Quaternary of Scotland

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Chapter 10

South-west Highlands

INTRODUCTION
D. G. Sutherland

The area termed the south-west Highlands in this chapter extends south of the Great Glen to the Highland boundary and from the central Grampians to the west coast, including the Kintyre peninsula (Figure 10.1). As elsewhere, there is a considerable range of environments in this region, which is reflected in its Quaternary history. Deposits older than the Late Devensian occur in southern Kintyre, but the main mountain area has been the major centre of successive episodes of ice accumulation and dispersion in Scotland (see Chapter 1), with the result that no deposits older than the Loch Lomond Stadial are known from the central part of the area. The often impressive features of glacial erosion, both in the mountains and in the fjord-like sea lochs, have developed through many periods of both ice-sheet and partial glaciation during the Pleistocene.

Only two glacial episodes are therefore clearly recognized, related to the Late Devensian ice-sheet and the Loch Lomond Readvance. Both are associated with ice flow principally to the west and south-west, radiating out along the troughs and valleys away from the central ice accumulation areas; during the Loch Lomond Readvance, the largest ice-field was centred over the south-west Highlands. The main themes of research in this area have focused on the geomorphology, chronology and vegetation history of the Lateglacial and the significance of the pre-Late Devensian landforms and deposits.

Around the southern Kintyre peninsula there are marine landforms and deposits that pre-date the last glaciation. These consist of rock platforms up to 10 m above present sea level (see Glenacardoch Point), and which are overlain by glacial deposits, and high-level shell beds at altitudes of as much as 45 m OD (see Tangy Glen). The rock platforms are thought to have been formed during interglacials (Gray, 1978a; Sissons, 1981a) although no direct evidence for this is available. The origin and age of the high-level shell beds have been controversial, there being uncertainty as to whether they are *in situ* or ice-transported (Horne *et al*., 1897; Munthe, 1897; Jessen, 1905; Synge and Stephens, 1966; Sutherland, 1981a) and, if *in situ*, whether they were partly coeval with the last ice-sheet or were significantly older, or represent a glacial–interglacial–glacial cycle. Amino acid analysis of mollusc shells suggests that the deposits are older than the Ipswichian (Gray, 1985; D. G. Sutherland, unpublished data). Their exact position in the Scottish Pleistocene sequence awaits further work.

Studies of raised shorelines around the Scottish coast have indicated that the greatest isostatic depression resulting from the last ice-sheet was in the area of the south-west Highlands (Sissons, 1967a, 1976b, 1983a). That this was the area of thickest ice is also demonstrated by the transport of erratics such as Glen Fyne granite and Rannoch granite to both the east and the west (Sissons, 1967a; Sutherland, 1984a; Thorp, 1987).

Decay of the Late Devensian ice-sheet was accompanied by high relative sea levels (typically 30–40 m OD), marked by raised glaciomarine deltas, shingle ridges and beach terraces, such as occur at Glenacardoch Point. Particularly good examples of outwash terraces grading into raised shorelines occur at the mouth of Glen Scamadale and in the Ford–Kilmartin valley (Gray and Sutherland, 1977). During this period of ice retreat deposition of the fossiliferous Clyde beds began around the coasts (Peacock, 1975c), and dating of the included mollusc shells suggests that the greater part of the Clyde Sea area was free of ice by at least 13,000 BP (Sutherland, 1986). Analysis of the marine macro- and micro-faunas in the Clyde beds has indicated that after an initial relatively mild phase at the beginning of the Lateglacial Interstadial, sea temperatures along the west coast of Scotland were 2–3°C cooler than the present for much of the interstadial (Peacock, 1981b, 1983a, 1989b). Interestingly, there is evidence in the inshore marine palaeotemperature record for a brief warmer phase at the end of the interstadial (Graham *et al*., 1990; Peacock and Harkness, 1990).

The change in terrestrial environments during the Lateglacial Interstadial has been studied by pollen analysis at a number of sites along the western coastal fringe, as at Drimnagall and Pulpit Hill (Donner, 1957; Rymer, 1974, 1977; Birks, 1980; Tipping, 1984, 1986, 1989a, 1991b). During the interstadial these studies demonstrate that the vegetation was dominantly grassland interspersed with clumps of juniper, willow and *Empetrum*. As elsewhere in Scotland, certain sites suggest a brief period of climatic deterioration during the earlier or middle part of the interstadial.

