Quaternary of Scotland

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Chapter 11

Inner Hebrides

INTRODUCTION
D. G. Sutherland

The Inner Hebrides comprise the islands from Skye in the north to Islay in the south (Figure 11.1). By virtue of their position and topography, they give rise to a diverse series of environments. The Quaternary history of the islands can be understood in terms of the interplay of changes in the local environments resulting from climatic and sea-level variations and the, at times, dominant influences from the nearby mainland. Thus the history of glaciation is that of the interaction of locally nurtured ice caps and the invading mainland ice-sheet. The Holocene vegetational history is also one of local floristic diversity resulting from plant migration from the mainland, with a number of trees and shrubs reaching the northern or western limits of their ranges in the islands. No interglacial or interstadial sites are known from the Inner Hebrides and the established Quaternary history is thus relatively short, being confined to the Late Devensian. Although various shore platforms have been ascribed to interglacial or pre-glacial episodes, their origins remain uncertain. The area is a classic one for features of mountain glaciation, shore platforms and raised beaches. The principal themes of research have therefore focused on these aspects and, in addition, on the interaction of local and mainland ice, landforms of the Loch Lomond Readvance and Lateglacial and Holocene vegetation history.

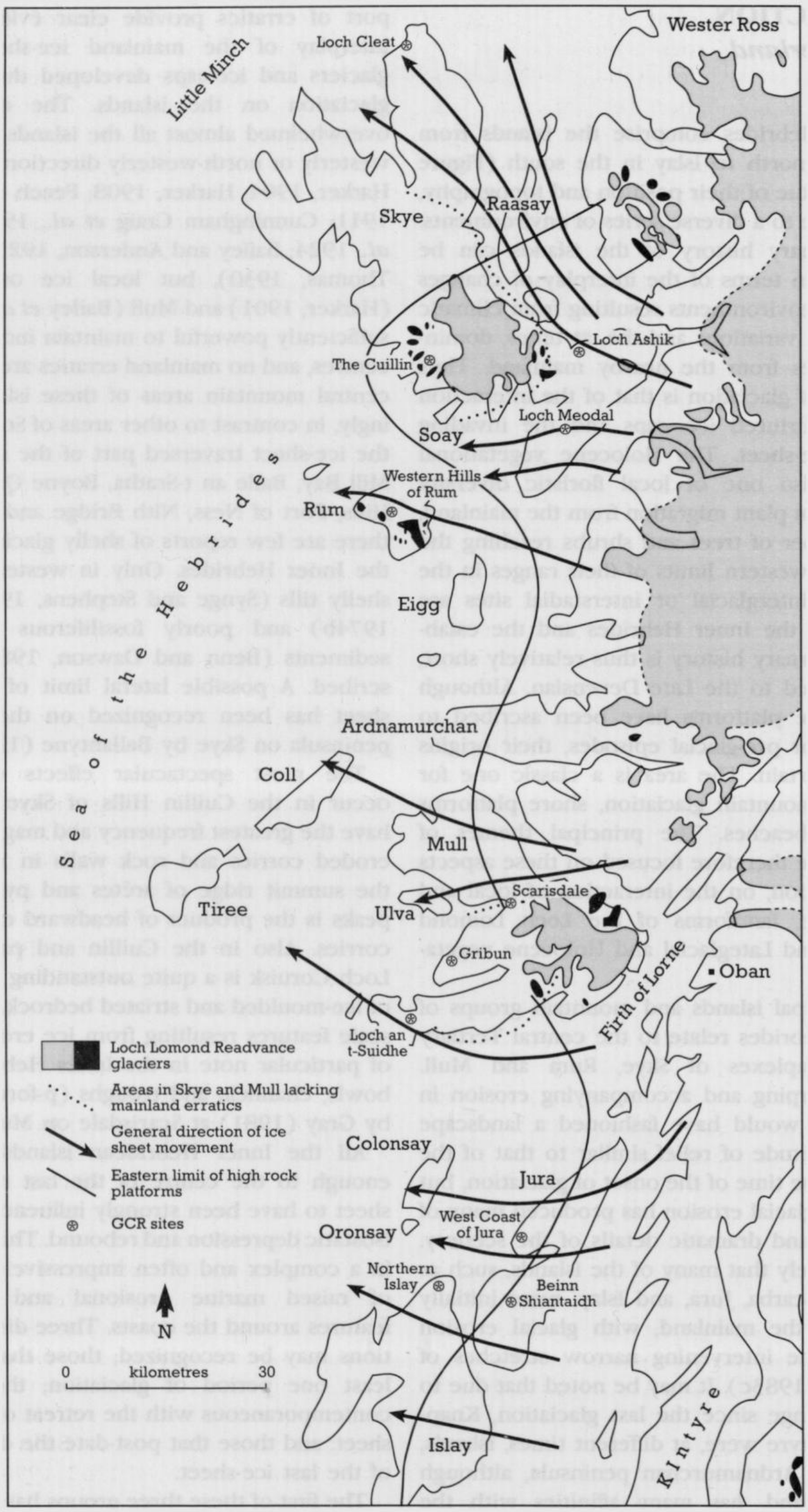
The principal islands and mountain groups of the Inner Hebrides relate to the central Tertiary igneous complexes of Skye, Rum and Mull. Tectonic warping and accompanying erosion in the Tertiary would have fashioned a landscape with a magnitude of relief similar to that of the present by the time of the onset of glaciation, but subsequent glacial erosion has produced many of the familiar and dramatic details of the scenery. Thus it is likely that many of the islands, such as Skye, Mull, Scarba, Jura, and Islay, were initially attached to the mainland, with glacial erosion producing the intervening narrow stretches of sea (Sissons, 1983c). It may be noted that due to sea-level change since the last glaciation, Knapdale and Kintyre were, at different times, islands, whereas the Ardnamurchan peninsula, although never an island, has many affinities with the neighbouring islands.

Striations, roches moutonnées and the transport of erratics provide clear evidence of the interplay of the mainland ice-sheet and the glaciers and ice-caps developed during the last glaciation on the islands. The mainland ice overwhelmed almost all the islands, flowing in a westerly or north-westerly direction (Clough and Harker, 1904; Harker, 1908; Peach *et al.*, 1910b, 1911; Cunningham Craig *et al.*, 1911; Bailey *et al.*, 1924; Bailey and Anderson, 1925; Richey and Thomas, 1930), but local ice on both Skye (Harker, 1901) and Mull (Bailey *et al.*, 1924) was sufficiently powerful to maintain independent ice centres, and no mainland erratics are found in the central mountain areas of these islands. Surprisingly, in contrast to other areas of Scotland where the ice-sheet traversed part of the sea floor (see Mill Bay, Baile an t-Sratha, Boyne Quarry, Kippet Hills, Port of Ness, Nith Bridge and Port Logan), there are few reports of shelly glacial deposits in the Inner Hebrides. Only in western Islay have shelly tills (Synge and Stephens, 1966; Peacock, 1974b) and poorly fossiliferous glaciomarine sediments (Benn and Dawson, 1987) been described. A possible lateral limit of the last ice-sheet has been recognized on the Trotternish peninsula on Skye by Ballantyne (1990).

The most spectacular effects of glaciation occur in the Cuillin Hills of Skye. The Cuillin have the greatest frequency and magnitude of ice-eroded corries and rock walls in Scotland, and the summit ridge of arêtes and pyramid-shaped peaks is the product of headward erosion of the corries. Also in the Cuillin and particularly by Loch Coruisk is a quite outstanding development of ice-moulded and striated bedrock. Other small-scale features resulting from ice erosion that are of particular note in the Inner Hebrides are the bowls, channels and troughs (p-forms) reported by Gray (1981) at Scarisdale on Mull.

All the Inner Hebridean islands were close enough to the centre of the last mainland ice-sheet to have been strongly influenced by glacio-isostatic depression and rebound. This has resulted in a complex and often impressive development of raised marine erosional and depositional features around the coasts. Three distinct generations may be recognized; those that pre-date at least one period of glaciation; those that are contemporaneous with the retreat of the last ice-sheet; and those that post-date the disappearance of the last ice-sheet.

The first of these three groups has two separate elements: the first at close to present sea level and the second at high level, generally above



Wester Ross
Loch Cleat
Little Minch
Skye
Raasay
Loch Ashik
The Cuillin
Loch Meodal
Soay
Western Hills of Rum
Rum
Eigg
Sea of the Hebrides
Ardnamurchan
Coll
Mull
Scarisdale
Ulva
Tiree
Gribun
Oban
Firth of Lorne
Loch an t-Suidhe
Loch Lomond Readvance glaciers
Areas in Skye and Mull lacking mainland erratics
General direction of ice sheet movement
Eastern limit of high rock platforms
GCR sites
Colonsay
Jura
West Coast of Jura
Oronsay
Northern Islay
Beinn Shiantaidh
N
0 kilometres 30
Islay
Kintyre

18 m OD. Close to present sea level is a set of apparently horizontal rock platforms. Their surfaces are striated and the backing cliffs can, in places, be seen to disappear beneath glacial drift. On Northern Islay and the West Coast of Jura, Dawson (1980a) has termed this set of platforms the Low Rock Platform and it, or they (as there appear to be a number of levels in different parts of the Hebrides), have been suggested to be of interglacial origin (Dawson, 1980a; Sissons, 1981a, 1983c). There is no direct evidence for this, however.

These low platforms are in marked contrast to the second set of platforms comprising the so-called High Rock Platform, examples of which occur widely throughout the Inner Hebrides as well as on certain of the neighbouring peninsulas, such as Ardnamurchan and Applecross. These rock platforms are frequently spectacularly developed, as in Northern Islay, and range in altitude from 18 m to as much as 51 m OD. Originally thought to be 'preglacial' (Wright, 1911) because of the striations and glacial deposits found in places on the platform surfaces, their age is today considered much less certain. An interglacial origin was favoured until recently (McCann, 1964, 1968; McCann and Richards, 1969; Jardine, 1977), but has been supplanted in favour of the idea that the platforms formed contemporaneously with the last ice-sheet (Sissons, 1981a, 1982b; Sutherland, 1981a; Dawson, 1984; Gray, 1985). Sissons (1981a, 1982b) noted that not all fragments of the platform carried evidence of glaciation and, further, that there was a distinct line running through the Inner Hebrides to the east of which high rock platforms were either absent or only very poorly developed, whereas to the west they were typically very clear and extensive features (Figure 11.1). Sissons argued that this contrast was due to ice occupying the eastern area while the platforms were being formed to the west. Minor advances and retreats of the ice-sheet would have resulted in glaciation of certain of the platforms, but those formed during ice retreat would not be glaciated. A corollary of Sissons' hypothesis is that the platforms should be isostatically tilted. Unfortunately, the number of accurate altitudes available on the inner margin of the platform fragments is as yet too few to test this prediction. Sissons (1981a, 1982b) also suggested a chronology for the development of the rock platforms, envisaging initial expansion of the Scottish ice-sheet in the Early Devensian (see Sutherland, 1981a) and glaciation (and accompanying platform formation) continuing throughout the Devensian until final decay of the ice towards the end of the Late Devensian. There is as yet no direct evidence to support such a chronology.

Figure 11.1 Location map and principal Quaternary features of the Inner Hebrides (from Peacock, 1983b; Sissons, 1983c; Ballantyne and Benn, 1991).

During ice-sheet retreat in the Late Devensian, the most rapid deglaciation initially occurred in the deep-water channels between the islands, and the residual ice masses on the islands then flowed outwards into these ice-free areas. At a relatively late stage, however, a north-westerly ice flow was maintained across Islay and Jura, and as the Paps of Jura emerged from the ice as nunataks, the remarkable medial moraine of Scriob na Caillich (Dawson, 1979b) on the West Coast of Jura was deposited. At about this time the end moraine at Coir' Odhar in Northern Islay (McCann, 1964; Synge and Stephens, 1966; Dawson, 1982) was also formed. Sea level at this period was relatively high and the second generation of raised marine features was formed during the subsequent fall. These features consist of glaciomarine deltas as well as gravel spreads and shingle ridges. The last are most spectacularly developed along the West Coast of Jura (McCann, 1964; Dawson, 1979a, 1982), where staircases of over 20 distinct ridges have been mapped. In central Islay a moraine records the position of the ice-sheet margin while relative sea level fell by up to 12 m (Dawson, 1982).

The precise timing of deglaciation is unclear. A radiocarbon date of 16,470 ± 300 BP (SRR–118) (Harkness and Wilson, 1979) from marine sediments offshore from Colonsay (Binns *et al.*, 1974) may be too old due to contamination. The earliest dates from basal terrestrial sediments of 13,870 ± 150 BP (SRR–3121) at Loch Ashik on Skye (Walker *et al.*, 1988) and 13,140 ± 100 BP (SRR–1805) at Loch an t-Suidhe on Mull (Walker and Lowe, 1982; Lowe and Walker, 1986a) are also uncertain because of possible contamination (Sutherland, 1980). Lateglacial vegetational development has only been studied in detail on Mull and Skye (Birks, 1973; Birks and Williams, 1983; Walker and Lowe, 1982, 1990, 1991; Lowe and Walker, 1986a; Walker *et al.*, 1988). Throughout the Lateglacial Interstadial the vegetation of the islands was essentially treeless, and although tree birch occurred in the more southerly islands, its distribution was limited to those areas not exposed to westerly winds (Lowe and Walker, 1986a). It may have reached its north-westernmost limit at this period in south-east Skye (Birks and Williams, 1983). The early vegetation of the interstadial consisted primarily of open grass- and sedge-dominated communities, but a juniper scrub and then an *Empetrum* heath developed. As with the tree birch, exposure to westerly winds may have been the main factor in limiting plant diversity during this period (Walker *et al.*, 1988).

The Loch Lomond Stadial had a major impact on the Inner Hebrides. Glaciers readvanced or built-up anew on Skye (Walker *et al.*, 1988; Ballantyne, 1989a), Rum (Ballantyne and Wain-Hobson, 1980) and Mull (Gray and Brooks, 1972). The age of the readvance is established by the ice-transported shells at Loch Spelve on Mull, which gave a radiocarbon date of 11,330 ± 170 BP (I–5308) (Gray and Brooks, 1972), and the occurrence of only Holocene sediments in enclosed basins from within the readvance limits (Walker and Lowe, 1985). Radiocarbon dating and accompanying pollen analyses from such sites implies that the glaciers on Mull had largely disappeared by between 10,500 BP and 10,000 BP. On Skye comparisons of the pollen spectra from the basal sediments in enclosed basins within the readvance limits has indicated a diachronous retreat of the glaciers (Lowe and Walker, 1991). Initial retreat may have been underway by 10,200 BP and was apparently completed by the time of the juniper peak of the early Holocene vegetational succession, that is, no later than 9,600 BP.

During the latter part of the Lateglacial period a distinctive shoreline was eroded around the coasts of the southern islands. This shoreline, termed the Main Rock Platform, is isostatically tilted (Gray, 1978a; Dawson, 1980b; Sutherland, 1984a) and slopes away from the area of maximum isostatic depression in the south-west Highlands, such that it passes below present sea level in Northern Islay and around the coast of Mull. It has also been identified on the coast of southern Skye (Peacock, 1985). The evidence from the Isle of Lismore (see above) (Gray, 1987; Gray and Ivanovich, 1988) suggests that the platform could in part be a reoccupied, older feature.

The Loch Lomond Stadial vegetation reflected the harshness of the climate, with a dominance of open-habitat taxa and species characteristic of disturbed soils (Lowe and Walker, 1986a). Periglacial processes were particularly active (Ballantyne, 1991b), and the large-scale patterned-ground features found in the Western Hills of Rum (Ballantyne and Wain-Hobson, 1980; Ballantyne, 1984) were most probably fashioned at this period. On Jura the impressive protalus rock glacier of Beinn Shiantaidh (Dawson, 1977) was formed.

The early Holocene was initially characterized by rapid vegetational development as the climate ameliorated, and a plant succession from tundra heath through *Empetrum* heath and juniper scrub to hazel–birch woodland probably occurred in the first 1500 years. Details of this early phase are particularly well preserved at Gribun on Mull (Walker and Lowe, 1987). Subsequent development of the Holocene vegetation cover reflected the diversity of local environments, as is illustrated by the pollen sites in Skye at Loch Ashik, Loch Meodal and Loch Cleat (Birks, 1973; Birks and Williams, 1983). Around Loch Meodal, in the Sleat peninsula, during the middle Holocene the dominant vegetation was mixed birch–hazel–alder woods with some oak, elm, ash, rowan and holly. This was probably close to the northern limit of predominant oak at that time (Birks, 1977; Birks and Williams, 1983). Pine was absent, yet a short distance to the north around Loch Ashik pine flourished (Williams, 1977). In contrast again, at Loch Cleat in northern Skye only birch, hazel and willow scrub developed at this time (Williams, 1977; Birks and Williams, 1983). These three sites, considered together, demonstrate the diversity of vegetational development resulting from the geological, topographical and climatic variations on a single island in the Inner Hebrides.

Farther south than Skye, the vegetation of the middle Holocene consisted of birch–hazel scrub or woodland with some oak and elm (Andrews *et al.*, 1987; Walker and Lowe, 1987; Hirons and Edwards, 1990). Subsequent to 4000 BP woodland contracted and heathland and grassland expanded. A reduction in woodland cover at about this time has been widely noted in Scotland (see Allt na Feithe Sheilich and Loch Maree) and may be due to either an increase in storminess or human impact, or a combination of the two (Birks, 1987).

The final generation of raised marine features formed around the coasts of the inner Hebrides was produced at the maximum of, and subsequent to the Main Postglacial Transgression. As with the Lateglacial shorelines, the features are most impressively developed along part of the West Coast of Jura, particularly at Inver where as many as 30 distinct shingle ridges occur one above the other (Dawson, 1979). Radiocarbon dates on marine shells from Oronsay (Jardine, 1978, 1987) suggest that the maximum Holocene sea level was attained at around 6500–7000 BP. Thus the 'staircase' of shingle ridges at Inver was likely to have been formed in the last 6500 years.

Small-scale periglacial features are currently active on a number of mountains on Rum (Western Hills) and Mull (Godard, 1959).

THE CUILLIN

D. G. Sutherland

Highlights

The Cuillin is an outstanding area for glacial geomorphology. It is particularly noted for landforms of mountain glacier erosion, demonstrating an assemblage of classic features unmatched elsewhere in Britain. This interest is also complemented by an excellent range of moraine types formed by corrie and icefield glaciers of the Loch Lomond Readvance.

Introduction

The Cuillin site in southern Skye includes the main ridge of the Black Cuillin, extending *c.* 13 km from Gars-bheinn (NG 468187) in the south to Sgùrr nan Gillean (NG 472253) in the north, the slopes leading down to Glen Brittle to the west and the Bealach a'Mhàim to the north, the central trough of Loch Coruisk (NG 485205), and to the east, Glen Sligachan (Figure 11.2A). The Cuillin are arguably the most spectacular mountain range in Scotland. Taking the form of a semicircle concave to the south-east, the mountains rise abruptly from sea level to a maximum altitude of 993 m OD in Sgùrr Alasdair (NG 451208). Bitten into on all sides by corries, the central ridge to the mountains never drops below 750 m OD and is typically sharp and narrow. The individual peaks, overlooking corries on several sides, have the form of triangular pyramids and pinnacles and the spectacular glacial scenery is enhanced by the dominance of bare rock at the ground surface, there being little glacial drift within the area of the mountains (Figure 11.3). The Cuillin are of particular geomorphological interest as an outstanding example of the effects of glacial erosion, at both large and small scales, on a mountain massif (Forbes, 1846; Harker, 1901; Lewis, 1938, 1947; Haynes, 1968; Dale, 1981). They also contain evidence for two phases of glaciation during the Late Devensian: the main ice-sheet and Loch Lomond Readvance (Harker, 1901; Sissons, 1977c; Walther, 1987; Walker *et al.*, 1988; Ballantyne, 1989a; Ballantyne and Benn, 1991). The lower slopes and valleys are also important for depositional landforms associated with the Loch Lomond Readvance (Donner and West, 1955; Ballantyne, 1989a; Benn, 1991).

Description

The Cuillin occur on the western side of the Skye Tertiary central igneous complex (Richey, 1961; Emeleus, 1983). The principal rock in this part of the complex is a layered gabbro and the semicircular nature of the gabbro outcrop defines the mountain range. The layering dips steeply inwards at right angles to the trend of the hills, resulting in the steep western mountain front. The gabbro is cut by many minor intrusions including cone sheets and dykes of dolerite.

The intrusions of the igneous complex reached to a shallow depth in the Earth's crust and were unroofed and eroded while igneous activity continued, as is shown by the presence of clasts derived from the intrusive rocks contained in fluvial sediments interbedded with basaltic lavas to the west. By the time of cessation of volcanic activity the mountain mass had dimensions approximately similar to those of today, although it may be anticipated that the lavas abutted against the lower flanks of the hills and the major valleys had yet to be eroded.

Extensive erosion of the western Highlands and the Inner Hebrides during the Tertiary may be inferred from the relationship of the Tertiary dykes to the valley system, the disrupted nature of the once continuous lava flows and the distribution of erosion surfaces (Godard, 1965; George, 1966; Sissons, 1967a). Thus at the onset of Pleistocene glaciation the broad outlines of the topography were unlikely to have been significantly different from today, although without those features of detail, such as corries, overdeepened valleys and stripped and polished

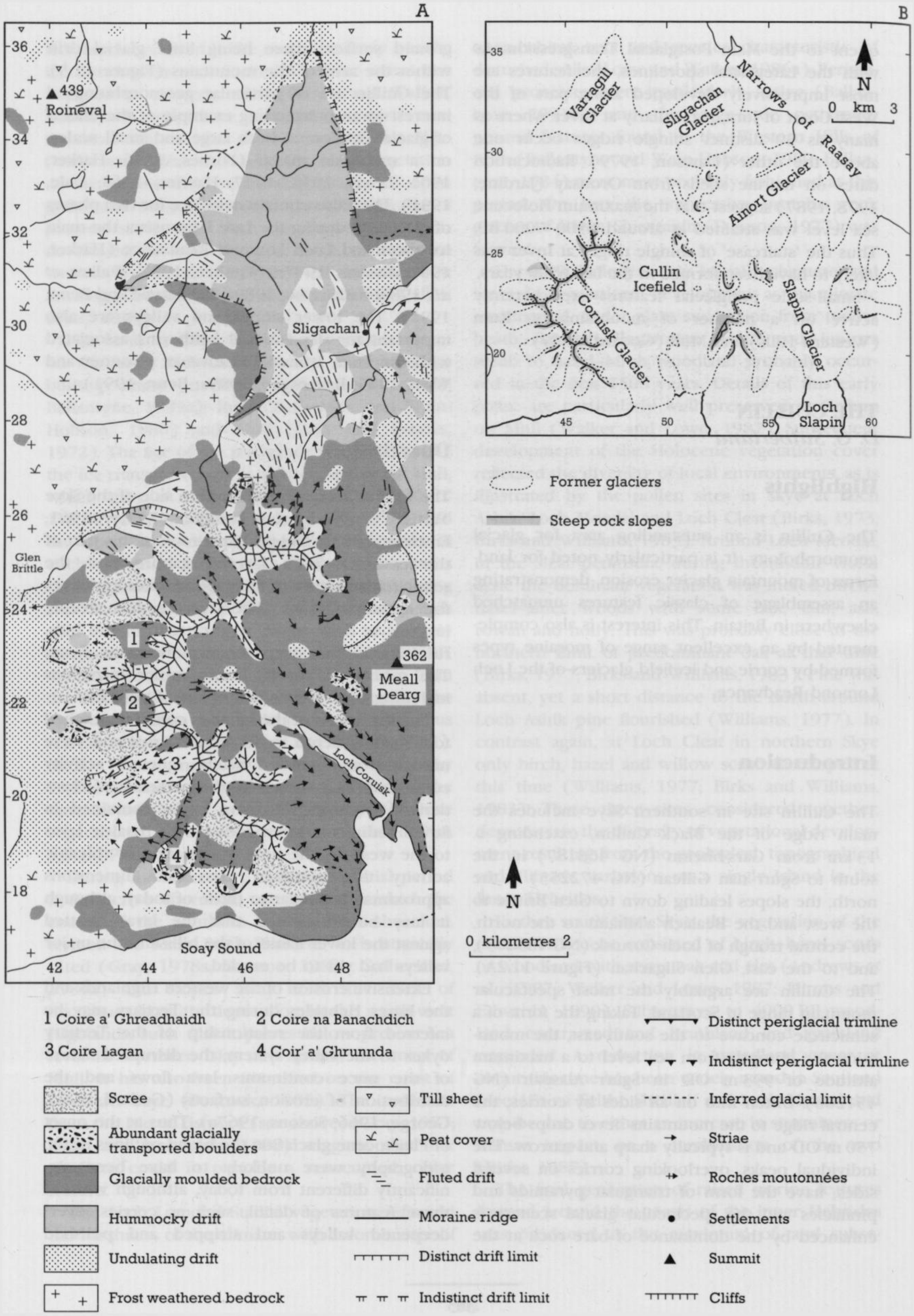

A
B
Roineval
439
Sligachan
Glen Brittle
362
Meall Dearg
Loch Coruisk
Soay Sound
N
0 kilometres 2
1
2
3
4
Varragill Glacier
Sligachan Glacier
Narrows of Raasay
Ainort Glacier
Cullin Icefield
Coruisk Glacier
Slapin Glacier
Loch Slapin
N
0 km 3
Former glaciers
Steep rock slopes
1 Coire a' Ghreadhaidh
2 Coire na Banachdich
3 Coire Lagan
4 Coir' a' Ghrunnda
Scree
Abundant glacially transported boulders
Glacially moulded bedrock
Hummocky drift
Undulating drift
Frost weathered bedrock
Till sheet
Peat cover
Fluted drift
Moraine ridge
Distinct drift limit
Indistinct drift limit
Distinct periglacial trimline
Indistinct periglacial trimline
Inferred glacial limit
Striae
Roches moutonnées
Settlements
Summit
Cliffs

Figure 11.3 Landforms of glacial and periglacial erosion are strikingly developed in the Cuillin of Skye. The serrated aspect of the main Cuillin ridge reflects intense periglacial weathering, whereas the lower slopes are heavily ice-scoured. (British Geological Survey photograph B168.)

bedrock surfaces, that can be ascribed to glacial action.

