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 17

Lothians and Borders

INTRODUCTION

D. G. Sutherland

This area includes the lowlands of the Lothians along the southern shore of the Firth of Forth and the coastal area south to Berwick (Figure 17.1). Inland it extends west to the A74 across the Southern Uplands and south to the Tweed Valley. The area of highest ground, rising to 840 m OD at Broad Law, lies between Peebles and Moffat, and other hill groups (Lammermuir Hills, Moorfoot Hills) have summits up to 500–700 m OD. The Lothians area was one of the key areas in Scotland for the elaboration of many of the concepts related to ice-sheet glaciation and glacial sediments and landforms. In this area many of the early observations on both large- and small-scale features of ice moulding were made and the relationships between clast orientation, striations on rock surfaces and ice-flow direction were noted.

The earliest interpretation of striations in the region as being the product of ice flow was that of Agassiz (1841b) for a rock surface on Blackford Hill, which is today commemorated by a plaque at Agassiz Rock. Although the concept of multiple glaciation was also advanced at an early stage in this area (Croll, 1870b; J. Geikie, 1877, 1894) and sequences containing distinct glacial sedimentary units were described (see below), all the presently known glacial deposits are now attributed to the advance and retreat of the last ice-sheet and the subsequent Loch Lomond Readvance. However, marine erosional features are known that pre-date at least the last glaciation and these are well displayed at Dunbar. There, an ice-moulded high rock platform occurs at approximately 23 m OD (Sissons, 1967a), and a platform at about present sea level can also be seen to pass under glacial sediments along the East Lothian coast.

The earliest phase of the last glaciation was an advance into the Lothians and northern Southern Uplands by ice originating in the south-west Highlands. This ice deposited a basal till, with a characteristic erratic assemblage, found widely in the Midlothian basin (Kirby, 1968) as well as across the Moorfoot Hills (Aitken *et al.*, 1984). The direction of movement was generally from west to east in the north-west of the region, with a south-easterly component near the east coast. Subsequently, Southern Uplands ice expanded to exclude the Highland ice from virtually the whole of the region, with the exception of the coastal fringe of the Firth of Forth. As elsewhere along the southern Central Lowlands (Chapter 16) this second phase of glaciation resulted in the deposition of a till containing Southern Uplands erratics on top of the earlier till (see Hewan Bank and Keith Water). In the Lothians this ice moved in a north-easterly direction carrying erratics of Tinto Hill felsite to the outskirts of Edinburgh and the Midlothian basin (McCall and Goodlet, 1952; Mitchell and Mykura, 1962). In the Borders area the only evidence of glaciation is that of Southern Uplands ice which flowed down the Tweed Valley, the direction of flow being demonstrated by transport of erratics (Kerr, 1978) and by a major drumlin field (Sissons, 1976b). This ice was dominantly nurtured in the hills of the eastern Southern Uplands, but a small ice-cap may have developed on the Cheviot Hills (Clapperton, 1970).

The retreat phase of the ice-sheet resulted in the production of spectacular sequences of meltwater channels and glaciofluvial sediments. These are best developed and have been most intensively studied in the Lothians and northern hills of the Southern Uplands (Sissons, 1958a, 1958b, 1960, 1961a, 1963b; Price, 1960, 1963a; Kirby, 1969c; McAdam and Tulloch, 1985; Davies *et al.*, 1986). Particularly outstanding meltwater channels occur along the northern face of the Lammermuir and Moorfoot Hills, as at Rammer Cleugh and by Carlops in the Midlothian basin. These channels were formed as the Southern Uplands ice retreated towards the south-west. In the area between the retreating Southern Uplands ice and the Highlands ice, which still occupied the Firth of Forth, a sequence of outwash terraces was deposited (Kirby, 1969c). A third till unit (the Roslin Till) in the Midlothian basin was interpreted by Kirby (1968, 1969b) as having been deposited on top of these outwash gravels during a readvance of the Highland ice, but Martin (1981) disputed this interpretation. Instead, he suggested that the Roslin Till was not a single lodgement till but the result of deposition of debris flows during the general deglaciation sequence.

Few details are available on shorelines formed during ice retreat and it is not known whether there are shorelines that correlate with those identified in eastern Fife by Cullingford and Smith (1966) (Chapter 15). However, the proximity of the two areas suggests that deglaciation of the East Lothian coastline probably occurred at some

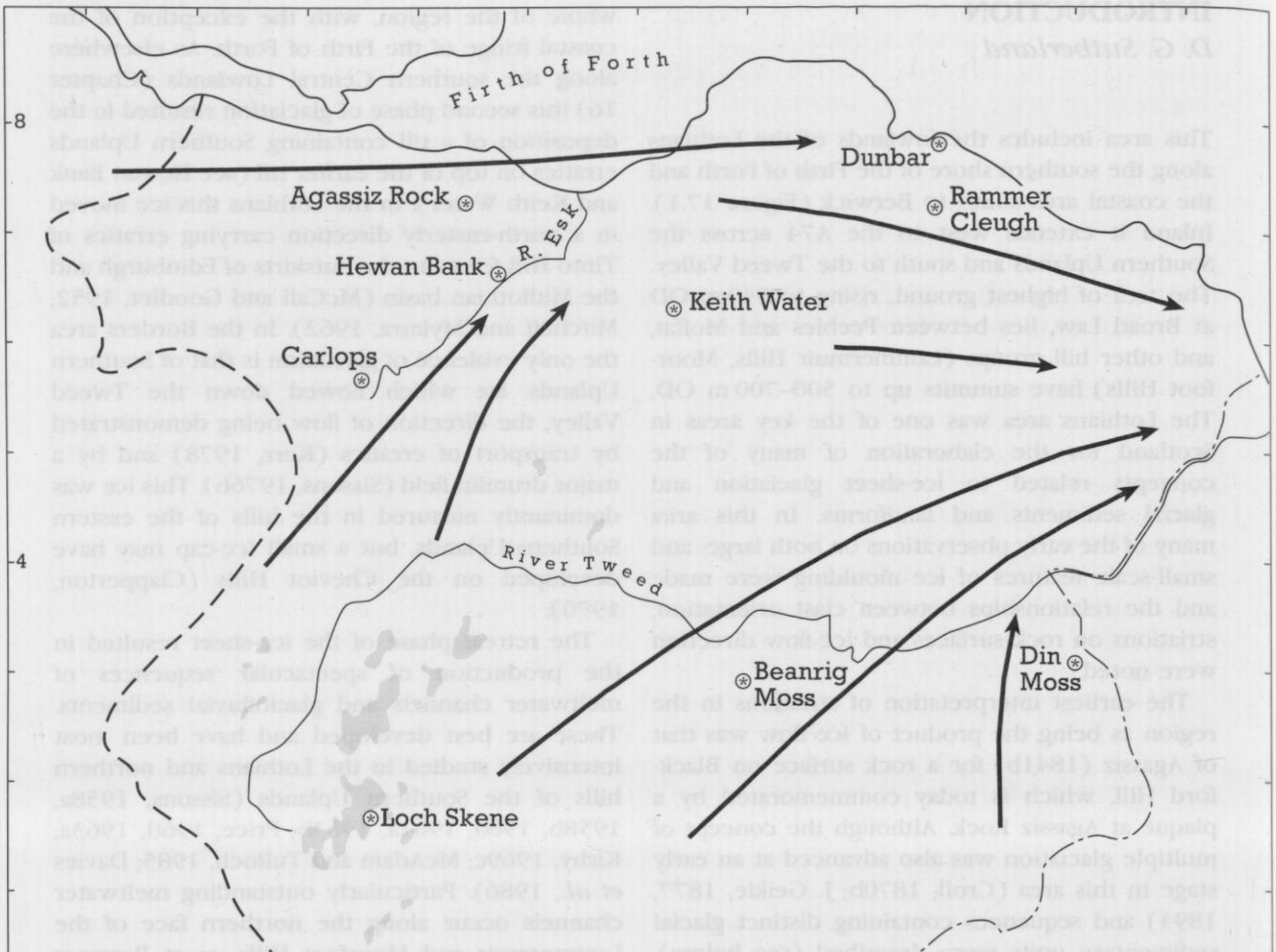


Figure 17.1 Location map of the Lothians and Borders area.

time between 17,000 and 14,000 BP. The marine limit, formed at the time of deglaciation, rises westwards along the coast from around 14 m OD (Sissons *et al.*, 1966) or 22 m OD (Davies *et al.*, 1986) near Dunbar to over 34 m west of Edinburgh and up to 38 m at Stirling (Sissons *et al.*, 1966). Deglaciation of the coast west of Edinburgh probably occurred between 14,000 and 13,000 BP, and a particularly pronounced shoreline was formed when the ice-front was in the Stirling/Larbert area. This shoreline, termed the Main Perth Shoreline (Sissons and Smith, 1965a), slopes towards the south-east at a gradient of about $0.43\ \mathrm{m\ km^{-1}}$ (Smith *et al.*, 1969), declining in altitude to about 5 m OD near Dunbar. As the ice retreated up the Firth of Forth, poorly-sorted glaciomarine deposits were laid down close to the ice-front (Sissons and Rhind, 1970); these were succeeded at greater distance from the ice by laminated silts and clays containing a restricted arctic marine fauna (Browne *et al.*, 1984).

A number of sites have been investigated that provide information on the evolution of the vegetation during the Lateglacial (Newey, 1965a, 1970; Mannion, 1978a; Webb and Moore, 1982; Alexander, 1985). Particularly interesting among these sites is Beanrig Moss (Webb and Moore, 1982) because of its detailed macrofossil record. The earliest vegetational communities following deglaciation were of pioneer plants. No radiocarbon dates are available from the earliest phase of vegetational development, although it is reasonable to infer that some areas were deglaciated well before the opening of the Lateglacial Interstadial (at around 13,000 BP). It was probably at this time of cold climate that the fossil ice-wedge polygons identified in Berwickshire (Greig, 1981) were formed.

During the interstadial itself a mosaic of different vegetational communities developed, Webb and Moore (1982) identifying juniper scrub with sparse tree birches, well-drained grasslands, damp, tall-herb meadows, dwarf-shrub heaths and open-ground communities as the principal elements. As elsewhere in Scotland, certain sites suggest a single uninterrupted phase of vegetational development during the interstadial, whereas others show a period of vegetational 'revertence' during the first half of the interstadial, (Alexander, 1985). This is typically reflected in a reduction in the proportion of woody plants, as represented in the pollen record. No radiocarbon dates closely bracket this brief phase and its status remains uncertain.

The Loch Lomond Stadial is registered unequivocally across the region as a period of severe climate during which small valley and corrie glaciers developed in the higher hills of the Southern Uplands, as around Loch Skene. The vegetation was composed of bare-ground communities, even at low altitudes, and a subdivision of the stadial sediments can be made into an early phase with relatively low values of *Artemisia* pollen and a later phase with much increased values of *Artemisia*. This may reflect an earlier more moist and a later drier climate. A similar inference may be drawn from an assemblage of fossil beetles from Corstorphine in Edinburgh (Coope, 1968). Along the coast marine erosion was apparently particularly effective during the stadial and a pronounced erosional surface and accompanying shoreline, the Main Lateglacial Shoreline, was produced (Sissons, 1969, 1976a; Browne *et al.*, 1984; Browne, 1987). This shoreline is isostatically tilted at approximately $0.17\ \mathrm{m\ km^{-1}}$ towards the south-east, descending from close to present sea level near Grangemouth to well below it along the Berwickshire coast (Eden *et al.*, 1969; Sissons, 1976a), and rivers such as the Tweed (Rhind, 1972) may have eroded deep valleys in their lower reaches at this period. Fluvial and slope activity were also enhanced inland, as is indicated by the contemporaneous deposition of a large alluvial fan in the former Corstorphine Loch (Bennie, 1894; Tait, 1934; Newey, 1970), and solifluction deposits in the former Holyrood Loch (Sissons, 1967a, 1971).

The early Holocene witnessed a rapid progression of vegetational communities from a period of juniper scrub dominance at around 10,000 BP through a period of birch and hazel woodland to the development of mixed deciduous forest of mainly oak and birch throughout most of the region by 8500 BP. A detailed and well-dated record of these changes is available from Din Moss (Hibbert and Switsur, 1976). Just before 5000 BP a reduction in elm pollen marks the start of human interference, with the eventual expansion of heath, grassland and bog communities as the forest was cleared. A trend in climate to more moist and cooler conditions over the same period may also have contributed to this change in the vegetation. A detailed record of Holocene environmental changes based on pollen and diatoms is also available from Linton Loch (Mannion, 1978a, 1978b, 1978c, 1978d, 1981a, 1981b, 1982).

Sea level was relatively low during the early Holocene but marine transgression was under way by about 7500 BP (Robinson, 1982). The transgression culminated in the formation of the Main Postglacial Shoreline some time between the above date and 5500 BP, at which time extensive shell beds were deposited along part of the East Lothian coast (Smith, 1971; McAdam and Tulloch, 1985). After the formation of the Main Postglacial Shoreline a series of lower shorelines was formed. These have not been accurately dated.

THE GLACIATION OF THE EDINBURGH AND LOTHIANS AREA

J. E. Gordon

The Quaternary landforms and deposits of this area have a long record of scientific study. The earlier 19th century work is dominated by accounts of the superficial deposits and bedrock markings which were explained in terms of diluvial or marine processes. Nevertheless, many of the original field observations and reports stand the test of time, and they remain valuable and pertinent contributions to the literature, most notably those of Maclaren (1828) and Milne Home (1840). In the years following the visit of Agassiz to Scotland in 1840 (see Agassiz Rock), the glacial theory gradually became established.

In an early keynote paper Milne Home (1840) described in some detail the superficial deposits of the Edinburgh and Lothians area, erecting an eight-unit stratigraphic succession. Boulder clay, sometimes resting on a layer of sand and gravel, was overlain by a sequence of sands, gravels and clays. Although he explained the full sequence in terms of marine inundation, his carefully set out field observations represent a landmark in Scottish Quaternary stratigraphy. Later, Nicol (1844) and Chambers (1853) quoted extensively from Milne Home's succession, Chambers adding further observations of his own in support. In the first editions of the Geological Survey Memoirs for the Edinburgh and East Lothian areas, Geikie (in Howell and Geikie, 1861) and Young (in Howell *et al*., 1866) presented broadly similar successions to those of Milne Home: boulder clay overlain by sands and gravels and brick clays, then succeeded by raised beach deposits.

Fleming (1847, 1859) described essentially the same succession as Milne Home, but classified the deposits using different terminology. At one locality he noted an upper boulder clay resting on sand (Fleming, 1859, p. 75).