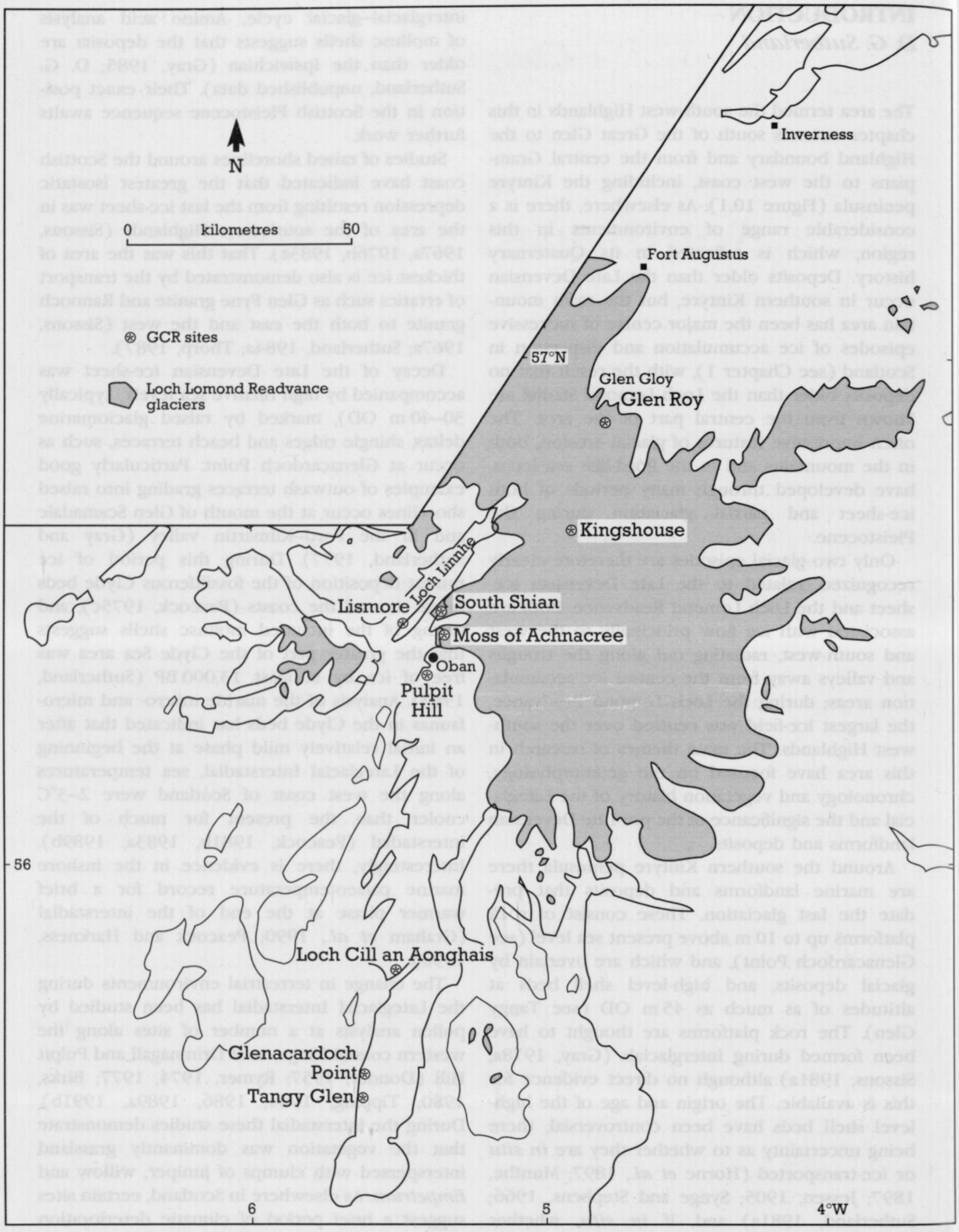


Figure 10.1 Location map of the south-west Highlands.

Introduction

The effects of the Loch Lomond Stadial climatic deterioration were particularly pronounced in the south-west Highlands. The extent of deglaciation during the preceding interstadial is not known but it seems probable that at least all the sea lochs were ice-free (Sutherland, 1981b). Thereafter, a major readvance of the ice occurred, with the principal ice mass being centred on the hills to the west of Rannoch Moor (Thorp, 1986, 1991a, 1991b) and in the mountains north of the Cowal peninsula (Figure 10.1). Outlet glaciers extended to the mouths of many of the sea lochs, overriding or eroding fossiliferous marine sediments, which has allowed the dating of the readvance, as at South Shian (Peacock, 1971b, 1971c; Peacock *et al.*, 1989). Impressive sequences of ice-marginal features were also formed by these glaciers, as with the kame terraces and outwash plains at Moss of Achnacree at the mouth of Loch Etive (McCann, 1961b; Gray, 1975a). Two separate groups of features largely dating from this time are of particular prominence in the south-west Highlands and deserve special comment. They are the Main Rock Platform and the landforms of the Glen Roy area.