Within the area of the Cuillin there is evidence for only two glacial phases, both during the Late Devensian: one during the period of the last ice-sheet glaciation and the other during the Loch Lomond Readvance. However, it is only reasonable, given the evidence from surrounding areas in the British Isles (Bowen *et al.*, 1986), to presume that the hills have been repeatedly glaciated, perhaps from as early as 2.4 Ma BP (Shackleton *et al.*, 1984). The features of glacial erosion, which are so outstandingly developed in the Cuillin, can therefore be anticipated to have developed over a very long period.

The major features of glacial erosion centre on the main Cuillin ridge which has the form of a semicircular arête produced by the intersection of multiple corries (Figure 11.2). The floors of the corries display extensive areas of ice-moulded bedrock and rock steps, while taluses occur below the rock headwalls. At the centre of the massif there is a spectacular glacial trough with extensive areas of ice-scoured bedrock and the basin occupied by Loch Coruisk.

That the area showed evidence of glaciation was recognized at an early stage after the introduction of the glacial theory (Forbes, 1846), but despite occasional references (Geikie, 1863a, 1984; Bonney, 1871) it was not until the turn of the century that the glacial deposits and the effects of glacial erosion were discussed in detail (Harker, 1899a, 1899b, 1901; Clough and Harker, 1904). Harker (1901), in one of the first detailed systematic papers on glacial erosion, noted that the form of the valleys both in cross-profile and long profile was a direct result of glaciation. He pointed out that many of the corries 'hang' above the main valley and that this could be explained by glacial overdeepening of the main valley, or

Figure 11.2 (A) Principal glacial features of the Cuillin. (B) Reconstructed Loch Lomond Readvance glaciers in central Skye (from Ballantyne, 1989a).

the erosion of the valley sides. Harker attributed variations in the long profiles of the corries and the valleys, including valley steps as well as rock basins, to the tendency of ice to exaggerate any pre-existing marked inequalities in the profile: increased erosion under those parts of a glacier where the ice was thicker was considered the mechanism to explain these features. The form of the ridges and the summits was attributed to the backward erosion of the corrie heads which came close to intersecting, leaving only narrow arêtes and triangular, slightly concave-faced pyramids. An asymmetry was also apparent to Harker in the ridges of the Cuillin, with the northern slopes typically being steeper than the southern. A similar asymmetry was noted in the distribution of the corries, in particular among those towards the edges of the mountains, with the majority facing the north to north-east sector. These asymmetries Harker ascribed to periods of partial glaciation when the distribution of glaciers and their activity was influenced by their exposure (or lack of it) to the Sun.

In detail, Harker also noted the lack of discrimination by glacial erosion in the exploitation of small geological features in those areas where erosion was intense, the surface of dykes being planed smooth with the surrounding bedrock. This, as was evidenced by the mountain summits, was not typical of subaerial erosion. Harker thought, however, that the mechanism for the erosion of the dykes was distinct from that of the gabbro, for he recorded that there was a disproportionate amount of dyke rock in the cobble to boulder-sized material in the glacial deposits. He concluded that the dykes had been eroded by plucking and tearing away, whereas the gabbro had been ground down by debris lodged in the sole of the ice. It is of note that almost all of these observations and explanations on glacial erosion subsequently came to be accepted in standard texts (Flint, 1957; Sissons, 1967a; Andrews, 1975; Embleton and King, 1975a; Sugden and John, 1976).

W. V. Lewis also made significant contributions to the theory of glacial erosion, drawing on field examples from the Cuillin. He described the morphology of several of the Cuillin corries, noting the sharp contrast between the shattered headwalls and the ice-moulded floors, and such observations in part laid the foundations for his meltwater theory of corrie formation (Lewis, 1938). He also quoted notable examples of rock steps and roches moutonnées in support of his theories of glacial valley erosion (Lewis, 1947).

The morphology of the corries in the Cuillin has subsequently been investigated as a part of a larger study by Haynes (1968, 1969), who concluded that a large proportion of the long profiles of the corries did not fit the idealized mathematical shapes to which many other corries on the Scottish mainland closely approximated. This she attributed to the complex rock structure of the Cuillin Hills.

Dale (1981) studied the rock walls that comprise the corries and considered their development with respect to similar features in an east–west transect across the Scottish Highlands. She identified 28 individual rock walls in the Cuillin corries and demonstrated that the frequency of occurrence was among the highest measured. The size of the rock walls, as determined by both amplitude and area, was the greatest in the region studied; the average altitude of the base of the rock walls was the lowest, but this figure disguised two distinct altitudes of formation, one between 607 m and 649 m OD and the other between 470 m and 535 m OD. There was a strong northward component in the orientation of the rock walls, and even in corries that faced the west or south-west, the rock walls were best developed on their north- to north-west-facing sides. This conclusion mirrors the observations of Harker (1901) on the asymmetry of the ridges in the Cuillin Hills. Dale (1981) attributed the exceptional development of rock walls in the Cuillin to a combination of available relief, glacial history (the lack of inundation by the mainland ice-sheet) and by the mountains being particularly susceptible to glacier initiation, leading to relatively long periods of local glaciation.

Drawing on the then unpublished work of Harker, Geikie (1894) first reported that during the last glacial maximum the hills of Skye nurtured an independent ice-cap which had sufficient strength to prevent the main Scottish ice-sheet from overriding them. Harker (1901) and Clough and Harker (1904) amplified the ice-flow pattern, tracing the direction of flow of the coalescent ice-sheet and ice-cap both by the orientation of striae and by one of the earliest quantitive analyses of the erratic content of glacial drift. By such stone counts Harker (1901) traced the line of contact in Glen Sligachan between ice originating from the (granitic) Red Hills and ice from the (gabbroic) Cuillin Hills, and noted how the combined northwards ice flow was deflected to the west and then southwest by the mainland ice-sheet.

Subsequent to the period of ice-sheet glaciation, Harker (1901) recognized a distinct phase of local glaciation in which local corrie and valley glaciers flowed outwards from the hills. The impressive end moraine at the mouth of Coir' a'Ghrunnda (NG 445184) (Forbes, 1846) was considered to have been formed at this time. Various other authors have agreed on the existence of later glaciation, but its extent and age have remained in dispute. Charlesworth (1956) reconstructed a small ice-field over the mountains of southern Skye, with the corries on the west of the Cuillin feeding an outlet glacier in Glen Brittle. He correlated these glaciers with his Stage M glaciation (considered to be a readvance) and depicted various retreat stages. Anderson and Dunham (1966) argued that what they termed a 'late-glacial readvance' extended well beyond the limits of the hills.

A more complex scheme was proposed by Birks (1973) who interpreted an extensive local glaciation prior to 12,000 BP, followed by a phase of corrie glaciation in the Cuillin during the Loch Lomond Readvance. Sissons (1977c) also inferred limited glaciation during the Loch Lomond Readvance, identifying seven corrie and one valley (Coruisk) glacier in the Cuillin. This reconstruction was not accepted by Walther (1984, 1987) who envisaged a much greater extent of ice, reaching to north of Sligachan. He proposed certain retreat stages with a final glacial episode in the corries during the early Holocene, when block moraines were formed.

The most recent reconstruction (Walker *et al.*, 1988; Ballantyne, 1989a) favoured the development of a large ice-cap over the southern mountains of Skye during the Loch Lomond Readvance with contemporaneous corrie glaciers in the western Cuillin (Figure 11.2B). These last small glaciers were similar to those identified by Sissons (1977c).

The detailed geomorphological evidence for this reconstruction is outlined in Ballantyne (1989a). Ballantyne (1989a) also reconstructed the three-dimensional form of the Loch Lomond Readvance glaciers on Skye and derived a number of palaeoclimatic inferences. The area-weighted mean equilibrium line altitude of the glaciers conforms with the overall pattern of an eastwards rise in equilibrium line altitude reconstructed for the Loch Lomond Readvance glaciers in the Inner Hebrides and Western Highlands (Sissons, 1979d, 1980b). Local variations in the reconstructed equilibrium line altitude were inferred to reflect precipitation patterns associated with southerly winds (see Sissons, 1979d, 1980b). Mean July sea-level temperature for the stadial was estimated to be about 6°C. A notable feature of Ballantyne's glacier reconstruction is the north–south asymmetry of the Cuillin ice-field. Although the southern outlet glaciers descended steeply to Loch Scavaig, the main outlets to the north in Glen Varragill and Glen Sligachan were relatively more extensive and had relatively lower surface gradients. Such asymmetry could have reflected, in part, variations in the respective glacier mass budgets, but an intriguing possibility explored by Ballantyne is that it relates to differences in the nature of the beds over which the former glaciers flowed. The glaciers on the south side of the ice-field moved over ice-scoured bedrock and their reconstructed surface profiles are typical of those predicted for rigid beds from glacier physics theory (cf. Paterson, 1981). The northern glaciers, however, were associated with extensive deposits of fluted and hummocky moraine which are believed to have formed subglacially (see below), in effect forming a deformable glacier bed. Under such conditions, the predicted ice surface profile is lower than for the rigid bed case (cf. Boulton and Jones, 1979; Nesje and Sejrup, 1988).

Particularly good examples of depositional landforms associated with the Loch Lomond Readvance glaciers include the end and lateral moraines below Coir' a'Ghrunnda in Glen Brittle and the hummocky and fluted moraine at Sligachan (Figure 11.2A) (see Donner and West, 1955; Ballantyne, 1989a; Benn, 1991; Benn *et al.*, 1992). Benn (1989b) discussed aspects of the asymmetry of the end moraines in Coire na Banachdich (NG 430218) and Coire a'Ghreadhaidh (NG 430234). The origins of hummocky moraine are controversial and it seems probable that several landform types exist (see Coire a'Cheud-chnoic). Ballantyne (1989a) noted that large areas of moraine in Glen Varragill were fluted and streamlined, reflecting subglacial deformation comparable to that described from Coire a'Cheud-chnoic (Hodgson, 1982, 1987) and elsewhere in Torridon (Hodgson, 1986). As in the case of Coire a'Cheud-chnoic, the Sligachan and Glen Varragill areas provide potentially important evidence for further investigation of the genesis of hummocky moraine, and the different landform types, together with comparative studies of other sites and related landform assemblages, may allow not only the possibility of recognizing different styles of glaciation and deglaciation (see Eyles, 1979, 1983; Sharp, 1985; Evans, 1989), but also inputs to, and the testing of, theoretical models of glacier behaviour on deformable beds (cf. Boulton and Jones, 1979; Alley *et al.*, 1986; Boulton and Hindmarsh, 1987).

Small-scale erosional landforms are also spectacularly developed and owe their final detail of form to the Loch Lomond Readvance glaciers. Notable examples are in the corries above Glen Brittle (e.g. Coire Lagan – NG 444209) and around Loch Coruisk, where the ice-moulded and striated bedrock and roches moutonnées are among the best examples of their kind in Britain (Figure 11.4). These landforms, some described by Lewis (1947) and Haynes (1969), have significant potential for detailed studies of subglacial erosional processes, as in the types of investigation reported from Snowdonia in North Wales (Gray, 1982b; Gray and Lowe, 1982; Sharp *et al.*, 1989a).

The nature of the very steep and sharp ridges and summits of the Cuillin has precluded the extensive development of periglacial features (Ballantyne, 1991b). Harker (1899b, 1901) and Clough and Harker (1904) noted the extent of rock shattering on the summit areas and the spectacular development of scree slopes, the formation of which was considered to have commenced during the period of local glaciation. Harker (1899b, 1901) also commented on the contrast in the nature of the rock surfaces of the intensely glaciated areas and on the summits, and Ballantyne (1989a) noted that this contrast relates to the upper surface of the Loch Lomond Readvance glaciers. Ballantyne (1989a) used periglacial trimlines to delimit, in part, the limits of Loch Lomond Readvance glaciers. The assignment of the local glaciation to the Loch Lomond Readvance also implies that the accumulation of the scree in the corries must have occurred in the Holocene. Aspects of scree-slope development were investigated by Statham (1976a), who concluded that the debris movement and morphological characteristics accorded with a rockfall model of genesis. Modification of some of the taluses by snow avalanches may also have occurred (Benn, 1990). The Holocene talus accumulations may be the most outstanding

Figure 11.4 Detail of ice-moulded bedrock near Loch Coruisk showing glacially abraded and smoothed stoss slopes and localized joint-block removal. (Photo: D. G. Sutherland.)

features of their type in Britain (Ballantyne, 1991b).

Interpretation

The Cuillin is an area of spectacular scenery which owes its striking impact to the outstanding development of features of glacial erosion. It represents probably the single most intensive area of mountain glacier erosion in Britain. Within Scotland the Cuillin represent the classic development of corrie, arête, rock step, ice-moulded bedrock and glaciated-valley landforms typical of the zone of high-intensity glacial erosion of western Scotland (see Chapter 2), and in this respect rank ahead of even such areas as An Teallach, Rum and the mountains of North Arran, where excellent features of glacial erosion are also present. The intensity of erosion of the Cuillin contrasts markedly with that of the mountains in the central and eastern Highlands, such as the Cairngorms and Lochnagar, where more extensive elements of the pre-glacial landscape have survived and the dominant landform pattern is the equally distinctive one of selective glacial erosion. Elsewhere in Britain the area most comparable to the Cuillin is North Wales, where glacial erosion has left a strong imprint on the landscape (see Campbell and Bowen, 1989). Nevertheless, the Cuillin remain pre-eminent, particularly for the fine detail, compactness and overall impact of the geomorphology. Although the Lake District has fine landforms of glacial erosion, many classic in their own right, the overall intensity of glacial erosion there has been less.

Historically, the Cuillin have played a significant role in the study of glacial erosion, beginning with the work of Forbes (1846) and continued through that of Harker (1901), and Lewis (1938, 1947) to the recent investigations of Haynes (1968, 1969) and Dale (1981). These studies, which have provided textbook examples and laid the foundation for modern developments, have been essentially complemented by the important historical work on glacial erosion in North Wales (see Campbell and Bowen, 1989).

The Cuillin are also important in the evidence they provide for the development of local glaciers during the Loch Lomond Stadial. This evidence has allowed the reconstruction of a number of corrie glaciers and a central mountain ice-field, together with the associated palaeoclimatic controls. This has provided important insights into climatic conditions during the stadial and has raised questions about the nature of the glacier dynamics which have potentially wide-ranging implications (Ballantyne, 1989a): first, deformable-bed models of glacier dynamics may apply to relatively small glaciers and ice-caps as well as to large ice-sheets, and second, where such conditions pertain, they provide additional constraints on palaeoclimatic reconstructions derived from glacier–climate relationships.

Finally, the excellent assemblage of depositional landforms, particularly the fluted and hummocky moraine, has significant potential for studies of glacial sedimentation and styles of deglaciation (cf. Benn *et al.*, 1992), for example in comparison with the assemblages of hummocky moraine types at Coire a'Cheud-chnoic, the Cairngorms and Loch Skene.

Conclusion

The Cuillin is an area of outstanding importance for glacial geomorphology. It is a classic locality for landforms of glacial erosion and has played an important part in the development of ideas in this field. The features of erosion, many among the best of their kind in Britain, are notable in spanning a range of scales, from corries and arêtes to ice-moulded and striated bedrock surfaces. The area is also of great interest for a fine assemblage of morainic landforms produced by Loch Lomond Readvance glaciers (approximately 11,000–10,000 years ago).

SCARISDALE

J. M. Gray

Highlights

The bedrock surfaces exposed on the coast at Scarisdale demonstrate the best examples in Britain of p-forms, small-scale features produced by a combination of meltwater and glacial erosion.

Introduction

The Scarisdale site covers approximately a 3 km long stretch of coast on the southern shore of

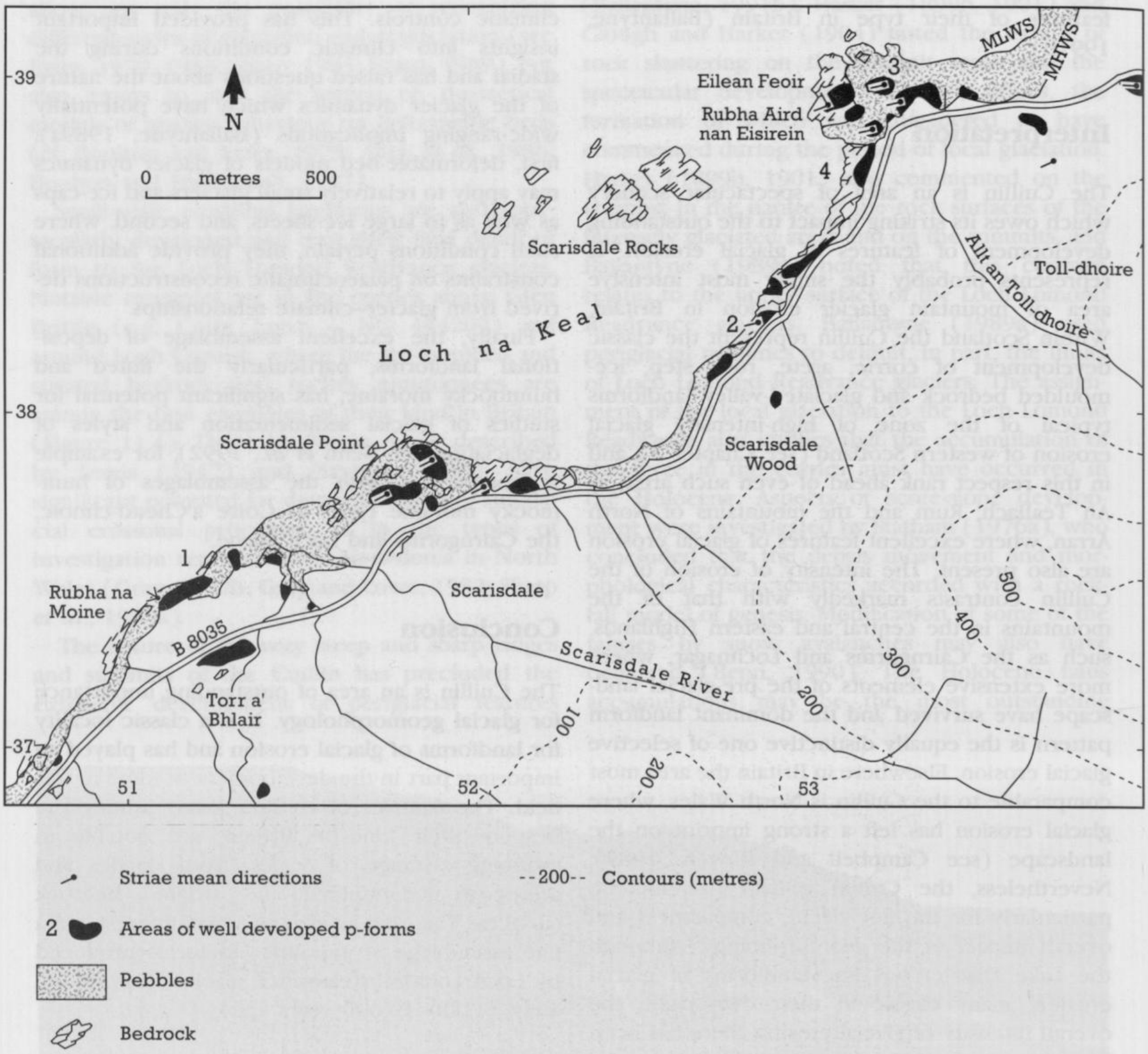


Figure 11.5 Scarisdale: localities with well-preserved p-forms (from Gray, 1981).

Loch na Keal on the Isle of Mull, between the head of the loch (NM 535389) and Rubha na Moine, about half way along the loch (NM 510372). The site does not have a long history of investigation. It was first noted by J. E. Richey in the Geological Survey Memoir for Mull (Bailey *et al.*, 1924, p.396) for a 'remarkable series of little striated hollows and winding grooves' eroded in the bedrock. Over 50 years later the site was reinvestigated by Gray (1981) who recognized the features as p-forms (cf. Dahl, 1965). He described them, mapped their distribution, and discussed their origin. He argued that no single genesis could explain all the characteristics of the p-features and instead suggested that they were formed by meltwater erosion, but later striated by active ice moving through them (see also Gray, 1984).