The existence of more than one till in the area was possibly first recognized by Maclaren (1828; see also Maclaren, 1838, 1866). He described the following sequence of deposits in sections along the Dalkeith railway:

3. Bedded sands.
2. Upper boulder clay; redder, looser texture and with fewer and more angular stones than the lower boulder clay.
1. Lower boulder clay; stiff, blackish and bluish clay interspersed with boulders and stones.

This sequence is similar to that at Hewan Bank (see below) and has recently been widely recognized throughout the Edinburgh area in the regional stratigraphic scheme of Kirby (1966, 1968, 1969b). Maclaren's valuable early observations, however, have largely been neglected by subsequent workers.

Maclaren (1828, 1838) originally interpreted the deposits as the product of ocean currents or a succession of great waves in the style of Hall (1815). Later, as a confirmed glacialist, he proposed that the lower boulder clay was formed as a glacial deposit, but, surprisingly, suggested that the upper one was formed by icebergs and ocean currents. However, in the preface to the second edition of his book (Maclaren, 1866) he does note that his interpretations of the surface deposits of the area were not fully recast with his revised views on glaciation. Significantly, Maclaren (1866) inferred that the two compositionally different boulder clays were formed in one uninterrupted depositional event.

J. Geikie (1877, p. 72) first introduced the idea of the interaction of more than one ice mass in the southern part of the Midland Valley. He suggested the presence of ice from separate sources in the Highlands and Southern Uplands in what he termed 'the debatable ground'. As part of his evidence he cited the intermingling of stones of both northern and southern origins in the till of the Esk Valley in Midlothian and noted the occurrence of Highland erratics as far south as Tynehead. Subsequently, Somervail (1879) inferred two directions of erratic transport in the Pentland Hills: from south-west to north-east and from north-west to south-east. This idea of shifts in ice-movement direction later assumed considerable importance in 20th century investigations of till clast fabric and till lithology patterns.

The glaciation of the Edinburgh and Lothians area

In the second edition of the Geological Survey Memoir, Peach *et al.* (1910a) envisaged a composite ice-sheet from sources in the Highlands and Southern Uplands moving eastwards across the Edinburgh area. They emphasized that variations in the character of the till were related to variations in the underlying bedrock. However, they made no references to multiple till sequences nor the previous accounts of them.

Peach *et al.* (1910a) considered that the thick sequences of sand and gravel above the till in the Midlothian basin were deposited when the southern ice had receded, but drainage was still obstructed by ice to the north. Significantly, they noted that the gravels largely comprised greywacke pebbles derived from the Silurian rocks to the south.

Campbell (1951) identified three separate boulder clays in the Esk Valley in the Pentland Hills. The lithological character of the deposits suggested that the lowest one was associated with ice moving east-north-east, the middle one with local ice in the Pentland Hills and the uppermost one with ice moving east-south-east. Eckford (1952), however, considered that the yellow colour of the middle till could reflect weathering, whereas the other two could be explained by changes in direction of flow of the dominant ice mass. Eckford in fact described two tills from the southern part of the Pentland Hills, but suggested that both were associated with the same ice-sheet, the lower one being a basal lodgement till, the upper one being formed by ablation of englacial and supraglacial debris. On lithological grounds Eckford considered that the last ice invasion of the area was from the Southern Uplands and was represented by extensive sand and gravel deposits overlying the Highland drift.

McCall and Goodlet (1952) studied indicator stones (erratics indicative of a particular lithological source), especially felsites, in various Midlothian deposits and concluded that the lower boulder clay of the area (which they did not differentiate) was the product of Highland ice.

Tulloch and Walton (1958) reached a similar conclusion to Peach *et al.* (1910a) that the composition of the till in the area of the Midlothian Coalfield closely reflected the character of the local bedrock. This view was again echoed by Mitchell and Mykura (1962). The latter summarized the glacial sequence in the Edinburgh area as:

3. Southern Uplands Readvance Boulder Clay and Gravel.
2. 'Middle' Sands and Gravels.
1. Basal Boulder Clay.

The available evidence suggested that a single ice-sheet flowed eastwards across the area. From erratics of distinctive lithology they inferred that most of this ice originated in the western Highlands but coalesced in the southern part of the Edinburgh area with ice from the Southern Uplands. Like Eckford (1952), they found no definite evidence that the two tills were deposited by separate ice-sheets, or even different phases of a single ice-sheet. Significantly, also, they found no evidence of three tills as recorded by Campbell (1951). During the retreat of the Highland ice, the extensive suite of 'Middle' sands and gravels was deposited.

Charlesworth (1926b) introduced the idea of a Lammermuir–Stranraer 'moraine' formed during the retreat phase of the last ice-sheet. In its eastern part, he correlated the 'moraine' with the extensive deposits of sand and gravel along the northern flanks of the Lammermuir and Moorfoot Hills. The 'moraine' was formed by a readvance of Highland ice from the north. Sissons (1961c), however, showed that the sand and gravel deposits were not ice-marginal moraines but were rather 'dead'-ice features formed diachronously. Moreover, several lines of evidence in the area to the west strongly suggested that the last ice movement was from the south and south-west, not from the north (McCall and Goodlet, 1952; Bailey and Eckford, 1956; Sissons, 1958b, 1961c).

Kirby (1966, 1968, 1969a, 1969b, 1969c) carried out a detailed investigation of the glacial deposits in the Lothians area. On the basis of stratigraphy, fabric analyses and stone counts he recognized a sequence of:

5. Roslin Till
4. Sand
3. Intermediate Till
2. Sand
1. Basal Till

The Basal Till occurs widely above bedrock throughout the area, from sea level up to about 250 m in the Esk basin. The Intermediate Till is best developed at the southern end of the basin on higher ground, but appears to be absent as a separate unit near the coast. At a number of localities the two tills are superimposed, and the

Intermediate Till occupies an analogous position to the reddish-brown till in the Pentland Hills, recorded by Eckford (1952) and Mitchell and Mykura (1962). Indeed the stratigraphy described by Kirby is basically that noted first by Maclaren in 1828. Kirby also recorded a similar stratigraphy for East Lothian (see Keith Water).

From its lithology and fabric, Kirby inferred that the Basal Till was deposited by ice moving from the west, as noted by many of the early workers in the area (see above) and also more recently by Burke (1968); the Intermediate Till was deposited by ice from the south. Since both tills graded up into their own meltwater deposits, Kirby envisaged two temporally separate stages of ice movement, with ice from Highland sources being succeeded by ice from the Southern Uplands. Locally, however, he also identified complex sequences of till and glaciofluvial sediments formed during a single phase of glaciation (Kirby, 1969c) (see also Young, 1966).

Several authors have referred to washed tills in the Lothians area, usually comprising a sandy clay overlying the more typical tills (for example, Geikie, 1863a; Burke, 1968, Kirby, 1968). Kirby considered them to be subglacial deposits; Burke, the result of washing in the immediate post-glacial period.

In addition to the Basal and Intermediate tills of Kirby, a third and later till unit has been identified in the Midlothian area. Peach *et al.* (1910a) first referred to a reddish-brown boulder clay overlying sands and gravels in the Eskbank and Newton Grange areas, but did not attach any particular significance to it. Later, Anderson (1940) described between 3 and 10 ft (0.9–3.0 m) of what he called 'Upper Boulder Clay' overlying considerable thicknesses of sand and gravel in a number of sandpits around Roslin. Anderson also recorded clay-filled fissures in the sands and gravels, interpreting them as frost cracks. Additional examples of the latter were subsequently reported by Common and Galloway (1958). Anderson considered the Upper Boulder Clay to represent a readvance of ice. He did not specify Highland ice as Mitchell and Mykura (1962) stated, although it might be a logical inference from the indicator stones that he recorded.

Carruthers (1941, 1942), however, considered that the frost wedges described by Anderson were post-glacial and that the till–sand contact was not typical of readvancing ice, but rather was the product of subglacial meltout during a single event (Carruthers, 1939). Anderson (1941, 1942) countered by arguing that there was no trace of the fissures in the boulder clay.

Contrary to Anderson's results, McCall and Goodlet (1952) found no rocks of Highland origin in what they now called the 'Roslin Upper Boulder Clay', but there was abundant felsite which they referred to the Tinto Hill outcrop. They therefore concluded that the boulder clay was laid down during a readvance of Southern Uplands ice after the retreat of the main Highland ice which deposited the lower till of the area.

Kirby (1966, 1968) proposed the term 'Roslin Till' for this third till after the area where it was best exposed. He noted that it was only identified there because it overlay thick glaciofluvial deposits (cf. Tulloch and Walton, 1958). Elsewhere it was visually indistinguishable from the underlying till. However, Kirby put forward a variety of evidence to show that the Roslin Till represented a distinctive readvance of ice. His main arguments included the presence of frost wedges and deformation in the top of the sands below the Roslin Till and variations in lithological content between the Roslin Till and the two earlier tills. Mechanical analysis and fabrics excluded the possibility of the Roslin Till being an ablation moraine (Kirby, 1969b, 1969c). The fabric also suggested that it was not a solifluction deposit and, although its orientation was similar to that of the underlying intermediate till, the lithologies of the two units were quite distinctive. On the basis of the fabrics and stone counts he inferred that after a phase of glaciation by Highland ice, ice from the Southern Uplands entered the area from the south. From geomorphological evidence (Kirby, 1969c), he suggested that the ice then bifurcated near the present watershed at Kingside. One lobe retreated southwards (Sissons, 1958b, 1963b). The northern lobe receded northwards downslope into Midlothian and, during a subsequent readvance of this lobe, the Roslin Till was deposited on top of some of the earlier deglaciation features.

Subsequently, Martin (1981) has reassessed the status of the Roslin Till and presented a revised interpretation of the glacial stratigraphy. From sedimentological studies and comparisons with contemporary glacial environments, he concluded that there is no basis for regarding the Roslin Till as a separate stratigraphic unit. The sequence of glacial deposits in Midlothian shows considerable lateral and vertical variation and is clearly analogous to that seen along present-day glacier margins, for example in Iceland, where outwash, flow till and subaerial fan depositional environments are all closely related. Thus the till overlying the sands and gravels of the Roslin area has been interpreted by Martin as part of a complex sequence of diachronous debris flows draped over sediments deposited at receding ice margins. Martin considered features such as the till-filled cracks in the sand and gravel to reflect loading pressures rather than ice wedging. Martin also questioned whether the two lower tills are temporally discrete, and suggested rather that they represent a single complex meltout sequence such as described by Young (1966) and Kirby (1969a). He argued that the clast fabrics were not sufficient evidence to assign the tills to separate glacial episodes. Variations in flow conditions in a single glacier could produce clast fabrics both normal and parallel to the ice flow. Also, the observed lateral variations in clast composition could be explained by variations in solid geology, whereas the vertical variations could reflect the reverse order of lithologies traversed by the glacier (cf. Boulton, 1970).

Martin therefore proposed a single Late Devensian ice-sheet derived from the west, but with a flow component from the south to account for the transport of the Southern Upland erratics into the Lothian basin. This ice-sheet deposited a heterogeneous lodgement till, possibly with a melt-out component, with sand and gravel deposits formed as diachronously off-lapping wedges during the recession and marginal stagnation of the ice; the latter deposits were then buried by debris flows. Such a pattern accords with observed associations of depositional environments at modern glacier margins (Boulton, 1972b; Lawson, 1979). These observations demonstrate that the tripartite sequences comprising sands and gravels between tills, conventionally interpreted in terms of multiple glaciation, can quite normally relate to a single phase of ice retreat (Boulton, 1972b). Similarly, reappraisal of lodgement till complexes (Eyles *et al.*, 1982) has shown that observed variations in their sedimentary characteristics can be satisfactorily explained in terms of a single glacial episode. For example, till deposition may be interrupted by phases of erosion or deposition of subglacial meltwater sediments, and lateral migration of basal flow-lines may produce the unconformable superimposition of lodgement till units derived from different source areas.

AGASSIZ ROCK

J. E. Gordon

Highlights

The striated rock surface at Agassiz Rock was first recognized by Louis Agassiz in 1840 to have been eroded by glacier ice. The site is historically significant for its part in the development of the glacial theory in Scotland.

Introduction

Agassiz Rock (NT 254702) is located on the south side of Blackford Hill in Edinburgh. It is principally of historical interest as a striated rock surface that was associated with the early development of glacial theory in Scotland. In addition, Agassiz Rock represents an important landmark in geological conservation, being one of the earliest Quaternary sites recognized as requiring safeguarding. The site has been referred to in a number of papers (Rhind, 1836; Milne Home, 1840, 1846, 1847a; Buckland, 1841a; Maclaren, 1841, 1842a; Fleming, 1859; Panton, 1873; Brown, 1874; Peach *et al.*, 1910; Mitchell and Mykura, 1962). It was included in field excursions of the 1948 International Geological Congress in Britain (International Geological Congress, 1948) and, in addition, it features in the itineraries recommended by Geikie (1901), Campbell (1951) and Waterston (1960).

Description

Agassiz Rock is located on the south side of Blackford Hill where an andesite cliff has been undercut to form a shallow cave, the rock surfaces of which are grooved and striated like the overhanging cliff (Figure 17.2). Early descriptions of the site include those of Rhind (1836) and Milne Home (1840). The former explained the grooving by molten rock falling on a bed of sand and retaining the moulded impression of its surface; the latter in terms of marine submergence. However, it was on 27 October 1840 that the site attained its fame when it was visited by Louis Agassiz. A few weeks earlier, Agassiz had delivered a paper at a British Association meeting in Glasgow in which he argued that all the northern parts of Europe, Asia and America were

Figure 17.2 Part of the smoothed and grooved rock surface at Agassiz Rock, Edinburgh, which has been attributed to glacial abrasion. The form of the rock surface bears a strong resemblance to glacially abraded surfaces elsewhere in Scotland and in modern glacial environments (Photo: J. E. Gordon.)

formerly covered with a mass of ice (Agassiz, 1841a). Although it is not recorded in the abstract of his paper, Agassiz apparently alluded to the former existence of glaciers in Scotland (Anon, 1840; Maclaren, 1840). After the meeting he departed on a tour of Scotland to investigate the field evidence (Davies, 1968a, 1968b). In the course of this journey, accompanied by William Buckland, he found many striking and convincing traces of former glaciers. When he visited Edinburgh he was taken on a tour to search for glacier markings on the south side of the city by a group of Edinburgh geologists, including Charles Maclaren, then editor of *The Scotsman*. Agassiz was doubtful about some of the features initially shown to him, but on seeing the cave at Blackford Hill is reputed to have exclaimed 'That is the work of the ice' (Maclaren, 1841, 1842a; Cox and Nicol, 1869).