The Main Rock Platform occurs widely around the coasts of the south-west Highlands where it is a prominent feature up to 100 m (occasionally more) wide, with a backing cliff typically over 10 m high. The platform surface carries numerous stacks (as the Dog Stone by Oban) and the cliffline has many undercuts and caves (as on Lismore) (Gray, 1974a, 1978a). The platform is tilted, and declines in altitude away from the centre of isostatic uplift (Gray, 1978a; Sutherland, 1984a) from a maximum of over 11 m OD in the inner sea lochs to about present sea level along the Mull of Kintyre (see Glenacardoch Point). It was originally considered to be a Holocene marine feature (Bailey *et al.*, 1924) but subsequently was assigned an earlier interglacial origin (Gray, 1974a). Sissons (1974d), however, noted similarities with the erosional Main Lateglacial Shoreline of the south-east of Scotland and suggested, controversially, that the Main Rock Platform was formed towards the end of the Lateglacial, principally in the severe climate of the Loch Lomond Stadial. This view was accepted by those mapping the platform (Gray, 1978a; Dawson, 1979a, 1980b; Sutherland, 1981b, 1984a) although the possibility of inheritance from an earlier feature was pointed out (Peacock *et al.*, 1978; Sutherland, 1981b). This latter idea was also put forward by Browne and MacMillan (1984), and the uranium-series disequilibrium dating of speleothems from caves and undercuts in the cliff backing the platform on Lismore (Gray, 1987; Gray and Ivanovich, 1988) has also supported the concept (see also Dawson, 1989; Gray, 1989).

The Glen Roy area is quite outstanding for its assemblage of landforms and sediments related to the sequence of ice-dammed lakes when Loch Lomond Readvance glaciers blocked the mouths of Glen Spean, Glen Roy and Glen Gloy. These landforms have long been famous, the most detailed early work being that of Jamieson (1863, 1892); in recent years Sissons has added many details to the known sequence of events and the nature of the landforms (Sissons, 1978, 1979a, 1979b, 1979c, 1981d; Sissons and Cornish, 1982a, 1982b, 1983). Important results of Sissons' work are the clarification of the pattern of ice advance and retreat and the corresponding successive lake levels; the mode of formation of the shorelines; the fact that the shorelines in Glen Roy were formed principally during the rising lake sequence; the catastrophic drainage of the lakes; the warping and dislocation of the shorelines, particularly near ice-margins suggesting a glacio-isostatic influence; and the complex sequence of river terraces developed after lake drainage.

Glen Roy is not the only locality in the south-west Highlands where ice-dammed lake shorelines are of note, similar features having been formed by Loch Tulla during ice retreat at the end of the readvance (Ballantyne, 1979).

The severity of the climate during the Loch Lomond Stadial is reflected in a very reduced marine fauna of arctic affinity which inhabited the waters around the coasts of Scotland at that time (Peacock *et al.*, 1978; Peacock, 1981b; Graham *et al.*, 1990; Peacock and Harkness, 1990). Periglacial processes were particularly active on the mountain summits, resulting in a clear differentiation between the ice-moulded cols and mountain slopes buried by the readvance ice and the frost-riven and shattered bedrock surfaces that extended above the ice surface (Thorp, 1981a, 1981b, 1986, 1991a).

The decay of the readvance glaciers has been studied by examining the basal sedimentary sequences in enclosed basins inside the glacier limits (Lowe and Walker, 1981; Walker and Lowe, 1981; Tipping, 1988, 1989b). The basal pollen assemblages become progressively younger towards Rannoch Moor and this implies progressive deglaciation in that direction. A particularly valuable site is that at Kingshouse (Lowe and Walker, 1976; Walker and Lowe, 1977), where a radiocarbon date on moss fragments suggests that this area could have been deglaciated as early as 10,200 BP. The pollen zonation at the base of various enclosed depressions confirms deglaciation by the time of widespread expansion of juniper shrubs, but radiocarbon assays on this characteristic and widely recognized phase in the vegetation development are not sufficiently accurate to provide a clear limiting date on deglaciation (Tipping, 1987).

In the south-west Highland region two distinct zones of forest development are recognized during the Holocene. In the western coastal areas oak forest with birch developed (Loch Cill an Aonghais), whereas to the east, in the mountainous zone, pine became the major element of the forest during the middle Holocene (Birks, 1977; Bennett, 1984). The pine appears to have expanded after 8000 BP, following a phase of birch–hazel woodland dominance, and after about 4000 BP blanket bog expanded at the expense of pine. Human impact on the vegetation has been inferred from the time of the elm decline and possibly earlier in Kintyre (Nichols, 1967; Edwards and McIntosh, 1988).

Following low relative sea levels during the early Holocene, the Main Postglacial Transgression reached its climax, probably between 7000 and 6000 BP and a distinct, isostatically tilted shoreline was formed, equivalent to the Main Postglacial Shoreline of the east coast (Gray, 1974b; Sutherland, 1981b). Subsequently, as sea level fell towards its present level, four (Gray, 1974b) or five (Sutherland, 1981b) lower shorelines were formed.

The mountainous nature of much of the south-west Highlands has resulted in the rivers having a very 'flashy' regime and alluvial fans are common in many of the valleys. Although parts of these fans are active today, they typically have a complex history of development during the Holocene, as is illustrated by Eas na Broige in Glen Etive (Brazier *et al.*, 1988). The radiocarbon dating of the debris-flow and alluvial-fan deposits there indicates two periods of activity, one during the early to middle Holocene when glacial debris was available for reworking, and the other in recent times initiated by either climatic deterioration or overgrazing (Innes, 1983b; Brazier *et al.*, 1988).