Description

The landforms are best seen between low water mark and a few metres above high water mark, probably mainly due to the absence of masking sediment, soil and vegetation. They comprise an assemblage of small-scale, smooth depressions eroded in the Palaeogene basalt and have the appearance of plastically sculptured forms (p-forms) (Dahl, 1965). The p-forms occur on

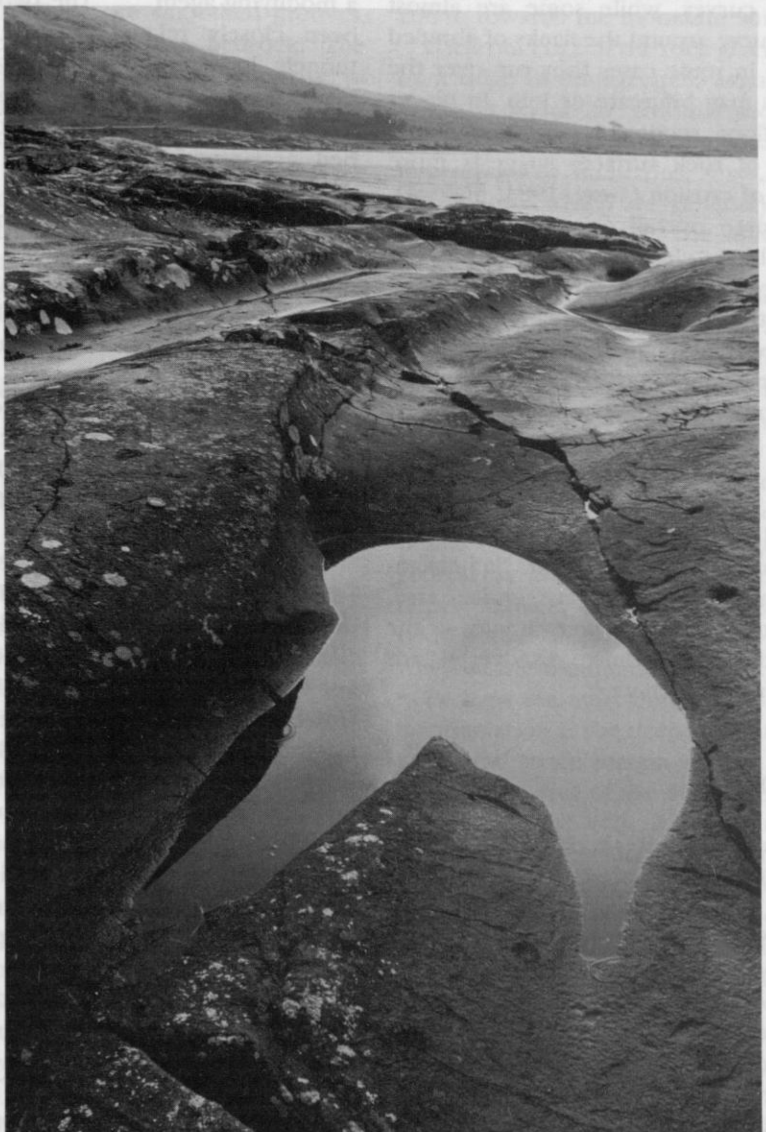


Figure 11.6 P-form channels at Scarisdale, Mull. (Photo: S. Campbell.)

flattish rock surfaces, but they have been cut irrespective of geological structure. Although p-forms occur along the entire length of the site there are areas where they are particularly common (Figure 11.5). The most impressive suites of features are at localities 1 and 2.

Although channels are by far the most abundant p-form type at Scarisdale, they are very variable in both size and morphology (Figure 11.6). The largest channel (at site 3) is about 3 m wide with steep side walls over 1 m high. It consists of a single curve about 12 m long with an undercut outer wall and smooth inner wall, both of which are covered with glacial striae that follow the curvature of the channel. At the other extreme, some channels are only 0.01 m or so deep and under 0.1 m wide. Occasionally, individual channels can be traced for over 20 m.

Channel sides vary from very gently sloping to vertical or even undercut. A particularly good example of undercutting (site 2) has a depth of 0.05 m, but the deepest undercut (site 3) is 0.1 m high. Asymmetrical cross-profiles are common, with the south (inland) slopes usually being the steeper. Most channels have rounded upper edges, although in several places sharp edges occur.

In plan, some channels are winding, others describe single curves, while some are almost straight. Some curve around the flanks of abraded hillocks, though in some cases they run over the crests. Channels may bifurcate or join. In places overdeepened floor sections occur and sometimes facetting of rock surfaces suggests more than one phase of erosion (Gray, 1981, plate 2).

The approximate overall orientations of 142 channels reveals a clear pattern, with 96% orientated between 50° and 90°E of N. This is consistent with the trend of Loch na Keal and the main striae direction. Where a number of channels with similar orientations occur together, the rock may take on a furrowed appearance (Gray, 1981, plate 7).

Other p-form types also occur at Scarisdale. Bowls are fairly common, most being under 2 m in diameter and only a few centimetres deep. A few larger examples are also present. 'Sichelwannen' (sickle-shaped troughs) are quite rare, although two exceptionally large examples occur (at sites 1 and 4). All those discovered are concave to the west-south-west.

Interpretation

The three most favoured theories for p-form formation are (1) glacial abrasion (for example, Boulton, 1974), (2) movement of water-soaked till (Gjessing, 1965) and (3) meltwater moving under high velocities (for example, Dahl, 1965). The main characteristics of the Scarisdale channels are most successfully explained by meltwater flow, which accounts particularly well for the sinuousity, overdeepened floors, undercut lips, sharp edges, facets, and asymmetrical cross-profiles of the channels. None of the p-forms explained in the literature by glacial abrasion or till squeezing has all these characteristics. On the other hand, turbulent meltwater flow cannot account for the regular striae on the walls and floors of the channels. Thus it has been suggested that a two-stage origin is likely. First, the channels were cut by turbulent, high-velocity meltwater flow probably involving corrasion and/or cavitation associated with current vortices. Subsequently, active ice moved through the channels striating their floors and sides (Gray, 1981, 1984). This explanation had previously been proposed by J. E. Richey (*in* Bailey *et al.*, 1924) when first describing the Scarisdale site – 'the hollows are almost certainly potholes; the winding channels stream courses. Ice has been merely a modifying agent . . .'. The two phases may have been closely related in time since subglacial tunnels kept open by meltwater flow would probably close if the flow diminished or shifted, allowing active ice to come into contact with the bed.

Although not accepted by all workers such ideas have gained wide acceptance in Canada, where research is leading to a realization of the importance of meltwater as a subglacial erosional agent (see Sharpe, 1987). Shaw (1988) and Sharpe and Shaw (1989) have described comparable features from Ontario and Quebec and emphasized the important role of turbulent subglacial meltwaters in their formation. They suggested that the glacier was decoupled from its bed during periodic subglacial floods, then subsequently reattached.

Other British p-form sites occur on the Isle of Islay (Gray, 1984), the Isle of Seil (J. M. Gray, unpublished data), the shore of Loch Treig (see Glen Roy and the Parallel Roads of Lochaber), and in Snowdonia (Gray and Lowe, 1982). However, the Scarisdale site represents the best assemblage of p-forms in Britain. The site is important since the characteristics of the features may be used to test the various hypotheses proposed to explain the formation of such smooth depressions. In particular, the wider importance of glacial meltwater as a subglacial erosional agent is suggested, especially in association with subglacial floods.

The significance of subglacial meltwater in understanding both subglacial erosion and glacier dynamics at both large and small scales has become increasingly apparent (for example Bindschadler, 1983; Kamb *et al.*, 1985; Drewry, 1986; Röthlisberger and Lang, 1987). Sites such as Scarisdale potentially provide important field evidence for reconstructing former subglacial drainage systems on bedrock and their hydrological characteristics (for example, see Hallet and Anderson, 1980; Sharpe and Shaw, 1989; Sharp *et al.*, 1989b). Such reconstructions would not only allow field testing of theoretical models of glacier hydrology, but would also provide valuable insights into the local dynamics of Pleistocene glaciers.

Conclusion

Scarisdale is the best example in Britain of an assemblage of small-scale features of erosion known as p-forms. These are smoothed grooves, channels and scalloping in the bedrock. The range of features present and their clarity of detail provides an unrivalled opportunity to test the different explanations proposed for their origin. The most likely of these is that they were formed by a combination of glacial meltwaters and moulding by overlying glacier ice, and therefore they may allow a reconstruction of aspects of glacier hydrology.

BEINN SHIANTAIDH

A. G. Dawson

Highlights

This site is of geomorphological interest for one of the best examples in Scotland of a fossil rock glacier formed at the base of a talus accumulation. It is believed to have been active during the Loch Lomond Stadial and provides information about slope processes and environmental conditions at that time.

Introduction

The site (NR 521749) is located on the island of Jura at the foot of the eastern slopes of Beinn Shiantaidh, one of the Paps of Jura. It is notable for one of the most spectacular fossil rock glaciers in Scotland. The only detailed account of the feature is given in Dawson (1977).

Description

The rock glacier consists of a lobate accumulation of poorly-sorted quartzite debris and has an area of 0.045 km^2, the maximum width along the foot of the hill being 380 m and the maximum length 180 m (Figure 11.7). It is located between 355 m and 400 m OD on the margin of the exposed col that separates Beinn Shiantaidh (755 m OD) from its neighbouring summit Corra Bheinn (569 m OD). The constituent boulders, many of which exceed 0.5 m in diameter, are arranged in a nested series of arcuate ridges and depressions which terminates in a sharply defined frontal margin. On the eastern margin of Beinn Shiantaidh, above the mass of debris, a talus of angular quartzite blocks rises by as much as 200 m towards the mountain summit.

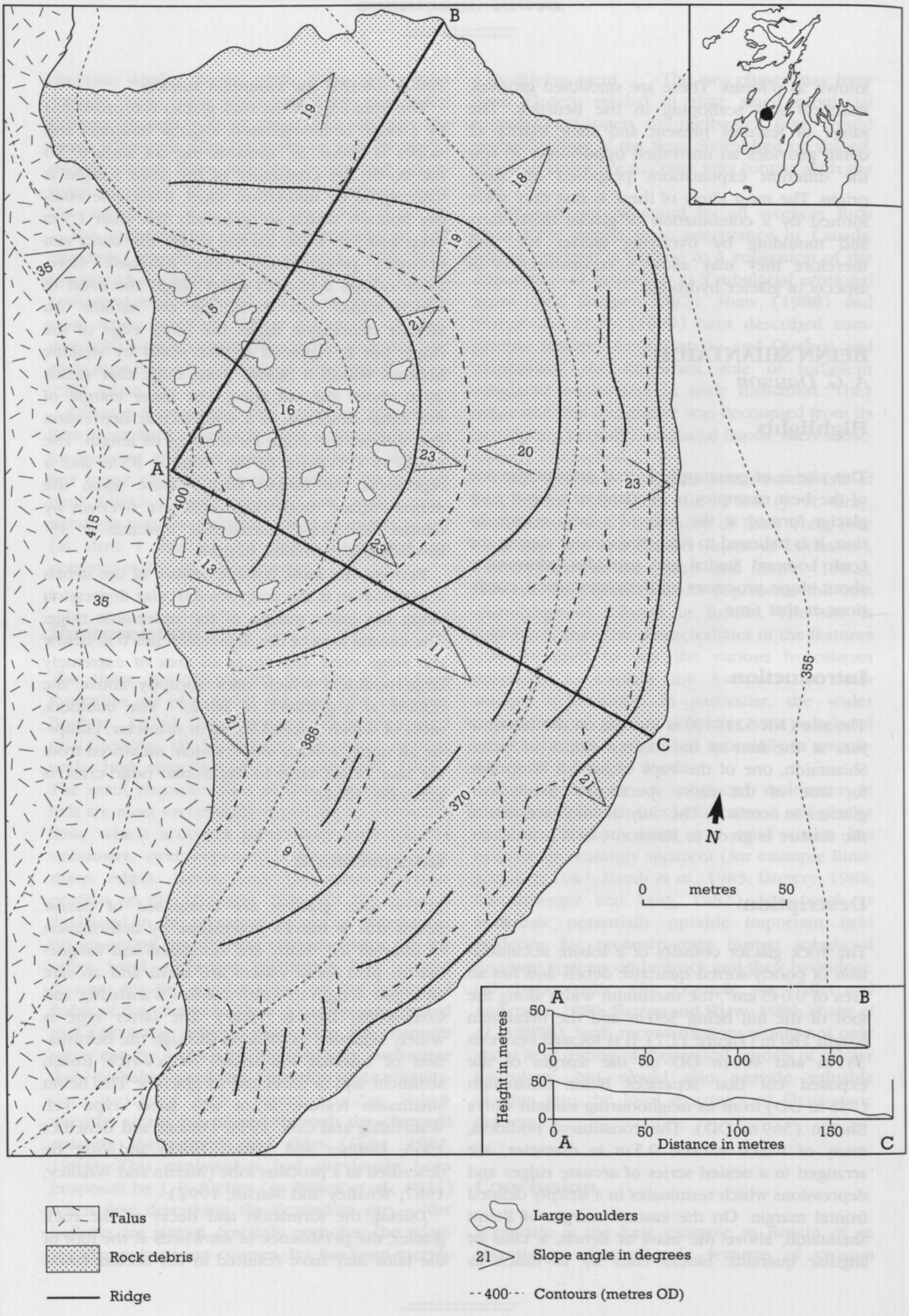
The front edge of the rock glacier is represented by a ridge of unvegetated, angular boulders and slopes at about 20° towards the col surface. To the north, the continuity of the front margin is interrupted by numerous, small, transverse boulder hollows which are generally less than 1.5 m deep and 3 m wide. To the south, the outer rim becomes progressively more subdued. Here, there occurs a distinct outer ridge, the crest of which stands 5 m above the col surface. An arcuate depression flanks the inner edge of the ridge, but is replaced farther north by shallow hollows within a higher front ridge that stands 20 m above the col floor. The inner margin of this ridge descends to a semicircular depression that follows the ridge for most of its length. The radius of curvature of the ridge is 85 m and it represents the largest such feature upon the debris surface. Both ridge ends are overlain by taluses that slope consistently upwards at 35° towards the mountain summit.

Perhaps the most notable feature of the debris accumulation is the deep semicircular depression along the inner margin of the outermost ridge. The central area of the depression lies 6 m below the ridge crest and abuts an area of extremely large boulders which rises abruptly above the hollow at a gradient of 20–25°. The boulders, most of which exceed 0.5 m in diameter, comprise an upper surface slope which, measured from the base of the talus to the frontal ridge crest, is generally 10–16°.

Interpretation

Active rock glaciers are composed of coarse debris that is moved downslope by deformation of internal ice. Many are elongated and tongue-like in plan form; others are small and arcuate with low length-to-width ratios (Wahrhaftig and Cox, 1959; Barsch, 1969). The latter type is widely regarded as forming through the deformation of internal ice lenses or ice-rich frozen sediment and is unrelated to glaciers. The Beinn Shiantaidh feature is of this latter type (cf. Wahrhaftig and Cox, 1959; Outcalt and Benedict 1965; Lindner and Marks, 1985) and may be described as a protalus lobe (Martin and Whalley, 1987; Whalley and Martin, 1992).

During the formation and decay of the rock glacier, the persistence of snowbeds at the foot of the talus may have resulted in the accumulation



A
B
C
N
0
metres
50
400
415
385
370
355
35
19
18
15
21
16
23
20
13
11
9
Height in metres
Distance in metres
100
150
Talus
Rock debris
Ridge
Depression
Large boulders
Slope angle in degrees
Contours (metres OD)
Section line

of small protalus ramparts that were incorporated within the rock glacier. Indeed, in front of the talus slope that flanks the high north-facing buttress of Beinn Shiantaidh there is an arcuate ridge, 50 m long and composed of angular boulders, that was interpreted by Dawson (1977) as a fossil protalus rampart that formed contemporaneously with the rock glacier.

The east-north-east aspect of the fossil rock glacier would appear to have favoured the accumulation and persistence of snow and ice. Its development may have been assisted by the presence of permafrost which is thought to have last occurred in Scotland during the Loch Lomond Stadial (Sissons, 1974c). Although permafrost may not have been essential if the debris cover was sufficient to insulate the internal snow and ice, it is nevertheless reasonable to infer that the feature was formed (or at least last active) at that time.

Dawson (1977) estimated that the average rate of debris supply to the rock glacier from the cliffs upslope during the stadial was about 185 m^3a^{-1}, assuming a maximum duration of 1000 years for the period of formation. He also calculated that the average cliff retreat rate behind the rock glacier was approximately 9 mma^{-1}. This inferred cliff retreat rate is much larger than cliff retreat rates that can be inferred for other locations in Scotland during the Loch Lomond Stadial (Ballantyne and Kirkbride, 1987).

It is not known with complete certainty, however, that the material comprising the Bheinn Shiantaidh rock glacier was produced entirely during the cold climate of the Loch Lomond Stadial. For example, it is entirely possible (although not proven) that talus production on the slopes of Bheinn Shiantaidh may have commenced during ice-sheet deglaciation (cf. Chattopadhyay, 1984; Wilson, 1990a, 1990b). Under such circumstances the inferred rates of cliff retreat and talus production would be significantly lower than stated above.

The Bheinn Shiantaidh fossil rock glacier is one of the few such landforms in Great Britain and it represents a classic example of the lobate type (compare with Beinn Alligin). The almost complete lack of vegetation cover makes the detailed surface morphology resulting from former debris flowage particularly clear and impressive. The rock glacier is also potentially of palaeoclimatic significance, possibly indicating the former presence of permafrost in the mountains of the Inner Hebrides, probably during the Loch Lomond Stadial. If this is confirmed, it corroborates other lines of evidence of permanently frozen ground at low levels in western Scotland (Sissons, 1974c, 1976b). Similar landforms occur on granite in the Cairngorms (Sissons, 1979f; Chattopadhyay, 1984; Maclean, 1991), but at much higher altitudes (*c.* 800–1000 m OD). Although smaller, the Beinn Shiantaidh rock glacier also resembles the excellent examples on quartzite at altitudes of 150–400 m OD on Errigal Mountain and Muckish Mountain in County Donegal in north-west Ireland (Wilson, 1990a, 1990b). Together, such sites provide an opportunity to assess the relative roles of climate and debris supply factors in rock glacier (protalus lobe) formation.

Figure 11.7 The Beinn Shiantaidh rock glacier (from Dawson, 1977).

Conclusion

Beinn Shiantaidh provides one of the best examples in Scotland of a 'rock glacier' formed at the foot of a scree slope. This lobate landform developed through the slow deformation of ice that formed within the scree during the cold climatic conditions of the Loch Lomond Stadial (about 11,000–10,000 years ago). The feature is important in demonstrating geomorphological processes during the stadial, and its presence may support the suggestion that permanently frozen ground existed at relatively low altitudes at that time in western Scotland.

WESTERN HILLS OF RUM

C. K. Ballantyne

Highlights

This upland site is important for an assemblage of periglacial landforms developed on different rock types in an exposed maritime environment and includes both active and fossil features.

Introduction

The Western Hills of Rum, Sròn an t-Saighdeir (NM 323989), Oryal (NM 334991) and Ard Nev

(NM 346986), do not exceed 571 m OD in altitude and occupy an area of only 5 km^2. However, they contain a remarkable assemblage of periglacial landforms, including some of the few examples of large-scale patterned ground known on Scottish mountains (Clark, 1962; Godard, 1965; Ryder, 1968, 1975; Ryder and McCann, 1971; Ballantyne and Wain-Hobson, 1980; Ballantyne, 1984). As the Late Devensian ice-sheet apparently overrode these hills (Harker, 1908; Charlesworth, 1956; Clark, 1962; Peacock, 1976), all of the features present post-date its downwastage, and the formation of large-scale periglacial forms can be attributed to the operation of periglacial processes during ice-sheet decay or the Loch Lomond Stadial. During the latter, two small glaciers occupied corries on the north side of these hills (Peacock, 1976; Ballantyne and Wain-Hobson, 1980). Small-scale periglacial forms including sorted stripes and circles are active at present.

Description

The Western Hills are underlain by acid igneous rocks and basalts and have broad, rounded outlines. Lithology has been of paramount importance in determining the nature of the frost-weathered regolith on the high ground. The microgranite of Sròn an t-Saighdeir has yielded the openwork, clast-supported, 'Type 1' regolith of Ballantyne (1981, 1984), whereas the basalt of Orval and, to some extent, the granophyre of Ard Nev have weathered to produce matrix-supported, 'Type 3' regolith. This latter type has a sufficient proportion of silt and fine sand to make the detritus frost-susceptible, so that periglacial features dependent upon ice-segregation for their formation occur on the last two hills.

Relict periglacial features are best represented on the Type 1 regolith of Sròn an t-Saighdeir, which is almost entirely covered by an openwork blockfield of large angular boulders (Figure 11.8). The blockslopes that surround the summit are partly vegetation-covered; they descend westwards to an altitude of only 270 m OD, where they terminate at sea cliffs. The lack of bedrock outcrops testifies to the susceptibility of the well-jointed microgranite to large-scale frost wedging, as does the remarkable cover of frost-shattered rocks in the corrie north of Sròn an t-Saighdeir. Former solifuction on these slopes has resulted in the formation of terraces and lobes of large boulders (Ballantyne and Wain-Hobson, 1980). On the summit plateau the blockfield detritus has been frost-sorted into circles 2–3 m in diameter and, on gentle slopes, into stripes of similar width. Sorted features of this size are generally regarded as indicative of permafrost conditions (Williams, 1975; Goldthwait, 1976).

The basalt and granophyre regoliths on Orval and Ard Nev support a completely different suite of periglacial features. On these hills, frost weathering has produced fine as well as coarse material and, where wind has stripped the vegetation cover, active sorted circles and polygons up to 0.5 m in diameter have developed under present conditions (Figure 11.8) (Ryder, 1975; Ballantyne and Wain-Hobson, 1980). Active sorted stripes 0.2 m in width are found on nearby slopes. Although the boulder sheets and lobes that occupy the gentler slopes around these hills are apparently inactive, the presence of 'ploughing' boulders (Figure 11.8) indicates that limited solifuction is still taking place.

Interpretation

There is a notable contrast between the debris-mantled slopes and blockslopes that fringe much of the Western Hills and the bedrock slopes partly covered by active talus within the limits of the two Loch Lomond Readvance glaciers in the corries on the northern face of Sròn an t-Saighdeir (Ballantyne and Wain-Hobson, 1980). This implies that the production of almost all of the frost-weathered debris pre-dates the Holocene. It is possible that much of the debris was formed during the decay of the Late Devensian ice-sheet, as the Rum hills may have been deglaciated at a time when the climate was still severe (see Sissons, 1983c; Sutherland, 1984a). However, the final morphology of the relict periglacial features developed on such debris probably reflects cryogenic activity during the Loch Lomond Stadial (Sissons, 1976b, 1983b).

Kotarba (1984) has also noted that major slope processes have been relatively inactive during the Holocene and that slow mass movements have been dominant on the slopes of the western Rum hills. According to Kotarba (1987) this contrasts with the situation in the Cairngorms, where high-magnitude processes have been more common.

The Western Hills of Rum support one of the most varied assemblages of fossil and active periglacial features of any Scottish mountain. The

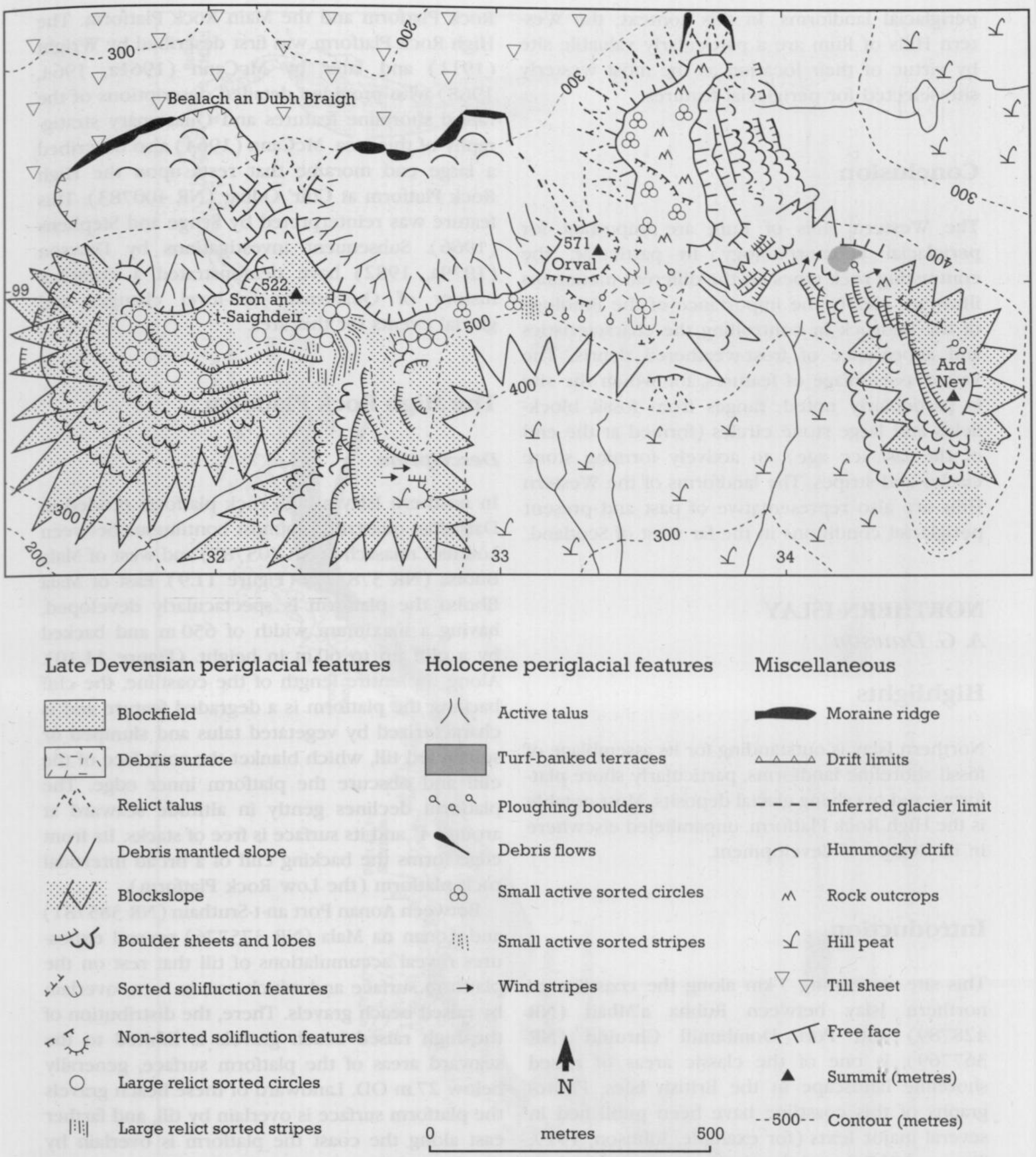


Figure 11.8 Periglacial features on the Western Hills of Rum (from Ballantyne, 1984).

types of landforms occur at apparently low altitudes by comparison with similar features on the mountains on the mainland (see An Teallach, Ben Wyvis and the Cairngorms) but, as Ballantyne (1984, 1987a) has demonstrated, this is part of a general pattern in the decline in altitude westwards of periglacial features across the Scottish Highlands and Islands. The reasons for such a decline relate to both past and present climatic variation and the limits of former glaciers, and emphasize the role of a network of national sites in understanding the genesis of periglacial landforms. In this context, the Western Hills of Rum are a particularly valuable site by virtue of their location as the most westerly site selected for periglacial features.