The striations at Agassiz Rock form part of a local assemblage of features that indicate ice moving eastwards across the area (Figure 17.3). Blackford Hill itself is a crag and tail, 1.5 km long, with deep erosional grooves on both its north and south sides, comparable to those around Edinburgh Castle Rock (Sissons, 1971). A smaller superimposed crag and tail occurs at Corbie's Craig south of the hill top, and to the east clast fabric measurements in the main drift tail also conform with ice flowing to the east (Kirby, 1969b).

In the Edinburgh area, a prominent theme in many of the earlier 19th century accounts is the recognition of the overall easterly movement of the agent responsible for the superficial deposits and bedrock striations (Figure 17.4). Typical lines of evidence included the disposition of crag-and-tail forms (Hall, 1815; Maclaren, 1828, 1866); the transport of erratics (Milne Home, 1840, 1871, 1874a, 1874b; Nicol, 1848; Fleming, 1859; Campbell and Anderson, 1909); deformation and overfolding of strata to the east (Milne Home, 1840, 1871; Fleming, 1859; Brown, 1874); bedrock striations and moulding (Imrie, 1812; Hall, 1815; Maclaren, 1828, 1842b,, 1866; Milne Home, 1840; Fleming, 1847, 1859; Chambers, 1853; Miller, 1864; Henderson, 1872; Richardson, 1877a, 1877b; Goodchild, 1896); and striations on stones in till (Milne Home, 1840; Maclaren, 1849; 1866; Miller, 1864, 1884; Henderson,

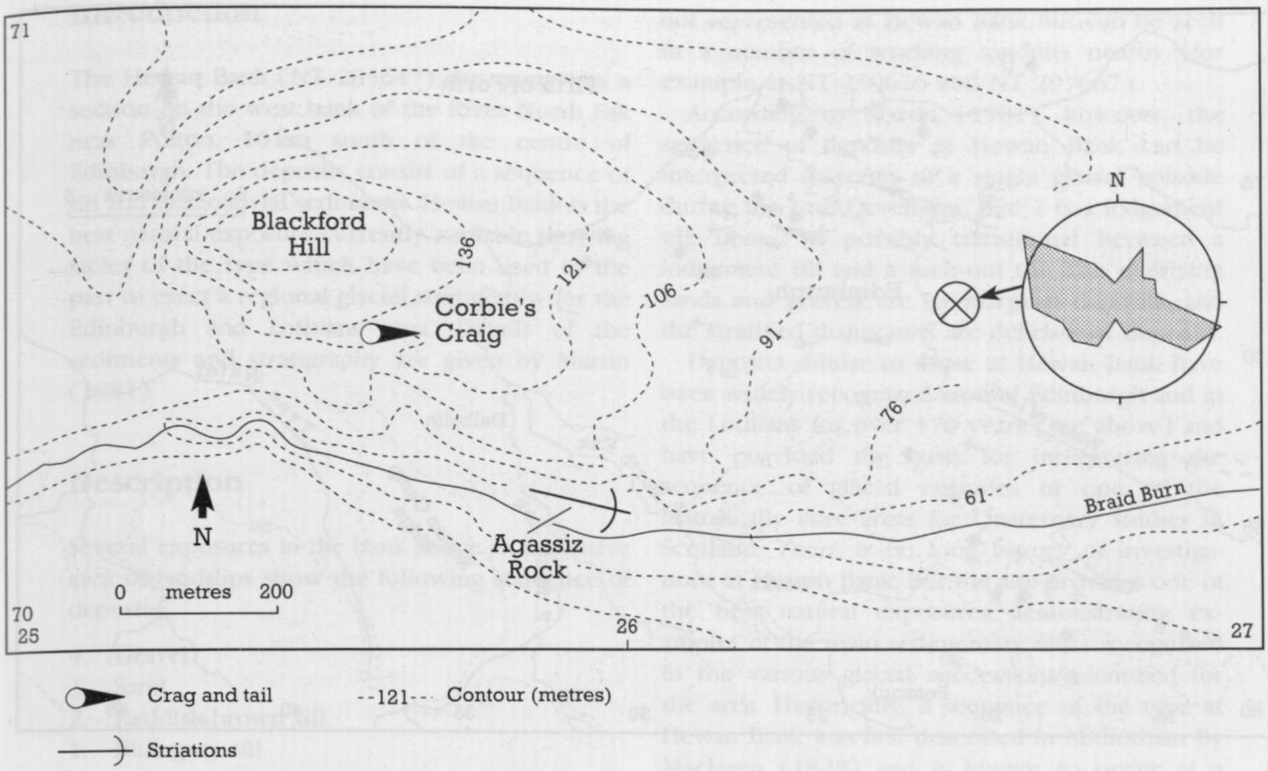


Figure 17.3 Blackford Hill crag and tail, showing a till clast fabric in the tail, the Corbie's Craig crag and tail and the direction of ice movement inferred from the striations at Agassiz Rock (from Kirby, 1969b).

1874). Miller (1884) produced the first map showing the pattern of striations on bedrock and till clasts. Further instances of striations and movements of erratics are given by Peach *et al.* (1910a), and Peach (1909) described the classic Lennoxtown essexite boulder train (see also Shakesby 1978, 1979, 1981). More recently Burke (1968, 1969) has quantified some of the evidence for these ice-movement trends, and Sissons (1971) has described the strong imprint of glacial erosion in central Edinburgh.

Interpretation

Although Agassiz Rock does not bear the distinction of being the first site in Scotland to have been recognized as the product of land ice, it was nevertheless of considerable significance (Buckland, 1841a; Davies, 1968a, 1968b), since the striations under the overhang could not have been produced by marine-drifted icebergs, the hypothesis of many contemporary geologists to explain such phenomena. Nor could they have been formed by debris-laden catastrophic deluges or floods as suggested by Hall (1815) in order to explain striations on nearby Corstorphine Hill, because of their close parallel arrangement over short distances.

Nevertheless, Milne Home (1846, 1847a) and Fleming (1859) were not convinced of the glacial origin of the striations at Blackford Hill and other localities around Edinburgh. The former persisted with the diluvial hypothesis, and the latter explained them as a local phenomenon associated with the Braid Burn. Geikie (1863a), however, in his important exposition on the evidence for former glaciers in Scotland clearly established that striations, including those at Blackford Hill, were the product of land ice. Brown (1874) also believed the striations to be glacial but considered that a large landslip had brought the striated rock to its present position.

Subsequent references in the literature to Agassiz Rock (Panton, 1873; Peach *et al.*, 1910a; Mitchell and Mykura, 1962) acknowledge the historical significance of the site, although critics have suggested that some of the striations may in fact be tectonic slickensides (Mitchell and Mykura, 1962).

Agassiz Rock is a site of considerable historical interest as one of the classic localities that played a significant part in the development of glacial

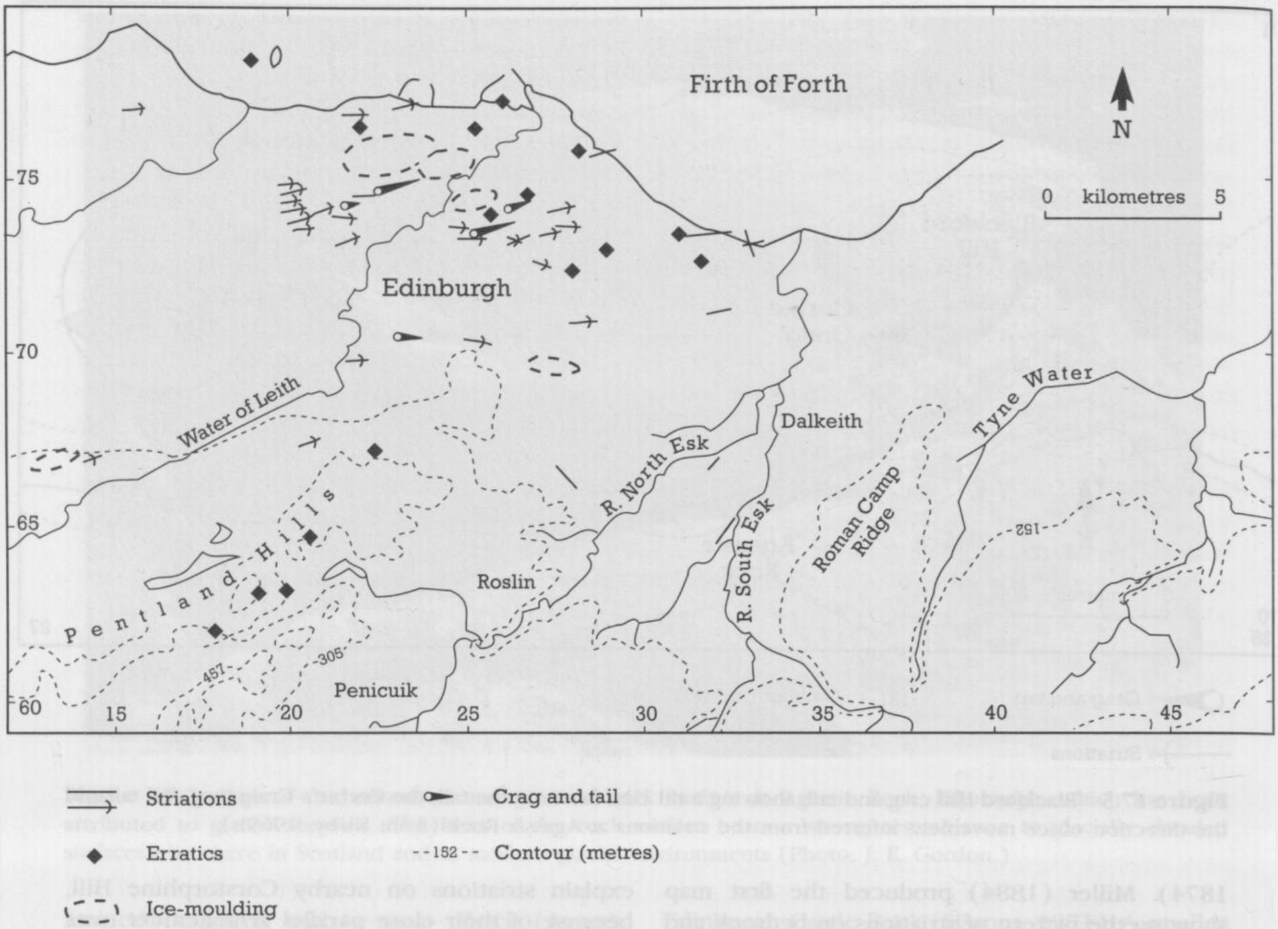


Figure 17.4 Indicators of ice movement in the Lothians area recorded up until 1863 (from Kirby, 1969b).

theory in Scotland. Its striated rock surface was among the first of such features to be recognized as the product of glacier ice by Louis Agassiz in 1840. It is also significant in another historical context, being one of the first geological sites recognized to require practical measures to ensure the preservation of its interest. In 1908 the Council of Edinburgh Geological Society successfully negotiated with Edinburgh Town Council to place a railing around the site and erect a memorial tablet (Watson, 1934). The railing and tablet are now dismantled, but it is planned to restore the plaque to mark the significance of the site.

Conclusion

Agassiz Rock is a site of considerable historical importance. Its significance stems from its association with Louis Agassiz, one of the principal figures in the introduction of the glacial theory in Scotland. The striated rock surface was unequivocally attributed by Agassiz to the effects of the passage of glacier ice. Agassiz Rock was also one of the first geological sites in Scotland to be conserved.

HEWAN BANK

J. E. Gordon

Highlights

The deposits in the section at Hewan Bank include two superimposed tills. These provide sedimentary evidence for the sequence and pattern of ice flow in the Lothians area during the Late Devensian and show successive ice movements from sources in the Highlands and Southern Uplands.

Introduction

The Hewan Bank (NT 285647) site comprises a section on the west bank of the River North Esk near Polton, 10 km south of the centre of Edinburgh. The deposits consist of a sequence of till and glaciofluvial sediments. Hewan Bank is the best natural exposure currently available showing facies of the type which have been used in the past to erect a regional glacial stratigraphy for the Edinburgh and Lothians area. Details of the sediments and stratigraphy are given by Martin (1981).

Description

Several exposures in the bank above an extensive area of landslips show the following sequence of deposits:

4. Gravel
3. Sand
2. Reddish-brown till
1. Blue-grey till

Details of these sediments are given by Martin (1981); the site corresponds with his Polton site. Martin described bed 1 as a massive, fissile diamicton. The upper diamicton (bed 2) is weathered with larger, more widely dispersed clasts; primary fissility cannot be distinguished. The contact with bed 3 is sharp and irregular, although lenses of till and clasts occur in the overlying sand. Deposits of sand, gravel, silt and clay are exposed above, and Martin (1981) recorded several facies variations including sands with load casts, stratified diamictons and stratified, reworked diamictons. Various sedimentary structures, notably sand pillars, are also present, as are small faults.

Interpretation

In terms of the conventional stratigraphies, the tills (beds 1 and 2) at Hewan Bank correspond with the Lower Boulder Clay of Mitchell and Mykura (1962) and the Basal and Intermediate Tills, respectively, of Kirby (1968); the overlying sands and gravels (beds 3 and 4), with the 'Middle' Sands and Gravels of Mitchell and Mykura (1962) and the outwash deposits associated with Kirby's Intermediate Till. The so-called Roslin Till or Southern Uplands Boulder Clay is not represented at Hewan Bank but can be seen in a number of working sandpits nearby (for example at NT 259626 and NT 297667).

According to Martin (1981), however, the sequence of deposits at Hewan Bank can be interpreted in terms of a single glacial episode during the Late Devensian. Bed 1 is a lodgement till; bed 2 is possibly transitional between a lodgement till and a melt-out till. The overlying sands and gravels are ice-marginal deposits, and the stratified diamictons are debris-flow deposits.

Deposits similar to those at Hewan Bank have been widely recognized around Edinburgh and in the Lothians for over 170 years (see above) and have provided the basis for interpreting the sequence of glacial episodes in one of the historically core areas for Quaternary studies in Scotland. There is no long history of investigations at Hewan Bank, but the site provides one of the best natural exposures demonstrating examples of the main sedimentary units recognized in the various glacial successions identified for the area. Historically, a sequence of the type at Hewan Bank was first described in Midlothian by Maclaren (1828) and is known to occur at a number of other localities (Kirby, 1968). However, apart from Hewan Bank, few sections are currently exposed.

