Quaternary of Scotland

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Chapter 3

The Shetland Islands

INTRODUCTION

D. G. Sutherland and J. E. Gordon

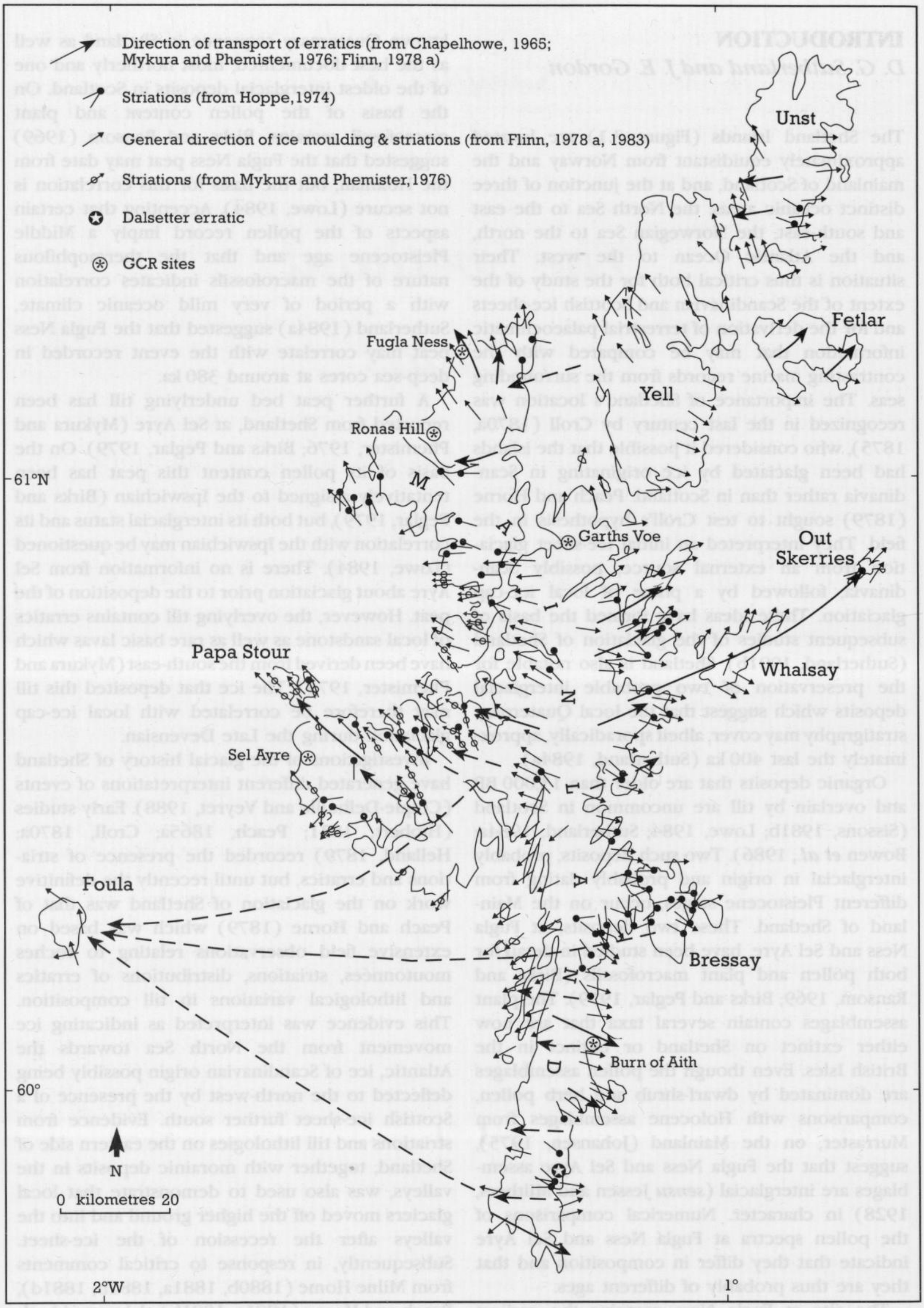
The Shetland Islands (Figure 3.1) are located approximately equidistant from Norway and the mainland of Scotland, and at the junction of three distinct oceanic areas: the North Sea to the east and south-east, the Norwegian Sea to the north, and the Atlantic Ocean to the west. Their situation is thus critical both for the study of the extent of the Scandinavian and Scottish ice-sheets and for the derivation of terrestrial palaeoclimatic information that may be compared with the contrasting marine records from the surrounding seas. The importance of Shetland's location was recognized in the last century by Croll (1870a, 1875), who considered it possible that the islands had been glaciated by ice originating in Scandinavia rather than in Scotland. Peach and Horne (1879) sought to test Croll's hypothesis in the field. They interpreted an initial ice-sheet glaciation from an external source, possibly Scandinavia, followed by a phase of local ice-cap glaciation. These ideas have formed the basis of subsequent studies of the glaciation of Shetland (Sutherland, 1991b). Shetland is also notable for the preservation of two probable interglacial deposits which suggest that the local Quaternary stratigraphy may cover, albeit sporadically, approximately the last 400 ka (Sutherland, 1984a).

Organic deposits that are older than 13,000 BP and overlain by till are uncommon in Scotland (Sissons, 1981b; Lowe, 1984; Sutherland, 1984a; Bowen *et al*., 1986). Two such deposits, probably interglacial in origin and probably dating from different Pleistocene stages, occur on the Mainland of Shetland. These two deposits, at Fugla Ness and Sel Ayre, have been studied in detail for both pollen and plant macrofossils (Birks and Ransom, 1969; Birks and Peglar, 1979). The plant assemblages contain several taxa that are now either extinct on Shetland or extinct in the British Isles. Even though the pollen assemblages are dominated by dwarf-shrub and herb pollen, comparisons with Holocene assemblages from Murraster, on the Mainland (Johansen, 1975), suggest that the Fugla Ness and Sel Ayre assemblages are interglacial (*sensu* Jessen and Milthers, 1928) in character. Numerical comparisons of the pollen spectra at Fugla Ness and Sel Ayre indicate that they differ in composition and that they are thus probably of different ages.

The site at Fugla Ness contains the earliest known Quaternary sequence in Shetland as well as the best documented, most northerly and one of the oldest interglacial deposits in Scotland. On the basis of the pollen content and plant macrofossil remains, Birks and Ransom (1969) suggested that the Fugla Ness peat may date from the Hoxnian, but the basis for this correlation is not secure (Lowe, 1984). Accepting that certain aspects of the pollen record imply a Middle Pleistocene age and that the thermophilous nature of the macrofossils indicates correlation with a period of very mild oceanic climate, Sutherland (1984a) suggested that the Fugla Ness peat may correlate with the event recorded in deep-sea cores at around 380 ka.

A further peat bed underlying till has been reported from Shetland, at Sel Ayre (Mykura and Phemister, 1976; Birks and Peglar, 1979). On the basis of its pollen content this peat has been tentatively assigned to the Ipswichian (Birks and Peglar, 1979), but both its interglacial status and its correlation with the Ipswichian may be questioned (Lowe, 1984). There is no information from Sel Ayre about glaciation prior to the deposition of the peat. However, the overlying till contains erratics of local sandstone as well as rare basic lavas which have been derived from the south-east (Mykura and Phemister, 1976). The ice that deposited this till may therefore be correlated with local ice-cap glaciation during the Late Devensian.

Investigations of the glacial history of Shetland have generated different interpretations of events (Coque-Delhuille and Veyret, 1988). Early studies (Hibbert, 1831; Peach, 1865a; Croll, 1870a; Helland, 1879) recorded the presence of striations and erratics, but until recently the definitive work on the glaciation of Shetland was that of Peach and Horne (1879) which was based on extensive field observations relating to roches moutonnées, striations, distributions of erratics and lithological variations in till composition. This evidence was interpreted as indicating ice movement from the North Sea towards the Atlantic, ice of Scandinavian origin possibly being deflected to the north-west by the presence of a Scottish ice-sheet further south. Evidence from striations and till lithologies on the eastern side of Shetland, together with morainic deposits in the valleys, was also used to demonstrate that local glaciers moved off the higher ground and into the valleys after the recession of the ice-sheet. Subsequently, in response to critical comments from Milne Home (1880b, 1881a, 1881b, 1881d), Peach and Horne (1881a, 1881b) elaborated both


Direction of transport of erratics (from Chapelhowe, 1965; Mykura and Phemister, 1976; Flinn, 1978 a)
Striations (from Hoppe, 1974)
General direction of ice moulding & striations (from Flinn, 1978 a, 1983)
Striations (from Mykura and Phemister, 1976)
Dalsetter erratic
GCR sites
Unst
Fetlar
Fugla Ness
Yell
Ronas Hill
61°N
Garths Voe
Out Skerries
Papa Stour
Whalsay
Sel Ayre
Foula
Bressay
Burn of Aith
60°
N
0 kilometres 20
2°W
1°

on the field evidence and their interpretation of it.