TANGY GLEN

D. G. Sutherland

Highlights

The stream sections at this locality provide exposures in high-level, shelly clays. These are believed to be a unique occurrence of *in situ* marine sediments deposited during a Middle Pleistocene glaciation when relative sea level was higher than at present.

Introduction

The Tangy Glen site comprises stream sections along three burns on the west coast of Kintyre *c.* 13 km north-west of Campbeltown: Tangy Burn (NR 659279), Drumore Burn (NR 670329) and Allt a'Ghlaoidh (NR 670337). During the last century a number of localities were discovered in Scotland at which marine shells contained in sands or clays were overlain by glacial sediments (see Jamieson, 1858, 1866; Smith of Jordanhill, 1862; Crosskey and Robertson, 1873b; Fraser, 1882a, 1882b). These sites occurred at altitudes considerably in excess of the more widely distributed fossiliferous clays which post-dated the glacial deposits, and considerable debate ensued as to the nature of the high-level deposits and their place in the glacial sequence (J. Geikie, 1874; see also Clava). As a consequence a special committee of the British Association was convened to investigate these occurrences and one of the three areas they investigated was the sequence of shelly clays on the west coast of the Mull of Kintyre. These deposits were first reported by Crosskey and Robertson (1873b) at Tangy Glen and, although the main exposures of the clays are found in stream-cut sections to the north (Horne *et al.*, 1897), it is by the name of the original locality that the site is commonly known. The most detailed description of the stratigraphy of the shelly clays of Kintyre is that given by Horne *et al.* (1897). Subsequently the deposits have been investigated by Munthe (1897), Jessen (1905) and Gray (1985). Gray (1985) and Bowen and Sykes (1988) provided details of amino acid analyses of shells from the clays, and Sutherland (1981a) placed them in a wider context of related deposits in Scotland.

Description

The glaciation of the Kintyre peninsula was recorded by Horne *et al.* (1897) as being in a generally westerly direction based on the evidence of striae as well as the occurrence of erratics of Arran granite across the area.

Horne *et al.* (1897) reported clays occurring in three separate localities along approximately 4 km of coastline. In Tangy Glen the clays occur up to a height of about 135 ft (41 m) above present sea level, whereas to the north in Drummore Glen the top of the clays was taken to be 199 ft (60 m) and beside the Cleongart Burn (Allt a'Ghlaoidh), about 179 ft (55 m). Of these three exposures that at Cleongart was by far the most fossiliferous and it is the one that has been most closely investigated.

Horne *et al.* (1897) excavated two trenches across the top and base of the shelly clays in the Allt a'Ghlaoidh exposure as well as drilling three holes upstream and two in a line to the south in order to determine the continuity of the deposit in those directions. The stratigraphy they established is given below and illustrated in Figure 10.2.

3. Till, reddish-brown with abundant boulders most of which are local schist. No Arran granite erratics were observed in the section, but these occur frequently in the neighbourhood. 22.5 m
2. Shelly clay, stiff, dark bluish. The upper part is relatively stone-free, but fragments of schist occur in the lower part. Shells occur throughout. 8.4 m
1. Compact coarse sand and gravel. Unfossiliferous. >1.2 m

This succession has been confirmed in its broad details by subsequent workers (Munthe, 1897; Jessen, 1905; Gray, 1985) although more detailed descriptions have been given of the shelly deposits. Both Munthe (1897) and Gray (1985) identified a stoney layer in the clays, which Munthe compared to a 'veritable boulder clay', although Jessen (1905) disagreed that it could be compared to a glacial sediment.

Interpretation

The initial work of Crosskey and Robertson (1873b), Brady *et al.* (1874) and Horne *et al.* (1897) produced lists of species of marine molluscs, Foraminifera and ostracods, but did not attempt to establish whether there were any vertical variations in the species representation except for sequential analyses in the most southerly of the boreholes. No comment was made on the significance of any changes in the occurrence of different species at different levels in the clays. The most common molluscs recorded by Horne *et al.* (1897) were the bivalves *Arctica islandica* (Linné), *Astarte sulcata* (da Costa),