In addition to its stratigraphic interest, Hewan Bank is also of glaciological and sedimentological note for the multiple-unit depositional sequence that appears to reflect the convergence and interaction of ice flow-lines from separate source areas during the Late Devensian glaciation. In this respect close analogies exist between Hewan Bank and several other sites, for example at Den Wick, Baile an t-Sratha, Nigg Bay, Boyne Quarry and Nith Bridge. Together these sites have important research potential for interpreting processes and patterns of debris entrainment and sedimentation beneath former ice-sheets where the interaction of ice masses from different sources has produced distinctive sedimentary units. Such sites will also provide the field evidence to underpin mathematical modelling and reconstruction of ice-sheet dynamics and the controls that determine changes in ice-sheet flow patterns.

Conclusion

The deposits at Hewan Bank are important for interpreting the glacial history of the Lothians area. They show that during the Late Devensian glaciation (around 18,000 years ago) the area was first covered by Highland ice issuing from the west, then by ice from sources in the Southern Uplands. There has been much discussion about whether these ice movements represent separate glacial episodes, but current interpretations favour a single ice-sheet in which the direction of flow shifted. Hewan Bank is a valuable reference site not only for establishing the glacial sequence in this area, but also for studying the interaction between ice masses from different sources.

KEITH WATER

J. E. Gordon

Highlights

Stream sections along the Keith Water reveal sequences of tills and glaciofluvial sediments. These deposits are important both for interpreting the sequence and patterns of movement of the Late Devensian ice-sheet, and for demonstrating the complex sedimentary environments associated with the melting of the ice which included flow components from separate sources in the Highlands and Southern Uplands.

Introduction

The site comprises a series of stream and gravel pit exposures along the valley of the Keith Water (NT 440621 to NT 452639), a tributary of the River Tyne, located about 20 km south-east of the centre of Edinburgh. On the north side of the Keith Water and in the area between the Keith Water and the Humbie Water, the landscape is underlain by thick drift deposits heavily dissected by former meltwater streams and the present rivers. The deposits comprise thick sequences of till and glaciofluvial materials which appear at the surface as flat-topped areas or mounds. The hummocky glaciofluvial deposits form part of an extensive suite extending along the northern flanks of the Lammermuir and Moorfoot Hills (Young, in Howell *et al.*, 1866; J. Geikie, 1877; Kendall and Bailey, 1908; Charlesworth, 1926b; Sissons, 1958a; McAdam, 1978; McAdam and Tulloch, 1985).

A number of the sections along the Keith Water are of longstanding interest and have sometimes been taken to represent a regional glacial stratigraphic standard for the Edinburgh–Lothians area, for which up to three separate glacial episodes have been recognized (see above). An alternative view, however, holds that the considerable lateral and vertical variability in the stratigraphy is a function of purely local ice-margin conditions associated with a single ice-sheet (Young, 1966, 1969; Martin, 1981). The deposits at Keith Water have been described by Kendall and Bailey (1908), Kirby (1966, 1968, 1969b), Young (1966, 1969), Ragg and Futty (1967) and Martin (1981).

Description

Six main sections and a number of smaller exposures have been described from the valley of the Keith Water. These show multiple, interbedded sequences of till and glaciofluvial deposits. Section 1, at NT 440621, was described by Young (1966) as showing the following beds:

3.	Reddish-brown till containing Carboniferous sandstone and greywacke erratics	1.2–1.4 m
2.	Current-bedded sands with inclusions of reddish-brown till at the top	at least 4.6 m
1.	Dark-grey till containing coal fragments and Carboniferous sandstone, greywacke and limestone erratics	at least 3.1 m

In 1980 only beds 1 and 2 were exposed.

Section 2, at NT 438623, has been the most intensively studied exposure, particularly through the work of Young (1966, 1969) who examined the stratigraphy, till clast-fabrics, particle-size distributions, heavy mineral assemblages, pH and soluble carbonates. The sequence comprises:

6.	Dark brown sands	0.9–1.1 m
5.	Dark reddish-brown till containing coal fragments, Carboniferous sandstone and greywacke erratics	1.2–1.5 m
4.	Pebbly sand	0.6 m
3.	Dark-brown till containing coal fragments, Carboniferous sandstone, greywacke and tuff erratics	at least 3.7 m
2.	Current-bedded sands with bands of coal fragments	0.9 m

1. Dark-grey till containing coal, Carboniferous sandstone, greywacke and limestone erratics at least 3.0 m

Young found that variations in clast fabrics were often greater within the same till units than between different ones, and that the dip analyses were inconclusive in demonstrating the ice-movement direction. Particle size, mineralogy and stone-count studies showed no significant differences between the till units. Greywacke and Carboniferous sandstone clasts were the dominant constituents of the deposit; limestone clasts occurred only in the bottom part of the middle till and in the lowest till. No identifiable Highland rocks were found.

Section 3, at NT 438631, is the notable Red Scar exposure first described by Kendall and Bailey (1908). They described the following sequence:

4.	Sand	16.1 m
3.	Boulder clay	4.0 m
2.	Sand	4.6 m
1.	Boulder clay	up to 11.3 m

Gravel layers interbedded with the sands contained a noticeable proportion of greywacke pebbles, whereas the larger blocks in the tills comprised sandstone.

The succession of deposits was confirmed by Kirby (1966, 1968) and Young (1966). Young described the lower till as very dark grey and containing Carboniferous sandstone, greywacke and limestone erratics and coal fragments; the upper till as reddish brown and containing coal fragments and Carboniferous sandstone and greywacke erratics. Kirby noted that the lower till merged, and was interbedded with, the sand above; inorganic laminated clays occurred near the top of the lower sand layer; a sharp junction existed between the lower and upper till; and there was a transitional change from the upper till to the upper sands.

Section 4, at NT 449637, was first described by Kendall and Bailey (1908) who recorded:

3.	Boulder clay	1.8 m
2.	Sand	19.8 m
1.	Boulder clay	10.1 m

In more detail, Kirby (1966, 1968) described:

6.	Red till	2.1 m
5.	Fine- and medium-grained bedded sands	*c.* 20 m
4.	Red till	0.9 m
3.	Sand with red till inclusions	1.8 m
2.	Silty till	0.9 m
1.	Dark till grading up into bed 2	5.2 m

In 1980 the section was completely vegetated over. In the same area, in sections also no longer exposed, Young (1966) had recorded sands and gravels variously overlying dark grey till containing coal fragments and Carboniferous sandstone and greywacke erratics, and reddish-brown till containing similar erratics overlying current-bedded sands.

Between sections 3 and 4 both Kirby (1966) and Young (1966) recorded several small exposures showing either sands and gravels overlying dark grey till or reddish brown-till overlying sands.

Section 5 is at Keith Marischal sandpit (NT 450640) (Kirby, 1966; Young, 1966; Ragg and Futty, 1967). As described by Young in greatest detail it shows:

4.	Dark, reddish-brown till containing Carboniferous sandstone, Old Red Sandstone, coal and greywacke erratics	1.2 m
3.	Current-bedded, dark reddish-brown sands	0.08–0.13 m
2.	Dark, reddish-brown till containing coal fragments, greywackes, Old Red Sandstone and Carboniferous sandstone erratics	0.05–0.10 m
1.	Current-bedded sands	at least 10.7 m

Section 6 is a sandpit, at NT 453637. Here Kirby (1966) described thick, horizontally bedded sands overlain by beds of till of variable thickness interlayered with sands and clays, capped by a horizon of red till.

Interpretation

The first significant synthesis of the glacial stratigraphy of East Lothian was that of Young (in Howell *et al.*, 1866) who established a basic succession of till overlain by sands and gravels. He noted variations in the colour of the till according to the local bedrock and also referred to a sandier till near the coast which merged with the main till of the area.

Following J. Geikie (1877), Kendall and Bailey (1908) confirmed the presence of Highland erratics in East Lothian and distinguished on lithological grounds the till containing Midland Valley material and the overlying sands and gravels dominated by Silurian greywackes. They explained the sequence of deposits in the Keith Water area in terms of an oscillating ice margin. Following deposition of the lower till the ice retreated northwards, and great accumulations of sand and gravel were laid down either in temporary ice-dammed lakes or as gravel spreads extending between the ice and the Lammermuir Hills. Debris washed in from the hills to the south explained the high content of local lithologies. The upper till was subsequently deposited during a forward oscillation of the ice margin. Kendall and Bailey's observations were substantially incorporated into the second edition of the Geological Survey Memoir for East Lothian (Clough *et al.*, 1910). Sissons (1958a), however, disputed Kendall and Bailey's interpretation of oscillatory retreat, and suggested instead that the balance of evidence favoured widespread thinning and stagnation of the ice.

Kirby (1966, 1968) correlated the beds in the different sections along the Keith Water. Using clast fabrics and stone counts as evidence, he inferred that the stratigraphy in the Keith Water area was similar to that in the Esk basin (see Hewan Bank). The two tills in sections such as that at Red Scar corresponded to the Basal and Intermediate tills of his regional stratigraphic scheme. The Intermediate Till was distinguished by a higher percentage of greywackes of southern origin and clast fabrics indicating ice moving to the north, whereas the Basal Till consisted largely of material of western derivation and had clast fabrics orientated to the east. Although the topmost till at sections 5 and 6 corresponded in its stratigraphic position with the Roslin Till (see Hewan Bank), it could be distinguished from the latter on the basis of its fabric and lithology (Kirby, 1968, 1969b). Its characteristics suggested that it was an ablation till associated with the decay of the Southern Uplands ice that produced the Intermediate Till.

Young (1966) studied the stratigraphy of a large number of individual sites in the Upper Tyne area. He stressed the appearance of 'rapid and radical changes' in the succession over very short distances and concluded that 'it would be impossible to construct an isopachyte map of any clarity for any one strata from the results obtained' (p. 15). However, a broad pattern emerged of a dark grey till underlying much of the area, with an overlying reddish-brown till restricted largely to the Keith Water area. From his detailed studies of section 2, Young concluded that all the deposits were laid down by the same ice flowing northwards into the Midlothian basin from the Southern Uplands, subsequently being directed south-eastwards into the Upper Tyne area. In contrast to Kirby, Young found no significant differences in lithology or clast fabric among the tills, including those of section 2 which he studied in great detail.

More recently, Martin (1981) has supported Young's interpretation. From detailed sedimentological studies and comparisons with contemporary glacial environments he concluded that the Keith Valley deposits are best interpreted in terms of a basal lodgement till succeeded by an interbedded sequence of flow tills and delta-fan deposits formed at the receding or thinning ice margin of the Late Devensian ice-sheet.

The Keith Water deposits are of considerable interest from a historical viewpoint because of their role in the development of a regional stratigraphy (see also Hewan Bank). However, more recent studies have emphasized the local variability of the deposits and their spatially restricted distribution. Taken together, therefore, the various sections provide a valuable record of the complex depositional environments associated with Pleistocene ice-sheets. They provide significant evidence for interpreting the patterns and processes of sedimentation beneath and at the margins of former ice-sheets, and thus may allow analogies with modern glacier sedimentary systems (for example see Boulton, 1972b; Lawson, 1979).

Conclusion

The sequences of deposits at Keith Water are important for studying the glacial history of the Lothians area and processes of glacial sedimentation. They were formed by ice from sources both to the west and south during the Late Devensian glaciation (around 18,000 years ago) and are particularly significant in illustrating the complex depositional patterns arising from the interactions of these sediment-carrying ice masses and their subsequent melting. The site is therefore valuable both as a reference locality for the Lothians area and for studies of glacial sedimentary environments.

CARLOPS

J. E. Gordon and D. G. Sutherland

Highlights

The landforms at Carlops comprise an outstanding assemblage of subglacial meltwater channels. These are particularly well developed and are noted for their anastomosing pattern.

Introduction

One of the most outstanding examples of meltwater channels in Scotland is located near Carlops, 21 km south-west of Edinburgh. The principal features extend over a distance of 3 km (from *c.* NT 140538 to NT 160557). The Carlops channels are part of an extensive glacial drainage system running south-west to north-east from the Clyde Valley to the Firth of Forth (see Sissons, 1967a, figure 47; Price, 1973, figure 43; Sutherland, 1984a, figure 9) in which meltwater flow was concentrated through the gap between the Pentland Hills and Moorfoot Hills during the wastage of the Late Devensian ice-sheet. The most detailed description of the channels at Carlops is that of Sissons (1963b) although the features were earlier mentioned by Milne Home (1840), Maclaren (1866), Day (1923), Charlesworth (1926b) and Eckford (1952).

