplemented by four radiocarbon dates (SRR–1732 to SRR–1735).

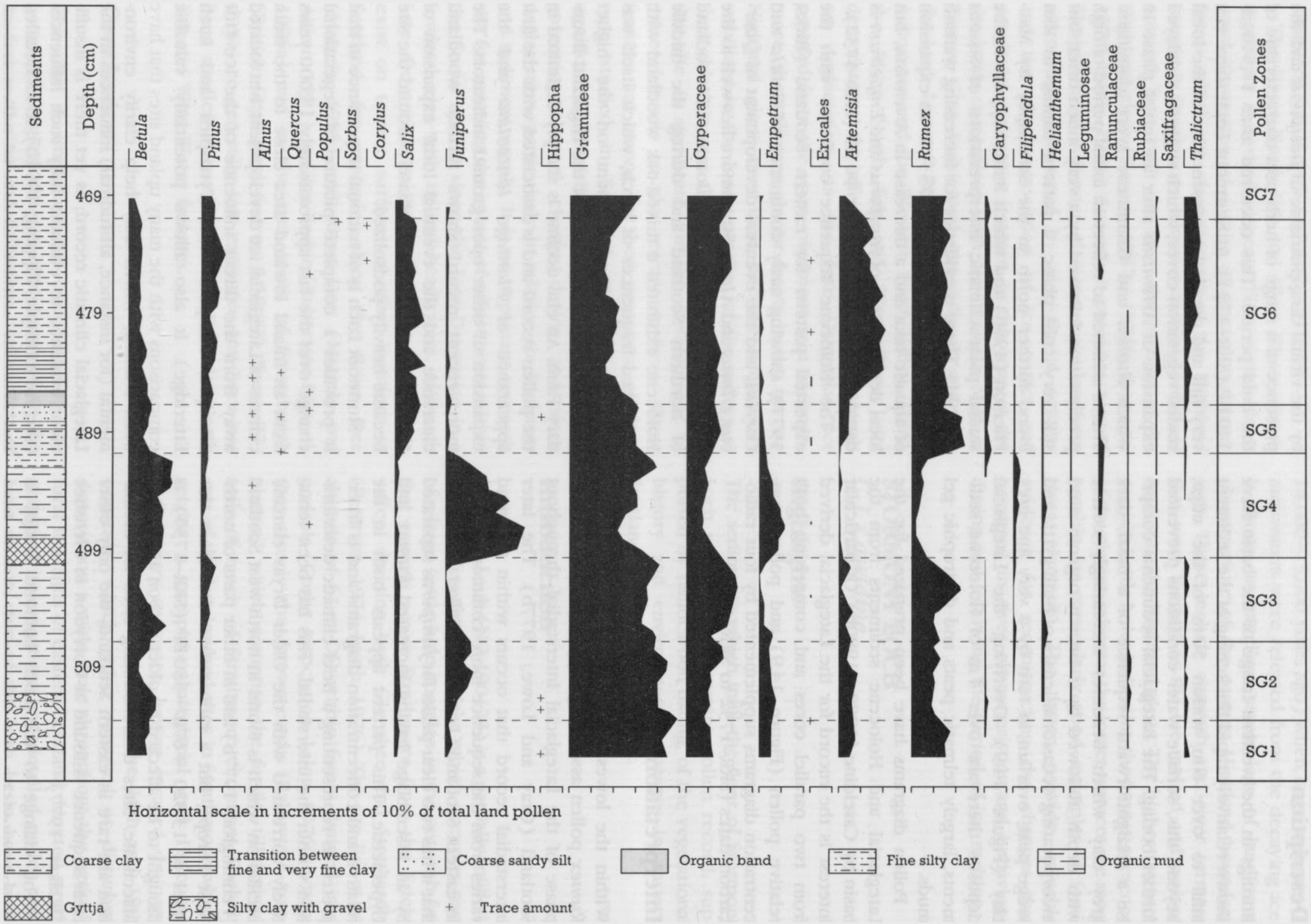
Interpretation

Within the lowest clay there is a Gramineae–*Rumex* pollen assemblage typical of the earliest phase of the Lateglacial Interstadial throughout Scotland (Gray and Lowe, 1977b). The later interstadial record that occurs within the mud varies from the sequence more commonly found in eastern Scotland (Lowe and Walker, 1977), in that it has two clear peaks for *Juniperus* separated by an assemblage having increased *Rumex* and Cyperaceae. This pattern appears both in the relative and concentration diagrams and is interpreted as representing a brief climatic deterioration within the interstadial. This has been tentatively correlated with the Older Dryas climatic oscillation which is found in north-west Scotland (Pennington, 1977b) and in other parts of north-west Europe, but a radiocarbon date from this level of 13,820 +670/−580 BP (SRR–1735), is thought to be affected by older carbon and hence inaccurate. Sites demonstrating such an oscillation are rare in eastern Scotland; the only other clear sequence is found at Corrydon in Glenshee (Walker, 1977).