Since the paper by Peach and Horne (1879) the debate as to the nature of the last glaciation of Shetland and the relative importance of Scandinavian and local ice has been concerned almost exclusively with two types of evidence: striated and ice-moulded rock surfaces and the distribution of erratics (Figure 3.1). In assessing the influence of Scandanavian ice, Hoppe (1974) placed emphasis on an older set of striations occurring on and to the west of Bressay, which he considered to have been formed by ice flowing from the north-east. However, this interpretation of the sense of direction of some of these striations has been contradicted by Flinn (1977, p. 141). Hoppe inferred that during an early stage of glaciation Shetland was overridden by an ice-sheet from the east, probably from Scandinavia; during a later stage, a local ice-cap formed over the islands. Further, since the patterns of striations suggested progressive change in the ice movements, Hoppe concluded that both stages were of Late Devensian age. Following the ice maximum, rapid calving of the margin of the Scandinavian ice in the northern part of the North Sea led to the isolation of the local Shetland ice-cap.

Flinn (1977, 1978a) argued that the only evidence for the glaciation of Shetland by Scandinavian ice was in the southern part of the islands. There, westward transport of certain local rock types across the reconstructed ice shed of the later local ice-cap, at least as far as Foula, indicated that Scandinavian ice crossed the area during either a previous glaciation or an early phase of the last glaciation. It is also in this area, at Dalsetter, that the only Scandinavian erratic that has been found in Shetland occurs (Finlay, 1926). However, the history of transport of a single erratic may be complex (Hoppe, 1974). The westward transport of erratics has also been described from certain of the northern isles and here too the influence of Scandinavian ice has been invoked (Mykura, 1976).

The evidence for Scandinavian ice reaching Shetland is therefore rather weak and relates solely to the margins of the island group. In particular, it may be noted that no shelly tills or North Sea Basin erratics have been reported from Shetland, a situation in marked contrast to the eastern Orkney Islands. It may be concluded that if Scandinavian ice did cross the Shetland Islands, the evidence for this has been largely obliterated by the subsequent local glaciation(s). It is also clear that any such ice movements pre-dated the Late Devensian, since offshore studies have shown that the floor of the central North Sea was unglaciated at that time (Jansen, 1976; Flinn, 1978a; Cameron *et al.*, 1987; Sejrup *et al.*, 1987).

The distribution of most erratics and ice-moulded surfaces can be explained by a local ice-cap having covered the Shetland Islands, with ice flowing outwards from an ice shed located along the long axis of the islands. Since westerly-directed ice moulding and erratic transport on the western side of the islands is compatible with local as well as Scandinavian glaciation, more significance has been given to the evidence for eastward movement of ice on the eastern side of the islands. Such evidence includes, for example, the transport of erratics from the Mainland as far east as the Out Skerries (Mykura, 1976) and has been found along the length of the eastern Mainland and other islands.

All workers since Peach and Horne (1879) agree that Shetland has been glaciated by a local ice-cap, but the age and extent of this ice-cap have been the subject of debate. Although it is broadly agreed that the last phase of local ice-cap glaciation dates from the Late Devensian, direct evidence for this is lacking (Sissons, 1981b). If the Sel Ayre peat is indeed of Ipswichian age and the overlying till relates to the latest, local ice-cap, then this only indicates Devensian glaciation. It is generally accepted that the ice-cap extended on to the adjacent shelf, but in the north of the islands there is some recent evidence that the ice margin during the last glacial maximum may have been located relatively close inshore (Flinn, 1983; Long and Skinner, 1985).

Similarly, little is known about the mode and timing of retreat of the local ice-cap. A 'moraine belt' has been described from the western island of Papa Stour (Mykura and Phemister, 1976) but its significance is unclear. The absence of raised shorelines limits the possibilities for studying ice-cap retreat: Hoppe (1974), on the basis that striation patterns reflect calving during deglaciation, has suggested that the contemporaneous sea level was only 20–25 m lower than it is today, but this figure must be regarded as speculative. A minimum age for the termination of the local ice-

Figure 3.1 Location map and principal features of the glaciation of Shetland, including patterns of striations, directions of transport of erratics and general directions of ice moulding (from Sutherland, 1991b).

cap is provided by radiocarbon dates on basal organic sediments resting on the glacial deposits. The oldest such date is 13,680 ± 110 BP (at Burn of Aith), but this is not critically linked to glacier retreat.

The only evidence for the vegetation history of Shetland during the Lateglacial comes from the detailed work of Birnie (1981) at the Burn of Aith. Her results suggest that a relatively mild phase occurred during the early Lateglacial Interstadial. During the middle part of the interstadial juniper and possibly some birch scrub was present on the islands prior to a return during the Loch Lomond Stadial to soil instability and a vegetation pattern dominated by open habitat species. Minor moraines have been described on some of the hills (Charlesworth, 1956; Mykura, 1976; Mykura and Phemister, 1976; Flinn, 1977) and attributed to the Loch Lomond Readvance, but which of these features are in fact moraines has been disputed among the authors quoted. Whichever interpretation is adopted, however, it is clear that the Loch Lomond Readvance was of very limited extent on Shetland.

In contrast, the Holocene vegetational history has been studied at a number of sites (Hawksworth, 1970; Johansen, 1975, 1978, 1985; Hulme and Durno, 1980; Birnie, 1981; Bennett *et al.*, 1992). Despite the early records of fossil wood within the peat on Shetland (Lewis, 1907, 1911), it was widely thought that Shetland had remained essentially treeless during the Holocene, a view supported by the relative scarcity of tree pollen (Erdtman, 1924). However, radiocarbon dating and pollen evidence from Garths Voe (Birnie, 1981, 1984) show beyond all doubt that during the middle Holocene there was a distinct phase when willow, birch or hazel developed widely. On Foula it seems probable that trees were restricted to sheltered areas (Hawksworth, 1970).

Shetland is also notable for certain periglacial landforms. Although the uplands seldom exceed 300 m in altitude, the highest area, Ronas Hill (450 m OD), has a notable range of both fossil and active periglacial features (Ball and Goodier, 1974). The original mountain-top detritus is likely to have been produced during the Late Devensian, but present activity, particularly influenced by the wind, is producing stripes, sand sheets ('dunes') and various types of terrace (Veyret and Coque-Delhuille, 1989). Elsewhere in Shetland, small, active stone stripes are present at 60 m OD on Keen of Hamar on Unst (Spence, 1957; Carter *et al.*, 1987).

The coastline of Shetland is essentially one of submergence (Flinn, 1974), but there have been few detailed studies of relative sea-level change. Submerged peat deposits are common (Finlay, 1930; Flinn, 1964, 1974; Chapelhowe, 1965; Birnie, 1981), and radiocarbon dates from Whalsay suggest relative sea level at least 9 m below present before 5500 BP (Hoppe, 1965). Birnie (1981) reported radiocarbon dates of 5840 ± 50 BP (SRR – 1796) and 4586 ± 40 BP (SRR – 1795) from intertidal peats at Leebotten and the Houb, respectively, and although these dates confirm the trend of submergence, they are not related to specific sea-level altitudes.

FUGLA NESS

H. J. B. Birks

Highlights

The sequence of deposits in the coastal section at Fugla Ness includes two tills and an interglacial peat, ascribed to the Hoxnian. These deposits provide critical evidence for interpreting the Quaternary history of Scotland in an area peripheral to the main centres of glaciation.

Introduction

Fugla Ness is a promontory on the north-west coast of North Roe on the Mainland of Shetland. A broad platform slopes gently from about 30 m OD at the base of the Beorgs of Uyea to form a small sea-cliff about 10 m high. A drift-filled geo (at HU 312913) within this marine-eroded cliff reveals a succession of Pleistocene deposits. These are of great scientific interest, particularly since they include one of the oldest known interglacial peat deposits in Scotland. The stratigraphy of the succession is described by Chapelhowe (1965), and the vegetation history has been reconstructed by Birks and Ransom (1969) on the basis of the fossil assemblages of pollen and plant macrofossil remains in the peat.

Description

The following sequence of deposits is revealed in the cliff section (Figure 3.2) (Chapelhowe, 1965; Birks and Ransom, 1969):