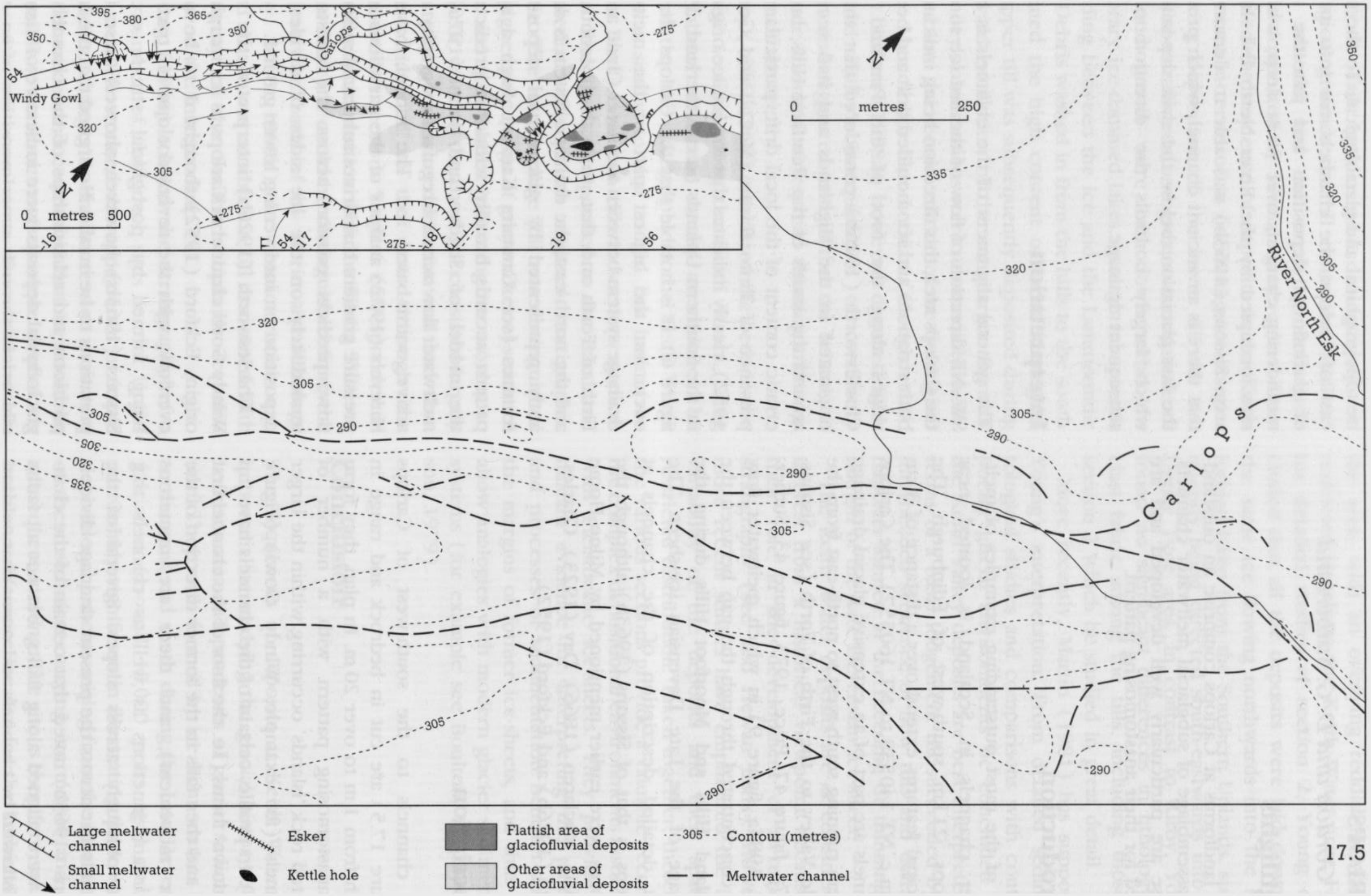
Description

The channels to the south-west of Carlops (Figure 17.5) are cut in bedrock and range in depth from 1 m to over 20 m. In plan, they form an anastomosing pattern with a number of isolated rock 'islands' occurring within the larger channels (for example, Windy Gowl) (Figure 17.6). In profile, certain of the channels have 'up and down' forms (i.e. the floor of the channel first rises and then falls in the former direction of the water movement), and there are numerous discordant junctions as well as channels that trend obliquely across slopes. Several of the channels cut across the present drainage divides. Sissons (1963b) noted that certain of the channels were aligned along faults, but not all faults are followed by channels and many channels are not apparently fault-guided, so the principal controls on channel location may be presumed to be topographical and glaciological. To the north-east of Carlops, the channels cut into an area of glaciofluvial deposition and join the major meandering channel, over 30 m deep, which is now occupied by the River North Esk. In this area, Sissons (1963b) was able to demonstrate that there is an ancient channel, which pre-dates the last glaciation, below the drift deposits and which largely controls the direction of the subsequent drainage.

Interpretation

The general alignment of the channels is in the SW–NE direction of flow of the last ice to cover the Carlops area, this direction being indicated by both striations and ice-moulded drift and bedrock ridges along the foot of the Pentland Hills. Charlesworth (1926b) considered that this ice originated in the Highlands and had recurved around the south of the Pentland Hills, but the erratic content of the local drift, particularly the presence of Tinto felsite (McCall and Goodlet, 1952), clearly indicates that the last ice originated in the Southern Uplands (see Sutherland, 1984a, figure 6). It is notable that the Carlops channels occur on the highest part of the meltwater drainage system between the River Clyde and the Firth of Forth and that, to both the south-west and the north-east, the drainage system is dominantly represented by glaciofluvial depositional features (see Carstairs Kames). Such a spatial pattern accords broadly with that predicted in the model of Sugden and John (1976) for meltwater flow across irregular topography under active, warm-based ice. The model, based on Shreve's (1972) analysis of the variations in the pressure gradient that drives subglacial meltwater flow, predicts erosion across the crests and immediately on the lee sides of divides, and deposition on intervening lower ground.

Charlesworth (1926b) interpreted the major Windy Gowl channel at Carlops as ice marginal in origin; Eckford (1952) thought it to be a lake overflow, with the reversed slope on part of it being formed by post-glacial stream erosion. Sissons (1963b), however, showed these interpretations to be invalid. He argued that the forms, positions and relationships of the channels and glaciofluvial deposits were indicative of a subglacial origin through superimposition of an englacial stream system on to the underlying topography, an interpretation supported by Price



Windy Gowl
Carlops
N
0 metres 500
0 metres 250
River North Esk
Carlops
350
335
320
305
290
275
395
380
365
54
16
17
18
19
56
Large meltwater channel
Small meltwater channel
Esker
Kettle hole
Flattish area of glaciofluvial deposits
Other areas of glaciofluvial deposits
305 Contour (metres)
Meltwater channel

17.5

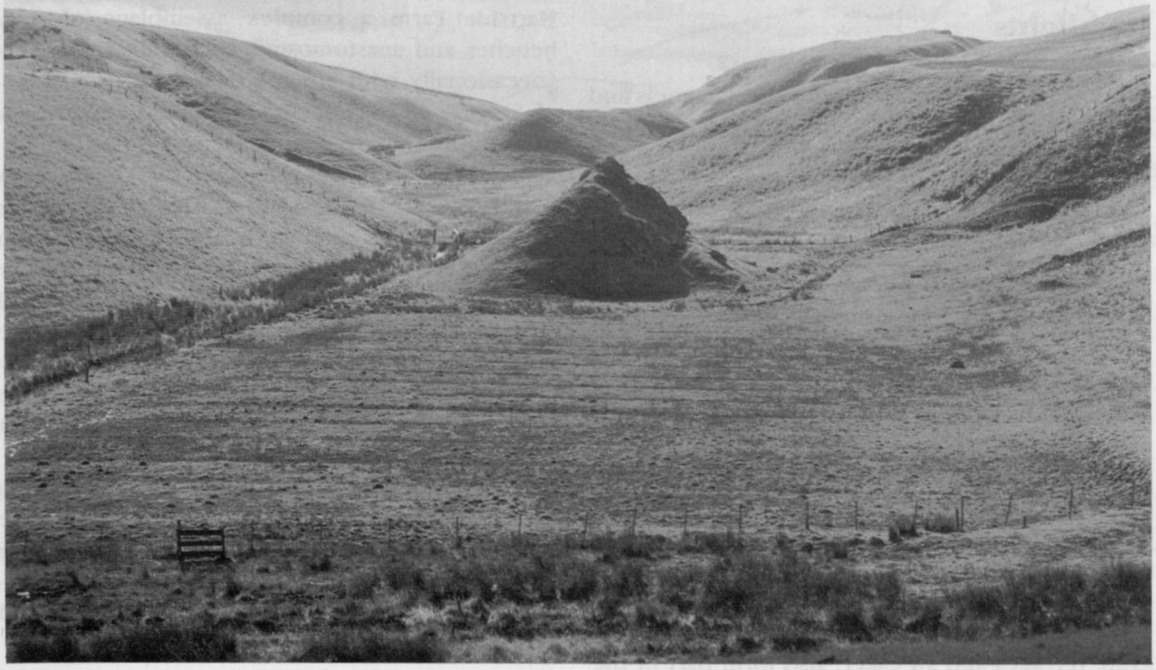


Figure 17.6 The main meltwater channel at Carlops showing the anastomosing form of the channel system and the isolated interfluve 'islands' between constituent channels. (Photo: J. E. Gordon.)

(1973). In the overall evolution of the system, Sissons envisaged a progressive change from subglacial to open ice-walled to proglacial drainage as the ice-sheet downwasted and the Carlops area became ice-free.

The features at Carlops are classic landforms which demonstrate strikingly the morphology of subglacial meltwater channels. They illustrate very clearly the anastomosing pattern of subglacial meltwater flow and the hydraulic gradient reflected in the 'up and down' channel profiles. The Carlops channels are representative of the ice-directed type of meltwater channel (cf. Sugden and John, 1976) and in this respect are similar to certain of the channels in the Cairngorms, at Muir of Dinnet and at Rammer Cleugh. In contrast to these other areas, they demonstrate particularly well an anastomosing subglacial meltwater flow pattern. Further, in their overall pattern, the Carlops channels differ from the channel systems in the Cairngorms and at Muir of Dinnet, where they formed in submarginal positions in association with a progressively downwasting ice-sheet. The Carlops channels are also part of a much more extensive system of meltwater landforms formed during the retreat of the Late Devensian ice-sheet and hence are important in a regional context for reconstructing the pattern of glacial meltwater drainage.

Figure 17.5 The meltwater channel system at Carlops. The detailed pattern of channels immediately to the south-west of the village (main diagram) forms part of a more extensive glacial drainage system represented by channels and glaciofluvial deposits (inset) (from Sissons, 1963b).

Conclusion

Carlops is important for glacial geomorphology. It is an outstanding example of a subglacial meltwater channel system that formed beneath the last ice-sheet. It is particularly noted for the fine development of its individual channels, which include a variety of anastomosing forms. The Carlops channels form part of a wider regional pattern of glacial meltwater drainage that developed during the melting of the last ice-sheet (around 14,000 years ago).

RAMMER CLEUGH

J. E. Gordon

Highlights

The assemblage of glacial meltwater channels and deposits at Rammer Cleugh provides a particularly clear illustration of the development and evolution of a glacial drainage system during the wastage of the Late Devensian ice-sheet.

Introduction

The Rammer Cleugh site, 8 km south-west of Dunbar, covers an area of 5 km^2 between Stoneypath (NT 616711) and Hartside (NT 653721). It is important for an assemblage of glacial meltwater drainage channels, including the large and spectacular Rammer Cleugh, probably formed subglacially, and a series of subglacial chutes, ice-marginal benches and small marginal and submarginal channels. Glaciofluvial deposits, including kame terraces and an esker, also form part of the landform assemblage. Rammer Cleugh has been described by Young (in Howell *et al.*, 1866), Kendall and Bailey (1908) and Sissons (1958a, 1961a, 1975c), the last of whom published detailed geomorphological maps of the area (Sissons, 1958a, figure 2; Sissons, 1961a, figure 13).

Description

The meltwater channels at Rammer Cleugh comprise three principal sets of features (Sissons, 1958a): the large channel of Rammer Cleugh itself, channels running steeply downslope and a series of channels and benches with a much gentler gradient. The main feature, called Rammer Cleugh (see plate I of Kendall and Bailey, 1908, and plate IX of Wright, 1937), occupies the col between Deuchrie Dod and Lothian Edge. It comprises a 60 m deep glacial drainage channel extending some 5 km from Stoneypath to east of Pathhead. It has an 'up and down' long profile and at its western end near Stoneypath is cut on its southern side by numerous deep gullies and channels joining it at right angles (Figure 17.7). Above the main channel of Rammer Cleugh, particularly on the south side, several smaller channels and benches cut in bedrock run parallel, or at a low angle to the hillside contours. A number of these features turn steeply downslope at their eastern ends. To the west and north of Hartside Farm a complex assemblage of rock benches and anastomosing, rock-walled channels (occasionally with 'up and down' long profiles – cf. Sissons, 1975c) occurs in a broad embayment in the hills (Figure 17.7).

Meltwater deposits occur in two main areas within the site. To the east of Deuchrie, a series of aligned gravel mounds up to 12 m high form an esker on the floor of Rammer Cleugh. Farther east in the area between Hartside and Pathhead (Figure 17.7), kame terraces occur both to the north and south of Rammer Cleugh, locally interspersed with kame mounds. Further examples of kames occur north of Stoneypath at the west end of Rammer Cleugh.

In a wider context, Rammer Cleugh and its associated features are part of an extensive sequence of meltwater drainage phenomena along the northern flanks of the Moorfoot and Lammermuir Hills (Sissons, 1958a, 1967a; McAdam and Tulloch, 1985; Davies *et al.*, 1986).

Interpretation

Young (in Howell *et al.*, 1866) provided the first account of Rammer Cleugh and other dry valleys on the northern flanks of the Lammermuir Hills. He noted that their consistent north-east orientation was discordant with the present drainage system and that they shared similarities with dry channels in Berwickshire described earlier by Geikie (1863b). Although further investigation was necessary to explain their origin, Young discounted present stream processes and direct glacial erosion. Geikie (1894) later identified deposits associated with the channels as glaciofluvial in origin.

Kendall and Bailey (1908) mapped the large drainage channels in their study of the deglaciation of East Lothian. They explained them as the product of a retreating ice-sheet, applying the ideas developed by Kendall (1902) to account for similar features in Yorkshire. In their view, the channels were formed by meltwater torrents linking marginal ice-dammed lakes along the hillsides. Kendall and Bailey inferred oscillations in the receding ice-front from several lines of evidence and explained the mounds at the western end of Rammer Cleugh as the result of a minor readvance. In the second edition of the

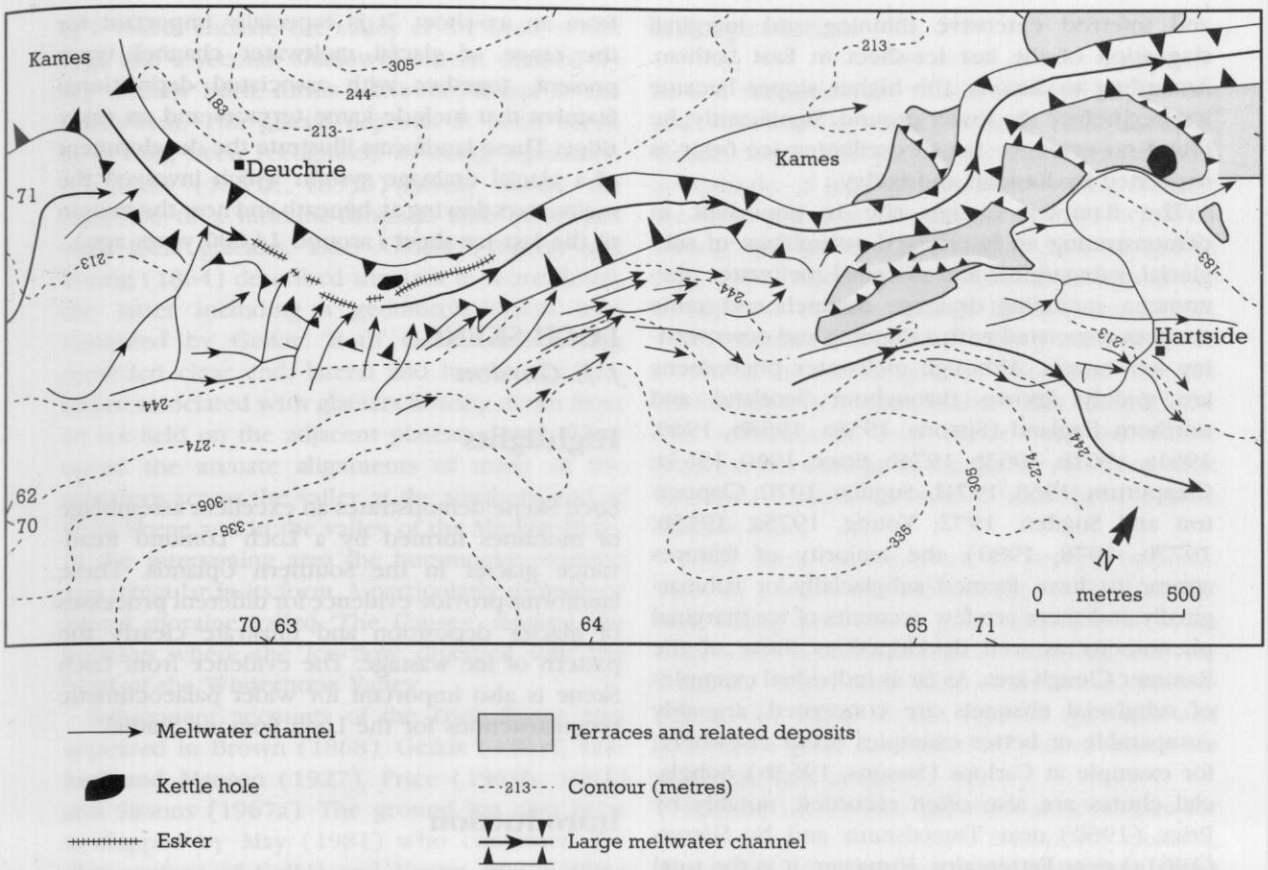


Figure 17.7 Geomorphology of the meltwater channel system at Rammer Cleugh (from Sissons, 1958a).