Conclusion

The Western Hills of Rum are important for periglacial geomorphology. In particular, the contrasting rock types on the different mountains illustrate clearly the importance of the lithology of the bedrock in controlling the characteristics and appearance of frost-weathered debris. The varied assemblage of features, for which the site is particularly noted, ranges from fossil blockfields and large stone circles (formed at the end of the last ice age), to actively forming stone circles and stripes. The landforms of the Western Hills are also representative of past and present periglacial conditions in the far west of Scotland.

NORTHERN ISLAY

A. G. Dawson

Highlights

Northern Islay is outstanding for its assemblage of fossil shoreline landforms, particularly shore platforms, and overlying glacial deposits. Most notable is the High Rock Platform, unparalleled elsewhere in its degree of development.

Introduction

This site, extending 7 km along the coastline of northern Islay between Rubha a'Mhàil (NR 428789) and Port Domhnuill Chruinn (NR 367769), is one of the classic areas of raised shoreline landscape in the British Isles. Photographs of this coastline have been published in several major texts (for example, Johnson, 1919; Sissons, 1967a), and the Quaternary geomorphology of this area has been extensively discussed (Wright, 1911; McCann, 1961a, 1964, 1968; Synge and Stephens, 1966; Dawson, 1979a, 1982, 1983a, 1983b).

The coastal zone of northern Islay is dominated by a spectacular, high, coastal rock platform and cliff (the High Rock Platform). In addition, two other shore platforms are present, the Low Rock Platform and the Main Rock Platform. The High Rock Platform was first described by Wright (1911) and later by McCann (1961a, 1964, 1968) who provided detailed descriptions of the raised shoreline features and Quaternary stratigraphy of this area. McCann (1964) also described a large end moraine that rests upon the High Rock Platform at Coir' Odhar (NR 400783). This feature was reinterpreted by Synge and Stephens (1966). Subsequent investigations by Dawson (1979a, 1982) have demonstrated a complex history of Quaternary sea-level changes and glacial events for this area.

The High Rock Platform

Description

In northern Islay a high rock platform eroded in Dalradian quartzite is almost continuous between Lòn na Cnuasachd (NR 405787) and west of Mala Bholsa (NR 378777) (Figure 11.9). East of Mala Bholsa the platform is spectacularly developed, having a maximum width of 650 m and backed by a cliff up to 60 m in height. (Figure 11.10). Along the entire length of the coastline, the cliff backing the platform is a degraded feature and is characterized by vegetated talus and slumped or soliflucted till, which blanket the rock face of the cliff and obscure the platform inner edge. The platform declines gently in altitude seaward at around 4° and its surface is free of stacks. Its front edge forms the backing cliff of a broad intertidal rock platform (the Low Rock Platform).

Between Aonan Port an-t-Sruthain (NR 385781) and Aonan na Mala (NR 375776) several exposures reveal accumulations of till that rest on the platform surface and which are, in turn, overlain by raised beach gravels. There, the distribution of the high raised beach gravels is limited to the seaward areas of the platform surface, generally below 27 m OD. Landward of these beach gravels the platform surface is overlain by till, and farther east along the coast the platform is overlain by the Coir' Odhar moraine (Figure 11.9).

Owing to the presence of drift deposits on the platform, its inner edge is only visible at six locations along stream channels and on the sides of geos. The altitudes (from 32.1 to 34.9 m OD) measured at these six locations indicate only minor variations in platform altitude and are similar to the values (32.1 m and 34.1 m OD) obtained for the west coast of Jura High Rock

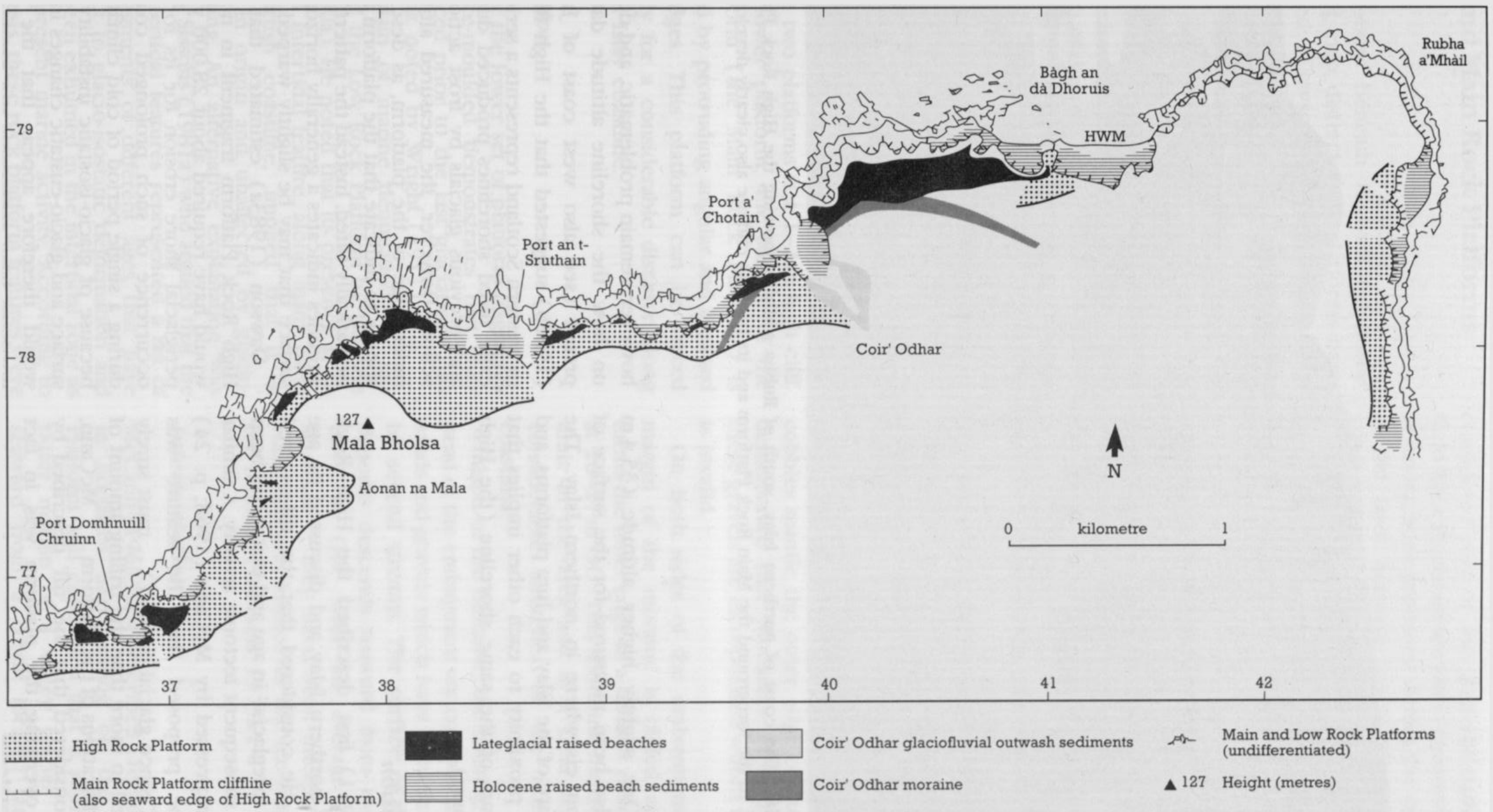


Figure 11.9 Geomorphology of northern Islay between Rubha a'Mhàil and Port Domhnuill Chruinn.

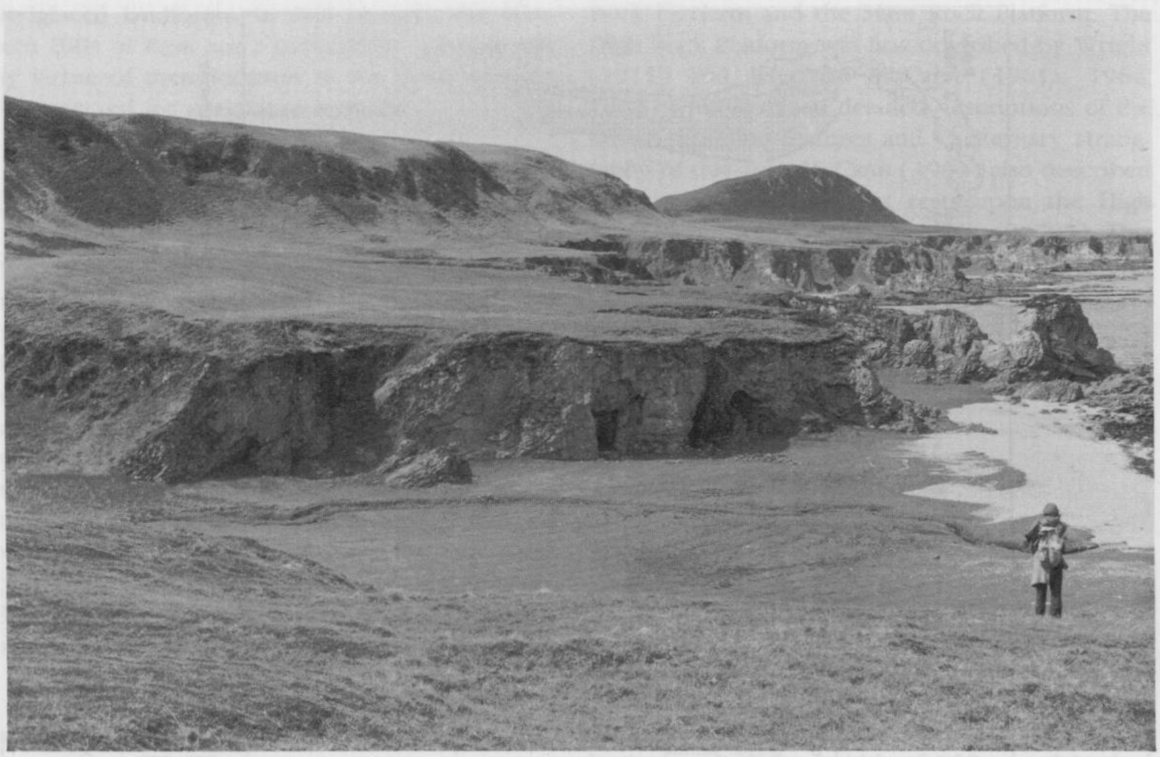


Figure 11.10 The coast of northern Islay, south of Rubha a'Mhàil, showing the High Rock Platform and its backing cliff. In the foreground the Main Rock Platform and its backing cliff are also clearly developed. (Photo: J. E. Gordon.)

Platform. One slightly higher altitude (35.4 m OD) has also been measured for the surface of the platform elsewhere in northern Islay. The similar nature of the Islay and Jura platforms, and their close proximity to each other implies that they are part of the same shoreline (the High Rock Platform).

Interpretation

Wright (1911) first described the High Rock Platform of northern Islay and discussed its age and origin. He considered that the till-covered feature was 'preglacial' in age and that it had been affected by subsequent tectonic activity. A similar view was expressed by McCann (1968, p. 24) although he proposed that the feature was 'interglacial' since glacial erosion '. . . must surely have resulted in more than the trifling amount of surface modifications of the platform . . .'. McCann, however, considered that the 'till' described by Wright as overlying the platform was in fact soliflucted material.

The origin and age of the High Rock Platform, however, remain problematic, and depend largely on how the shoreline altitude data are interpreted (see also west coast of Jura). Sissons (1982b) suggested that the High Rock Platform in western Scotland represents a series of isostatically tilted shorelines produced during the last and previous glacials by frost action and wave action. However, the measured altitudes of the inner edge of the platform, as described above, appear to indicate that the platform is not glacio-isostatically tilted. Instead the pattern of measured altitudes indicates a generally horizontal platform surface that may be slightly warped.

Dawson (1983a) estimated that the widest High Rock Platform fragment in northern Islay would have required about 28,000 years of rapid periglacial shore erosion for its formation. The occurrence of such prolonged coastal erosion during a single period of cold climate is unlikely because of glacio-isostatic instability of the land surface and glacio-eustatic changes in sea level. It would therefore appear that the platform in northern Islay represents the product of several periods of shore erosion during the Pleistocene.

The Low and Main Rock Platforms

Description

On the foreshore beneath Rhuvaal lighthouse (NR 426792), two distinct rock platforms have been reported (Dawson, 1979a, 1980a). Both platforms occur in the intertidal zone but are markedly different not only in width, but also in morphology. The lower is the more conspicuous and forms an almost continuous feature along the northern Islay coastline. This platform is generally 100 m wide and in the Coir' Odhar embayment reaches a maximum width of almost 300 m. With the exception of the area near Rhuvaal lighthouse this platform is terminated landwards by quartzite cliffs, generally 30–35 m in elevation. In addition, its smooth ice-moulded surface and its considerable width strongly suggest that it forms part of the similar feature described in south-west Jura.

At Rhuvaal, however, the inner edge of the lower platform is separated from the main cliff by a second shore platform, which is 20–25 m wide. Between the two platforms is a 1–2 m high cliff. Unlike the lower platform, the surface of the higher platform (the Main Rock Platform) is characterized by protruding angular and inclined quartzite ridges. This platform can be traced intermittently for a considerable distance along the northern Islay coastline.

Interpretation

The fact that the lower set of platform fragments has been ice-moulded demonstrates that they were produced prior to the last glaciation. This platform, first noted by Wright (1911) as a '... preglacial plain of marine denudation ...' has been termed the Low Rock Platform by Dawson (1979a, 1980a). He noted that its presence as an ice-moulded intertidal feature, along many parts of the Scottish coastline, implied that it is interglacial in origin and unaffected by glacio-isostatic tilting. An alternative explanation was proposed by Sissons (1981a) who argued that the glaciated intertidal features represented a set of platform fragments of different ages that have been subject to glacio-isostatic deformation and which has been exhumed in the intertidal zone as a result of present marine activity. According to this hypothesis, these rock platform features were initially produced by cold-climate shore erosion processes. The higher platform fragments are considered part of the glacio-isostatically tilted Main Rock Platform (see Isle of Lismore), regarded as having been produced during the cold climate of the Loch Lomond Stadial (Dawson, 1979a, 1980b) (but see Isle of Lismore). This shoreline, owing to its glacio-isostatic deformation, is generally considered to pass below sea level west of Mala Bholsa (Dawson, 1980b).

The Coir' Odhar Moraine

Description

The Coir' Odhar moraine forms two distinct north-west-facing arcuate ridges which are separated by a small embayment 200 m wide (Figure 11.9). On both sides of the embayment the ridges rest on the High Rock Platform.

Exposures in the eastern ridge (at NR 400785) reveal angular quartzite blocks embedded in a matrix of stiff, orange clay. The deposits, together with the morphology of the feature, indicate clearly that it is a moraine. Rounded raised beach cobbles mantle the outer edge of the ridge and demonstrate that McCann's (1964) view that these gravels are incorporated within the moraine is invalid.

On both sides of the embayment the outer margin of the moraine is cliffed and the cliff forms the inner edge of a distinct raised shoreline at 26–27 m OD. This shoreline forms the marine limit in the area and is a clear feature along considerable stretches of the northern Islay coastline.

Inland of the moraine, the backing cliffs at the head of the embayment are composed of stratified sands and gravels which have been deeply incised by several streams. The surface of the stratified deposits descends seaward from over 42 m to 26–27 m OD, with an average gradient of 40 m km^{-1}; they have been interpreted as outwash deposits formed as the ice retreated from the moraine (Dawson, 1979a).

Interpretation

McCann (1964) first described a terminal moraine in northern Islay resting on the High Rock Platform and concluded that it represented the outer margin of a valley glacier that flowed seaward from a corrie located farther inland (McCann, 1964. p. 5). He considered that, since raised beach deposits were apparently incorporated within the moraine, a readvance of ice had occurred in northern Islay that was contemporaneous with the Highland (Loch Lomond) Readvance identified by Charlesworth (1956). McCann (1964, p. 5) stated that '... the outer face of the morainic ridge at 77 ft (23.5 m) above high water mark is unmodified by marine erosion showing that the sea must have fallen below this level before the onset of the readvance of the ice'.

In direct contrast, Synge and Stephens (1966, p. 107–8) concluded that the moraine was '... one of a series of drift ridges deposited by the general glaciation on this coast ... the seaward edge of this 'moraine' is the erosion scarp, or cliff, of the Lateglacial marine limit. An accumulation of rounded beach gravels occurs at the foot of this small cliff at 90–99 ft (29.3–30.2 m) ... (the) marine limit along this stretch of coast is uniform in height, and uninterrupted by any later glacial phase'.

Dawson (1979a) agreed with Synge and Stephens and established that the outwash deposits, formed as ice retreated from the moraine, were graded to the raised shoreline at an altitude of 26–27 m OD. The Coir' Odhar moraine was therefore formed during the retreat of the main Late Devensian ice-sheet and was not of Loch Lomond Readvance age as proposed by McCann (1964). The raised shoreline at *c.* 26–27 m OD at Coir' Odhar was considered by Dawson (1982) to be contemporaneous with the Central Islay moraine: no other moraine systems have been correlated with the Coir' Odhar moraine.

Following the first account of the High Rock Platform of northern Islay by Wright (1911), Johnson's (1919) description of the feature in his standard textbook, *Shore Processes and Shoreline Development*, focused international attention on this coastal zone as a superb example of a raised shoreline landscape (cf. Dawson, 1991). Stratigraphic studies and accurate levelling have since demonstrated the complexity of Late Quaternary sea-level changes (including glacio-isostatic shoreline deformation) and glaciation history in this area (Dawson, 1979a, 1982), and although a considerable amount of detailed information is now available, the origins and ages of certain geomorphological features still remain controversial. Thus the origin and age of the High Rock Platform are the subject of considerable disagreement (see Sissons, 1982b; Dawson, 1983a, 1984). Moreover, Sissons (1981a) and Dawson (1980a) maintain opposing views on the nature of the Low Rock Platform. Finally, the Coir' Odhar moraine, although now firmly established as having been produced during deglaciation of the last ice-sheet, appears to be related to a glacial episode for which there is only limited evidence in western Scotland. To a large extent, the detailed discussions of these features have arisen from their superb development in the Northern Islay landscape. The area is thus of outstanding scientific interest both for the classic development of shore platforms and for the associated geomorphological and stratigraphic evidence, which together provide an important record of Late Quaternary sea-level changes and glacier fluctuations in western Scotland.

Conclusion

Northern Islay is outstanding for Quaternary coastal geomorphology, displaying some of the finest examples of isostatically uplifted raised shoreline features in Europe. These have been raised to their present levels above the sea by the uplift that followed the depression of the Earth's crust by the weight of ice-sheets during the ice ages. It is a classic locality for raised shore platforms, most notably the High Rock Platform of western Scotland. The superb development of raised coastal terraces, together with the presence of a moraine formed by the last ice-sheet (approximately 15,000 years ago), makes the area quite unique in Scotland.

WEST COAST OF JURA

A. G. Dawson

Highlights

The coastal area of western Jura contains a remarkable assemblage of raised shoreline landforms. These include shore platforms and the best-developed spreads of Lateglacial shingle ridges in Britain which provide valuable information for understanding changes in relative sea level. The area is also noted for a medial moraine formed by the Late Devensian ice-sheet.

Introduction

This site comprises a *c.* 37 km long stretch of the west coast of Jura, between Glengarrisdale Bay

(NR 659985) in the north, and Rubha Aoineadh an Reithe (NR 448751) in the south, and also a small area (*c.* 0.2 km^2) at Inver (NR 442724). It is one of the classic localities in Great Britain for raised coastal landforms, most notably spectacular unvegetated spreads of Late Devensian and Holocene raised beach shingle. The area also includes excellent examples of three raised shore platforms, the High Rock Platform, Main Rock Platform and Low Rock Platform. Also represented in Sgriob na Caillich (NR 475765) is the finest example of a medial moraine in Great Britain.

There is only a limited amount of published information on the Quaternary features of this area. The raised shingle spreads were first described by officers of the Geological Survey (Wilkinson, 1900, 1907; Peach *et al.*, 1911), and Ting (1936, 1937) gave further details of the ridges. The first major study of the raised beaches was by McCann (1961a, 1964), who sought to describe and explain the origin of the western Jura shingle spreads and relate them to patterns of Lateglacial relative sea-level change. In a later paper, McCann (1968) extended his discussion to include the raised coastal rock platforms. More recently, the raised shorelines of western Jura have been investigated in detail by Dawson (1979a). The results of this research are published in a number of later papers (Dawson, 1980a, 1980b, 1982, 1983a, 1984, 1988b, 1991).

High Rock Platform

Description

A high rock platform and associated cliffline are almost continuous between Shian Bay (NR 530875) and Ruantallain (NR 505833). In this area the platform has an average width of 350 m and in places is as wide as 600 m; the backing cliffs are typically 5–15 m high although they reach a maximum of 50 m at Loch an Aoinidh Dhuibh (Figure 11.11). The inner edge of the platform is only visible in two stream sections and hence the altitude of the feature is only known for these locations: north of Shian Bay (NR 53858915) at an altitude of 34.1 m OD and 150 m north of Bhrein Port (NR 50948415) at 32.1 m OD. Along this stretch of coastline the platform possesses an average seaward slope of about 4°, its gently sloping surface having provided an environment favourable for the later deposition of the overlying Late Devensian shingle spreads.

The western Jura platform pre-dates one period of general glaciation, since at two locations it is separated from the overlying raised beach sediments by lodgement till. First, at Bhrein Port (NR 50688405) 1 km north of Ruantallain, a wedge of orange lodgement till is embedded in a platform depression between two inclined ridges of quartzite and is overlain by thick accumulations of shingle. Second, on the banks of a stream channel 150 m north of Bhrein Port (NR 50948415) the inner edge of the platform is choked by 2.5 m of creamy lodgement till beneath shingle. Additional evidence for glaciation is the occurrence of an ice-moulded and striated bedrock sea stack immediately north of Loch a'Mhile (NR 51398501). It is also possible that the exceptionally low altitude of the platform surface at Shian Bay may be due to the effects of glacial erosion.