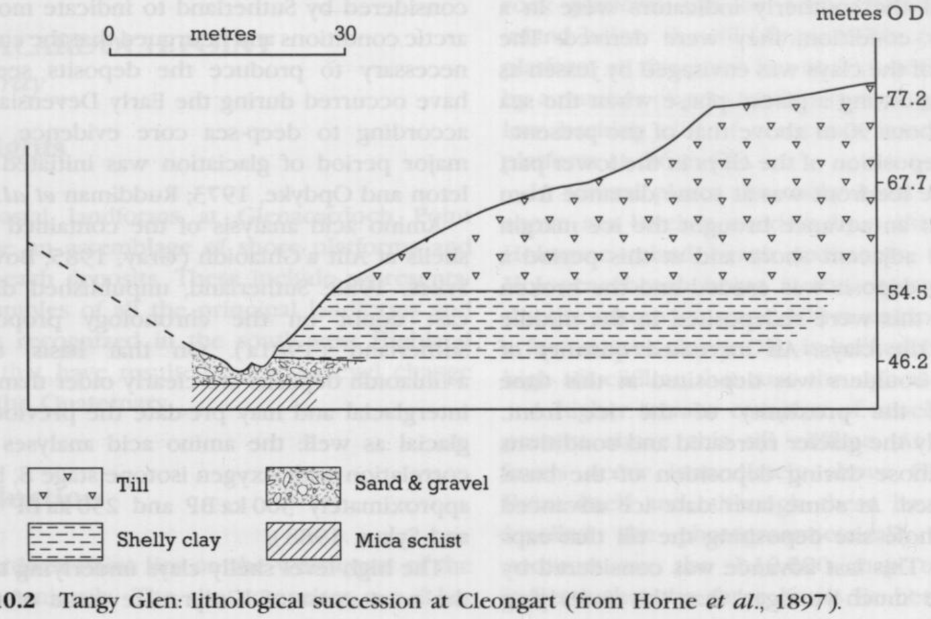


Figure 10.2 Tangy Glen: lithological succession at Cleongart (from Horne *et al.*, 1897).

Macoma calcarea (Gmelin), *Nicania montagui* (Dillwyn), and *Nuculana pernula* (Müller) and the gastropod *Turritella tenebra* (Linné). It was noted, however, that there was an apparent mixture of species deriving from both arctic and more southerly latitudes. It was also noted that the majority of the mollusc shells were broken.

In contrast to this initial work, Munthe (1897) examined twelve samples taken vertically through the deposit. On the basis of the fossil content of these samples Munthe concluded that the period of deposition of the clays coincided with a succession of cold to warm to cold climate. Munthe further interpreted the gravel at the base of the section (bed 1) as a glacial deposit, and hence argued that the warm phase in the middle portion of the clays was an interglacial. He considered that during the two cold phases water depth would have been at least 40 m (that is, upwards of 95 m above present sea level), but that during the warm phase a water depth of between 6 m and 25 m was more likely (between 51 m and 70 m above present sea level). Munthe accepted, however, that there were certain species which apparently implied different climatic conditions from those he interpreted and he suggested that these were reworked from previous deposits.

Jessen (1905) did not accept Munthe's (1897) subdivision of the deposit on the basis of its fauna. In contrast, he pointed out that the only mollusc shells to be found with valves together and in growth position were those indicative of an arctic climate. He suggested that since the shells of all the southerly indicators were in a fragmentary condition, they were derived. The deposition of the clays was envisaged by Jessen as taking place during a glacial phase when the sea level was about 90 m above that of the present.

During deposition of the clays in the lower part of bed 2 the ice front was at some distance from the site, but an advance brought the ice margin near to the adjacent shore and at this period a pre-existing deposit was eroded and the broken shells from this were redeposited in the middle portion of the clays. An increased quantity of gravel and boulders was deposited at this time because of the proximity of the ice front. Subsequently the glacier retreated and conditions similar to those during deposition of the basal clays resumed. At some later date ice advanced over the whole site depositing the till that caps the section. This last advance was considered by Jessen to be 'much younger' than the underlying clays. Both Munthe (1897) and Jessen (1905) accepted that during the glaciation(s) of the area ice movement was from east to west.

A quite distinct glacial history was offered for the southern Kintyre peninsula by Synge and Stephens (1966). They suggested that the Tangy Glen shelly clays were a till emplaced during an early glaciation with ice movement from north to south. There was a subsequent 'main' ice movement from east to west during which the overlying red till was deposited, but after this there occurred a final ice movement, again from the north, with an ice margin in the general area of Tangy Glen, where 'morainic accumulations' were referred to as being present. Striae oriented S10°E were cited as supporting evidence for this final ice movement. No further justification was advanced for regarding the shelly clays as being glacial in origin.

The shelly clays were regarded by Sutherland (1981a) as being *in situ* marine deposits and he argued that they had a common origin with the other similar deposits encountered around the Scottish coast, such as at Clava and Afton Lodge. He noted that the maximum altitude to which the high-level shell beds had been encountered decreased with increasing distance along glacier flow-lines, and presented a model explaining the distribution in terms of crustal depression in front of an expanding ice-sheet, with world sea level being relatively high during the initial glacial advance but subsequently falling as the large ice-sheets in the Northern Hemisphere expanded. The fauna of the shell beds was considered by Sutherland to indicate moderately arctic conditions and he argued that the conditions necessary to produce the deposits seemed to have occurred during the Early Devensian when, according to deep-sea core evidence, the last major period of glaciation was initiated (Shackleton and Opdyke, 1973; Ruddiman *et al.*, 1980).

Amino acid analysis of the contained mollusc shells at Allt a'Ghlaoidh (Gray, 1985; Bowen and Sykes, 1988; Sutherland, unpublished data) has cast doubt on the chronology proposed by Sutherland (1981a). On that basis, the Allt a'Ghlaoidh deposits are clearly older than the last interglacial and may pre-date the previous interglacial as well: the amino acid analyses suggest correlation with oxygen isotope stage 8, between approximately 300 ka BP and 250 ka BP (Bowen and Sykes, 1988).