Geological Survey Memoir on the geology of East Lothian Clough *et al.* (1910) drew heavily on Kendall and Bailey's work.

Charlesworth (1926b) related the meltwater channels and deposits along the northern flanks of the Lammermuir Hills to his Lammermuir–Stranraer Readvance.

Based on his detailed mapping, Sissons (1958a) reinterpreted the Rammer Cleugh features and placed them in the context of the wider pattern of deglaciation in East Lothain. Many of the meltwater channels and benches running across the slopes at low angles to the contours were largely formed by ice-marginal streams, and not by glacial lake overspill as suggested by Kendall and Bailey (1908). Some of the channels, for example those running steeply downslope on the south side of Rammer Cleugh near Stoneypath, were subglacial chutes similar to features described from Scandinavia by Mannerfelt (1945, 1949). In several cases, the marginal channels terminated abruptly at the chutes, indicating that the meltwaters turned abruptly to flow beneath the ice margin.

Subsequently, in an important contribution, Sissons (1960, 1961a) offered further detailed criticisms of the haphazard application of the lake overspill hypothesis (Kendall, 1902; Kendall and Bailey, 1908), and he elaborated on alternative processes of meltwater channel formation that agreed better with the field evidence. According to Sissons (1961a) the main Rammer Cleugh channel was probably a subglacial feature, its 'up and down' long profile being cut by meltwaters under hydrostatic pressure at a stage before the subglacial chutes were formed on its flanks and the esker on its floor. Subsequent work elsewhere suggests that Rammer Cleugh and the other channels with 'up and down' long profiles may have been formed by superimposition of submarginal, englacial meltwaters on to the underlying topography, in the manner outlined for similar channels in southern Scotland and northern England (Price, 1960, 1963a; Clapperton, 1968, 1971b).

From his detailed mapping of benches, channels and kame terraces, including those of the Rammer Cleugh area, Sissons (1958a) reconstructed a series of former ice-margin positions and inferred extensive thinning and marginal stagnation of the last ice-sheet in East Lothian. According to Sissons, the higher slopes became ice-free before the lower ground. Significantly, he found no evidence for an oscillating ice front as suggested by Kendall and Bailey.

The Rammer Cleugh site is important in demonstrating an interlinked assemblage of subglacial, submarginal and marginal meltwater phenomena, including drainage channels and kame terraces associated with a thinning and downwasting ice margin. Although meltwater phenomena are widely known throughout Scotland and northern England (Sissons, 1958a, 1958b, 1960, 1961a, 1961b, 1963b, 1974b; Price, 1960, 1963a; Clapperton, 1968, 1971b; Sugden, 1970; Clapperton and Sugden, 1972; Young, 1975a, 1975b, 1977b, 1978, 1980), the majority of features appear to have formed subglacially or submarginally and there are few accounts of ice-marginal phenomena as well developed as those of the Rammer Cleugh area. As far as individual examples of subglacial channels are concerned, arguably comparable or better examples occur elsewhere; for example at Carlops (Sissons, 1963b). Subglacial chutes are also often recorded, notably by Price (1960) near Tweedsmuir and by Sissons (1961a) near Fettercairn. However, it is the total assemblage of different types of feature and the particular component of marginal channels which distinguishes Rammer Cleugh.

The Rammer Cleugh area is also significant in a historical context. It forms an integral part of the landform assemblage on the northern flanks of the Lammermuir Hills. This area was one of the first to be interpreted by Sissons (1958a) in terms of a downwasting model of ice-sheet deglaciation, in contrast to earlier interpretations that involved active ice-margin recession. The downwasting model has formed the basis of most subsequent studies of the pattern of deglaciation of the last ice-sheet. However, as a universal model, like those before it, it is probably an oversimplification. Deglaciation probably proceeded by a combination of downwasting and frontal recession, with considerable local variations controlled by factors such as ice dynamics, topography, debris content, and, where appropriate, calving.

Conclusion

Rammer Cleugh is notable for an assemblage of landforms produced by meltwater rivers flowing from an ice-sheet. It is especially important for the range of glacial meltwater channel types present, together with associated depositional features that include kame terraces and an esker ridge. These landforms illustrate the development of a glacial drainage system which involved the meltwaters flowing at, beneath and near the margin of the last ice-sheet (around 14,000 years ago).

LOCH SKENE

J. E. Gordon

Highlights

Loch Skene demonstrates an excellent assemblage of moraines formed by a Loch Lomond Readvance glacier in the Southern Uplands. These landforms provide evidence for different processes of glacier deposition and illustrate clearly the pattern of ice wastage. The evidence from Loch Skene is also important for wider palaeoclimatic reconstructions for the Loch Lomond Stadial.

Introduction

The Loch Skene site (NT 168162) covers an area of *c.* 5.75 km^2 on the north-west side of Moffat Dale, a classic, fault-guided, glacial trough in the Southern Uplands. It is important for an assemblage of glacial landforms, including fine examples of a corrie and hanging valley which were occupied by part of the largest glacier system in the Southern Uplands during the Loch Lomond Stadial. The locality is therefore significant for glacier and palaeoclimatic reconstructions, and good examples of end and hummocky moraines also provide a valuable means of interpreting the recession of the glacier. The Loch Skene landforms have a long history of research (Chambers, 1855a, 1855b; Geikie, 1863a, 1901; Young, 1864; Brown, 1868; Eckford and Manson, 1927; Price, 1963b, 1983; Sissons, 1967a; May, 1981), and aspects of vegetational history recorded in the peat deposits on the corrie floor have also been examined (Lewis, 1905; Erdtman, 1928).

Description

The hills around Loch Skene rise to an altitude of 822 m OD at White Coomb. The steep headwalls of a corrie enclose the valley at the head of the loch and a second, shallower corrie, drained by the Midlaw Burn, forms a tributary basin to the south-west. The glacial deposits at Loch Skene have long been recognized as being significant. Chambers (1855a, 1855b) briefly noted the presence of a moraine-dammed lake associated with local glaciers. Later Geikie (1863a) and Young (1864) described the area in more detail, the latter including a geomorphological map compiled by Geikie. Both Geikie and Young recorded clear end, lateral and hummocky moraines associated with glaciers flowing down from an ice-field on the adjacent plateau slopes. They noted the arcuate alignments of many of the moraines across the valley at the southern end of Loch Skene and in the valley of the Midlaw Burn. In the intervening area the hummocky moraine was irregular in its form. A particularly prominent lateral moraine called 'The Causey' marked the position where the ice flow diverged into the head of the Winterhope Valley.

Subsequent accounts of the Loch Skene area appeared in Brown (1868), Geikie (1901), Eckford and Manson (1927), Price (1963b, 1983) and Sissons (1967a). The ground has also been re-mapped by May (1981) who confirmed the observations of Geikie and Young. May (1981) provided a detailed map of the area showing the form and distribution of the moraines (Figure 17.8). He also described their main characteristics, elaborating on the earlier accounts. Sections in the ridges along the Tail Burn revealed locally derived till comprising angular and subangular clasts in a gravelly matrix.

In a brief reference, Sissons (1977a) recorded the presence of fluting on the hummocky moraine at Loch Skene, implying that active ice overrode 'dead'-ice topography.

As part of a wider study of the Holocene vegetational history of Scotland, Lewis (1905) examined the peat deposits in the Tweedsmuir area, including Loch Skene, and identified layers of birch tree remains and two 'arctic beds', layers in the peat where the plant macrofossils had predominantly northern affinities. However, from pollen analysis and a re-examination of the peat deposits on the north-east side of Loch Skene, Erdtman (1928) questioned some of Lewis' interpretations, particularly the occurrence of a second 'arctic bed' (see Loch Dungeon).

Interpretation

As first recognized by Chambers (1855a, 1855b) and followed by later authors (for example, Geikie, 1894), the Loch Skene moraines relate to an episode of local glaciation following the last ice-sheet and now recognized to have occurred during the Loch Lomond Stadial (Sissons, 1967a; May, 1981; Price, 1983). Similar moraines occur in adjacent valleys (Young, 1864; Price, 1963b, 1983; Sissons, 1967a; May, 1981;) indicating the extent of the former glaciers associated with the ice-field that developed in the White Coomb area. The moraines at Loch Skene mark successive stages in ice wastage as the glacier retreated back into the corries at the head of Loch Skene and the Midlaw Burn.

Loch Skene is important in several respects. First, in a historical context the work of Geikie and Young provides a good example of early, large-scale geomorphological mapping and description. Their basic field observations demonstrated the value of this type of approach and provided a good contemporary record which has stood the test of time.

Second, Loch Skene provides an ideal area for the study of the formation of hummocky moraine, the origin of which is controversial (see Coire a'Cheud-chnoic). Three main hypotheses exist: it is a form of stagnant-ice topography formed by rapid wastage of ice with a thick cover of supraglacial debris (Sissons, 1967a; Thompson, 1972); it is a product of controlled or uncontrolled deposition by actively retreating glaciers (Eyles, 1983; Day, 1983; Horsfield, 1983; Benn, 1990, 1991; Bennett, 1990, 1991; Bennett and Glasser, 1991); or it is a subglacial deposit formed by deformation of pre-existing till (Hodgson, 1982, 1987; Ballantyne, 1989a; Benn, 1991). All three types probably exist (see the Cuillin). Loch Skene provides a particularly good opportunity to investigate the genesis of different forms of hummocky moraine and their relationships since features of all three models exist in the area: chaotic assemblages of mounds, arcuate alignments of mounds and ridges which have the form of recessional moraines, and overridden and fluted mounds. The results of such work and comparative studies with other sites (see the Cuillin, Coire a'Cheud-chnoic and the Cairngorms) will facilitate the recognition of styles of deglaciation from the landform assemblages and sediment facies (see Eyles, 1979, 1983; Sharp, 1985; Evans, 1989; Benn, 1990, 1991; Benn *et al.*, 1992;

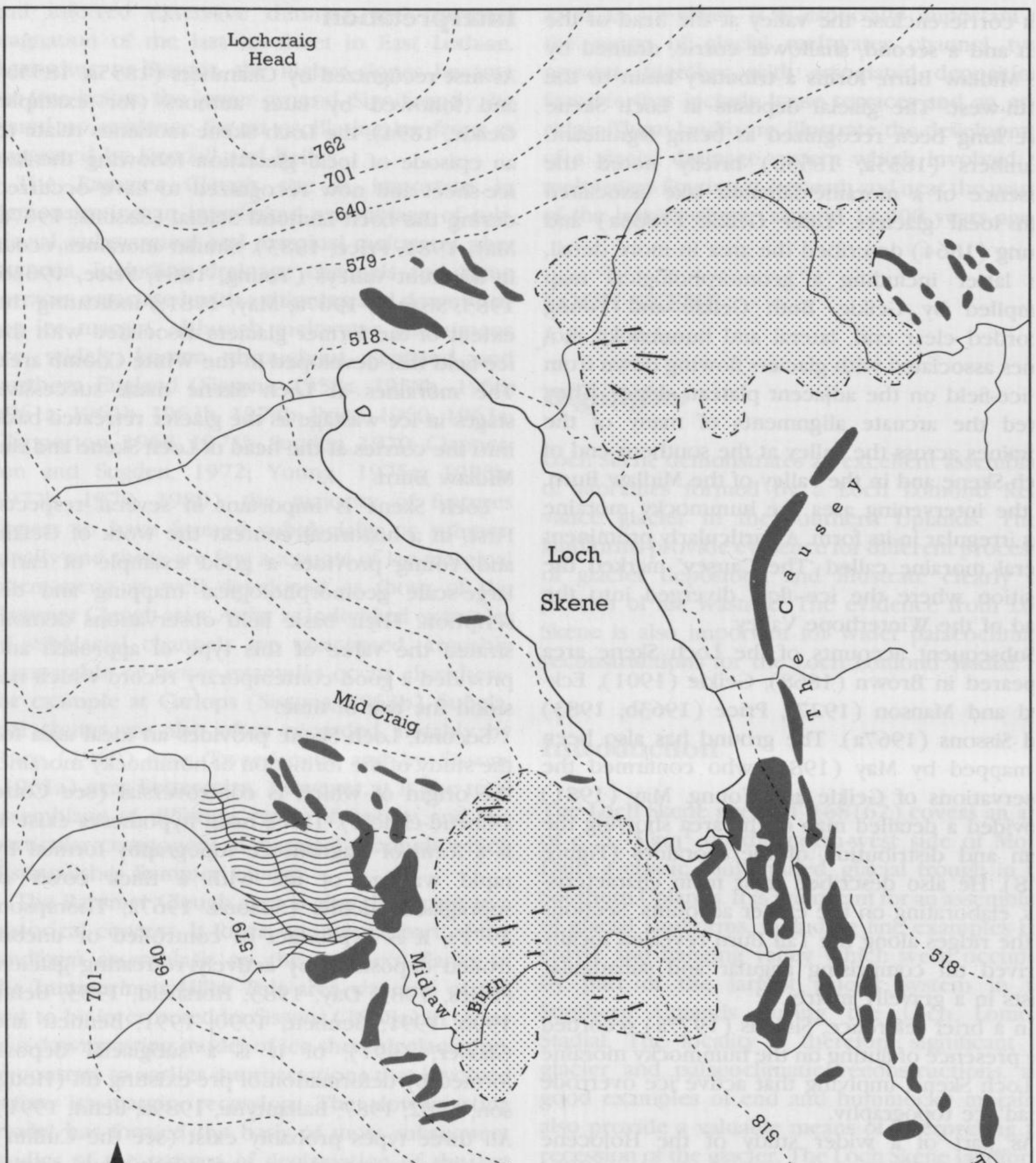


Figure 17.8 Loch Lomond Readvance moraines at Loch Skene (from May, 1981).