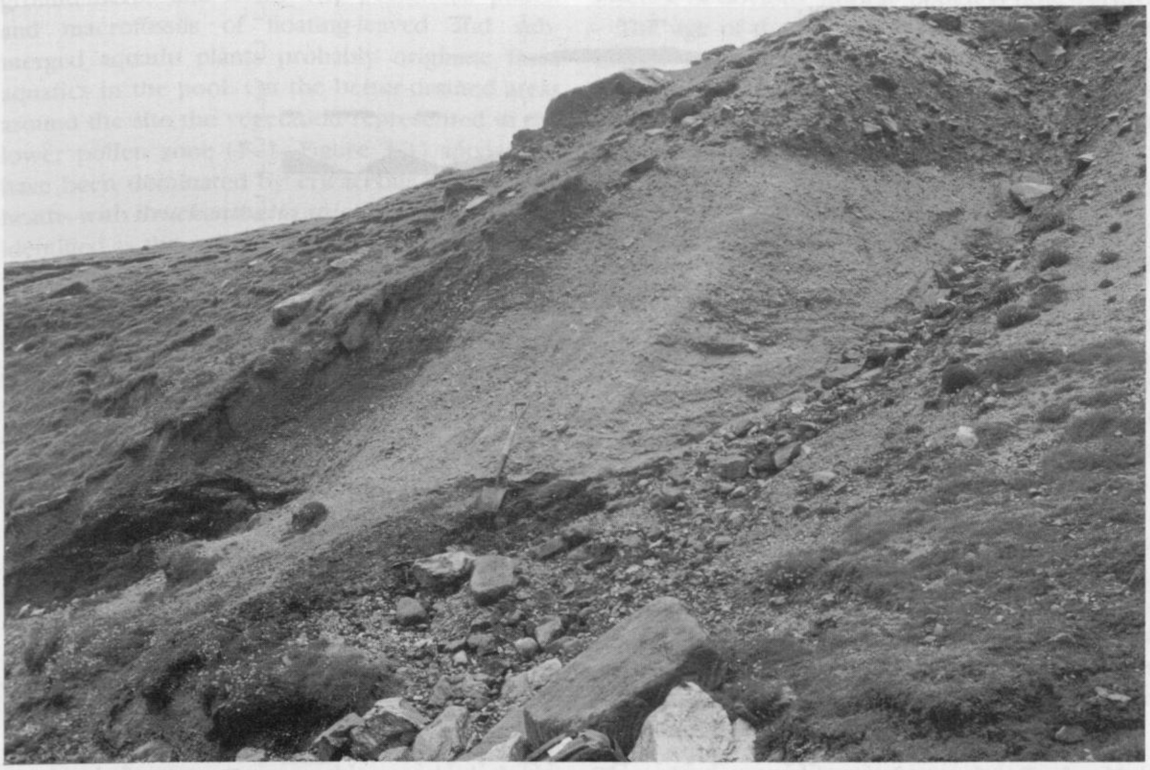


Figure 3.2 Sediment sequence at Fugla Ness, Shetland, showing interglacial peat (lower left) overlain by slope deposits, with till at the top. (Photo: J. E. Gordon.)

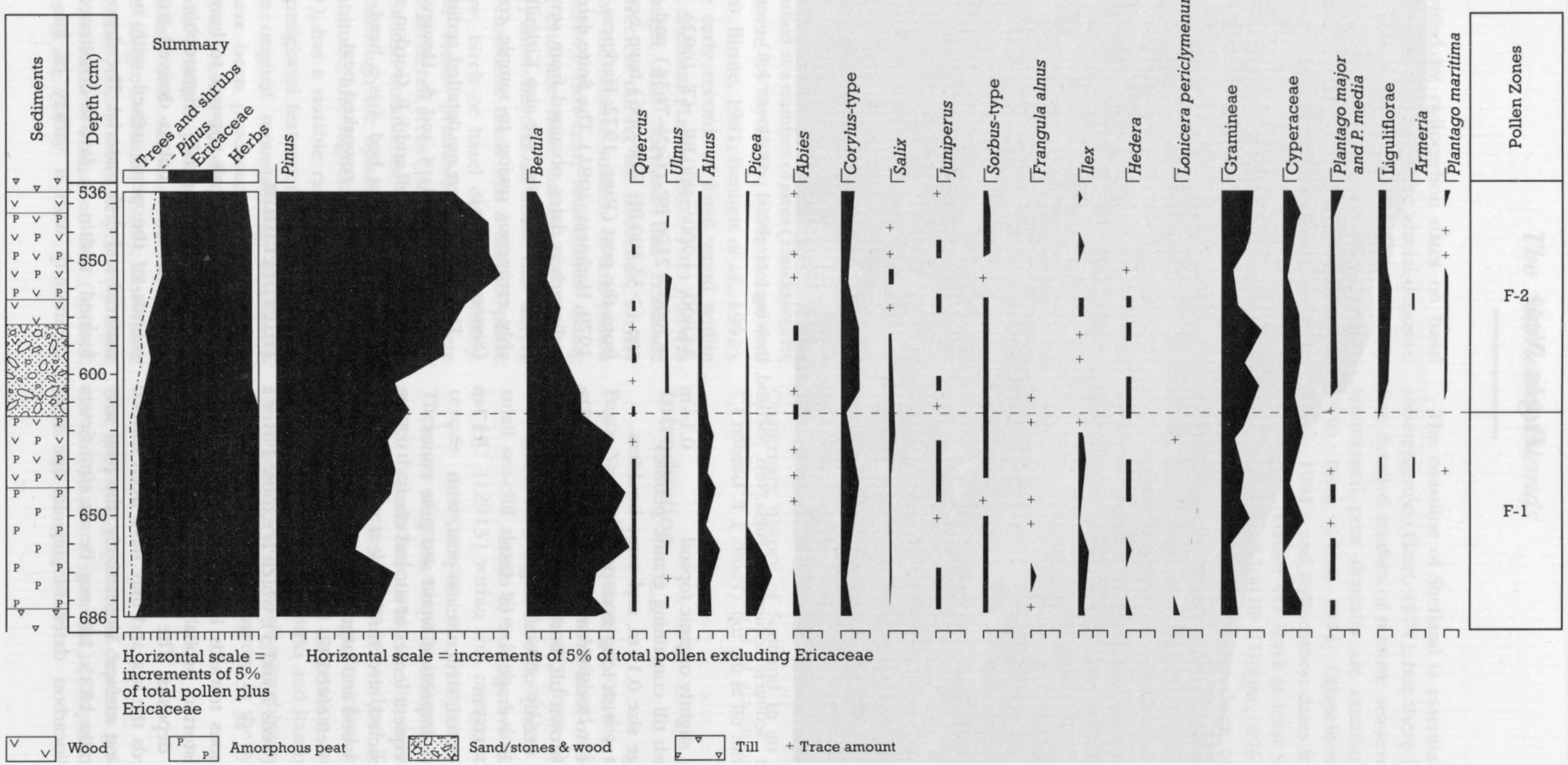
6.	Sandy, slightly organic topsoil	0.14 m
5.	Reddish till containing granite pebbles average size 0.12 m, and some boulders of 0.9 m with long axes orientated parallel to local striations	2.05 m
4.	Grey-brown till, horizontally stratified; clasts mainly of local origin with some granite; average size of clasts 0.005–0.03 m	3.17 m
3.	Compacted, structureless peat, with much compressed wood and pine cones and frequent lenses of silt and clasts	0.50 m
2.	Compacted, structureless peat with some wood and large clasts	1.05 m
1.	Grey, cemented till similar to bed 4.	

The peat (beds 2 and 3), which is exposed over a distance of at least 20 m, thins and becomes discontinuous towards its edges. In places it is slightly distorted, probably by the weight of the overlying deposits. The peat beds dip at about 20° towards the sea and may have been formed on a sloping surface. Alternatively, the peat may be an erratic block and not be *in situ*. Seven finite radiocarbon dates ranging in age from 34,800 +900/−800 BP (T–1092) to 47,500 +2900/−2100 BP (GrN–7634) and one infinite age (>33,300 BP SRR–666) have been obtained from the peat (Page, 1972; Harkness and Wilson, 1979; Harkness, 1981). The finite dates, like finite radiocarbon dates obtained from several English interglacial deposits (see also Kirkhill), are probably erroneous owing to sample contamination (Sissons, 1981b).

There have been no detailed sedimentological studies of beds 1, 4 and 5. However, work in progress (A. M. Hall and J. E. Gordon, unpublished data) suggests that bed 4 is a head deposit and contains bands of reworked peat.

Interpretation

The organic deposit appears to have formed at the edge of a small oligotrophic pond and consists of plant debris derived from the surrounds of the pond mixed with both *in situ* material and drift material. The deposit probably formed within a *Juncus*-dominated shoreline community with a variety of fen and damp-


Sediments
Depth (cm)
Summary
Trees and shrubs
Pinus
Ericaceae
Herbs
536
550
600
650
686
Pinus
Betula
Quercus
Ulmus
Alnus
Picea
Abies
Corylus-type
Salix
Juniperus
Sorbus-type
Frangula alnus
Ilex
Hedera
Lonicera periclymenum
Gramineae
Cyperaceae
Plantago major and P. media
Liguliflorae
Armeria
Plantago maritima
Pollen Zones
F-2
F-1
Horizontal scale = increments of 5% of total pollen plus Ericaceae
Horizontal scale = increments of 5% of total pollen excluding Ericaceae
Wood
Amorphous peat
Sand/stones & wood
Till
+ Trace amount

ground herbs and ferns. The occasional pollen and macrofossils of floating-leaved and submerged aquatic plants probably originate from aquatics in the pool. On the better-drained areas around the site the vegetation represented in the lower pollen zone (F–1, Figure 3.3) appears to have been dominated by ericaceous dwarf-shrub heaths with *Bruckenthalia spiculifolia* (originally identified as the extinct taxon *Erica scoparia* var. *macrosperma* by Birks and Ransom, 1969), a plant now confined to the mountains of the Balkans and Asia Minor. *Juniperus*, *Lycopodium annotinum* and *Jasione montana* probably grew in these heaths, and *Betula*, *Pinus*, *Abies*, *Picea*, *Ilex* and *Sorbus* may have occurred locally in sheltered areas.

In the succeeding pollen zone (F–2, Figure 3.3) the composition of the heaths changed, with an expansion of *Erica tetralix*, *E. mackaiana* (now confined in the British Isles to Connemara and Donegal), *Empetrum nigrum* and *Daboecia cantabrica* (now restricted in the British Isles to Connemara), and of grassland communities rich in herbs such as *Jasione montana*, *Centaurium erythraea* and *Plantago* spp. Plants of biogeographical interest present in this zone include the 'peat-alpines' *Rubus chamaemorus* and *Chamaepericlymenum suecicum*, both of which are absent from Shetland today.