The rock platform described above is considered to correlate with the classic High Rock Platform of northern Islay (Dawson, 1979a). The High Rock Platform has not been found, however, along the intervening south-west Jura coast probably due to the presence in that area of great thicknesses of till.

Interpretation

The High Rock Platform of the southern Inner Hebrides (see also Northern Islay) was first described by Wright (1911). Although he did not describe the Jura platform, Wright considered that the platform was 'pre-glacial' in age. Later, McCann (1968) provided the first description of the western Jura platform and suggested instead that it was 'interglacial'. Dawson (1979a, p. 161) accepted an interglacial origin for the western Jura (and also the northern Islay) platform but considered that the shoreline had been warped by neotectonic activity. A contrary view was expressed by Sissons (1982b), who proposed that the platforms that comprise the High Rock Platform were produced by cold-climate shore erosional processes and that the features exhibit glacio-isostatic tilting. On that view, the various platform fragments are part of a series of tilted shorelines. However, the available altitudes from the west coast of Jura and northern Islay do not demonstrate any tilt to the platform, which is

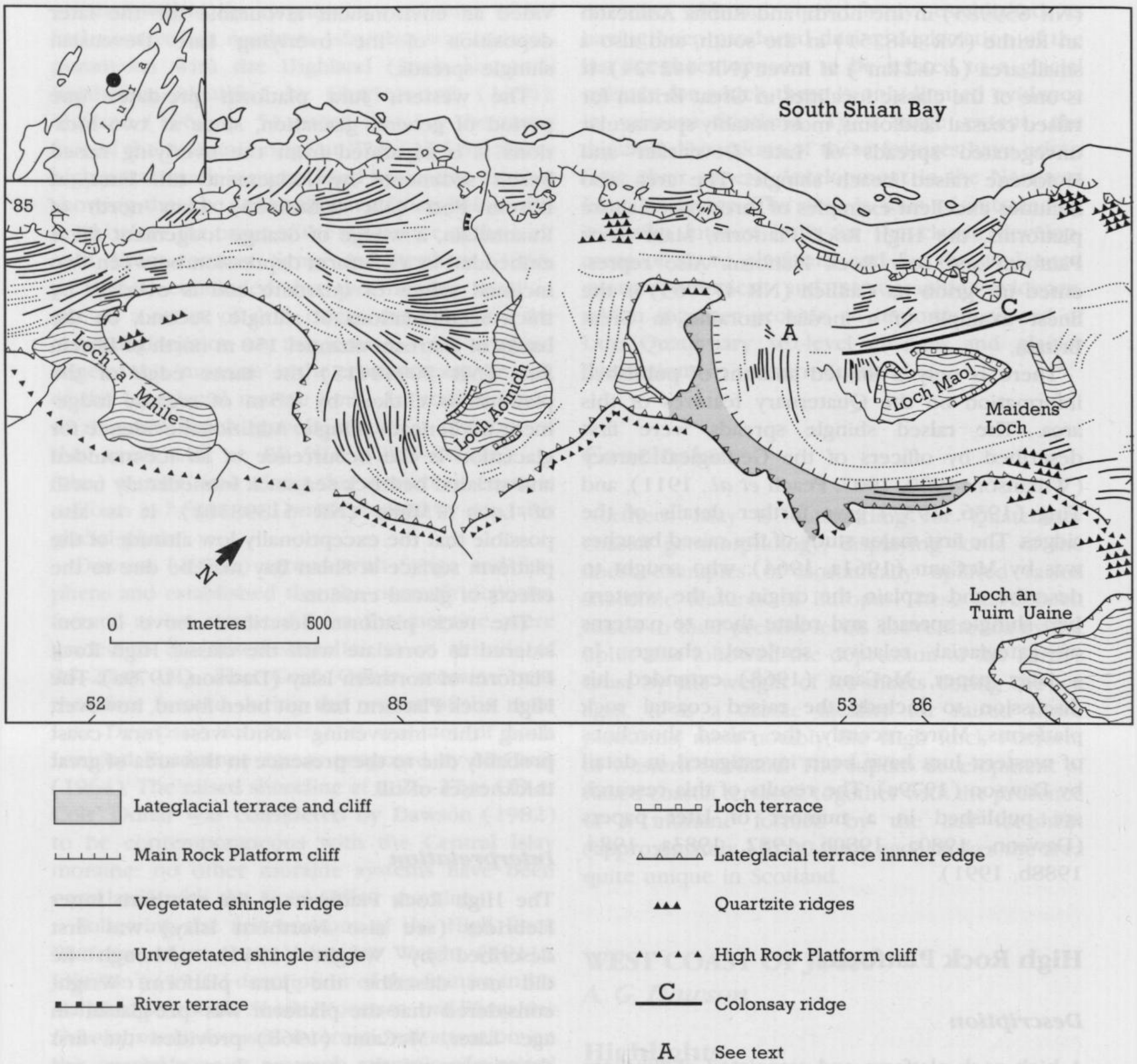


Figure 11.11 Geomorphology of western Jura in the area of South Shian Bay.

therefore regarded as a single feature. Thus there is at present no general agreement on their origin and age. Dawson (1983a) has argued on several grounds that formation of the western Jura platform by cold-climate shore erosion would have taken a minimum of 8000 years. Relative sea-level stability of such duration during a single period of cold climate is unlikely due to glacio-isostatic instability of the land surface and glacio-eustatic changes in sea level. It would therefore appear that the western Jura High Rock Platform represents the product of several periods of Pleistocene coastal erosion.

Main Rock Platform

Description

Between Shian Bay and Ruantallain the seaward edge of the High Rock Platform forms the cliffline of a lower platform 50–150 m wide (Figures 11.11 and 11.12). The inner edge of this platform occurs at 3–5 m OD. It is locally overlain by Holocene raised beach sediments and, along its length, the cliffline is indented by numerous raised sea caves. The platform is unglaciated and is characterized by inclined and jagged quartzite

Figure 11.12 View south along the west coast of Jura between Shian Bay and Ruantallain. Lateglacial shingle ridges extend across a high rock platform and to the west of Loch a'Mhile (centre). The loch was formerly a marine inlet prior to the deposition of the shingle ridges. Note also a prominent rock platform and backing cliff (the Main Rock Platform) seaward of the high shingle ridge 'staircases'. Holocene shingle ridges also cover the Main Rock Platform. (Photo: John Dewar Studios.)

ridges; the cliffs are typically crenulate and are usually 10–15 m high. The platform is also continuous between Shian Bay and Glendebadel Bay (NR 622951), where it is locally associated with cliffs up to 100 m high.

Interpretation

The platform constitutes part of a glacio-isostatically tilted shoreline that declines in altitude to the south-west, from 6 m OD in northern Jura to sea level in northern Islay (Dawson, 1980b). The shoreline gradient is $0.13\ \mathrm{m\,km^{-1}}$ and this, together with its rock-cut nature, general altitude and freshness of form, indicates correlation with the Main Rock Platform (Gray, 1974a, 1978a). McCann (1968) suggested that this feature exhibited evidence of glaciation, although Dawson

(1980b) did not report such evidence, and considered that McCann's evidence for glaciation related to the Low Rock Platform (see below). The origin and age of the Main Rock Platform in western Scotland have been discussed at great length in numerous publications (for example, McCann, 1968; Sissons, 1974d; Gray, 1978a, 1989; Dawson, 1979a, 1980b, 1983a, 1988a, 1989; Sutherland, 1984a). However, the occurrence of the regionally tilted Main Rock Platform in western Jura is of particular significance since it is in this area (and also northern Islay) that this platform merges with and crosses the regionally horizontal intertidal Low Rock Platform (Dawson, 1979a, 1980a) (see below).

Low Rock Platform

Description

In south-west Jura, low intertidal rock platform fragments are conspicuous along long stretches of coast. These are typically 100 m wide and are best developed on the foreshore between Rubh'-Aird na Sgitheich (NR 476793) and Allt Bun an Eas (NR 458763). At several locations, the continuity of the platform surfaces is interrupted by numerous Tertiary dolerite dykes. The platform surfaces are locally ice-moulded; throughout most of the area the platforms pass inland beneath till. Between Rubh'Aird na Sgitheich and Glenbatrick (NR 518801) the platform is overlain by considerable thicknesses (up to 15 m) of Late Devensian raised beach gravels.

Interpretation

Intertidal ice-moulded rock platforms also occur in north-west Jura, northern Islay and neighbouring Colonsay and were first described by Wright (1911) as representing a '... preglacial plain of marine denudation ...'. Dawson (1980a) referred to the Jura and Islay feature as the Low Rock Platform and explained its regional horizontality as having been produced by marine processes during interglacials. The shoreline is also of considerable significance since the glaciated platform fragments of south-west Jura, northern Islay and Colonsay were considered by McCann (1968) to demonstrate glaciation of the Main Rock Platform.

Late Devensian raised beaches

Description

The coastal zone of western Jura is dominated by conspicuous raised beach terraces and 'staircases' of unvegetated beach ridges, the widespread occurrence of which first attracted the attention of the Geological Survey (Wilkinson, 1900, 1907). Although discussed by Ting (1936, 1937), the most detailed studies of these raised coastal features are by McCann (1964, 1968) and Dawson (1979a, 1982).

In western Jura, raised coastal terraces can be traced almost continuously southward from Shian Bay as far as Inver (cf. Dawson, 1991, figure 5). Additional areas of raised coastal terrace occur at Corpach Bay (NR 568917) and Glendebadel. In most areas the raised marine deposits are ridges of unvegetated quartzite shingle (Figure 11.12). In western Jura the highest coastal terraces decline in altitude from north-east to south-west, from 40 m OD at Corpach Bay to 24.5 m OD at Inver. The raised beach terraces and shingle spreads were produced in association with the deglaciation of the Late Devensian ice-sheet in western Scotland and their altitudes reflect the effect of subsequent glacio-isostatic uplift.

Interpretation

Analysis of the regional altitude variations of the highest raised beach terraces on the western Jura coast suggest the existence of two shorelines. The older of these (shoreline L1) declines in altitude to the south-west, from 40 m OD at Corpach Bay to 34 m OD at Bàgh Gleann Righ Mór, 1.5 km east of Ruantallain. This raised shoreline is also thought to occur in northern Islay; it has a regional gradient of 0.56 m km^{-1} (Dawson, 1982). A separate and slightly younger shoreline (L2) is considered to be present in south-west Jura. This shoreline declines in altitude to the south-west, from 31 m OD at Glenbatrick to 24 m OD at Inver and has a regional gradient of 0.53 m km^{-1}. It was therefore inferred by Dawson (1979a, 1982) that south-west Jura remained ice-covered while shoreline L1 was formed between Corpach Bay and Shian Bay, and also on the northern Islay coastline. Dawson (1979a, 1982) also concluded that, owing to the drop in the marine limit between Corpach Bay and Glendebadel, north-west Jura was also ice-covered during this period. Deglaciation of south-west Jura took place at a slightly later date and was accompanied by the formation of shoreline L2.

The pattern of ridge-crest altitudes exhibited in the western Jura shingle 'staircases' indicates that, although stillstands may have occurred during the fall in the sea level from the marine limit, there were no major sea-level oscillations as relative sea level fell from near 35 m to 20 m OD. Most of the western Jura shingle spreads below this altitude terminate at the cliffline of the Main Rock Platform and consequently patterns of sea-level change lower than 20 m OD cannot be established. One exception, however, occurs at South Shian Bay, where owing to the exceptionally low altitude of the High Rock Platform, raised beach gravels descend to almost 11 m OD (Figure 11.11:A). McCann's (1964) proposal that a major sea-level oscillation is represented in this area by the Colonsay Ridge (a shingle spit) (Figure 11.11) may be correct and, if so, suggests that a pause in the overall fall in sea level occurred when relative sea level at South Shian Bay was at about 19 m OD (see Dawson, 1983a) (Figure 11.11). The other exception is at Lochan Maol an t-Sornaich (NR 547805) where a relative marine transgression is suggested, the sea rising from around 9 m to 14 m OD.

The presence on the west coast of Jura of extensive spreads of Late Devensian raised shingle is primarily due to the glacio-isostatic uplift of shoreline L1 and its altitudinal relationship with the till-covered High Rock Platform. Thus upon deglaciation, the maximum level of the sea along this stretch of coast (34–40 m OD) stood several metres higher than the inner edge of the High Rock Platform. Marine erosion of the till cover during the ensuing fall in relative sea level resulted in extensive shingle deposition. This process would have undoubtedly been promoted by the gentle seaward slope of the underlying platform surface and also by the exposure of the coastal zone to the effects of Atlantic waves.

The Sgriob na Caillich medial moraine

Description

On the western side of the Paps of Jura, there occurs perhaps the finest example of a fossil medial moraine in the British Isles (Dawson, 1979b). It is 3.5 km long and trends approximately NW–SE. It originates at 450 m OD at the western foot of Beinn an Oir (NR 498750) and descends gently to an altitude of 330 m OD before passing over the rock outcrop of Cnoc na Sgrioba (360 m OD). Seaward of this ridge, the boulder belts of the moraine lie on top of a thick till cover, until at 30 m OD, they are truncated by a low cliff and raised coastal platform, both of which are cut in till (Figure 11.13). At the junction of the till platform and the boulder belts is a small lochan (Loch na Sgrioba), impounded by a suite of raised shingle ridges which mantle the platform.

The boulder complex is composed in places of up to four parallel lines of angular blocks, each line rarely exceeding 27 m in width and 2.5 m in vertical thickness. The boulders in the belts, almost entirely of Dalradian quartzite (the local bedrock) though occasionally of slate and phyllite, bear no evidence of striation or ice moulding. They range from 0.2 m to 1.3 m in length and contrast markedly with the generally smaller quartzite blocks that are found in local till exposures. Additionally, the mean diameter of boulders measured at 500 m intervals along the feature decreases seaward by 0.07 m km^{-1}.

For most of its length the junction between each belt and the vegetation cover exhibits little variation in relief, though in places it is characterized by small boulder 'cliffs' up to 2 m in height. The main boulder belts are oriented parallel to each other; they are separate units which rarely merge. Coalescence of the belts is limited to the crest and flanks of Cnoc na Sgrioba, where the entire orientation of the feature changes slightly.

Interpretation

Dawson (1979b) argued that the medial moraine was produced during the waning of the Late Devensian ice-sheet. He suggested that the boulders of the moraine were deposited supraglacially from the Beinn an Oir nunatak on to a relatively thin, yet dynamically active, ice mass. Its preservation in the landscape as a series of unvegetated quartzite boulder belts is remarkable. Other medial moraines have been described from former Loch Lomond Readvance glaciers (see for example, Beinn Alligin). Only one similar feature, near Strollamus on Skye (Ballantyne, 1988; Benn, 1991), has been ascribed to the Late Devensian ice-sheet. No other medial moraines in Scotland

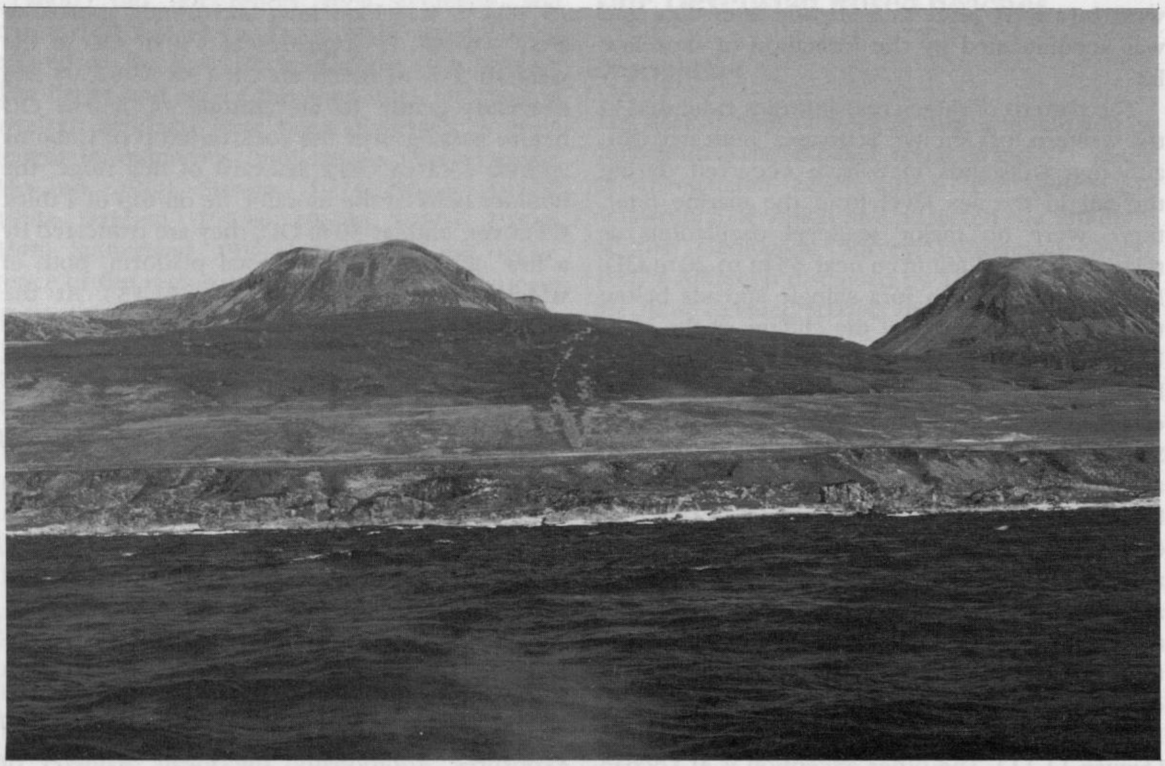


Figure 11.13 West coast of Jura. The Sgriob na Caillich medial moraine (centre) descends to the level of a high raised shoreline. (Photo: D. G. Sutherland.)

compare with Sgriob na Caillich in either size or complexity.

Holocene raised beaches

Description

Throughout western Jura, most Holocene beach accumulations mantle the rock surfaces of the Main and Low Rock Platforms. Relatively few raised coastal terraces are present and those that occur exhibit a gradual decline in altitude on Jura from near 10 m in the north-west to 8.5 m in the south-west. Most coastal areas, however, are characterized by banks of shingle and by shingle ridge 'staircases'. The most spectacular suite of Holocene shingle ridges occurs north of Inver, south-west Jura, where 31 unvegetated raised beach ridges descend from 12.3 m OD to the modern beach (Dawson, 1979a, 1991).

Interpretation

The highest ridge appears to have been produced during the culmination of the Main Postglacial Transgression. Hence the staircase of 31 ridges and intervening swales are likely to have been produced during the last 6000–7000 years, largely as a result of decreasing rates of glacio-isostatic uplift during this period.

Summary

The west coast of Jura is therefore outstanding for its assemblage of raised coastal landforms and deposits. Both the range of features and their extent and degree of development are exceptional. The interest includes not only examples of the three major rock platforms recognized in western Scotland, the High, Main and Low Rock Platforms, but also spreads of unvegetated Lateglacial and Holocene shingle beach ridges unparalleled elsewhere in Scotland for the length of their morphological record of sea-level changes. The latter features, in particular, distinguish the west coast of Jura from northern Islay (see above). Elsewhere in Scotland, there are notable sequences of raised shingle ridges at Spey Bay and Tarbat Ness on the Moray Firth coast (Ogilvie, 1923). Those at Spey Bay are comparable in their scale of development to the Jura features but occur in a different geomorphological process environment, being associated with a major river (the Spey) and significant longshore drift. Moreover, they have not been studied in comparable detail to the features on the west coast of Jura.

Conclusion

The coastline of western Jura is one of the classic localities in Britain for raised beaches (formed by isostatic uplift – see Northern Islay above). It is characterized by a variety of well-developed coastal landforms, of which the spectacular, unvegetated spreads of raised beach shingle (formed during the last 14,500 years) are without parallel in Britain and have allowed a detailed pattern of relative sea-level changes to be reconstructed. The area also includes excellent examples of raised platforms cut in bedrock as well as the finest example of a medial moraine in Britain, a ridge of boulders deposited by the last ice-sheet (approximately 15,000 years ago).

GRIBUN

M. J. C. Walker

Highlights

Pollen preserved in the sediments that infill a topographic basin at Gribun provide an unusually long and detailed record of Holocene vegetational history and environmental change. The sediments accumulated after the retreat of a Loch Lomond Readvance glacier, one of the lowest to have existed in Scotland during the Loch Lomond Stadial.

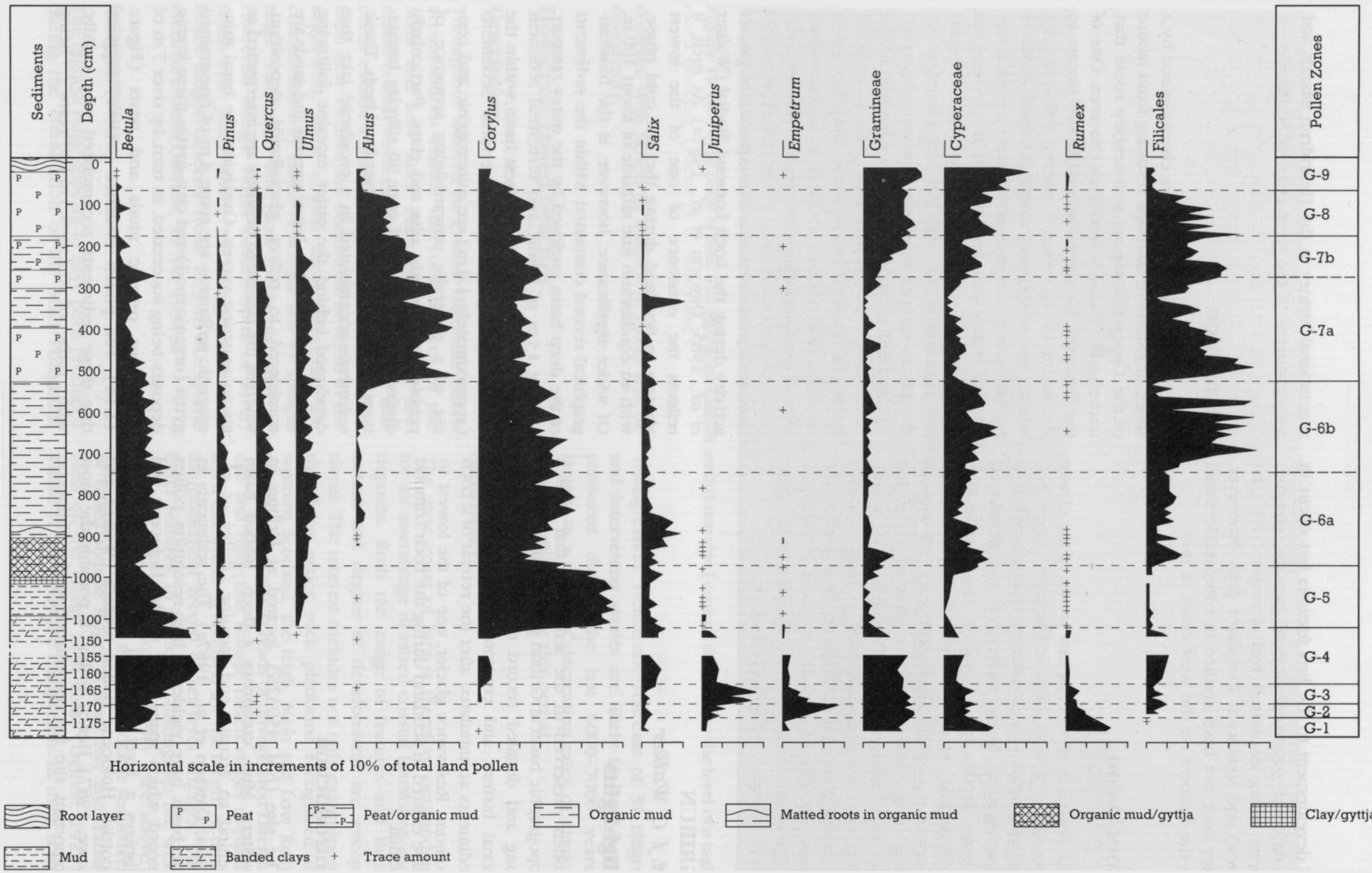
Introduction

The site (NM 450326), located at Gribun in western Mull, comprises a deep, infilled basin behind an arcuate end moraine (Bailey *et al.*, 1924; Dawson *et al.*, 1987a). The sediments in the basin have yielded a high-resolution pollen record which spans most of the Holocene and displays a level of detail seldom achieved in Scottish Holocene pollen profiles (Walker and Lowe, 1987). Hence Gribun is possibly the most important site for reconstructing the Holocene vegetational history in the Hebridean islands and adjacent areas of the west coast of Scotland.