Bennett, 1991). In some cases they will also provide field evidence for the characteristics of deformable glacier beds and information on sediment transfer patterns during the Loch Lomond Readvance (see Coire a'Cheud-chnoic).

Third, Loch Skene is important for palaeoclimatic reconstructions. The end moraines provide a clear geomorphological record of the pattern of glacier wastage during the Loch Lomond Stadial. At present little is known of climatic variations during the stadial, but comparative studies of the moraines at Loch Skene and other sites (e.g. Tauchers, the Cairngorms, Lochnagar, Cnoc a'Mhoraire and the Cuillin) should provide important information on glacier–climate relationships and the effects of other variables, such as topography, in controlling the mass balance and fluctuations of Loch Lomond Readvance glaciers.

Fourth, glacier development was of very restricted extent in the Southern Uplands during the Loch Lomond Stadial (Sissons, 1979d, 1980b; Cornish, 1981; Price, 1983), and the Loch Skene glacier is therefore significant in forming part of the largest ice mass in the area. This ice mass provides an important geographical link between those in the Highlands, Lake District and Wales (Sissons, 1979d, 1979e) and is a significant element in interpreting the wider national pattern of Loch Lomond Stadial glaciers and underlying climatic conditions (Sissons, 1979d, 1979e). Significant contrasts in glacier development between these areas are explicable in terms of regional precipitation differences associated with variations in the position of the Polar Front and Atlantic depression tracks (Sissons, 1979d, 1979e, 1980b). Such variations can also account for the marked contrast in the degree of glacierization during the Loch Lomond Stadial compared with earlier in the Late Devensian when the Southern Uplands formed a major centre of ice-sheet accumulation (Sissons, 1979d; Sutherland, 1984a). The evidence from Loch Skene therefore contributes significantly towards the establishment of wider palaeoclimatic reconstructions.

Conclusion

Loch Skene is important for an assemblage of landforms in the Southern Uplands representing the resurgence of glacier ice which occurred during the Loch Lomond Stadial, approximately 11,000–10,000 years ago. Principally, these landforms comprise an excellent range of moraine types which illustrate clearly the different processes of glacier deposition. The detailed form of the moraines also shows the pattern of ice decay in the corrie, which is significant for interpreting the glacier behaviour and its possible climatic controls. As part of a wider network of sites representing the pattern of glacier growth and retreat during the Loch Lomond Stadial, Loch Skene also contributes important geomorphological evidence for palaeoclimatic reconstructions.

BEANRIG MOSS

P. D. Moore

Highlights

The pollen and plant macro-fossils preserved in the sediments which infill the topographic depression at Beanrig Moss provide a detailed record of vegetational history and environmental change in south-east Scotland during the Lateglacial. The plant macro-fossils, in particular, have yielded a great wealth of palaeoecological information.

Introduction

Beanrig Moss (NT 517293) is part of the Whitlaw Mosses, a series of peat bogs located 5 km east of Selkirk and 6 km south-west of Melrose. It is about 200 m long and occurs at an altitude of about 240 m OD. The sediments of Beanrig Moss are of considerable palaeoecological value in that their rich fossil content provides evidence for a continental flora in eastern Scotland during Late Devensian times, several members of which are now rare or extinct in the British Isles. The site and its deposits have been described by Daniels (1972) and Webb and Moore (1982).

Description

The drift-covered Silurian shales of the Melrose area of the Borders have given rise to alternating ridges and hollows depending upon their susceptibility to glacial erosion (Ragg, 1960). Within the hollows is developed a series of valley fens, the Whitlaw Mosses, of which the most thoroughly studied is Beanrig Moss (Daniels, 1972; Webb and Moore, 1982). Calcareous groundwater during the Late Devensian led to the development of marl and clay deposits in these fens, which form the main feature of sedimentary interest. Similar sediments have been described at Whitrig Bog (Mitchell, 1948; Connolly, 1957) some 10 km to the north-east, and at Blackpool and Murder Mosses within the Whitlaw complex.

The deposits at Beanrig Moss comprise grey and pink, banded clays containing angular shale fragments. The succession at the deepest part of the site is as follows:

5.	Detritus (organic) muds and swamp peats interrupted at a depth of about 1 m below the surface by a clear depositional hiatus, followed by fresh, unconsolidated swamp peat	1.55 m
4.	Grey clay with angular rock fragments and with abundant bryophyte remains	0.50 m
3.	Coarse detritus muds	0.38 m
2.	Marls, muds and clays	0.60 m
1.	Grey and pink, banded clays containing angular shale fragments	0.97 m

The Late Devensian sediments of bed 2 have their greatest depth (about 3 m) in the centre of the basin. The hiatus in bed 5 can be traced across the entire basin and has evidently resulted from the harvesting of peat from the basin in the past. The current vegetation at the site is thus the consequence of secondary reinvasion of abandoned peat cuttings.

The sediments at Beanrig Moss contain an abundance of plant microfossils and macrofossils which provide material for a detailed reconstruction of the vegetation of the Lateglacial Interstadial and Loch Lomond Stadial (Figure 17.9). Evidence from the fossil plant materials within the sediments indicates that they represent the full Lateglacial sequence. The abundance of marl at the site, however, has so far precluded the use of radiocarbon dating techniques.

Interpretation

The basal clays (bed 1) do not contain a sufficient density of pollen for analysis, but plant macrofossils and other microfossils have been extracted (upper part of bed 2) and identified (Webb and Moore, 1982). These included ostracods, *Daphnia*, Chironomidae, and *Nitella* and *Tolypella* oospores. Terrestrial plants included *Artemisia* (a capitulum of *A.* sect. *dracunculus*), *Salix* and *Papaver* sect. *scapiflora*, reflecting open, cold tundra conditions.

Warmer conditions are indicated in the succeeding sediments (bed 3) by an increasing abundance of *Potamogeton* fruit stones, particularly within the marls, but terrestrial plant macrofossils, including *Dryas octopetala*, *Vaccinium vitis-idaea* and many mosses (for example, *Rhytidium rugosum*) show that dwarf-shrub vegetation persisted. Pollen density increases within these sediments and has provided evidence of local fens and willow thickets, together with both tree and dwarf birch (pollen assemblage zone BRM-a). Open ground was clearly still present in the early part of the interstadial, however, as is demonstrated both by flowering plants (such as *Saxifraga oppositifolia*, *Artemisia* cf. *norvegica*, *Minuartia rubella*), and mosses (for example, *Tortella fragilis*). Basic short-turf communities were also present forming a 'continental grass heath' (for example, *Medicago falcata*, *Astragalus danicus*).

A second pollen assemblage zone is distinguishable within the interstadial (BRM-b) (upper part of bed 3), differing from the lower zone (BRM-a) mainly in its greater abundance of *Juniperus* and *Filipendula*, and lower proportions of tree birch and willow. *Helianthemum* is extremely abundant in this zone, showing the persistence, perhaps extension, of basic grassland, and the continental grassland species *Gypsophila fastigiata/repens* and *Hedysarum* cf. *hedysaroides* also occur, together with *Astragalus alpinus* and *Artemisia* cf. *norvegica*. These changes of vegetation indicate a climatic cooling, and the grassland species show very distinct continental affinities, supporting an argument for a continental climate at the time.

The Loch Lomond Stadial is marked lithologically by clays (bed 4), and corresponds with a distinct pollen assemblage zone (BRM-c), the most marked features of which are high proportions of *Artemisia*, *Oxyria*-type and *Thalictrum* pollen. The decrease in warmth-demanding taxa, such as *Juniperus* and tree birches, confirms the onset of colder conditions. Of the *Artemisia* pollen, the most abundant type was *A.* cf. *norvegica*, indicating a 'fell-field' habitat, and also containing such taxa as *Papaver* sect. *scapiflora* and *Polytrichum alpinum*. Both snow patch (indicated by *Salix herbacea* and *Polytrichum norvegicum*) and wind-exposed areas (indicated by *Minuartia rubella*) were evidently present at this time.

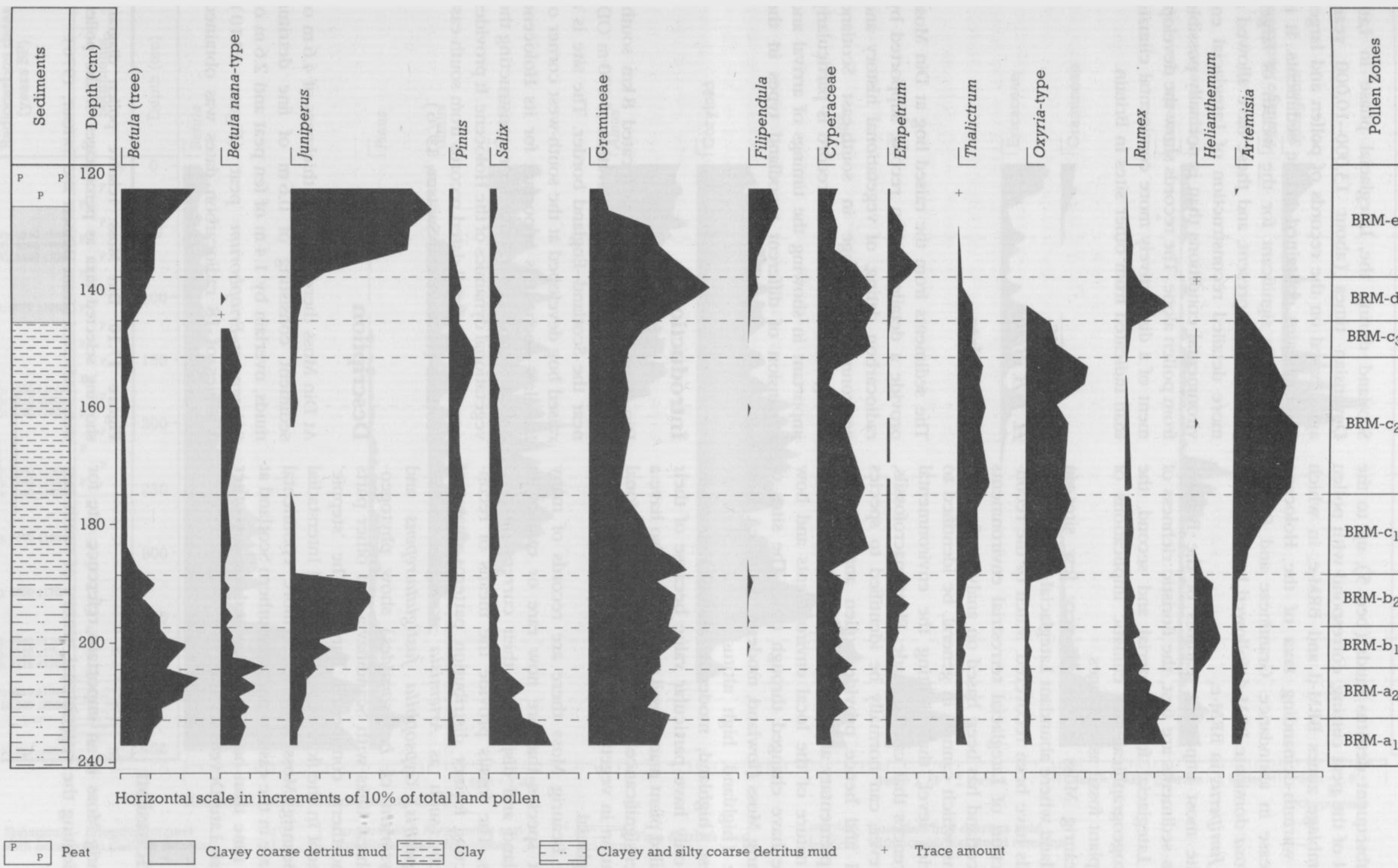


Figure 17.9 Beanrig Moss: relative pollen diagram showing selected taxa as percentages of total land pollen (from Webb and Moore, 1982).

Subsequent detritus muds (bed 5), up to the level of the peat cutting, correspond with pollen assemblage zones BRM-d and BRM-e, in which the warmth-demanding taxa of the Holocene increase in abundance. Gramineae and *Rumex acetosa* dominate BRM-d, followed by tree birch and *Juniperus* in BRM-e.

The most important features of the Beanrig Moss sediments are first, the floristic richness of the Lateglacial fossil material and second, the phytogeographical and climatic implications of the plant fossil assemblages.

Beanrig Moss is one of very few sites in Scotland where abundant Lateglacial plant macrofossils have been recovered. Much of the reconstruction of Lateglacial terrestrial environments in Scotland has been based on analysis of pollen grains which cannot, in general, be identified to species level, thus limiting the environmental inferences that can be made. Plant macrofossils, however, can normally be identified to species level and hence provide pollen analysis with complementary and more precise evidence as to the nature of the local environments and how these have changed through time. The sites of Beanrig Moss (lowland, moderate altitude), Morrone (highland, high altitude) and Abernethy Forest (highland, moderate altitude) therefore not only have particular value because of their detailed plant macrofossil records, but also have a wider significance in reconstruction of the regional variation in vegetational communities during the Lateglacial.

At Beanrig Moss there are records of many plant species that are now rare or extinct in Scotland and disjunct in their current distributions. The fossils provide the means of reconstructing former distribution patterns, many of which (such as *Artemisia norvegica*, *A.* cf. *campestris*, *Gypsophila fastigiata/repens* and *Hedysarum* cf. *hedysaroides*) show phytogeographical links with Scandinavia and other parts of northern continental Europe. The 'steppic' element in the flora of the Lateglacial Interstadial at Beanrig Moss suggests a more continental climate in the eastern part of southern Scotland at that time than has been proposed for any other British Late Devensian site.

Conclusion

Beanrig Moss is an important reference site for elucidating the vegetational history of south-east Scotland during the Lateglacial phase in Late Devensian times (about 13,000–10,000 years ago), based on the records of pollen and larger plant remains contained in the sediments. It is particularly significant for the wealth of larger plant remains present, and these have allowed a more detailed reconstruction of Lateglacial environmental conditions than is normally possible from pollen alone. The records show the development of a distinctively more continental climate than indicated from other sites in Britain.