The change in vegetation from zone F–1 to zone F–2 (Figure 3.3) was interpreted by Birks and Ransom (1969) to be the result of climatic deterioration, with a decrease in annual temperature and an increased frequency of frosts.

If the Holocene pollen spectra from Murraster (Johansen, 1975) are viewed as representative of present 'interglacial' conditions on Shetland Mainland, it is clear that the low values of tree pollen and the high frequencies of dwarf-shrub pollen at Fugla Ness are of interglacial character (*sensu* Jessen and Milthers, 1928). The strongly calcifuge character of the plant assemblages at Fugla Ness suggests that the sequence reflects the oligocratic phase of an interglacial cycle (*sensu* Andersen, 1966, 1969) when acid, humus-rich soils and peats were widespread. Given the proximity of the site to present sea level, the absence of obvious 'littoral' pollen is noteworthy.

The age of the organic deposits at Fugla Ness cannot be established by radiocarbon dating. However, several features of the plant assemblages suggest correlation with the Hoxnian or Gortian (Birks and Ransom, 1969). These are:

1. the complete absence of so-called 'Tertiary' pollen types such as *Tsuga* and *Pterocarya*, suggesting that the deposits are not of Early Pleistocene age (West, 1980);
2. the absence of any pollen of *Carpinus betulus*, the abundance of which is considered by some to be characteristic of the later phases of the Ipswichian in England at sites at least as far north as County Durham (Beaumont *et al.*, 1969; Phillips, 1974; West, 1977, 1980);
3. the presence of *Abies* pollen, suggesting a Middle Pleistocene age (West, 1977, 1980);
4. the presence of the heaths *Daboecia cantabrica*, *Erica mackaiana* and *Bruckenthalia spiculifolia*, suggesting close floristic affinities with the closing phases of the Gortian in Ireland (Watts, 1967).

The plant assemblages from the Fugla Ness deposits may thus reflect a northern, oceanic variation of the vegetation of the Hoxnian and Gortian (but see Lowe, 1984). The mild climate implied by the reconstructed plant assemblages at Fugla Ness invites comparison with the palaeoclimatic record of the deep-sea sediments (Ruddiman and McIntyre, 1976). Only two periods are apparent in the deep-sea record of the last 600,000 years when the north-east Atlantic oceanic climate was as mild as, or milder than, at present. These were 125 ka (the Ipswichian) and 380 ka. Given the likely Middle Pleistocene age of the Fugla Ness peat, then a correlation with the oceanic event at 380 ka in Oxygen Isotope Stage 11 seems most likely (Sutherland, 1984a).

There are two possible interpretations of the glacial history represented in the deposits at Fugla Ness (Sutherland, 1991b). On present information, it is possible that the till units (beds 1 and 4) that enclose the interglacial deposits are from the same glaciation, with the peat occurring as an erratic block (see Birks and Ransom, 1969). If this is so, then the site indicates only two periods of glaciation, both post-dating the peat and represented by beds 1–4 and bed 5, respectively. Alternatively, if the tills in beds 1 and 4 are from separate glacial events, then three

Figure 3.3 Fugla Ness: relative pollen diagram showing selected taxa based on sum of total pollen excluding Ericaceae (from Birks and Ransom, 1969; Lowe, 1984).

periods of glaciation are recorded at this site, the earliest of which pre-dates the interglacial peat and hence is possibly of Middle or Early Pleistocene age. If bed 4 is a head, as proposed by Hall and Gordon (unpublished data), then possibly three cold episodes, including two periods of glaciation, are represented at the site. The uppermost till unit (bed 5) contains granite erratics and is apparently derived from the south-east (Chapelhowe, 1965), which conforms with the direction of movement of the last local ice-cap glaciation of probable Late Devensian age. Fugla Ness therefore has significant potential for further research to amplify knowledge of the glacial sequence in Shetland.

Fugla Ness is of considerable scientific importance, not only because of its remarkable fossil flora, but also because it represents perhaps the oldest interglacial deposit known in Scotland and the northernmost known interglacial sequence in the British Isles. Although its implications in terms of glacial history remain to be elucidated in detail, it is a site of great potential importance.

Conclusion

The sequence at Fugla Ness includes the most northerly and one of the oldest known interglacial deposits in Scotland. Analysis of the pollen and larger plant remains preserved in the interglacial peat indicates a period of mild, oceanic climate and the occurrence of trees, including pine and fir, in sheltered areas. The interglacial deposits have been ascribed to the Hoxnian Stage of the Pleistocene (about 380,000 years ago), but they have not been dated directly. The sediments at Fugla Ness also provide evidence for at least two separate periods of glaciation in Shetland.

SEL AYRE

H. J. B. Birks

Highlights

The sequence of deposits in the coastal section at Sel Ayre includes an interglacial peat, assigned to the Ipswichian, which is overlain by a succession of slope deposits and a till. These sediments have contributed significantly to the understanding of the Quaternary history of Scotland in an area well to the north of the main centres of glaciation.

Introduction

Sel Ayre [HU 176540] is located on the west coast of the Walls Peninsula on Shetland Mainland. It is a site of considerable scientific importance for the succession of Pleistocene deposits infilling a channel or gully on the cliff top. The deposits include peat that appears to have formed during an interglacial period, probably the Ipswichian. As the peat contains a different pollen assemblage from that recorded at Fugla Ness, the peats at the two sites are probably of different ages and represent the closing phases, at least, of two different interglacials. The sequence of deposits at Sel Ayre is described by Mykura and Phemister (1976), and the vegetation history has been reconstructed from pollen analysis of the peat by Birks and Peglar (1979).

Description

The following sequence of deposits is revealed in the cliff section (Mykura and Phemister, 1976):

10.	Peat	0.3 m
9.	Till, with clayey matrix and angular to subangular pebbles and boulders of Walls Sandstone (Old Red Sandstone) and rare basic lavas	2.7 m
8.	Gravel, well-bedded with predominantly angular pebbles set in a silty to clayey matrix	1.8 m
7.	Sand, pale brown with patchy brown iron staining; sparse pebbly bands, up to 0.23 m thick, more common at the sides of the channel	1.4 m
6.	Sand, black to dark brown, limonite-impregnated and peaty	0.025 m
5.	Sand, pale ochre-brown, pebbly, locally bleached white; patchily ochre-stained at base	0.4 m
4.	Peat with scattered round sand grains and some sandy lenses	0.038 m
3.	Soft, pale clayey sand with thin laminae of clay and peat	0.23–0.26 m
2.	Peat with scattered sand grains in lower part; passes laterally into sand with thin peat bands and thickens to 1 mm	0.45 m
1.	Sand with scattered pebbles, base not seen	0.4 m