The high-level shelly clays underlying till along the west coast of Kintyre are some of the best examples of a type of deposit encountered at only a few sites in Scotland. Their origin has been controversial since their discovery last century. Current published opinion favours the interpretation of the deposits as being *in situ*. The amino acid analyses imply that the deposit is of Middle Pleistocene age, although the length of period during which they were deposited is unclear. A Middle Pleistocene age distinguishes the Tangy Glen deposits from those at Clava (Devensian age) and would mean that the deposits are the only known representatives in Scotland of a marine event, possibly associated with ice-sheet glaciation, during oxygen isotope stage 8.

Conclusion

The clays containing shells of marine molluscs at Tangy Glen form part of a suite of such deposits that occurs in Scotland well above present sea level. Although they have a long history of research dating back to the last century, their respective ages and origins remain a source of scientific argument. Current work suggests that the high-level clays at Tangy Glen were laid down when the land was depressed by ice during a Middle Pleistocene glaciation (approximately 275,000 years ago), which would make them the only known deposit of their kind in Scotland. They therefore have an important bearing on interpreting this significant part of the Quaternary history of Scotland, about which little is otherwise known.

GLENACARDOCH POINT

J. M. Gray

Highlights

The coastal landforms at Glenacardoch Point comprise an assemblage of shore platforms and raised beach deposits. These include representative examples of all the principal landforms and deposits recognized in the south-west Highland region, that have resulted from sea-level change during the Quaternary.

Introduction

Glenacardoch Point lies on the west coast of the Kintyre peninsula. The site comprises a *c.* 2 km length of coastline (between NR 667384 and NR 659366), and extends 0.25–0.55 km inland. It is important in demonstrating two shore platforms and a sequence of raised beach deposits which provide a record of sea-level changes in the south-west Highlands. Little research has been carried out on the site. Apart from a few brief mentions in the early literature (Nicol, 1852; Hull, 1866; Sinclair, 1911), the only recent work is by Gray (1978a) who mapped and levelled the two shore platforms.

Description

Several accounts of former shorelines in Kintyre appeared in the early literature, drawing attention to raised and intertidal platforms with well-developed rock cliffs and caves (Nicol, 1852; Hull, 1866). Sinclair (1911) also made an important observation that raised sea stacks on some of the platforms were covered by till and therefore pre-dated a period of glaciation. The geomorphology of the site is shown in Figure 10.3, and Figure 10.4 is a generalized cross-profile. As can be seen from these figures, the site consists of a series of terraces of marine origin. Four main features or groups of features can be recognized. The oldest is a till-covered platform occurring over a distance of about 400 m at, and immediately south of Glenacardoch Point, though poorer fragments occur both to the north and south. Till is exposed in a section in the cliff behind the platform (at NR 660377), and at this point the rock platform can be seen clearly to extend inland below the till (Gray, 1978a, p. 155). The platform at this point lies at 13.1 m OD. It is cut by a number of geos, and its front slope forms the low backing cliff of a second, lower, intertidal platform at 0.6 m OD.

In several places the rocky coast immediately above sea level is overlain by a thin veneer of Holocene raised beach sediments, the clearest Holocene beach being at the extreme south of the site where a terrace, 100 m or more wide and a few metres above OD, is backed by the 20 m high till cliffline that runs through the site.

A higher terrace complex of raised beaches is present above this till cliffline. At least three levels occur immediately above Glenacardoch Point itself and, although these have not been levelled, the photogrammetrically determined contours on the 1:10,000 map of the area indicate that the three levels lie between about