DIN MOSS

H. J. B. Birks

Highlights

The sediments from the raised bog at Din Moss provide a detailed pollen record, supported by radiocarbon dating, of vegetational history and environmental change in south-east Scotland during the Holocene. This record is particularly important in showing the timings of arrival and expansion of different woodland types in the area.

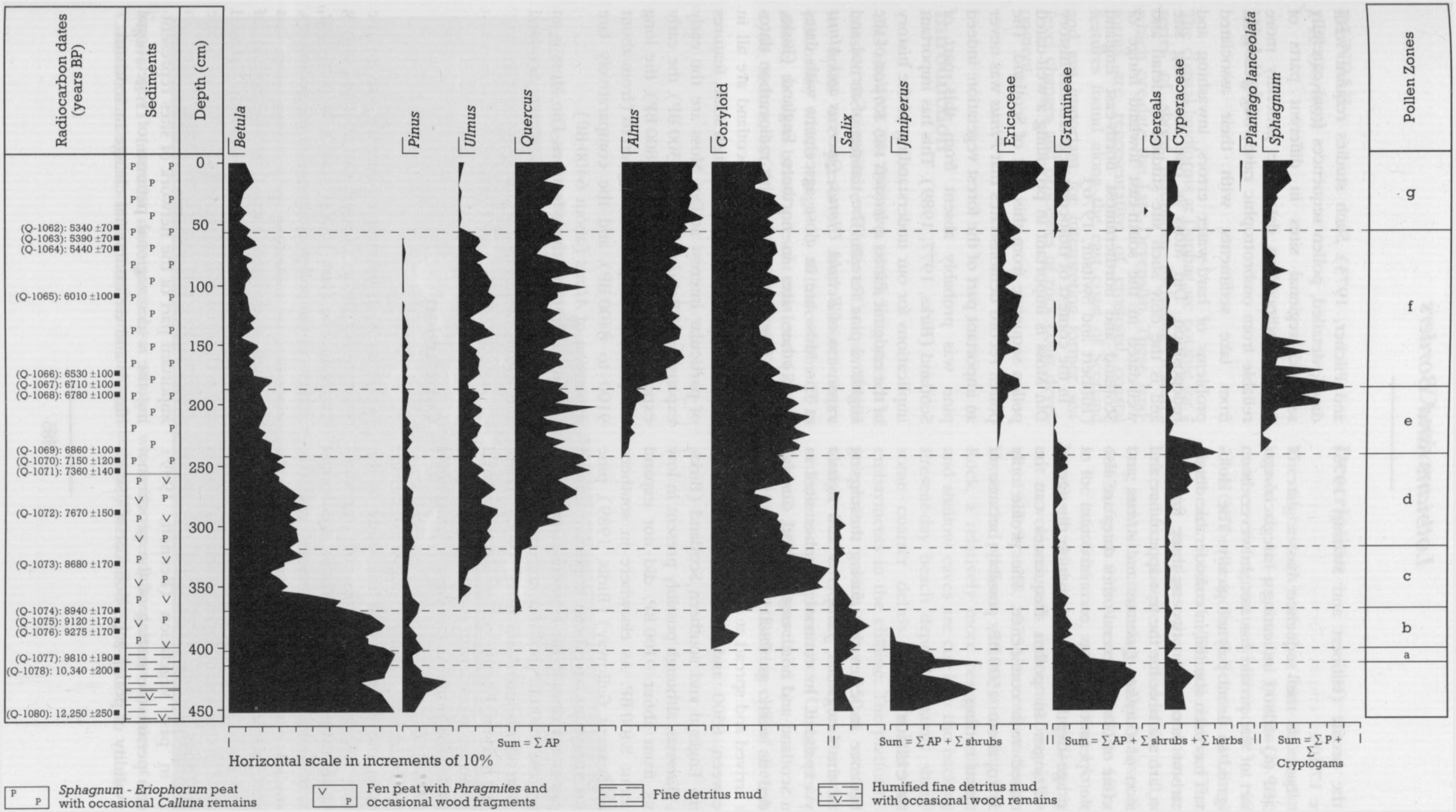
Introduction

Din Moss (NT 805314) is located 8 km south-west of Coldstream, at an elevation of 170 m OD, near the Scotland–England border. The site is a raised bog developed at the south-west corner of Hoselaw Loch. It is important for its Holocene pollen record, in particular for reconstructing the vegetational dynamics of the Holocene. It provides one of the few well-dated records from south-east Scotland (Hibbert and Switsur, 1976).

Description

At Din Moss there is a total thickness of 4.6 m of sediment consisting of 0.6 m of fine detritus muds, overlain by 1.4 m of fen peat and 2.6 m of *Sphagnum–Eriophorum* peat (Figure 17.10). A series of 18 radiocarbon dates was obtained

Figure 17.10 Din Moss: relative pollen diagram showing selected taxa as percentages of the pollen sums indicated (from Hibbert and Switsur, 1976).



Radiocarbon dates (years BP)
Sediments
Depth (cm)
Betula
Pinus
Ulmus
Quercus
Alnus
Coryloid
Salix
Juniperus
Ericaceae
Gramineae
Cereals
Cyperaceae
Plantago lanceolata
Sphagnum
Pollen Zones
(Q-1062): 5340 ±70
(Q-1063): 5390 ±70
(Q-1064): 5440 ±70
(Q-1065): 6010 ±100
(Q-1066): 6530 ±100
(Q-1067): 6710 ±100
(Q-1068): 6780 ±100
(Q-1069): 6860 ±100
(Q-1070): 7150 ±120
(Q-1071): 7360 ±140
(Q-1072): 7670 ±150
(Q-1073): 8680 ±170
(Q-1074): 8940 ±170
(Q-1075): 9120 ±170
(Q-1076): 9275 ±170
(Q-1077): 9810 ±190
(Q-1078): 10,340 ±200
(Q-1080): 12,250 ±250
0
50
100
150
200
250
300
350
400
450
g
f
e
d
c
b
a
Sum = Σ AP
Sum = Σ AP + Σ shrubs
Sum = Σ AP + Σ shrubs + Σ herbs
Sum = Σ P + Σ Cryptogams
Horizontal scale in increments of 10%
Sphagnum - Eriophorum peat with occasional Calluna remains
Fen peat with Phragmites and occasional wood fragments
Fine detritus mud
Humified fine detritus mud with occasional wood remains

from the profile (Hibbert and Switsur, 1976) (Figure 17.10).

The base of the sequence has a date of 12,250 BP (Q–1080), indicating a Lateglacial age. This part of the profile has not, however, been investigated in detail palynologically. The Holocene part has been studied in considerable detail. Radiocarbon dates, often two or three for each horizon, are available for the first appearance and expansion of *Corylus*, *Quercus* and *Alnus*, and the decline of *Ulmus*. Several other dates are also available, permitting the reconstruction of a reliable age–depth curve from which the age of other changes in pollen frequences can be interpolated with confidence. The profile only extends to about 4500 BP, possibly because of recent peat cutting.

Interpretation

The sequence indicates that during the closing parts of the Lateglacial, *Juniperus* and *Betula* quickly expanded. In contrast to other sites in eastern Scotland and north-east England, *Corylus* expanded as early as 9800 BP (Birks, 1989). *Ulmus* arrived and spread at about 8800 BP, as it did between 8500 and 9000 BP in much of northern England and southern Scotland (Birks, 1989). *Quercus*, although possibly present in low amounts from about 9100 BP, did not expand until about 8400 BP. As elsewhere in southern Scotland (except Galloway) (Birks, 1989), pine does not appear to have been important around Din Moss at any time in the Holocene. *Alnus* was present from 7000 BP but did not expand until after 6500 BP (Bennett and Birks, 1990). There is a well-marked *Ulmus* pollen decline, dated to 5400 BP, associated with the first occurrences of cereal-type and *Plantago lanceolata* pollen.

The dating of major pollen-assemblage changes in the Holocene and the study of the temporal and spatial patterns of important palaeobotanical events within Britain are critical aspects of Holocene palaeoecological research. Such studies permit the reconstruction of the directions, routes, rates and timings of the spread of forest trees (Birks, 1989), the spatial patterns of pollen assemblages at selected points in time (Birks *et al.*, 1975), and the spatial patterns in past vegetation (Bennett, 1989). They also permit the testing of the geochronometric validity of pollen-zone boundaries (Smith and Pilcher, 1973). Such studies require well-dated, detailed, pollen sequences from carefully selected regional sites in different parts of Britain. Radiocarbon dates are generally more reliable from ombrotrophic raised-bog peat than from lake sediments, with their associated problems of hard-water errors, inwashing and redeposition. Din Moss is one such bog site and is the only such site studied in detail and well-dated in the south-east lowland fringe of Scotland and northernmost north-east England (Hibbert and Switsur, 1976).

In the context of Holocene vegetational history Din Moss is important in providing a well-dated pollen sequence from this part of Scotland. The pollen record demonstrates that *Pinus* was never an important part of the forest vegetation: indeed pine was probably absent from this part of Scotland (Birks, 1977, 1989). This has important implications for our understanding of the history of the endemic *Pinus sylvestris* var. *scotica* of the Highland pine forests. The timings of arrival and expansion of *Betula*, *Ulmus*, *Quercus* and *Alnus* at Din Moss are in close agreement with dates from other sites in northern England (Birks, 1989). The nearest sites with radiocarbon dates for these events in southern Scotland are all in the west (Birks, 1989). At a British scale, features of particular interest at Din Moss are the early expansion of *Betula* (about 10,300 BP), the early expansion of *Corylus* (about 9800 BP), the long and protracted expansion of *Quercus* (from about 9100 to 8400 BP), and the comparatively late expansion of *Alnus* (about 6400 BP).

In the light of all these features, Din Moss is an important Holocene site both within Scotland and within Britain as a whole.

Conclusion

Din Moss is an important reference site for the vegetational history of south-east Scotland during the Holocene (last 10,000 years). In particular, analysis of the pollen contained in the sediments, supported by numerous radiocarbon dates, has provided a detailed record of the spread of successive woodland types. In view of its detailed and well-dated pollen record, the only such one available for this area, Din Moss forms an important part of the network of sites representing the wider regional patterns of vegetational history and environmental change in Scotland.

DUNBAR

J. E. Gordon

Highlights

The coastal landforms at Dunbar are notable for a series of shore platforms, including features which pre-date the Late Devensian. These landforms are representative of erosional coastal features found along the east coast of Scotland and are important for interpreting former sea-level changes and processes of rock coast development.

Introduction

This site (NT 661788) is a 1.9 km long stretch of coast in the immediate vicinity of Dunbar. Within its limits are preserved four distinct shore platforms, which range in altitude from 25 m above, to 11 m below present sea level (Rhind, 1965; Sissons, 1967a, 1976b; Hall, 1989a).

Description

The highest (A) of the four shore platforms known to be present at Dunbar is one of a number of fragments which occur at 18 m to 25 m OD between North Berwick and Berwick in south-east Scotland (Rhind, 1965). That this platform pre-dates the last ice-sheet may be inferred from the preservation of the drift tail of a crag and tail on its surface at Dunbar (see Sissons, 1967a, figure 83). A second platform (B) occurs in the intertidal zone, and for about 1 km west of the Castle ruins it is backed by a 20 m high cliff cut in volcanic tuffs and sandstones (Clough *et al.*, 1910; Francis, 1975). Several stacks protrude above the platform surface, including the Dove Rock, a relatively more resistant volcanic plug, and shallow caves are cut into the backing cliffs. Present-day beach deposits, mainly shingle and some coarser debris, occur at the heads of embayments in the cliffline. The platform attains its greatest width, about 350 m, west of Long Craigs, where it clearly truncates the underlying sediments and agglomerates (Clough *et al.*, 1910; Francis, 1975) (Figure 17.11).

To the west, the backing cliff of the intertidal

Figure 17.11 Intertidal shore platform at Dunbar, which has been planed across a series of Devonian–Carboniferous and Carboniferous sediments and agglomerates. (Photo: J. E. Gordon.)

platform is degraded and is fronted by Holocene raised beach deposits resting on a third platform (C) at an intermediate level and separated from the lower intertidal one by a rock step 1 m to 2 m high. These relationships are best seen in section at NT 66337899. A further platform (D) occurs offshore at about −11 m OD.

Interpretation

The highest platform (A) clearly pre-dates the Late Devensian glacation, although its age is unknown. Similarly the age or ages of the next two lower platforms (B and C) are unknown, although from evidence elsewhere on this part of the coast they pre-date the last ice-sheet (Hall, 1989a). Sissons (1976b) suggested the possibility that they were originally a single feature, the step between them having been cut by recent marine erosion since the sea attained its present level. Hall (1989a), however, has argued that the presence of till at the rear of the intertidal platform (B) at two sites nearby precludes significant erosion and retreat of the backing cliff during the Holocene. According to Hall (1989a) the two platforms (B and C) existed as separate features prior to the Late Devensian, and Holocene marine erosion has been confined to stripping a till cover. These platforms may form part of the intertidal platform that is developed extensively elsewhere in eastern Scotland (see Milton Ness and Kincraig Point). Dawson (1980a) has correlated this platform with the Low Rock Platform of western Scotland (see Northern Islay and West coast of Jura).

The offshore platform (D) has been correlated with a buried gravel layer and platform in the Firth of Forth and a submerged platform near Burnmouth to define the Main Lateglacial Shoreline in south-east Scotland (Sissons, 1976a, 1976b). Sissons (1974d) also correlated the Main Rock Platform of western Scotland (see Isle of Lismore) with this shoreline, suggesting that they were formed during the severe climatic conditions of the Loch Lomond Stadial.

Dunbar is important for demonstrating the geomorphology of shore platforms formed during the Pleistocene. Such platforms occur at a variety of altitudes along the east coast of Scotland (Walton, 1959; Rhind, 1965; Sissons, 1967a; Crofts, 1975; Browne and Jarvis, 1983; Stoker and Graham, 1985; Hall, 1989a) (see also Kincraig Point and Milton Ness) but are particularly well-preserved in the vicinity of Dunbar. Here also, the relationship of the uppermost platform (A) to glaciation is indicated by the superimposition of a drift tail on the platform, and two lower platforms (B and C) are also inferred to pre-date the last glaciation. The site therefore emphasizes the importance of inherited features in the coastal geomorphology of eastern Scotland (cf. Walton, 1959; Sissons, 1967a; Hall, 1989a).

Conclusion

Dunbar forms part of the site network demonstrating Quaternary coastal geomorphology and sea-level change. In particular, it is notable for an excellent series of rock platforms of different ages, including examples that pre-date the last ice age (i.e. formed before 26,000 years ago). Dunbar is one of the best sites in eastern Scotland illustrating the development of multiple shore platforms and it also highlights the contribution of older elements to the form of the present coastal landscape.