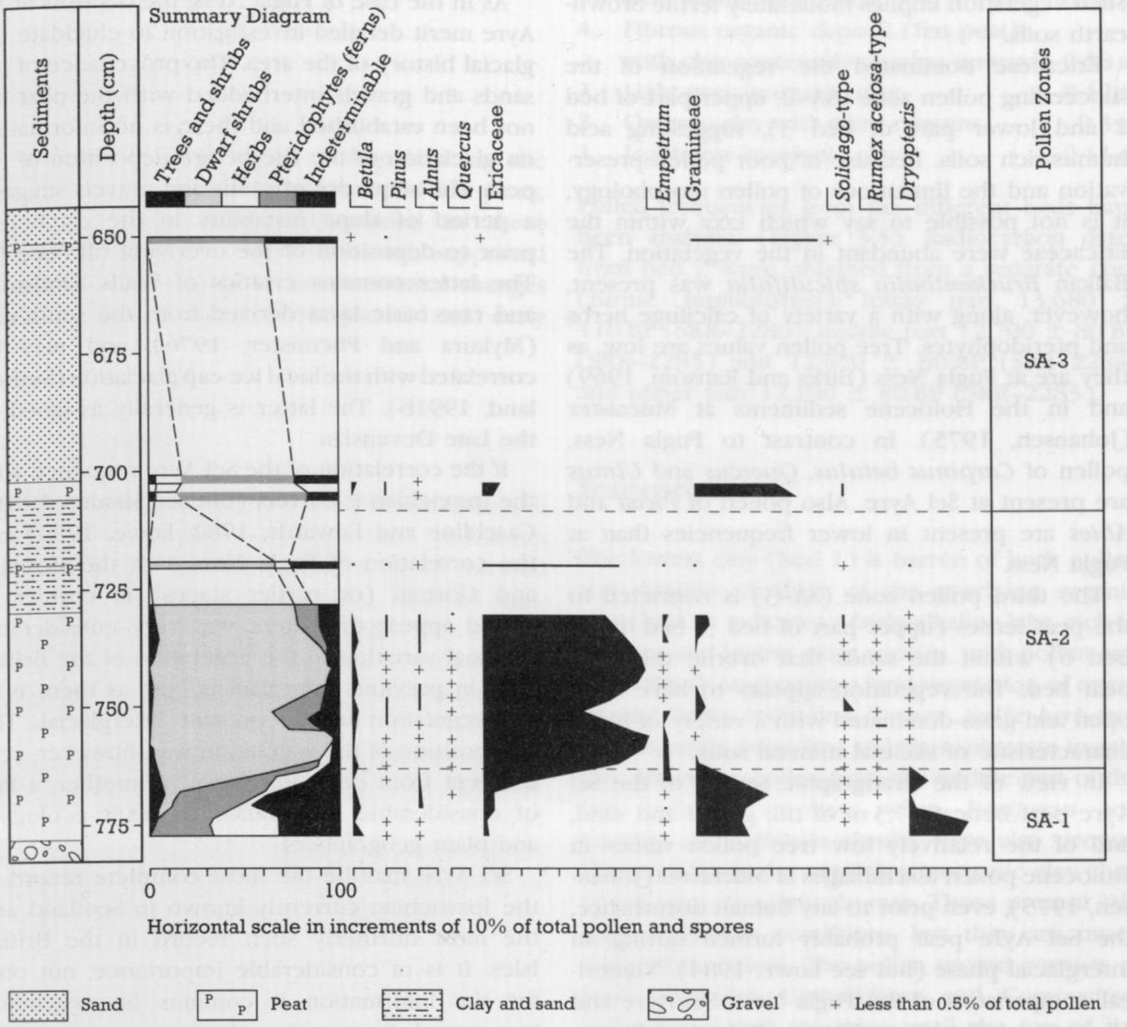


Figure 3.4 Sel Ayre: relative pollen diagram showing selected taxa as percentages of total pollen and spores (from Birks and Peglar, 1979; Lowe, 1984).

The deposits lie within an ENE-trending channel. There have been no detailed sedimentological studies. However, work in progress (A. M. Hall and J. E. Gordon, unpublished data) suggests that beds 1 and 4–8 comprise a series of slope deposits infilling the channel. The main peat bed (bed 2) splits laterally into a series of bands of sandy peat interspaced with sand lenses, often with ripple cross-laminations, as the section is traced from the centre of the channel to its edges. A radiocarbon date of 36,800 +1950/ −1960 BP (SRR–60) (Mykura and Phemister, 1976) has been obtained from the peat bed. This date is probably erroneous (Birks and Peglar, 1979; Sissons, 1981b).

The peat may have accumulated in a valley or basin mire within the channel or it may be highly compressed acid mor humus that accumulated within the channel. In the absence of any identifiable plant macrofossils, it has not been possible to distinguish between these two alternative origins. The pollen stratigraphy at Sel Ayre has been divided into three pollen assemblage zones (Figure 3.4) (Birks and Peglar, 1979).

Interpretation

The vegetation at the time of the lowest pollen zone (SA–1, lower part of bed 2) appears to have been dominated by fern and herb-rich grasslands, possibly similar to the ungrazed communities rich in ferns and tall-herbs that are confined to cliff-ledges and islands in lochs in Shetland today.

Such vegetation implies moderately fertile brown-earth soils.

Ericaceae dominated the vegetation of the succeeding pollen zone (SA–2, upper part of bed 2 and lower part of bed 3), suggesting acid humus-rich soils. Because of poor pollen preservation and the limitations of pollen morphology, it is not possible to say which taxa within the Ericaceae were abundant in the vegetation. The Balkan *Bruckenthalia spiculifolia* was present, however, along with a variety of calcifuge herbs and pteridophytes. Tree pollen values are low, as they are at Fugla Ness (Birks and Ransom, 1969) and in the Holocene sediments at Murraster (Johansen, 1975). In contrast to Fugla Ness, pollen of *Carpinus betulus*, *Quercus* and *Ulmus* are present at Sel Ayre. Also pollen of *Picea* and *Abies* are present in lower frequencies than at Fugla Ness.

The third pollen zone (SA–3) is restricted to the peat lenses (upper part of bed 3, bed 4 and bed 6) within the sands that overlie the main peat bed. The vegetation appears to have been open and grass-dominated with a variety of herbs characteristic of skeletal mineral soils.

In view of the stratigraphic setting of the Sel Ayre peat beneath 7.3 m of till, gravel and sand, and of the relatively low tree pollen values in Holocene pollen assemblages at Murraster (Johansen, 1975), even prior to any human disturbance, the Sel Ayre peat probably formed during an interglacial phase (but see Lowe, 1984). Numerical comparisons of the Fugla Ness, Sel Ayre and Murraster pollen assemblages (Birks and Peglar, 1979) indicate that the three sequences differ in their pollen composition, suggesting that they were formed in three different interglacials. The presence of *Carpinus betulus* pollen in the Sel Ayre profile suggests that the sequence was formed during the Ipswichian, as high *Carpinus* values are characteristic of its later phases in England (Phillips, 1974; West, 1977, 1980). The vegetational changes recorded at Sel Ayre suggest that the lowermost pollen zone (SA–1) reflects the mesocratic phase (*sensu* Andersen, 1966, 1969) of the Ipswichian, with fertile brown-earth soils. Pollen zone SA–2 represents the oligocratic phase (*sensu* Andersen, 1966, 1969), with acid podsols and peaty soils, and pollen zone SA–3 the cryocratic phase (*sensu* Iversen, 1958) of the Early Devensian, with skeletal mineral soils. The Sel Ayre sequence may thus represent an almost complete record of the Ipswichian on Shetland Mainland.

As in the case of Fugla Ness, the deposits at Sel Ayre merit detailed investigation to elucidate the glacial history of the area. The provenance of the sands and gravels interbedded with the peat has not been established and there is no information on glaciation of the site before deposition of the peat. The sequence of sands and gravels suggests a period of slope instability in the catchment prior to deposition of the overlying till (bed 9). The latter contains erratics of Walls Sandstone and rare basic lavas derived from the south-east (Mykura and Phemister, 1976), and may be correlated with the local ice-cap glaciation (Sutherland, 1991b). The latter is generally assigned to the Late Devensian.

If the correlation of the Sel Ayre sequence with the Ipswichian is correct (but see Sissons, 1981b; Caseldine and Edwards, 1982; Lowe, 1984) and the correlation of Fugla Ness with the Hoxnian and Gortian (or earlier stages) is correct, it would appear that there was very considerable regional variation in the vegetation of the British Isles in previous interglacials, just as there is in the vegetation of the present interglacial. The composition of the vegetation was, however, very different from one interglacial to another, a fact of considerable importance to plant ecologists and plant geographers.

Sel Ayre may be the most complete record of the Ipswichian currently known in Scotland and the most northerly such record in the British Isles. It is of considerable importance, not only for the information it contains on vegetation history and diversity, but also because it provides a limiting date on the last glaciation of Shetland, probably by a local ice-cap (Mykura and Phemister, 1976; Flinn, 1978a; Sutherland, 1984a).

Conclusion

The sequence at Sel Ayre includes an interglacial (temperate climate) peat deposit, the most northerly in Britain that has been ascribed to the Ipswichian Stage (about 125,000 years ago). The pollen preserved in this deposit provides a valuable record of vegetational history, showing a succession from grassland, through heathland with trees, to open, grass-dominated vegetation. The deposits also indicate an episode of later glaciation (probably Late Devensian), preceded by a cold phase during which slopes in the catchment were unstable.

BURN OF AITH

J. Birnie

Highlights

The sediments which infill a deep basin at the Burn of Aith comprise lake clays and fen peats. The pollen and diatoms contained in these sediments provide a detailed record, supported by radiocarbon dating, of environmental changes in Shetland during the Lateglacial and early Holocene.

Introduction

The Burn of Aith site [HU 441295] comprises a flattish area of lake and fen infill sediments approximately 1 km^2 in extent. It is located immediately inland from the east coast of Shetland Mainland near Cunningsburgh. The infill is exceptionally deep and contains a Lateglacial and Holocene sequence that is representative of lowland Shetland. Two cores have been analysed in detail, giving pollen, diatom and sedimentary characteristics (Birnie, 1981), and four radiocarbon dates have been obtained for the Lateglacial sequence in one core (J. Birnie, unpublished data). This is the earliest detailed information on the Lateglacial environment of Shetland.

Description

The infill sediments, lake clays and fen peats occupy a basin which exceeds 11 m in depth. It is formed in either till or bedrock and shallows gradually in the direction of the present outlet to the sea at Aith Voe. Despite the present surface being less than 5 m above sea level, all the infill sediments are of freshwater origin, so that the basin configuration must have prevented marine inundation, even with the rising Holocene sea level. The bedrock in the vicinity of the basin is Old Red Sandstone, although the adjacent upland catchment, drained by the Burn of Laxdale, is in phyllite and spilitic lavas (Mykura, 1976).