Description

The coastal cliffs at Gribun are characterized by a series of extensive landslips resulting from failure of the Upper Cretaceous sedimentary rocks that underlie the Tertiary basalts in this area. One of the largest of the debris accumulations occurs to the south of Balmeanach Farm (NM 448329), where an impressive multiple-ridged, arcuate rampart composed of large boulders within a fine-grained matrix has developed at the foot of the Creag a'Ghaill escarpment. Deep, infilled basins are enclosed within the rampart complex. Although the arcuate ridge was originally described by the Geological Survey as '... a landslip of the completely disintegrated type, and accordingly might be claimed with some propriety as a moraine' (Bailey *et al.*, 1924, p. 414), a combination of geomorphological and sedimentary evidence confirms the view that the feature is an end moraine that formed as a consequence of glacier activity during the Loch Lomond Stadial (Walker *et al.*, 1985; Dawson *et al.*, 1987a). As such, it reflects the existence of one of the lowest glaciers in Scotland during the last cold phase, with an equilibrium line altitude of about 100 m. Of wider significance, however, is the biostratigraphical record contained within the sediments of the deep basin enclosed by the outer rampart.

Over 13 m of limnic and terrestrial sediment have accumulated in the largest basin within the morainic complex. The lowermost sediments (approximately 1.8 m) are minerogenic and consist of a generally upward-fining sequence of pebbles, grits, sands, silts and clays. Particularly distinctive is a series of over 90 silt/clay laminations which overlies the coarser basal beds. These sediments accumulated in a proglacial lake that developed behind the outer moraine following glacier recession. The lower gravels and sands are considered to reflect glaciofluvial deposition, whereas the laminated deposits are interpreted as glaciolacustrine varves. Overlying the basal minerogenic sediments are some 4 m of fine-grained gyttja (organic mud) and clay–gyttja, these limnic deposits being succeeded, in turn, by over 7 m of amorphous organic muds and peats (Figure 11.14). The pollen evidence (below) suggests that these sediments accumulated very rapidly, with rates of 0.2 m–0.3 m 100 years^{-1} being


Sediments
Depth (cm)
Betula
Pinus
Quercus
Ulmus
Alnus
Corylus
Salix
Juniperus
Empetrum
Gramineae
Cyperaceae
Rumex
Filicales
Pollen Zones
0
100
200
300
400
500
600
700
800
900
1000
1100
1150
1155
1160
1165
1170
1175
G-9
G-8
G-7b
G-7a
G-6b
G-6a
G-5
G-4
G-3
G-2
G-1
Horizontal scale in increments of 10% of total land pollen
Root layer
Peat
Peat/organic mud
Organic mud
Matted roots in organic mud
Organic mud/gyttja
Clay/gyttja
Mud
Banded clays
Trace amount

recorded for the middle Holocene; and even during the early Holocene, organic sediment was accumulating at about 0.04 m 100 years^{-1}. These are significantly higher rates of deposition than are usually encountered in Holocene pollen sites in Scotland.

Interpretation

The minerogenic sediments at the base of the Gribun profile contained too little pollen for counting, but nine local pollen assemblage zones were identified in the overlying organic deposits (Figure 11.14). This sequence of pollen assemblage zones is broadly similar to that recorded at other Holocene sites on Mull (Walker and Lowe, 1985; Lowe and Walker, 1986b), although the early and late Holocene is more fully represented in the sediments from Gribun. On the wider scale, the sequence is comparable with Holocene pollen records from other parts of Scotland, including the north-west Highlands (see Cam Loch and Loch Sionascaig) (Pennington *et al.*, 1972), the Western Isles (Bennett *et al.*, 1990), Skye (see Loch Ashik) (Williams, 1977; Birks and Williams, 1983), Ardnamurchan (Moore, 1977), Argyll (see Loch Cill an Aonghais) (Rymer, 1974; Tipping, 1984) and the Rannoch Moor area of the Grampian Highlands (see Kingshouse) (Walker and Lowe, 1977, 1979, 1981). In terms of vegetational development, three distinct stages can be recognized.

1. An early Holocene succession in which open-habitat herbaceous vegetation was succeeded by heathland and ultimately by a landscape of trees and shrubs. This is reflected in the Gribun profile by a basal pollen assemblage zone (G–1) dominated by pollen of herbaceous plants including Gramineae, Cyperaceae, *Rumex* and *Artemisia*, along with spores of the clubmosses *Lycopodium selago* and *L. annotinum*. This initial pollen assemblage zone is succeeded by zones dominated by *Empetrum* with some *Salix*, *Juniperus* and *Betula* (G–2); *Juniperus*, *Salix* and *Betula* (G–3); *Betula* and *Salix* with a rising *Corylus* curve (G–4); and *Corylus* with *Betula* and *Salix* (G–5). No radiocarbon dates have been obtained from the Gribun profile, but there are profiles dated to the early Holocene available from other sites on Mull (Walker and Lowe, 1982). On the not unreasonable assumption that the early Holocene local pollen assemblage zones from the various profiles broadly correlate, then the earliest organic sediments at Gribun may be inferred to have accumulated prior to 10,200 BP, the *Empetrum* maximum may be dated to close to 10,000 BP, the phase of *Juniperus* expansion occurred around 9600 BP, the birch episode can be dated to near 9300 BP, and the *Corylus* rise began around 8800 BP.
2. A phase of middle Holocene woodland expansion and diversification following the establishment of *Corylus*, with *Quercus*, *Ulmus*, *Pinus* and *Alnus* forming the dominant elements. The first consistent pollen records for oak and elm are recorded in pollen zone G–5, but these taxa are better represented (along with *Pinus*) in pollen zone G–6. *Alnus* also appears during that zone and dominates the spectra along with *Corylus*/*Myrica* in pollen zone G–7. Radiocarbon dates from sites in western Scotland suggest that the *Alnus* expansion occurred around 6500 BP (Birks, 1972b; Pennington *et al.*, 1972; Williams, 1977). The generally low frequencies of arboreal taxa in the Gribun profile are found not only at other sites on Mull, but also in records from elsewhere in the Hebrides (Flenley and Pearson, 1967; Vasari and Vasari, 1968; Birks, 1973; Williams, 1977; Birks and Madsen, 1979; Birks and Williams, 1983), suggesting that only a scattering of oak, elm and pine woods developed on the islands of western Scotland even at the 'climatic optimum' of the Holocene. This reflects, above all, the effects of exposure to strong westerly winds, although generally thin soils which became rapidly leached during the course of the Holocene may also have significantly reduced tree vigour (Pennington *et al.*, 1972; Birks, 1975).
3. A period of woodland contraction and the replacement of woodland stands and tall-shrub-dominated communities by heathland and grassland. This phase is represented in the Gribun profile in pollen zones G–8 and G–9, throughout which there is a progressive

Figure 11.14 Gribun: relative pollen diagram showing selected taxa as percentages of total land pollen (from Walker and Lowe, 1987).

increase in pollen of Gramineae, Cyperaceae and other herbaceous taxa including *Potentilla*, *Rumex* and *Plantago*, and a marked reduction in woody plant pollen, a phenomenon which becomes particularly apparent in pollen zone G–9. Although these landscape changes largely reflect natural processes, namely progressive soil deterioration through accelerated leaching and increasingly stormy conditions along the western littoral, anthropogenic activity may be partly responsible for some of the inferred vegetational changes. There is abundant evidence on Mull to suggest a long history of human occupation (Morrison, 1980; Royal Commission, 1980), and hence the pollen changes that are apparent throughout zones G–8 and G–9 of the Gribun profile may reflect not only the decline of woodland stands through natural processes, but also the acceleration of that trend as a consequence of anthropogenic activity from the Neolithic period onwards.

Gribun is therefore a pollen site of major importance in the context of the Holocene in Scotland, for few profiles combine a length of stratigraphic record with such a high level of detail. The broad similarity between the local pollen assemblage zones in the Gribun diagram, and those from elsewhere on Mull and other sites in western Scotland suggests that the Gribun pollen assemblage zones have wider application and that they can constitute a basis for regional correlation of Holocene deposits. On the broader scale, the high degree of stratigraphic resolution in the Gribun profile and the relative scarcity of detailed pollen records from the islands of the Hebrides and nearby areas of the Scottish mainland, indicate that Gribun is possibly the most important site for the central stretch of the west coast of Scotland.

Conclusion

The sediments preserved in the infilled basin at Gribun provide an exceptionally detailed record of vegetational change during the Holocene (the last 10,000 years). Analysis of pollen contained in the sediments shows the development of open-habitat vegetation, heathland and trees during the early Holocene, a phase of woodland expansion during middle Holocene times and the subsequent contraction of the woodland and its replacement by heath and grassland. The pollen record from Gribun is particularly important because of its length and detail. Consequently Gribun is a key reference site for studies of vegetational history in the islands and the adjacent mainland of the central part of the west coast of Scotland.

LOCH AN T-SUIDHE

M. J. C. Walker

Highlights

The sediments that infill the floor of this loch contain a valuable pollen record, supported by radiocarbon dating, of vegetational history and environmental change on Mull during the Lateglacial.

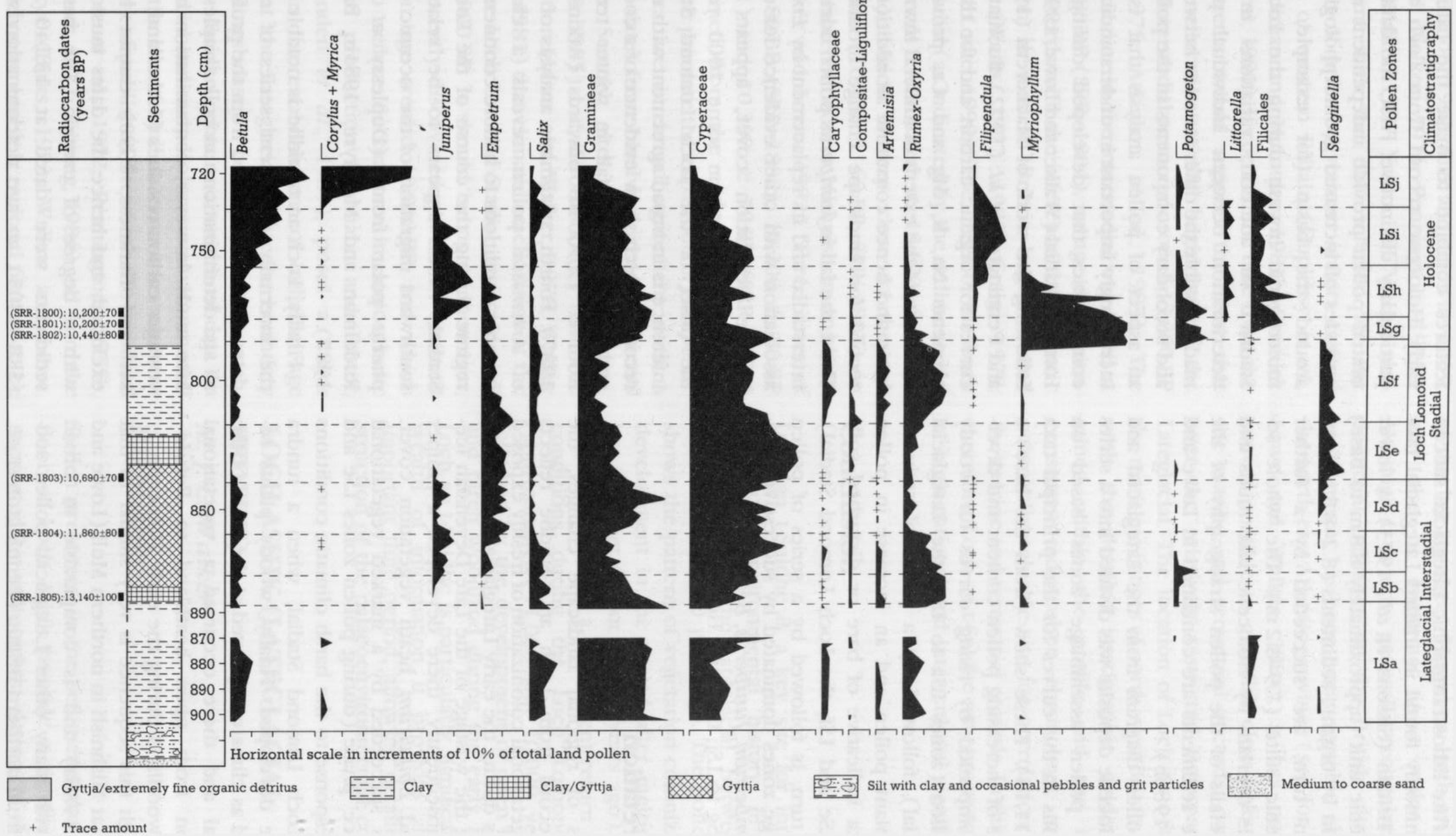
Introduction

Loch an t-Suidhe (NM 370215) is a small lochan at an altitude of 30 m OD, approximately 1 km west-south-west of Bunessan on the Ross of Mull. Although a large number of pollen sites have now been investigated on the Scottish mainland (Walker, 1984b), until recently relatively little information was available about the Lateglacial on the islands of the Inner and Outer Hebrides. The publication (Lowe and Walker, 1986a) of two radiocarbon-dated pollen diagrams from sites on the Isle of Mull was therefore of significance in the context of the Scottish Lateglacial. Of the two sites investigated, Loch an t-Suidhe offered the better stratigraphic resolution and a coherent series of six radiocarbon dates was obtained from the profile (Walker and Lowe, 1982). The wealth of palaeoenvironmental evidence contained within the sediments of this basin make it one of the most important Lateglacial pollen sites so far described from western Scotland.

Description

The sedimentary sequence (Figure 11.15) near the southern shore of the lochan clearly resembles

Figure 11.15 Loch an t-Suidhe: relative pollen diagram showing selected taxa as percentages of total land pollen (from Lowe and Walker, 1986a).


Radiocarbon dates (years BP)
Sediments
Depth (cm)
Betula
Corylus + Myrica
Juniperus
Empetrum
Salix
Gramineae
Cyperaceae
Caryophyllaceae
Compositae-Liguliflorae
Artemisia
Rumex-Oxyria
Filipendula
Myriophyllum
Potamogeton
Littorella
Filicales
Selaginella
Pollen Zones
Climatostratigraphy
(SRR-1800):10,200±70
(SRR-1801):10,200±70
(SRR-1802):10,440±80
(SRR-1803):10,690±70
(SRR-1804):11,860±80
(SRR-1805):13,140±100
720
750
800
850
890
870
880
890
900
LSj
LSi
LSh
LSg
LSf
LSe
LSd
LSc
LSb
LSa
Holocene
Loch Lomond Stadial
Lateglacial Interstadial
Horizontal scale in increments of 10% of total land pollen
Gyttja/extremely fine organic detritus
Clay
Clay/Gyttja
Gyttja
Silt with clay and occasional pebbles and grit particles
Medium to coarse sand
+ Trace amount

the tripartite lithostratigraphic Lateglacial succession commonly found in infilled Lateglacial lake sites in Britain (Sissons *et al.*, 1973). A lower minerogenic unit (approximately 8.8 m to base) is overlain by organic sediments (8.2–8.8 m) and these, in turn, are succeeded by a further minerogenic suite (7.9–8.2 m). The whole sequence is overlain by Holocene lake muds and peats. Details of the pollen stratigraphy of the Holocene sediments are contained in Lowe and Walker (1986b).

The pollen diagram from the Lateglacial and early Holocene deposits was divided into a series of local pollen assemblage zones based on fluctuations in the curves for the principal taxa (Figure 11.15). These show (from the base) a sequence of increasing pollen content and diversity accompanied by rising curves for woody plant pollen (zones LSa to LSd; the Lateglacial Interstadial), followed by a phase of reduced woody plant pollen and an increase in pollen from taxa indicative of bare or disturbed soils (zones LSe and LSf; the Loch Lomond Stadial). This, in turn, is followed by a series of pollen assemblage zones dominated by successive maxima in *Empetrum*, *Juniperus*, *Betula* and *Corylus* (zones LSg to LSj; the early Holocene).

Interpretation

In terms of regional landscape changes, the pollen record from Loch an t-Suidhe reflects initial vegetational colonization of freshly exposed substrates during the early Lateglacial Interstadial following the wastage of the Late Devensian ice-sheet. Subsequently, there developed a juniper scrub and *Empetrum* heath vegetation cover. This was succeeded by a marked vegetational 'revertance' phase (during pollen zones LSe and LSf) in response to the harsh climatic conditions of the Loch Lomond Stadial, when a tundra landscape developed. Finally, woody plants re-expanded as climate improved at the close of the Lateglacial and there occurred a vegetational succession from open heathland to *Betula*–*Corylus* woodland during the early Holocene.

Although this sequence is very similar to that recorded at Mishnish in northern Mull (Lowe and Walker, 1986a) and is comparable in broad outline with many other Lateglacial pollen successions from northern Britain (Pennington *et al.*, 1972; Gray and Lowe, 1977b; Pennington, 1977a, 1977b; Walker and Lowe, 1990), a number of features combine to make the Lateglacial and early Holocene record from Loch an t-Suidhe particularly distinctive. First, the data on deteriorated pollen provide independent evidence of episodes of increased geomorphological activity around the basin (for example, accelerated minerogenic inwash during the Loch Lomond Stadial). In addition, variations in levels of deterioration between individual pollen taxa made possible the differentiation between primary and secondary components in the pollen spectra, an aspect of pollen analysis that is becoming increasingly important in understanding the plant communities that developed during the Loch Lomond Stadial (Walker and Lowe, 1990). Second, following the work of Mackereth (1965, 1966) and Pennington *et al.* (1972), fluctuations in the curves for organic carbon and for the chemical elements Na, K, Mg and Ca, provide further evidence of the extent of mineral inwash into the basin and hence constitute an additional indirect record for landscape change around the site. Third, the fall in *Juniperus* pollen during the mid-interstadial and its replacement by *Empetrum*, in association with other evidence for disturbance in the vegetation cover, appears to reflect climatic deterioration some 1000 years before the onset of the Loch Lomond Stadial. This inference is in broad agreement with coleopteran records, which show evidence of a cooling trend, and particularly a fall in winter temperatures, from *c.* 12,500 BP onwards (Atkinson *et al.*, 1987). Fourth, systematic analysis of the record of *Artemisia* pollen reveals a change from oceanic conditions to a more continental climatic regime during the course of the Loch Lomond Stadial, which appears to be related to the southward migration of the oceanic and atmospheric polar fronts (Duplessy *et al.*, 1981; Ruddiman and McIntyre, 1981b; Bard *et al.*, 1987).

Finally, Loch an t-Suidhe is notable because of the internally consistent series of radiocarbon dates that was obtained from the profile. As with all age determinations on bulk samples of organic lake muds, however, contamination by older or younger carbon residues (Sutherland, 1980; Walker and Harkness, 1990) cannot be entirely excluded, and hence the dates must be treated with a degree of caution. The basal organic sediments were dated at 13,140 ± 100 BP (SRR–1805), an age determination which is in broad agreement with dates on comparable biostratigraphic horizons at sites on the Scottish mainland (Bishop, 1963; Kirk and Godwin, 1963; Sissons and Walker, 1974; Pennington, 1975b; Lowe and Walker, 1977; Vasari, 1977). It is also in agreement with the date inferred for the replacement of polar by warmer waters around the shores of western Britain (Duplessy *et al.*, 1981; Ruddiman and McIntyre, 1981b; Peacock and Harkness, 1990). If correct, the date from the basal sediments would support the view that climatic amelioration at the beginning of the Lateglacial Interstadial occurred around 13,000 BP (Coope, 1975; Atkinson *et al.*, 1987). The *Juniperus* decline in the interstadial was dated at 11,860 ± 80 BP (SRR–1804), an age determination that accords with the inference that climatic deterioration in western Britain began around 12,000 BP (Watts, 1977, 1985; Craig, 1978; Walker and Lowe, 1990). The onset of the Loch Lomond Stadial (as indicated by the sediment and pollen records) was dated at 10,690 ± 70 BP (SRR–1803), which is very close to the age determination (10,730 ± 60 BP; SRR–1807) on the comparable horizon at Mishnish in northern Mull (Walker and Lowe, 1982). Three dates of 10,440 ± 80 BP (SRR–1802), 10,200 ± 70 BP (SRR–1801) and 10,200 ± 70 BP (SRR–1800) were obtained from the early Holocene sediments which pre-date the expansion of *Juniperus*. These dates are in broad agreement with a number of dates from basal Holocene sediments from other Scottish sites (Walker and Lowe, 1979, 1980, 1985) and, if correct, they reinforce the suggestion (Lowe and Walker, 1976; Walker and Lowe, 1981) that climatic amelioration at the close of the Loch Lomond Stadial occurred well before 10,000 BP. It should be noted, however, that the recently discovered plateau of constant radiocarbon age around 10,000 BP, and which appears to reflect fluctuations in atmospheric radiocarbon production (Ammann and Lotter, 1989; Zbinden *et al.*, 1989), poses a major difficulty in the establishment of 'reliable' age estimates at the Lateglacial–Holocene boundary (see also Kingshouse).

Loch an t-Suidhe contains a wealth of data on the Lateglacial and early Holocene environmental history of the Isle of Mull. It forms a key element in a network of published sites from the mainland (Pennington *et al.*, 1972; Pennington, 1975b, 1977a; Rymer, 1977; Tipping, 1984) and from the Isle of Skye (Birks, 1973; Walker and Lowe, 1990) which now enable a regional picture to be established of environmental change along the western Scottish seaboard following the wastage of the last ice-sheet. However, Loch an t-Suidhe may also be important in a wider context. Although it is now generally recognized that a dominant influence on the British climate and environment has been oceanographic changes in the north-east Atlantic province (see, for example, Lowe and Walker, 1984), it has not always proved possible to establish clear links between the marine and terrestrial records, particularly over the relatively restricted timespan of the Lateglacial. The location of Loch an t-Suidhe on the maritime fringes of north-west Britain, coupled with the detailed stratigraphic evidence contained within the profile and the internally consistent radiocarbon chronology, make it a potentially valuable site for correlation between the marine and terrestrial records. In this respect, therefore, Loch an t-Suidhe may prove to be a site of both national and international significance.

Conclusion

Loch an t-Suidhe is a key site for interpreting Lateglacial environmental history in western Scotland during the Lateglacial, between about 13,000 and 10,000 years ago. The pollen record shows the pattern of vegetation colonization and development in the period after melting of the last ice-sheet (about 13,000 years ago). There is clear evidence for a subsequent return to tundra conditions during the Loch Lomond Stadial (approximately 11,000 and 10,000 years ago), followed by the development of open heathland and birch woodland during the early Holocene. Loch an t-Suidhe is particularly significant for the wealth of information it provides about this important time period, allowing detailed reconstruction of the palaeoenvironmental conditions.

LOCH ASHIK (LATEGLACIAL PROFILE)

M. J. C. Walker

Highlights

Pollen preserved in the sediments that infill the floor of Loch Ashik provide a detailed record, supported by radiocarbon dating, of the vegetational history and environmental changes on Skye during the Lateglacial.