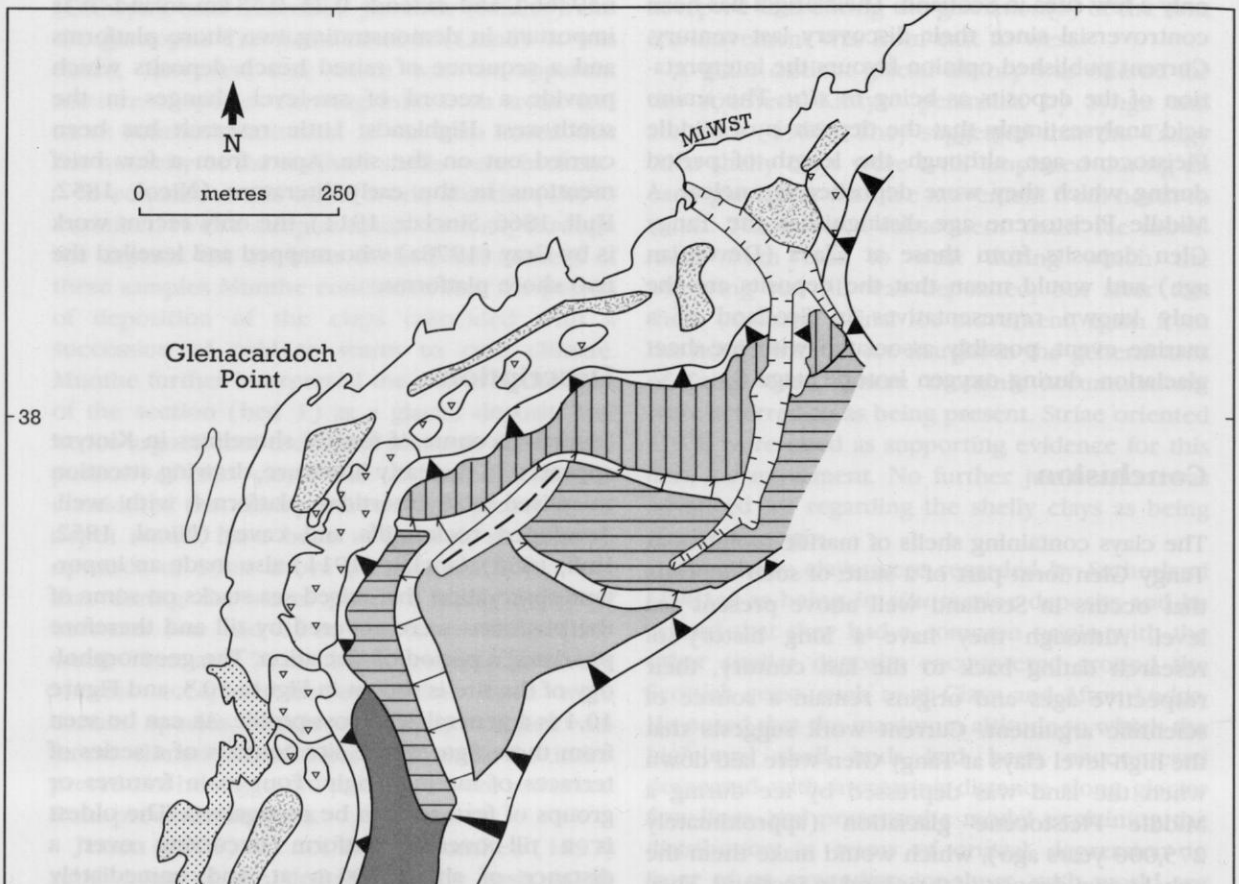


Figure 10.3 Geomorphology of the Glenacardoch Point area.

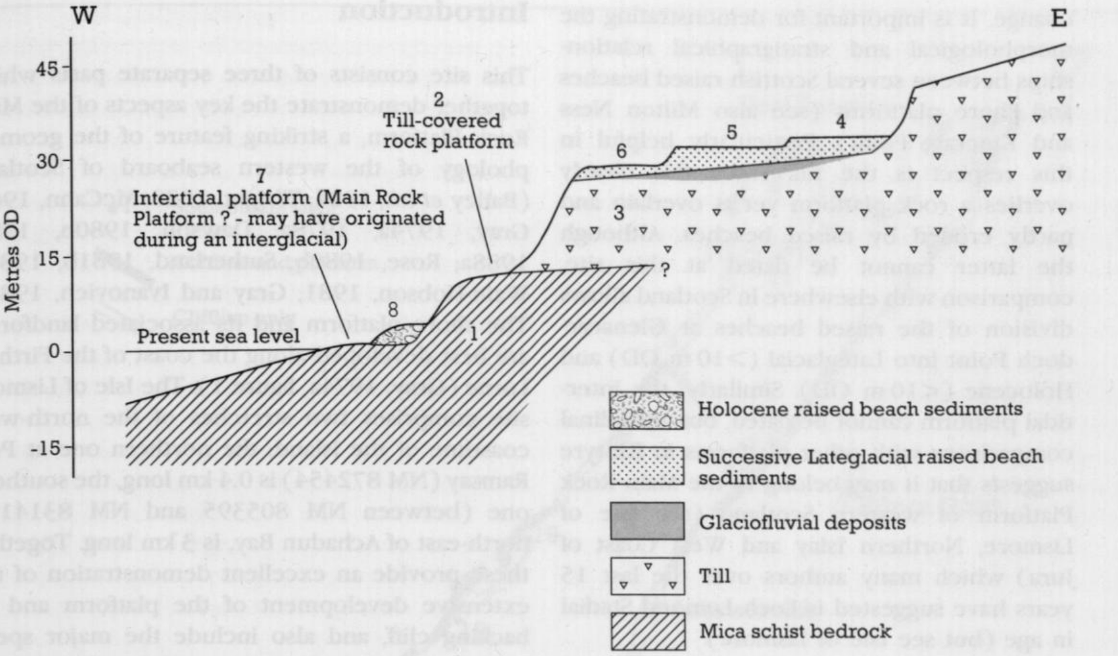


Figure 10.4 Coastal profile at Glenacardoch Point showing the relationships between the morphology and succession of the features and their probable sequence of formation (1–8).