The stratigraphy at the coring site consists of the following sequence (Birnie, 1981, Aith II site):

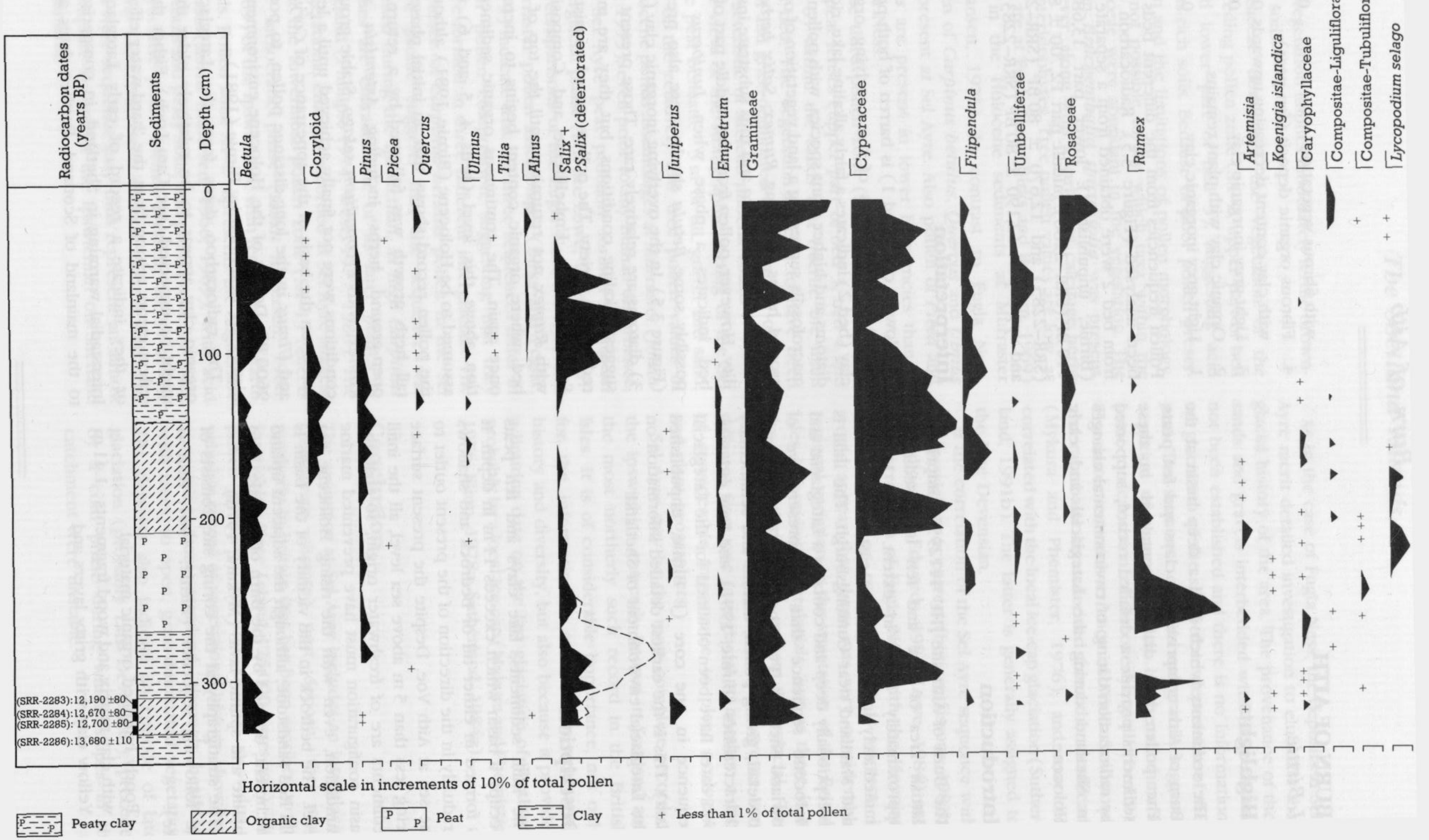
6.	Poorly humified organic material with clay matrix and wood fragments	1.41 m
5.	Yellow clay with gritty layers and with fibrous vegetation	0.68 m
4.	Fibrous organic deposit (fen peat) with clay content decreasing upwards	0.58 m
3.	Light-grey inorganic clay	0.42 m
2.	Organic clay with plant remains	0.3 m
1.	Light-grey inorganic clay	0.11 m

Pollen frequencies from the different beds have been analysed (Figure 3.5). Radiocarbon dates from bed 2 were obtained from a separate core (Birnie, unpublished): lower part 13,680 ± 110 BP (SRR–2286), middle part 12,700 ± 80 BP (SRR–2285) and 12,670 ± 80 BP (SRR–2284) and upper part 12,190 ± 80 BP (SRR–2283).

Interpretation

The lowest clay (bed 1) is barren of both pollen and diatoms. Analysis of the overlying organic clay (bed 2) indicates a fairly alkaline lake, rich in diatoms and higher plant species, with pollen and macrofossils suggesting a land vegetation of open-ground herbs including *Rumex*, *Salix herbacea* and *Koenigia islandica* and thus substrate instability. However, pollen from the middle part of the bed indicates a phase when *Juniperus* and possibly some *Betula* shrubs were also present (Figure 3.5). In the overlying inorganic clay (bed 3) diatoms are relatively rare. Those present still suggest alkaline conditions, but they are much reduced in variety. The pollen record consists of *Salix herbacea*, Umbelliferae and Compositae, with *Rumex* not returning until the top of the bed, where organic content begins to increase once again. The continuous organic sedimentation above this level (beds 4, 5 and 6) was assumed to be Holocene (Birnie, 1981), although the pollen record shows that an initial phase of tall herb growth was followed by a return of open-ground herbs including *Artemisia* and *Rumex*, with *Lycopodium selago*. Stable ground conditions were not finally achieved until a level dated, on the basis of the appearance of *Corylus* and *Ulmus* in the long-distance pollen, to post–9600 BP. Details of the Holocene environmental history are described by Birnie (1981).

The radiocarbon dates from the Lateglacial organic clay appear to be relatively older than might be expected (see Cam Loch). Either they reflect errors arising from the 'hard-water effect' or they indicate a record of early Lateglacial Interstadial warming in Shetland, in comparison to the mainland of Scotland. Further dates are



Radiocarbon dates (years BP)
Sediments
Depth (cm)
0
100
200
300
(SRR-2283):12,190 ±80
(SRR-2284):12,670 ±80
(SRR-2285): 12,700 ±80
(SRR-2286):13,680 ±110
Betula
Coryloid
Pinus
Picea
Quercus
Ulmus
Tilia
Alnus
Salix +
?Salix (deteriorated)
Juniperus
Empetrum
Gramineae
Cyperaceae
Filipendula
Umbelliferae
Rosaceae
Rumex
Artemisia
Koenigia islandica
Caryophyllaceae
Compositae-Liguliflorae
Compositae-Tubuliflorae
Lycopodium selago
Horizontal scale in increments of 10% of total pollen
Peaty clay
Organic clay
Peat
Clay
+ Less than 1% of total pollen

needed on the lower part of bed 4, which, with its indications of unstable ground conditions in the pollen record, may be part of the Lateglacial sequence, rather than the Holocene as had been assumed.

There is little published literature on the Holocene environment of Shetland, and nothing on the Lateglacial, apart from a moss identification (Hulme, 1979) and two radiocarbon dates on organic material within inorganic clays beneath Holocene peat. These were 12,090 ± 900 BP (St–1640) at Loch of Clickhimin, and 11,135 ± 135 BP (St–1714) on peat lenses within a minerogenic deposit at Tresta (Hoppe, 1974). The beginning of Holocene organic sedimentation has been dated to around 10,400 BP at two sites (Johansen, 1975; Hulme and Durno, 1980). Otherwise the stratigraphy from the Burn of Aith valley, described here, together with that of Spiggie Loch, which is undated, provides the only detailed information on the Lateglacial environment of Shetland (Birnie, 1981).

During the Lateglacial and early Holocene the oceanic circulation around the Shetland Islands was apparently rather different from that of today and this provides an instructive comparison with the evidence for environmental change at Burn of Aith. Following the last period of ice-sheet glaciation when arctic waters extended well to the south of the British Isles, an interstadial marine circulation with a weak North Atlantic Drift became established off western Scotland and in the Norwegian and North seas by 12,800 BP (Jansen and Bjørklund, 1985; Peacock and Harkness, 1990). The presence of the warmer waters off the British coast corresponds with the opening of the Lateglacial Interstadial in the terrestrial records from mainland Britain (Atkinson *et al.*, 1987), but contrasts with the very early date on the interstadial sediments from the Burn of Aith. Climatic deterioration during the Loch Lomond Stadial is clearly recorded both in the marine and the Burn of Aith records. Of particular interest at the Burn of Aith site, however, is the apparent delay in the onset of warm conditions at the Lateglacial–Holocene boundary, for the marine record along the Scandinavian coast suggests continuing colder conditions until approximately 9600 BP (Peacock and Harkness, 1990). At this time, therefore, the climate of Shetland may have been more closely akin to that of Scandinavia than the Scottish mainland.

Figure 3.5 Burn of Aith: relative pollen diagram showing selected taxa as percentages of total pollen (from Birnie, 1981).

Conclusion

Burn of Aith provides the only detailed record so far of the environmental history of Shetland during the Lateglacial (approximately 13,000–10,000 years ago). The pollen preserved in the sediments indicates a period of relatively mild climate with the development of herbs and shrubs during the Lateglacial Interstadial, about 13,000–11,000 years ago, followed by a return to more severe conditions with open-habitat vegetation during the Loch Lomond Stadial (about 11,000–10,000 years ago). At the start of the Holocene, the onset of stable ground conditions was delayed in comparison with sites elsewhere in Scotland, and shows more similarity in timing with events in Scandinavia. Burn of Aith is therefore an important reference site not only for studies of environmental history in Shetland, but also for establishing wider regional patterns of environmental change.