The change to the Loch Lomond Stadial is demonstrated by the lithological change from organic mud to grey clay and in the pollen record by the virtual disappearance of *Juniperus* and the presence of a range of herb taxa characteristic of the cold period. This occurred after 11,510 ± 140 BP (SRR–1734). At Stormont Loch there is a very full and detailed representation of the local stadial vegetation cover, which suggests a delayed expansion of *Artemisia* after an initial phase in which *Rumex* and Gramineae were dominant. This is assumed to reflect an initial period of high precipitation followed by a very much drier, but still very cold phase, a pattern similar to that found further north in the Strathspey by MacPherson (1980) and which lends support to the stadial palaeoclimatic interpretations of Sissons (1979d). There is evidence for increasing warmth at 10,150 ± 110 BP (SRR–1733) in an expansion of aquatic taxa and a decrease in *Artemisia*, but local development of *Juniperus* and *Empetrum* is dated rather late at 9700 ± 90 BP (SRR–1732).

The Holocene sequence conforms with the expected pattern for eastern Scotland (Birks, 1977), showing early dominance of *Betula* and *Corylus*, and the eventual development of *Quercus*, *Ulmus* and *Alnus*. Strathmore lies well to the south of the extensive pine-dominated woodland of northern Scotland and during the middle Holocene exhibited a mixed-oak woodland with enhanced frequences of birch, which itself was the major woodland element on the higher ground immediately north of the Highland Boundary Fault. An elm decline is sharply delimited in the pollen record and is associated with the first appearance of *Plantago lanceolata* and the expansion of other open-ground indicators. The more recent record shows further woodland clearance and the eventual local expansion of *Calluna* as the soils immediately around the site became heavily podsolized.

Stormont Loch is of national importance in that it provides a complete picture of vegetational change over the last approximately 13,000 years from an inland lowland area close to the main centres of Lateglacial ice development, but located away from the direct influence of the ice (for example, compare with Tynaspirit and Loch Etteridge). It also allows potentially valuable comparisons with the many upland sites that have been studied, which may help clarify environmental (for instance, altitudinal) influences in the Lateglacial climatic record; as yet there is insufficient evidence to evaluate fully such influences (see, for example, Tipping, 1991b). In its detailed and generally atypical Lateglacial pollen record, Stormont Loch is of wider importance in con-


Sediments
Depth (cm)
469
479
489
499
509
Betula
Pinus
Alnus
Quercus
Populus
Sorbus
Corylus
Salix
Juniperus
Hippopha
Gramineae
Cyperaceae
Empetrum
Ericales
Artemisia
Rumex
Caryophyllaceae
Filipendula
Helianthemum
Leguminosae
Ranunculaceae
Rubiaceae
Saxifragaceae
Thalictrum
Pollen Zones
SG7
SG6
SG5
SG4
SG3
SG2
SG1
Horizontal scale in increments of 10% of total land pollen
Coarse clay
Transition between fine and very fine clay
Coarse sandy silt
Organic band
Fine silty clay
Organic mud
Gyttja
Silty clay with gravel
+ Trace amount

tributing to a better understanding of the complexity and character of Lateglacial climatic change. By demonstrating consistent vegetational changes in duplicate cores, particularly within the interstadial part of the record, but also within the stadial, the results confirm Stormont Loch as an important reference site not only for eastern Scotland, but also for making the comparisons necessary to establish the wider patterns of Lateglacial climatic change (see Tipping, 1991b). Further, comparisons of the pollen record with the coleopteran record (Atkinson *et al.*, 1987) are also essential and in this respect Stormont Loch is significant in showing early climatic deterioration during the Lateglacial, a feature matched in the coleopteran record established at other sites (Atkinson *et al.*, 1987). Stormont Loch is also notable for its full and clear stadial record, showing increasing aridity as the stadial progressed, an aspect now attracting attention in explaining the pattern of glacier changes.

Further, Stormont Loch has great potential for the study of Holocene vegetational history in a dominantly agricultural landscape whose past land-use history is but poorly understood. This potential lies in the probable thick depth of sediments in the main part of the loch, affording a high level of analytical resolution, and in the relatively long period of anthropogenic influences identified in the preliminary Holocene pollen diagram.

Conclusion

Stormont Loch is an important reference site for studies of the environmental history of eastern Scotland during the Lateglacial and Holocene (approximately the last 13,000 years). It is particularly notable for the detail of its Lateglacial pollen record, which has allowed revealing insights into the environmental changes that occurred; for example, it is one of only a few sites in eastern Scotland to show that vegetational development was interrupted by a short, but separate climatic deterioration before the Loch Lomond Stadial (about 11,000–10,000 years ago). By virtue of its geographical location, Stormont Loch is also significant for the potential comparisons it allows between the different vegetational histories at sites in the uplands and lowlands.

Figure 14.9 Stormont Loch: relative pollen diagram for core SGI showing selected taxa as percentages of total land pollen (from Caseldine, 1980a).