Introduction

Loch Ashik (NG 691232) is located 4 km east of Broadford on the Isle of Skye. It lies at around 40 m OD and, at its maximum, is 175 m long and 125 m wide. In recent years the vegetational history of the island has undergone a major revision (Walker *et al.*, 1988; Walker and Lowe, 1990), and the pattern of Lateglacial and early Holocene environmental change that has emerged is more compatible with data from the Scottish mainland and other Hebridean islands than were the previously published interpretations from Skye (Erdtman, 1924, 1928; Blackburn, in Godwin, 1943; Vasari and Vasari, 1968; Birks, 1973; Vasari, 1977; Williams, 1977; Birks and Williams, 1983; Walther, 1984). A key element in this reinterpretation is the site of Loch Ashik, which contains an unequivocal Lateglacial pollen record and can now be regarded as the type Lateglacial profile for the Isle of Skye. Full details of the pollen record are contained in Walker and Lowe (1990), and a more concise description can be found in Walker and Lowe (1991).

Description

In an infilled embayment by an inflowing stream at the western end of the loch, a characteristic Lateglacial tripartite sediment sequence (cf. Sissons *et al.*, 1973) is preserved (Figure 11.16) (Walker and Lowe, 1990, 1991). This consists of basal minerogenic sediments (below 5.69 m) overlain by a unit of higher organic content (5.69–5.29 m) which, in turn, is succeeded by a further suite of minerogenic deposits (5.26–5.07 m). This Lateglacial sequence is overlain by over 5 m of Holocene lake muds and peats. Six radiocarbon dates (SRR–3116 to SRR–3121) have been obtained from the sediments (Figure 11.16).

The pollen diagram from the Lateglacial and early Holocene deposits (Figure 11.16) has been divided into eleven local pollen assemblage zones (LA–1 to LA–11) based on fluctuations in the curves for the principal taxa. These show an early Lateglacial pioneer vegetational stage dominated by open-habitat communities (LA–1 and LA–2), the expansion of woody plants, including birch and juniper (LA–3), and the subsequent establishment of *Empetrum* and *Erica* heaths (LA–5), the development of a grass-sedge tundra with some heathland stands during the Loch Lomond Stadial (LA–7), and finally the early Holocene vegetational succession from arctic–alpine communities to birch and hazel woodland (LA–8 to LA–11).

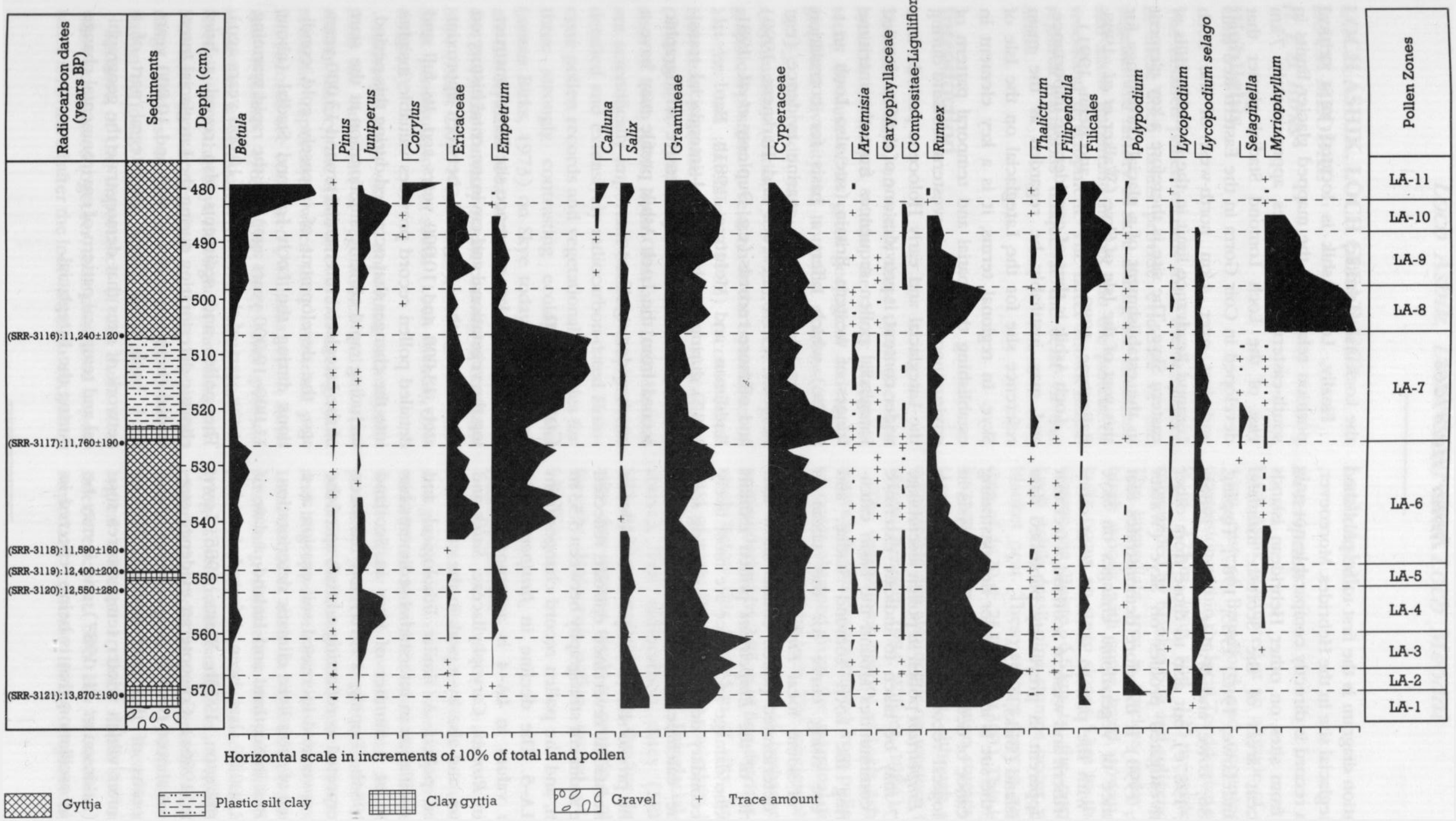
Interpretation

The sequence of vegetational changes represents a clear biotic response to climatic fluctuations at the last glacial–interglacial transition which began with rapid climatic amelioration around 13,000 BP, followed by gradual climatic deterioration during the Lateglacial Interstadial (from *c.* 12,000 BP onwards), the development of a climatic regime of arctic severity during the Loch Lomond Stadial (*c.* 11,000–10,200 BP), and a subsequent rapid rise in both winter and summer temperatures in the first five hundred years of the Holocene (Atkinson *et al.*, 1987).

Radiocarbon dating of the Loch Ashik sediments proved problematical, for although six age determinations were made on bulk samples of organic lake muds obtained from the site, the majority appear to be too old by comparison with radiocarbon dates on comparable biostratigraphic horizons from other sites in northern Britain. Indeed, only the date of 11,590 ± 160 BP (SRR–3118) on the late interstadial expansion of *Empetrum* appears to be consistent with the currently accepted radiocarbon chronology of Lateglacial biozones (Walker and Harkness, 1990). The measured ages most probably reflect the inwash of inert carbon residues into the lake basin, either in the form of mineral carbon from the local bedrock, or older organic carbon residues from soils around the lake catchment and/or from the inwashing of older carbon detritus (Olsson, 1979, 1986). Whatever the source of contamination, it is apparent that a reliable Lateglacial chronology cannot be established from the Loch Ashik sediments.

The Loch Ashik site is, nevertheless, significant in a number of respects. First, a high-resolution pollen record of the Lateglacial and early Holocene periods has been obtained from the basal sedimentary sequence, the percentage pollen counts being supported by pollen concentration, deteriorated pollen and sediment chemistry data (Walker and Lowe, 1990). Indeed the pollen

Figure 11.16 Loch Ashik: Lateglacial relative pollen diagram showing selected taxa as percentages of total land pollen (from Walker and Lowe, 1991).


Radiocarbon dates (years BP)
Sediments
Depth (cm)
(SRR-3116):11,240±120
(SRR-3117):11,760±190
(SRR-3118):11,590±160
(SRR-3119):12,400±200
(SRR-3120):12,550±280
(SRR-3121):13,870±190
480
490
500
510
520
530
540
550
560
570
Betula
Pinus
Juniperus
Corylus
Ericaceae
Empetrum
Calluna
Salix
Gramineae
Cyperaceae
Artemisia
Caryophyllaceae
Compositae-Liguliflorae
Rumex
Thalictrum
Filipendula
Filicales
Polypodium
Lycopodium
Lycopodium selago
Selaginella
Myriophyllum
Pollen Zones
LA-11
LA-10
LA-9
LA-8
LA-7
LA-6
LA-5
LA-4
LA-3
LA-2
LA-1
Horizontal scale in increments of 10% of total land pollen
Gyttja
Plastic silt clay
Clay gyttja
Gravel
+ Trace amount

concentration diagram is the first to be published from a Lateglacial site in the Hebrides. Moreoever, the pollen record is directly comparable not only to those from sites on other Hebridean islands and adjacent areas of the Scottish mainland (Walker and Lowe, 1982, 1985, 1987; Tipping, 1984, 1986; Lowe and Walker, 1986a, 1986b; Robinson, 1987c), but also to those from other recently-investigated profiles on Skye (Walker and Lowe, 1990). It therefore demonstrates that the sequence of vegetational changes on Skye conforms with the pattern inferred from other sites in northern and western Scotland, a fact that was not apparent in previously published data from the island (Birks, 1973).

Second, the site is important for demonstrating the significance of deteriorated pollen analysis in palaeoecological reconstructions. The very high counts for *Empetrum* pollen in pollen assemblage zone LA–7 may be taken to indicate extensive heathland communities around the basin catchment during the Loch Lomond Stadial, and certainly the rising curve for this taxon is indicative of some local *Empetrum* presence. However, deteriorated pollen counts show that the majority of the *Empetrum* pollen exhibit signs of exine damage and hence are most likely to be of secondary derivation from eroding soils around the catchment (see also Loch an t-Suidhe).

Third, the profile shows unequivocal evidence of a mid-interstadial 'revertance' episode, reflected in both the sediment stratigraphy between 5.53 m and 5.49 m, and the pollen record changes from LA–3 to LA–5. The decline in *Juniperus* and *Empetrum* values in LA–4 is accompanied by increases in *Rumex*, Caryophyllaceae, *Salix* and *Lycopodium*, and also by a peak in the curve for deteriorated pollen. A similar lithological and biological oscillation in interstadial sediments has been noted at a number of sites in Scotland (Walker, 1984b; Tipping, 1991b) and has been widely interpreted as reflecting a break-up of the vegetation cover and increased soil erosion as a consequence of short-lived climatic deterioration. At other sites in Scotland and Ireland, a date of around 12,000 BP has been inferred for this event (Pennington, 1975b; Watts, 1985; Lowe and Walker, 1986a). Coleopteran evidence suggests a fall of almost 10°C in temperatures of the coldest months of the year from 12,300 to 11,800 BP after which winter temperatures rose by 4–5°C (Atkinson *et al.*, 1987), and it may be this climatic oscillation that is being reflected in the Loch Ashik profile.

Finally, Loch Ashik is located in a critical position relative to the mapped glacier limits in south-eastern Skye. It lies approximately 7 km east of the Loch Lomond Stadial glacier that developed in Coir Gorm in the Eastern Red Hills and just over 4 km north-west of the Loch Lomond Readvance limit in the Kyleakin Hills of eastern Skye. The site is therefore a key element in the establishment of a glacial chronology for this part of the Isle of Skye (Walker *et al.*, 1988; Ballantyne, 1989a; Ballantyne and Benn, 1991).

Loch Ashik is thus of considerable importance, and may justifiably be regarded as the main reference site for the Lateglacial on the Isle of Skye. In regional terms, it is a key element in establishing the spatial and temporal pattern of environmental change in western Scotland during the Lateglacial and early Holocene periods. In a wider context, it provides one of the few detailed Lateglacial pollen sequences from the maritime fringes of western Britain (see also Loch an t-Suidhe) which offers a basis for correlation between the nearshore marine evidence (e.g. Peacock, 1989b; Peacock and Harkness, 1990) and offshore records (e.g. Duplessy *et al.*, 1981; Ruddiman and McIntyre, 1981b; Bard *et al.*, 1987) during the last glacial–interglacial transition. As such, the comprehensive stratigraphic record from the Loch Ashik profile may have a much wider significance.

Conclusion

Loch Ashik is a key reference site for reconstructing the vegetational and environmental history on Skye during the Lateglacial, between approximately 13,000 and 10,000 years ago. Its full and detailed pollen record provides valuable insights into the changes that occurred during this period, including rapid climatic amelioration at the start of the Lateglacial Interstadial around 13,000 years ago, the development of intensely cold conditions during the Loch Lomond Stadial (about 11,000–10,000 years ago) and the rapid warming at the start of the Holocene (10,000 years ago). The pollen and sediments also reveal a brief climatic deterioration during the Lateglacial Interstadial (between about 13,000 and 10,000 years ago). Loch Ashik forms an integral part of a network of sites that demonstrate the geographical and temporal pattern of environmental change during the Lateglacial.

LOCH ASHIK, LOCH CLEAT AND LOCH MEODAL

H. J. B. Birks

Highlights

The detailed pollen records from the sediments in these loch basins provide evidence of the vegetational history of Skye during the Holocene and allow important insights into the pattern of woodland development. The latter shows major regional variations unique at the scale of the island.

Introduction

The Isle of Skye, on which these three sites are located, is unique within the Inner Hebrides today because of its great geological and topographical diversity, its botanical richness (Birks, 1973), its wide range of present-day plant communities (Birks, 1973), and its critical geographical position in relation to the boundaries of McVean and Ratcliffe's (1962) reconstructed Holocene potential woodland zones of Scotland (Williams, 1977; Birks and Williams, 1983). The sites of Loch Ashik, Loch Cleat and Loch Meodal are scientifically important because they provide detailed and extensively radiocarbon-dated Holocene pollen records and vegetational histories for three strongly contrasting ecological regions (*sensu* Birks, 1973) on Skye today. The regions are the Kyleakin area in the east (Loch Ashik, NG 691232), the Tertiary basalt country of northern Skye (Loch Cleat, NG 416742), and the sheltered Sleat peninsula in the south (Loch Meodal, NG 656113).

Although each site is important individually from the viewpoint of vegetational and environmental history, the three sites are of even greater scientific importance when their individual pollen records are compared (Williams, 1977; Birks and Williams, 1983). The three sites provide important evidence for marked vegetational differentiation within Skye throughout the Holocene. Nowhere else in Scotland can this remarkable range of forest history and vegetational differentiation be found within such a small area.

Because of the importance of the three sites when considered together, their combined importance is reviewed after the individual site accounts.

Loch Ashik

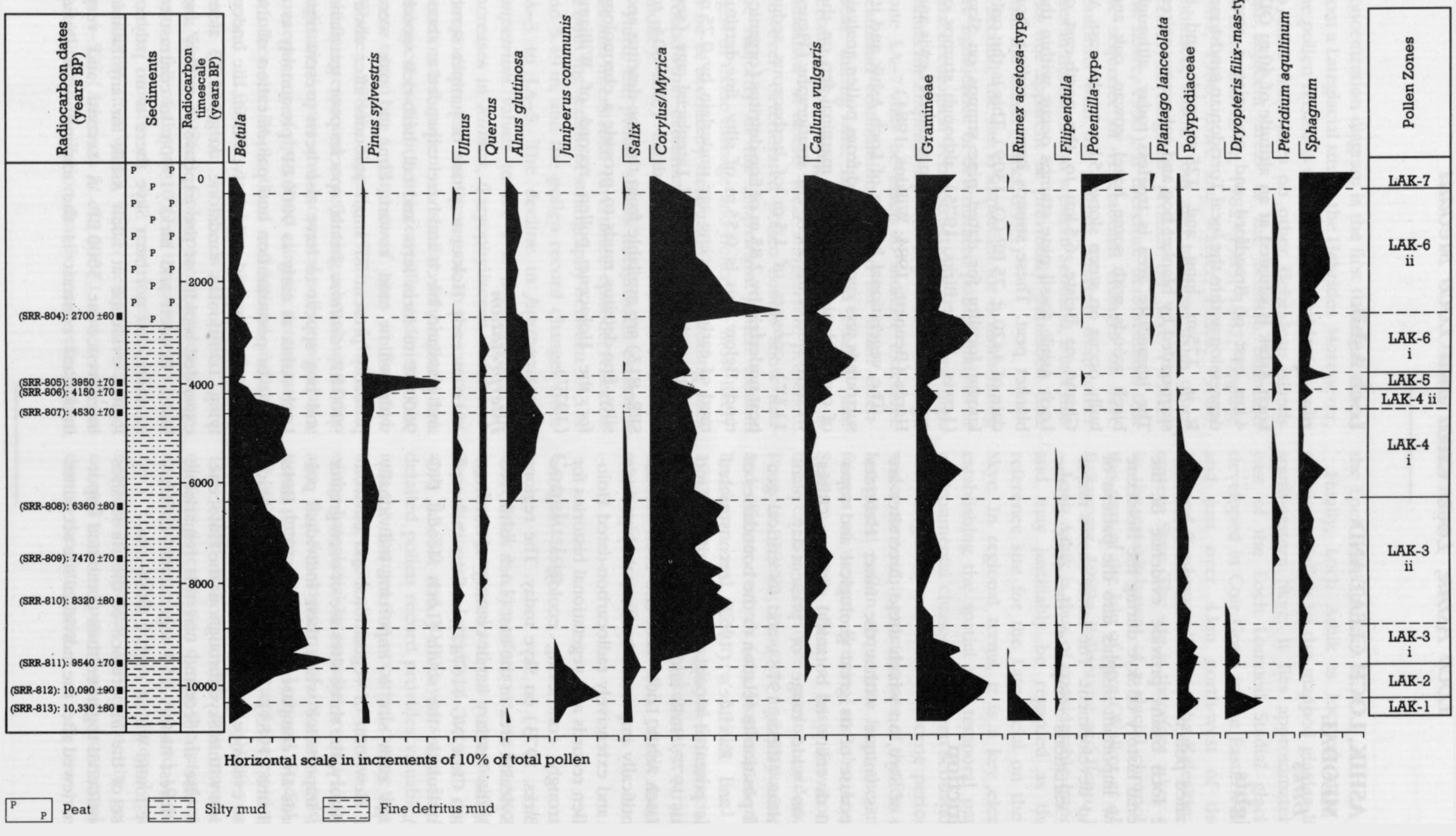
Description

Loch Ashik is situated at an altitude of 40 m OD, 4 km east of Broadford and occupies a small depression within the local Torridonian sandstone. It is 175 m long and 125 m wide and is surrounded by blanket bog and soligenous mires. The immediate area is treeless today, although birch woods with some hazel, rowan, oak and holly occur on steep slopes 5 km to the east. At Gleann na Beiste, 6.5 km to the north-east of Loch Ashik, fossil pine stumps occur within the blanket peat. These stumps have a radiocarbon date of 4420 ± 75 BP (Q–1309). This is the only known locality for dated pine stumps on Skye (Lewis, 1906; Birks, 1975), although stumps of comparable age also occur on western Lewis and Harris (Bennett, 1984; Wilkins, 1984).

The vegetational history of Loch Ashik and its surrounds was reconstructed from pollen analysis of cores obtained from the marginal fen on the western side of the loch. The stratigraphy (Figure 11.17) consists of 1.5 m of herbaceous sedge peat underlain by 2.85 m of fine-detritus (organic) mud. Below this is 0.55 m of silty, fine-detritus mud of early Holocene age underlain by 0.75 m of silts and silty muds of Lateglacial age (see above). Ten radiocarbon dates (SRR–804 to SRR–813) are available from the fine-detritus and silty, fine-detritus muds to provide a chronology for the Holocene pollen record of Williams (1977).

Interpretation

After an early Holocene phase of juniper scrub and grassland, birch and hazel expanded at about 9600 BP to form fern- and tall, herb-rich woods with willow and rowan. Elm and oak were probably present in small amounts after about 9000 BP. *Calluna* heath, species-poor grassland and bog appear to have also been present near Loch Ashik as early as 9000 BP, presumably as a result of podsolization and paludification of the predominantly acid soils derived from the underlying Torridonian sandstone. At 6300 BP alder expanded rapidly at the expense of willow and hazel (Bennett and Birks, 1990). In contrast to southern and northern Skye there is no palynological evidence at Loch Ashik for any human interference at 5000 BP. A second and very important contrast is the expansion of *Pinus*



Radiocarbon dates (years BP)
Sediments
Radiocarbon timescale (years BP)
(SRR-804): 2700 ±60
(SRR-805): 3950 ±70
(SRR-806): 4150 ±70
(SRR-807): 4530 ±70
(SRR-808): 6360 ±80
(SRR-809): 7470 ±70
(SRR-810): 8320 ±80
(SRR-811): 9540 ±70
(SRR-812): 10,090 ±90
(SRR-813): 10,330 ±80
0
2000
4000
6000
8000
10000
Betula
Pinus sylvestris
Ulmus
Quercus
Alnus glutinosa
Juniperus communis
Salix
Corylus/Myrica
Calluna vulgaris
Gramineae
Rumex acetosa-type
Filipendula
Potentilla-type
Plantago lanceolata
Polypodiaceae
Dryopteris filix-mas-type
Pteridium aquilinum
Sphagnum
Pollen Zones
LAK-7
LAK-6 ii
LAK-6 i
LAK-5
LAK-4 ii
LAK-4 i
LAK-3 ii
LAK-3 i
LAK-2
LAK-1
Horizontal scale in increments of 10% of total pollen
Peat
Silty mud
Fine detritus mud

pollen between 4600 BP and 3900 BP at Loch Ashik (Birks, 1989). This may reflect the local growth of pine on dried peat surfaces in eastern Skye, a widespread phenomenon in north-west Scotland at that time (Birks, 1975; Birks 1988, 1989; Gear and Huntley, 1991), as at Gleann na Beiste.

The sharp decline in *Pinus* pollen at Loch Ashik correlates with the widespread demise of pine throughout north-west Scotland at about 4000 BP (Birks, 1972b, 1975; Birks, 1977, 1988; Bennett, 1984; Gear and Huntley, 1991) and the widespread development and expansion of blanket bog with *Calluna vulgaris*, *Sphagnum* and *Narthecium ossifragum*, of acid grasslands, and of heaths around Loch Ashik. The reasons for this widespread and dramatic decline of pine in north-west Scotland, eastern Skye, and parts of Lewis are not fully understood (Birks, 1988). A combination of rapid climatic change and human activity may have initiated the replacement of pine on flat and gently sloping ground by treeless blanket bog. There is, however, independent chemical evidence from the Inverpolly area (Pennington *et al.*, 1972) that suggests a major change to a more oceanic climate with increased precipitation and stronger winds at about 4000 BP. Such an abrupt change would have caused waterlogging, encouraged the expansion of blanket bog, and inhibited the regeneration of pine by reducing the number of good seed years (Birks, 1972b).

By 2700 BP bog and heath were widespread near Loch Ashik and woodland, mainly of birch, was rare and presumably restricted, as today, to steep slopes where blanket bog could not develop. This situation has continued to the present day, suggesting that the modern bog-dominated landscape is of considerable antiquity.

The Holocene pollen record of Loch Ashik (Williams, 1977; Birks and Williams, 1983) indicates that pine was locally abundant between 4600 BP and 3900 BP and that the vegetational history of eastern Skye has affinities with parts of Wester Ross, in McVean and Ratcliffe's (1962) 'predominant pine forest zone'. In contrast, pine appears to have been absent from southern and northern Skye during the Holocene. Loch Ashik is thus of considerable palaeoecological importance in illustrating the extremely localized geographical distribution of *Pinus sylvestris* during the Holocene and the local, but very rapid, extinction of pine close to the limits of its natural geographical range (see also Gear and Huntley, 1991).

Figure 11.17 Loch Ashik: Holocene relative pollen diagram showing selected taxa as percentages of total pollen (from Birks and Williams, 1983). Note that the data are plotted against a radiocarbon time-scale.