GARTHS VOE

J. Birnie

Highlights

Pollen and wood remains from peat exposed in the stream section at Garths Voe provide a record of vegetational change in Shetland during the Holocene. They are important in dating a period when trees in Shetland were more widespread than today. The peat also contains a thin layer of sand which appears to represent a major coastal flood about 6000 years ago.

Introduction

The site is a roadside section [HU 409741] at the head of Garths Voe, an eastern arm of Sullom Voe. It was revealed at the mouth of a small burn draining the Hill of Garth by road building for the Sullom Voe oil terminal. At present it is one of only two sites in Shetland where radiocarbon dates have been obtained on wood within

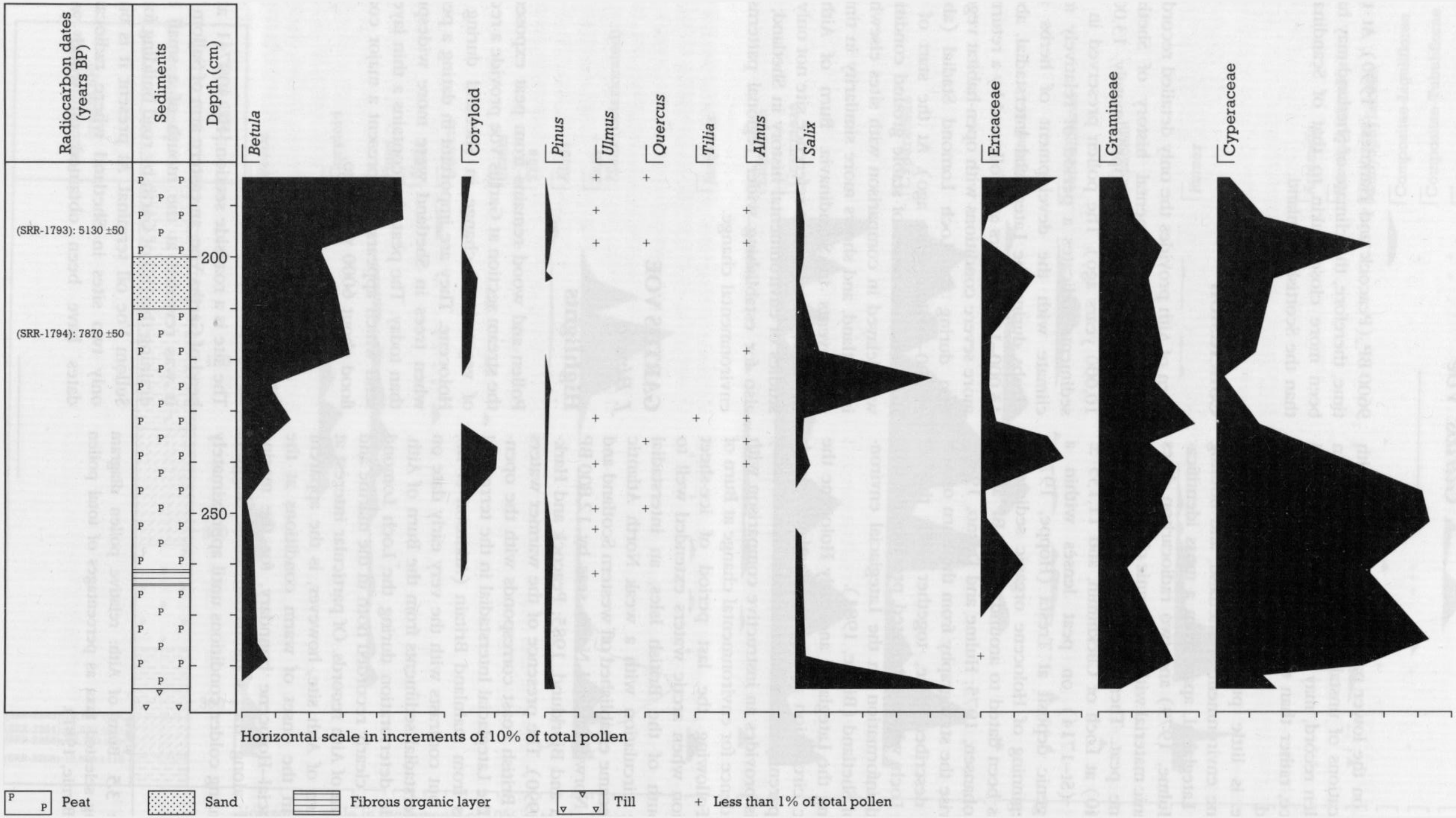

Radiocarbon dates (years BP)
Sediments
Depth (cm)
(SRR-1793): 5130 ±50
(SRR-1794): 7870 ±50
200
250
Betula
Coryloid
Pinus
Ulmus
Quercus
Tilia
Alnus
Salix
Ericaceae
Gramineae
Cyperaceae
Horizontal scale in increments of 10% of total pollen
Peat
Sand
Fibrous organic layer
Till
+ Less than 1% of total pollen

Table 3.1 Radiocarbon dates relating to the buried sand horizon at Garths Voe and Voe of Scatsta

Location	Material	Radiocarbon date	Laboratory number
Garths Voe	0.02 m thick layer of peat above sand	5315 ± 45 BP	SRR–3839
Garths Voe	0.02 m thick layer of peat below sand	5765 ± 45 BP	SRR–3838
Voe of Scatsta	0.02 m thick layer of peat above sand	3815 ± 45 BP	SRR–3841
Voe of Scatsta	0.02 m thick layer of peat below sand	5700 ± 45 BP	SRR–3840

Holocene peat deposits, with associated pollen analysis of the peat giving a record of regional vegetation history. Hence it indicates the past status of trees and shrubs in this northernmost part of the British Isles, which is currently treeless. The pollen stratigraphy of the site is described by Birnie (1981).

Description

The sequence, traced along both sides of the burn for approximately 8 m, is as follows (Birnie, 1981):

6. Blanket peat — 2.0 m
5. Sand, unconsolidated — 0.1 m
4. Peat, less-humified, containing twigs and small wood fragments, and including branches of 0.05 m diameter in the upper part of the bed — 0.52 m
3. Discrete, fibrous organic layer of detrital vegetation remains — 0.03 m
2. Peat, well-humified, with a few plant remains — 0.2 m
1. Till — >0.1 m

Small fragments of wood are present in the lowest 0.5 m of the blanket peat (bed 6), but above this it is composed only of sedge, *Sphagnum* and ericaceous remains. *Salix* wood in bed 4, from below the sand layer, was dated to 7870 ± 50 BP (SRR–1794), and *Betula* wood from above the sand, in bed 6, to 5130 ± 50 BP (SRR–1793).

Figure 3.6 Garths Voe: relative pollen diagram showing selected taxa as percentages of total pollen (from Birnie, 1981).

Interpretation

Pollen analysis (Figure 3.6) indicates the presence of open-ground herbs in the lowest organic layer (bed 2), being replaced by Cyperaceae, and then covered with inwashed detritus of *Sphagnum*, Cyperaceae and Ericaceae comprising the fibrous layer. Autochthonous deposition then recommenced, with Cyperaceae and some *Sphagnum* locally and Ericaceae nearby. The site then became a willow fen, with grassland, ferns and tall herbs associated. This is represented by the lower woody peat (bed 4), with *Salix* constituting over 40% of the pollen total. Prior to the deposition of the sand, birch also appeared at the site, with *Betula* pollen values reaching 33% of the total. The pollen and macrofossils together show that there was open woodland or scrub at the site at around 7900 BP. Following deposition of the sand, peat accumulation recommenced, with *Betula* pollen reaching its maximum representation of 50% and *Salix* virtually absent. The birch was initially associated with ferns, but then heaths appeared at the site, and at some time after 5130 BP (bed 6) shrubs or trees disappeared and heath- and sedge-dominated blanket peat communities predominated, as at present. Birnie (1981) interpreted the sand layer (bed 5) as reflecting either erosion of minerogenic soils in the stream catchment or encroachment of beach sediments landwards from Garths Voe. However, recent investigations (D. E. Smith, unpublished data) suggest that the sand is part of a widespread deposit in Shetland, and may possibly represent a major marine flood with a run-up of several metres. Smith *et al.* (1991a) obtained radiocarbon dates on peat at the upper and lower contacts of the sand layer at Garths Voe and the adjacent Voe of Scatsta (Table 3.1). Two possible explanations for the origin of the sand layer are that it is a tsunami deposit rather like that recorded from *c.* 7000 BP in eastern Scotland (see Maryton), since a third Storegga slide is known at *c.* 6000 BP (Jansen *et al.*, 1987), or that it is the deposit of a storm surge of unusual magnitude.