Loch Cleat

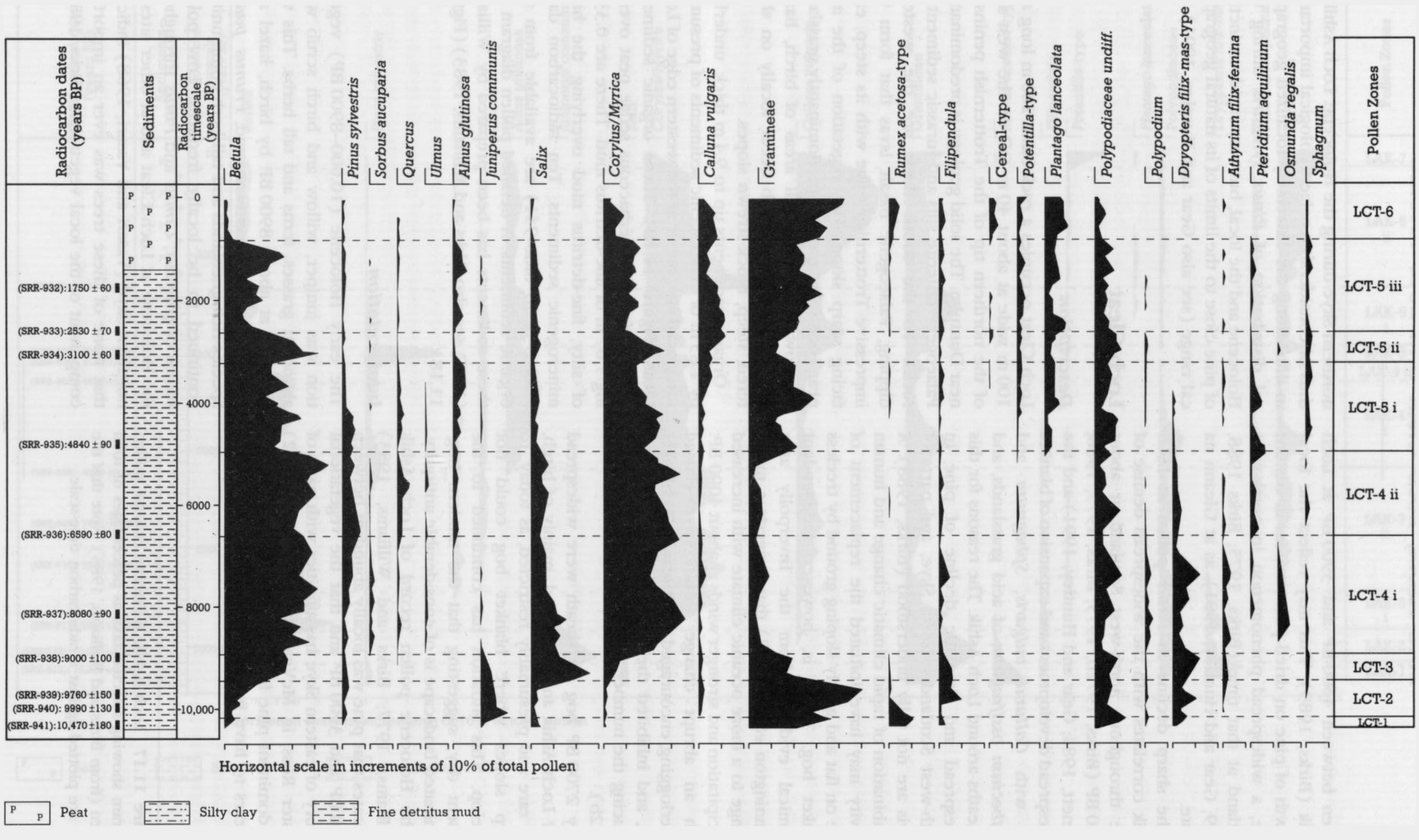
Description

Loch Cleat occupies a rock basin 200 m long and 100 m wide at about 40 m OD on the west side of the northern tip of the Trotternish peninsula near Duntulm. The solid geology is predominantly Palaeogene dolerite sills and Jurassic sedimentary rocks. To the south there are the westerly dipping, Palaeogene basalt lavas that form the impressive Trotternish ridge with its steep, east-facing scarp slope. The vegetation of the area near Loch Cleat today is predominantly grassland, meadow and bog. Small areas of birch, hazel, willow and rowan scrub occur locally on sheltered, steep, block-strewn slopes.

Organic sediments up to 9.4 m thick, underlain by 1.85 m of minerogenic sediments of presumed Lateglacial age, occur at the western edge of Loch Cleat (Figure 11.18). These organic sediments consist of 2 m of herbaceous sedge peat overlying 7.07 m of fine-detritus mud. There are 0.33 m of silty, fine-detritus mud overlying the basal minerogenic sediments. Ten radiocarbon dates (SRR–932 to SRR–941) are available from the organic sediments. A detailed pollen diagram for these sediments has been prepared by Williams (1977; see also Birks and Williams, 1983) (Figure 11.18).

Interpretation

The early Holocene (10,000–8900 BP) vegetation was juniper, willow and birch scrub with abundant grasses, ferns and tall herbs. This was replaced at about 8900 BP by birch, hazel and willow scrub with rowan and *Prunus padus*. Species-rich grasslands and tall herb communities continued to be locally frequent. Low pollen values of *Quercus*, *Ulmus* and *Pinus* throughout the Holocene at Loch Cleat and at other sites in northern Skye (Vasari and Vasari, 1968) indicate that none of these trees was ever an important component of the local vegetation (Birks, 1989),


Radiocarbon dates (years BP)
Sediments
Radiocarbon timescale (years BP)
(SRR-932):1750 ± 60
(SRR-933):2530 ± 70
(SRR-934):3100 ± 60
(SRR-935):4840 ± 90
(SRR-936):6590 ±80
(SRR-937):8080 ±90
(SRR-938):9000 ±100
(SRR-939):9760 ±150
(SRR-940): 9990 ±130
(SRR-941):10,470 ±180
0
2000
4000
6000
8000
10,000
Betula
Pinus sylvestris
Sorbus aucuparia
Quercus
Ulmus
Alnus glutinosa
Juniperus communis
Salix
Corylus/Myrica
Calluna vulgaris
Gramineae
Rumex acetosa-type
Filipendula
Cereal-type
Potentilla-type
Plantago lanceolata
Polypodiaceae undiff.
Polypodium
Dryopteris filix-mas-type
Athyrium filix-femina
Pteridium aquilinum
Osmunda regalis
Sphagnum
Pollen Zones
LCT-6
LCT-5 iii
LCT-5 ii
LCT-5 i
LCT-4 ii
LCT-4 i
LCT-3
LCT-2
LCT-1
Horizontal scale in increments of 10% of total pollen
Peat
Silty clay
Fine detritus mud

in contrast to southern Skye (Loch Meodal) where elm and oak were frequent, and eastern Skye (Loch Ashik) where oak, elm, and pine were present locally. Alder arrived at Loch Cleat at about 6300 BP but, in contrast to eastern and southern Skye, it was never abundant in northern Skye (Bennett and Birks, 1990).

The pollen record at Loch Cleat reveals a marked increase in herbaceous pollen types (mainly grasses, *Potentilla* type, Chenopodiaceae and Cruciferae) at 5000 BP along with the first appearance of cereal type and *Plantago lanceolata* pollen. At the same time there is a large decrease in the pollen values of birch and hazel, suggesting clearance of scrub and the local development of arable and pastoral agriculture. The pollen spectra suggest that between 5000 BP and 700 BP the landscape of northern Trotternish was mainly treeless, with patches of scrub probably restricted to steep, rocky slopes that were difficult to clear. There are abundant Iron Age archaeological remains in the area, such as brochs and duns, the ages of which are unfortunately not known.

In the last 700 years there has been widespread clearance of the remaining areas of birch and hazel scrub to produce the virtually treeless landscape of northern Skye today. Cereal-type pollen is present in significant amounts, suggesting extensive cereal cultivation in this part of northern Skye. With its fertile soils, northern Skye was noted for its cereal crops and the parish of Kilmuir, in which Loch Cleat is situated, was referred to as the 'granary of Skye' (MacSween, 1959).

The pollen record from Loch Cleat provides the most detailed record of the Holocene vegetational history currently available for the basalt areas of northern Skye. The landscape of this area is virtually treeless today with a few stands of birch and hazel scrub confined to steep, sheltered, coastal cliffs and to ravines. McVean and Ratcliffe (1962) suggest that northern Skye lies within the 'predominant birch forest' zone. The pollen stratigraphy at Loch Cleat (Williams, 1977) confirms this suggestion and shows that only birch, hazel and willow scrub developed near the site, even in middle Holocene times. The pollen record also shows that oak, elm, pine and alder were never important components of the Holocene vegetation of northern Skye, in contrast to southern and eastern Skye (Williams, 1977; Birks and Williams, 1983). This history contrasts markedly with southern and eastern Skye. Loch Cleat is thus important because of its detailed and well-dated pollen record, its contribution to the reconstruction and understanding of Holocene forest history of western Scotland, and its record of land-use history over the last 5000 years.

Figure 11.18 Loch Cleat: Holocene relative pollen diagram showing selected taxa as percentages of total pollen (from Birks and Williams, 1983). Note that the data are plotted against a radiocarbon time-scale.

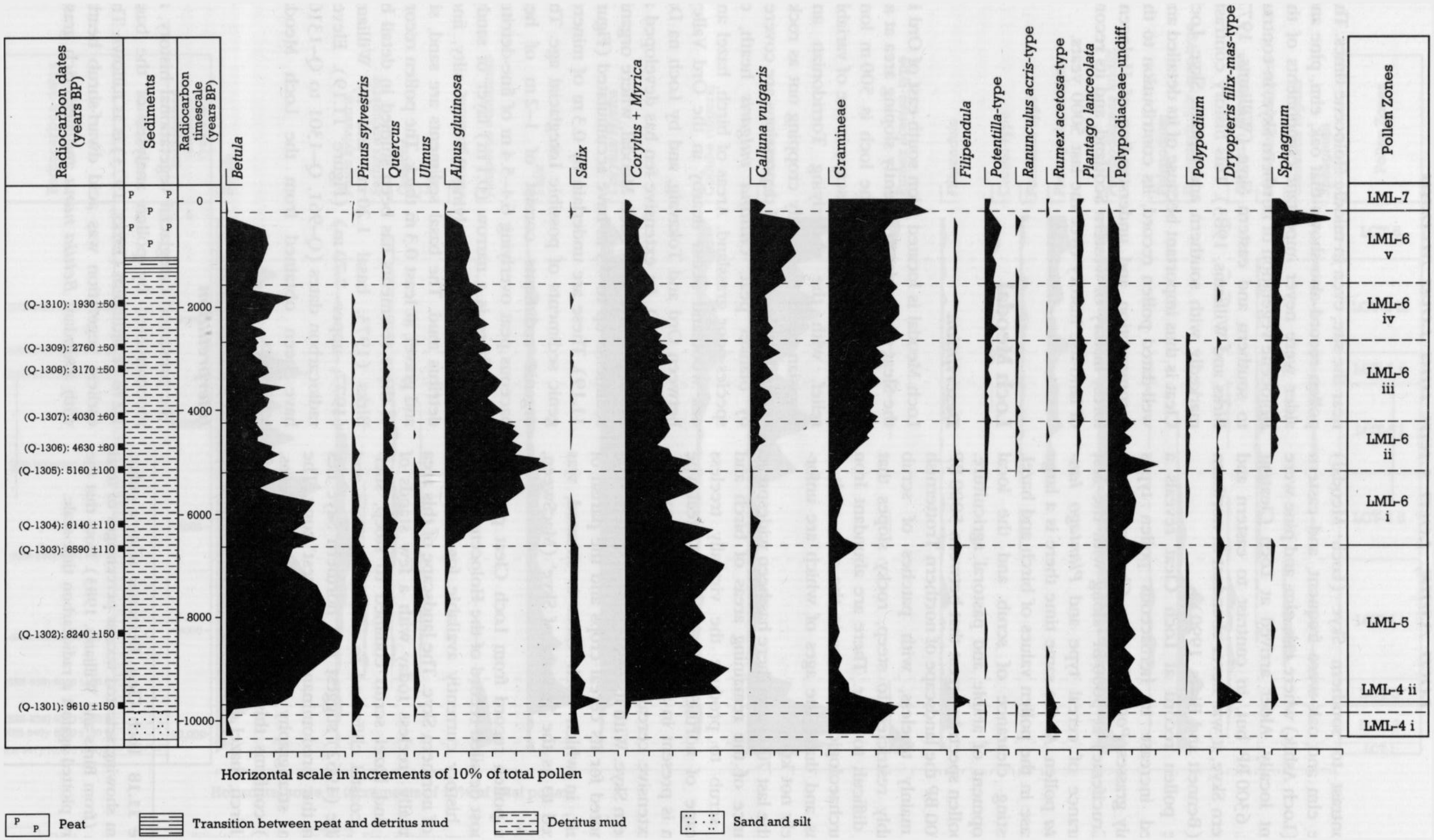
Loch Meodal

Description

Loch Meodal is located 5 km south-east of Ord in the Sleat peninsula, in a gently sloping area at an altitude of 105 m OD. The loch is 500 m long and 400 m wide. The landscape is one of variable relief, with the underlying Torridonian and Lewisian rocks frequently cropping out as rocky knolls. Gentle slopes and depressions are covered by blanket peat, *Calluna vulgaris* heath, or species-poor grassland. Areas of birch, hazel and oak woodland occur nearby in the Ord Valley, between Ord and Tokavaig, and by Loch na Dal (Birks, 1973). An extensive fen has developed at the northern end of Loch Meodal, where organic sediments up to 7.9 m have accumulated (Figure 11.19). These are underlain by 0.3 m of minerogenic sediments of possible Lateglacial age. The organic sediments consist of 1–2 m of herbaceous peat overlying 6.4–5.4 m of fine-detritus mud. There is a narrow (0.1 m) layer of sandy, fine-detritus mud overlying 0.4 m of silty, fine-detritus mud. The basal sediments are sand, silt and gravel, at least 0.3 m thick. The pollen record of these sediments has been studied in detail by Birks (1973; basal 1.20 m) and by Williams (1977; upper 7.70 m) (Figure 11.19). Eleven radiocarbon dates (Q–961, Q–1301 to Q–1310) have been obtained from the Loch Meodal sediments.

Interpretation

The presumed Lateglacial vegetational history, as reconstructed by pollen analyses of the basal 1.2 m of sediment (Birks, 1973) is as follows. The earliest vegetation was acid dwarf-shrub heaths with abundant *Betula nana* and herb-rich grass-



Radiocarbon dates (years BP)
Sediments
Radiocarbon timescale (years BP)
(Q-1310): 1930 ±50
(Q-1309): 2760 ±50
(Q-1308): 3170 ±50
(Q-1307): 4030 ±60
(Q-1306): 4630 ±80
(Q-1305): 5160 ±100
(Q-1304): 6140 ±110
(Q-1303): 6590 ±110
(Q-1302): 8240 ±150
(Q-1301): 9610 ±150
0
2000
4000
6000
8000
10000
Betula
Pinus sylvestris
Quercus
Ulmus
Alnus glutinosa
Salix
Corylus + Myrica
Calluna vulgaris
Gramineae
Filipendula
Potentilla-type
Ranunculus acris-type
Rumex acetosa-type
Plantago lanceolata
Polypodiaceae-undiff.
Polypodium
Dryopteris filix-mas-type
Sphagnum
Pollen Zones
LML-7
LML-6 v
LML-6 iv
LML-6 iii
LML-6 ii
LML-6 i
LML-5
LML-4 ii
LML-4 i
Horizontal scale in increments of 10% of total pollen
Peat
Transition between peat and detritus mud
Detritus mud
Sand and silt

lands. At an inferred age of about 12,200 BP juniper and willow scrub developed. This was replaced by open birch woods with aspen and abundant ferns. Subsequently, the extent of woodland decreased, and *Betula nana* heath expanded, presumably in response to the climatic deterioration associated with the Loch Lomond Stadial.

In the early Holocene (9700 BP) birch and hazel rapidly expanded with some aspen and willow, abundant ferns and tall herbs (Williams, 1977). From about 9000 BP oak and elm may have been present in small amounts within the predominantly birch-and-hazel-dominated landscape. Alder expanded rapidly at about 6500 BP to form mixed birch–hazel–alder woods with some oak, elm, ash, rowan and holly. The oak pollen values are lower than at comparable times on the adjacent mainland, for example the Morar peninsula (Williams, 1977), suggesting that the natural northern limit of predominant oak during the middle Holocene lay near southern Skye. Although oak was certainly present in Sleat, it was never a prominent component of the natural woodland cover. As on the adjacent mainland, *Pinus* was absent in the forests of southern Skye, in contrast to its abundance in parts of Wester Ross (Birks, 1972b; Birks, 1977, 1989) and in eastern Skye (Williams, 1977).

Forest clearance in Sleat began at about 5200 BP. By 4200 BP the landscape was still mainly wooded, but bogs, heaths and acid grasslands became frequent. There was little vegetational change between 2700 BP and 300 BP except for the spread of *Calluna vulgaris* at about 1600 BP. In the last 300 years there has been extensive forest clearance, a large decrease in the extent of heather moor and a massive spread of acid grassland, resulting in the lightly wooded landscape near Loch Meodal today. This widespread forest destruction and spread of grassland may have resulted from the onset of cattle breeding after AD 1650, reaching its peak at about AD 1750 (Williams, 1977). The woodlands surviving in southern Skye are clearly natural relics of the former forests of Sleat.

The Holocene forest history of Loch Meodal has greatest affinities with sites on the adjacent mainland in the 'predominant oak forest with birch' zone of southern and western Scotland (McVean and Ratcliffe, 1962), such as the Morar peninsula and the Loch Sunart area. The main difference between the pollen sequences from the mainland and from Loch Meodal is that oak was rarer in southern Skye than on the mainland.

Loch Meodal is of considerable scientific importance in the reconstruction of Lateglacial and Holocene vegetational history. First, it is situated within the Sleat peninsula of southern Skye and thus lies near the northern limit of McVean and Ratcliffe's (1962) potential 'predominant oak forest with birch' zone (Birks and Williams, 1983). Its detailed pollen stratigraphy shows that the site has been near important distributional limits of two major forest trees (birch and oak) during the last 12,000 years. It also illustrates that very marked vegetational differentiation has existed within Skye and between Skye and the adjacent mainland since the Late Devensian (Birks, 1973; Williams, 1977; Birks and Williams, 1983). Second, southern Skye supports today the largest areas of natural or seminatural woodland on Skye. These birch and birch–hazel woods, often with some oak, elm, ash, alder, holly, rowan and willow, are rich in several internationally rare and biogeographically important, warmth-demanding Atlantic species of ferns, bryophytes and lichens. Many of these species are growing at or near their northernmost known world localities (see Birks, 1973). The Holocene vegetational history of this area, as reconstructed at Loch Meodal (Williams, 1977) is thus of considerable importance in understanding the status of the existing woodlands in Sleat and in elucidating the development of the present ecological landscape of southern Skye. Third, the site contains sediments of Holocene and possible Lateglacial age that have been studied in some palynological detail by Williams (1977) and Birks (1973), respectively. The Lateglacial vegetational history may show that southern Skye was the northernmost known area of tree-birch growth during the Lateglacial Interstadial.

Figure 11.19 Loch Meodal: Holocene relative pollen diagram showing selected taxa as percentages of total pollen (from Birks and Williams, 1983). Note that the data are plotted against a radiocarbon time-scale.

Holocene forest history; an overview

The Holocene forest history of Skye (Williams, 1977; Birks and Williams, 1983) corresponds closely with the present-day distribution of natural or seminatural woodland stands on the

Table 11.1 Generalized comparison of the inferred Holocene vegetational history of the Isle of Skye based on the pollen records from Loch Cleat, Loch Ashik and Loch Meodal (from Birks and Williams, 1983)

Radiocarbon years BP: 0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000

Northern Skye Loch Cleat
Landscape virtually treeless. Abundant meadows and cereal cultivation
Grasslands abundant with some arable farming and tall-herb meadows. Heaths local. Birch-hazel-willow scrub rare
Grasslands frequent. Birch-hazel-willow scrub rare
Frequent grasslands and some arable agriculture. Birch-hazel-willow scrub occasional
Birch-hazel scrub with *Alnus*, *Sorbus aucuparia*, *Prunus padus* and *Salix*. Grasslands and tall-herbs locally frequent
Birch-hazel scrub with *Sorbus aucuparia*, *Salix* and *Prunus padus*. Grasslands and tall-herbs locally frequent
Birch-willow scrub. Grasslands and tall-herbs local
Juniper scrub, species-rich grasslands, tall-herbs, and local birch copses

Kyleakin Loch Ashik
Landscape virtually treeless
Abundant bogs and heaths. Birch woods very rare with some *Quercus* and *Alnus*
Birch woods local. Heaths, grasslands and bogs common
Pine-birch woods. Bogs, heaths and grassland local
Birch-hazel woods. Pine local. Heaths, bogs and grassland local
Birch-hazel-alder woods. *Quercus*, *Ulmus* and *Sorbus aucuparia* rare. Heaths, bogs and grasslands local
Birch-hazel woods with some *Quercus*, *Ulmus*, *Sorbus aucuparia*, *Salix* and *Prunus padus*. Heaths, bogs and grasslands local
Birch-hazel woods with *Salix*, *Sorbus aucuparia*, *Prunus padus*, ferns and tall-herbs
Juniper scrub, birch copses and grassland

Sleat Loch Meodal
Landscape virtually treeless. Grassland and bog abundant
Birchwoods local with some alder and hazel. Heaths abundant, grassland and bogs frequent
Birch-hazel-alder woods. Grasslands and heaths frequent. Bogs occasional
Birch-hazel-alder woods. *Quercus* very rare. Grasslands and heaths frequent. Bogs local
Birch-hazel-alder woods. *Ulmus* very rare. Grasslands and heaths local
Birch-hazel-alder woods. *Quercus*, *Ulmus*, *Populus* and *Sorbus aucuparia* rare
Birch-hazel woods with some *Quercus*, *Ulmus* and *Populus*. *Salix* locally common. Ferns and tall-herbs common
Birch-hazel woods with *Salix*, *Populus*, ferns and tall-herbs

island (Birks, 1973). Southern Skye has the most woodland today, eastern Skye has woodland confined to slopes that are too steep for blanket-bog development, whereas in northern Skye trees only grow in sheltered, rocky sites. This pattern may reflect climatic differences within Skye, with southern Skye being the mildest and most sheltered part today. The pollen records from Loch Meodal, Loch Cleat and Loch Ashik illustrate the very considerable variation in the Holocene vegetational history and forest composition of Skye (Table 11.1). The vegetational history of southern Skye has its closest affinities with the adjacent mainland of the Morar peninsula. Northern Skye corresponds, in its vegetational history, to sites on the mainland further north such as in northern Wester Ross and West Sutherland (see Loch Sionascaig, Cam Loch and Lochan an Druim). Eastern Skye has affinities with parts of Wester Ross (see Loch Maree) where pine was a major component of the forests for a comparatively short period within the Holocene. Nowhere else in Scotland or elsewhere in north-west Europe can such a range of variation in forest composition and vegetational history be found within such a small area.

Loch Meodal, Loch Ashik and Loch Cleat are three sites of great importance in the reconstruction and understanding of the Holocene forest history of Scotland. Each site has considerable scientific importance. Their importance is even greater, however, when the three sites are considered together. In combination, they provide a unique palynological record of forest history and fine-scale vegetational differentiation. They are of international importance in providing palaeoecological insights into past geographical patterns of forest composition, and into the dynamic nature of Holocene vegetational history.

Conclusion

Together these sites are important for the evidence they provide of the history of vegetation and forest development on Skye during the Holocene (the last 10,000 years), which occupies a critical geographical location in relation to the main woodland zones that occur in Scotland today. The detailed pollen records from each site indicate major regional differences in the vegetational history of the island. Such variations are unique within an area of this size and are of great importance in understanding the geography and dynamics of Holocene vegetation.