There are written records of wood in Shetland peat from at least the early 19th century, for example Brewster (1829) and Bryden (1845), and Lewis (1907, 1911) published accounts of wood and other plant macrofossils as part of a study of peat in the whole of Scotland. Lewis wrote that the 'Forest Bed' (principally of birch, hazel and willow) was remarkably widespread in Shetland' and concluded 'these trees do not represent copses growing in sheltered valleys away from the coast but . . . are just as well developed in the most exposed situations' (1911, p. 808). Hawksworth (1970) described the distribution of wood remains in peat on Foula, and concluded that on this small island they were restricted to the lower and more sheltered areas. Johansen (1975, 1978), examining the pollen record of a lake infill site on the Mainland, found that tree and shrub pollen did not exceed 50% of the sum of the land pollen at any one time, and so he disputed Lewis's term 'Forest' for what he interpreted as birch and hazel scrub. Birnie (1984) has examined wood and pollen records from a number of sites in Shetland and concluded that there was a distinct phase of widespread willow, birch or hazel development, with the radiocarbon dates from Garths Voe providing the only means of dating that phase at present – between 8000 and 5000 BP. The Garths Voe site is therefore an example of the vegetation record described by Lewis as representing forest, and by Johansen as scrub. It records the most advanced level of Holocene vegetation development in Shetland and as such will be significant in any interpretation of the climatic optimum, the timing and causes of environmental deterioration, and such issues as species dispersal and colonization rates.

There could, potentially, be very many sites in Shetland which demonstrate a similar Holocene stratigraphic record to that at Garths Voe (cf. Bennett *et al.*, 1992). Garths Voe is at present, however, the only site in which Holocene vegetation development has been examined by means of pollen and macrofossil analyses, with radiocarbon dates obtained from the wood. It appears to represent vegetation sequences described by Lewis in the early part of this century, and with the presence of macrofossils there is potential for more detailed examination of the age and relative importance of trees and shrubs contributing to the deposit. This would lead to a better understanding of the nature of former woodland cover in the Scottish Islands – an issue presently unresolved in the Western Isles and Orkney, let alone Shetland.

Conclusion

The deposits at Garths Voe provide a representative record of the vegetational history of Shetland during the Holocene (the last 10,000 years), based on pollen analysis and radiocarbon dating. A phase of open-habitat vegetation was followed by the development of willow, birch or hazel between about 8000 and 5000 years ago, but was subsequently replaced by blanket peat with heath and sedge communities. As a reference site for Shetland, Garths Voe and its record are also important for further investigation of the timing of the Holocene climatic optimum and the causes and wider patterns of the subsequent deterioration. In addition, the deposits at Garths Voe include a sand layer formed just after 6000 years ago, which may represent a tsunami (tidal wave) or storm-surge event in the North Sea.

RONAS HILL

J. E. Gordon

Highlights

The periglacial landforms and deposits at Ronas Hill include a range of active and fossil features formed by wind- and frost-related processes. On account of its northern location and relatively low altitude, Ronas Hill is a key locality for the study of periglacial activity in Scotland.

Introduction

Ronas Hill [HU 316835] is the highest summit (453 m OD) in Shetland. It is important for periglacial geomorphology and demonstrates an outstanding assemblage of both active and fossil patterned-ground landforms which are developed at relatively low altitudes. Combined wind and frost effects are particularly striking and include turf-banked terraces, wind-blown sand deposits and vegetated stripe features. The landforms of Ronas Hill have been described principally by

Ball and Goodier (1974), Goodier and Ball (1975) and Veyret and Coque-Delhuille (1989).

Description

Ronas Hill is formed of granophyre, part of the Ronas Hill Granite intrusion of Devonian age, which is itself cut by a series of north–south trending felsitic dykes (Mykura, 1976). Galloway (1958, 1961a) recorded the presence of blockfields and boulder terraces at 365–427 m OD on Ronas Hill similar to those on the Cairngorms at altitudes between 1067 and 1219 m OD. He posed the question whether the blockfields in such an oceanic environment as Shetland might derive in part from deep chemical weathering of the granite.

Ball and Goodier (1974) later identified four main groups of periglacial landforms developed on the granite regolith of Ronas Hill: turf-banked terraces, wind stripes, 'hill dunes' (wind-blown sand deposits) and composite stripe-terrace features. They also noted, but did not describe, large, fossil boulder terraces and blockfields, and small, active stone circles.

Turf-banked terraces include features aligned parallel to the ground surface contours, reflecting solifluction processes operating in a relatively mobile surface soil layer. A second type of terrace aligned obliquely to the contours probably reflects the combined influence of wind and solifluction activity. Wind stripes take the form of narrow strips of vegetation, with steeper windward and gentler leeward faces related to the effective wind direction. They occur both as continuous stripes and as fragmented crescents of vegetation. 'Hill dunes' appear as vegetated areas of sand rising up to 1 m above adjacent deflation surfaces. They are relics of a formerly more extensive soil and vegetation cover, but the presence of buried humic horizons indicates episodic accumulation. Composite features occur where terraces intersect wind stripes. Overall, however, it is important to emphasize the total assemblage of wind, frost and mass-movement features present and their spatial interactions according to local conditions of slope and exposure (Veyret and Coque-Delhuille, 1989); for example, terrace treads support wind stripes and bare areas between vegetated stripes show the effects of frost sorting.

Interpretation

Ball and Goodier (1974) considered that the large-scale relict landforms are probably of Late-glacial age and that the wind-blown material accumulated during the early Holocene. They also argued that erosion of the 'hill dune' vegetation cover and development of the turf-banked terraces occurred possibly during the Little Ice Age between about AD 1550 and 1750. Although possible wider correlations are premature in the absence of firm dating, it is worth noting that elsewhere in Scotland radiocarbon dating has indicated that there was active solifluction during the late Holocene (Sugden, 1971; Mottershead, 1978; Ballantyne, 1986c). Elsewhere, aeolian sand and silt deposits are represented on Ward Hill (see below) and mountain summits of north-west Scotland (Sissons, 1976b; Birse, 1980; Pye and Paine, 1984; Ballantyne, 1987a). On An Teallach (see below), Ballantyne and Whittington (1987) established that accumulation of niveo-aeolian sands began during the early Holocene, before about 7900 BP, and was reactivated more recently, possibly either during the 17th and 18th centuries when the Little Ice Age weather conditions were most severe in Scotland, or during the 19th century following overgrazing. In County Donegal in Ireland, Wilson (1989) identified two periods of Holocene sand-sheet accumulation, with the most recent erosion commencing before the late nineteenth century. Recognition and correlation of widespread climatic or anthropogenic causes, however, must await more detailed site-specific studies of sediments, palynology and dating. Ballantyne (1991a), in particular, has sounded a note of caution in ascribing late Holocene erosion to climatic deterioration, as the connection is based entirely on inferred coincidence of timing.

The assemblage of wind- and frost-related, patterned ground features has developed at a relatively low altitude on Ronas Hill under the subarctic, oceanic climatic conditions of the area (for details see Spence, 1957, 1974; Birse, 1971, 1974). Similar features typically occur at much higher altitudes in the mountains of mainland Scotland (see An Teallach, Sgùrr Mór, Ben Wyvis, and the Cairngorms) (Crampton, 1911; Peach *et al.*, 1913a; Crampton and Carruthers, 1914; Galloway, 1958, 1961a; Godard, 1965; Kelletat, 1970a, 1972; King, 1971b; Goodier and Ball, 1975; Ballantyne, 1981, 1987a; Pye and Paine, 1984). Ronas Hill is also distinguished by the range and quality of the features present in a relatively compact area, and Ball and Goodier (1974) noted that the interaction of wind and frost effects was more clearly demonstrated than at any other site in Britain known to them. Further, the combined effects of wind and frost can be readily investigated and evaluated in an area of uniform geology and with a range of slopes and aspects. Although Ward Hill in Orkney is similar in its range of landforms to Ronas Hill, active frost processes there are less evident, so that the two hill masses essentially complement each other in their periglacial interests.

In a national context Ronas Hill forms a northern end member of a network of sites representing past and present periglacial activity. It is a key site for studies of spatial variations in periglacial processes in Britain and the essential controlling variables (see Ballantyne, 1987a). Considerable potential exists for studies of current periglacial processes, landform history and dating of the buried soils. As yet no investigation has been undertaken of the larger relict landforms, their palaeoclimatic significance and their relationships to the active features. Ball and Goodier (1974) highlighted two important results that would arise from a comprehensive study of the wind- and frost-related features on Ronas Hill together with those on Ward Hill – 'on the one hand, it should help to elucidate the complex post-glacial and recent history of changing stability, wind erosion, and frost-induced disturbance and movement in the northern climatically stressed hill areas and, on the other, provide a sensitive long term monitor of regional climatic change'.

The fossil periglacial features form part of a network of such sites in Scotland (for example, An Teallach, the Cairngorms) which have attracted recent attention for their possible significance in delimiting the vertical dimensions of the last ice-sheet (Ballantyne *et al.*, 1987; Reed, 1988; Ballantyne, 1990). Those on Ronas Hill have not been studied in detail but merit investigation particularly in relation to their age or ages of origin and possible relationships to the limit of the last ice-sheet (Veyret and Coque-Delhuille, 1989). There appear to be three possibilities: such features may pre-date the last ice-sheet but were preserved beneath cold-based or inactive ice; they may have developed if Ronas Hill remained as a nunatak above the surface of the Shetland ice-cap; or they may have been formed or reactivated during the Loch Lomond Stadial.

Conclusion

Ronas Hill is outstanding for its assemblage of landforms developed under periglacial (cold climate) conditions, particularly those formed by the combined effects of wind and frost activity. It represents the northernmost occurrence of such features in Scotland and is notable for their development at relatively low altitudes. Ronas Hill has significant potential for research both on contemporary periglacial processes and on the history of upland geomorphological changes during approximately the last 13,000 years.