28 m and 34 m OD. A possible storm ridge occurs at the front edge of the highest level, and at the back edge there is a further low till cliff. A section in the middle beach terrace (at NR 665378) reveals 2 m of well-bedded sand and gravel and (at NR 666381) sections in a stream valley show these beach sediments overlying till and glaciofluvial deposits.

Interpretation

The interpreted relationships between the different features are summarized in Figure 10.4, together with the probable sequence of formation. The oldest feature is the till-covered platform which pre-dates at least the main Late Devensian glaciation represented by the till. Following deglaciation, the till was trimmed by the sea and a sequence of Lateglacial beaches, now isostatically uplifted to *c.* 28–34 m OD, was formed. Subsequently, sea level fell to close to its present level and the platform in the present intertidal zone developed. From the overall platform distribution in Kintyre and neighbouring areas, Gray (1978a) suggested that the intertidal platform at Glenacardoch Point correlates with the Main Rock Platform of western Scotland either formed or last occupied during the Loch Lomond Stadial (Gray, 1974a, 1978a). During the Holocene, sea level once again rose, resulting in deposition of the beach gravels that occur below 10 m OD.

Glenacardoch Point is important in two main respects:

1. Till covered low-level platform. It is one of the few sites in Scotland where a low-level shore platform can clearly be seen to pass below till (see Port Logan and Dunbar). Similar situations are common in Ireland, but on the Scottish coast the Kintyre peninsula provides the best examples. Neighbouring equivalent sites a few kilometres to the south between Bellochantuy and Westport have been disturbed. The succession demonstrates that the platform pre-dates at least one glacial episode and although much work remains to be done on dating and correlating the platforms of western Britain, current opinion regards such low-level, till-covered platforms as having formed during interglacials. It is probably part of a suite of subhorizontal, low-level platforms in western Britain (Sissons, 1981a).
2. Sequence of sea-level changes. The site is also notable in preserving, within a compact area, evidence for several phases of sea-level

change. It is important for demonstrating the morphological and stratigraphical relationships between several Scottish raised beaches and shore platforms (see also Milton Ness and Kincraig Point). Particularly helpful in this respect is the till, since this clearly overlies a rock platform yet is overlain and partly eroded by raised beaches. Although the latter cannot be dated at this site, comparison with elsewhere in Scotland allows division of the raised beaches at Glenacardoch Point into Lateglacial (>10 m OD) and Holocene (<10 m OD). Similarly, the intertidal platform cannot be dated, but altitudinal comparisons with other platforms in Kintyre suggests that it may belong to the Main Rock Platform of western Scotland (see Isle of Lismore, Northern Islay and West Coast of Jura) which many authors over the last 15 years have suggested is Loch Lomond Stadial in age (but see Isle of Lismore).

Conclusion

The landforms and deposits at Glenacardoch Point are important since within a 2 km stretch of coast it is possible to establish and demonstrate most of the major elements of the recognized sequence of sea-level changes which occurred in the south-west Highlands during Quaternary times. Of particular interest is a very clear example of a low-level, coastal shore platform overlain by glacial deposits (till), indicating that the former pre-dates at least one glaciation. Glenacardoch Point is therefore both a representative site and a valuable component in the network of sites demonstrating sea-level changes.

ISLE OF LISMORE, THE DOG STONE AND CLACH THOLL

J. M. Gray

Highlights

These three coastal localities together demonstrate key features relating to the geomorphology and dating of the Main Rock Platform, one of the most distinctive Quaternary shorelines in western Scotland. The speleothem deposits on Lismore, in particular, hold great potential for the dating of this shoreline.

Introduction

This site consists of three separate parts which together demonstrate the key aspects of the Main Rock Platform, a striking feature of the geomorphology of the western seaboard of Scotland (Bailey *et al.*, 1924; Wright, 1928; McCann, 1968; Gray, 1974a, 1978a; Dawson, 1980b, 1984, 1988a; Rose, 1980b; Sutherland, 1981b, 1984a; Wain-Hobson, 1981; Gray and Ivanovich, 1988). The shore platform and its associated landforms are best developed along the coast of the Firth of Lorne (Gray, 1974a, figure 1). The Isle of Lismore site comprises two stretches of the north-west coastline of the island; the northern one at Port Ramsay (NM 872454) is 0.4 km long, the southern one (between NM 805395 and NM 831411), north-east of Achadun Bay, is 3 km long. Together these provide an excellent demonstration of the extensive development of the platform and its backing cliff, and also include the major speleothem sites that have a significant bearing on interpreting the age(s) of the platform (Gray and Ivanovich, 1988). On the adjacent mainland, two classic erosional features are associated with the platform. The Dog Stone (NM 853311) is a raised sea stack located immediately north of the promenade at Oban. Clach Tholl (NM 900448) is a raised natural arch located *c.* 1 km south-west of Port Appin.

Description

The Isle of Lismore provides an example of the continuity and excellent development of the shoreline over a long stretch of coast (Figure 10.5; see Gray and Ivanovich, 1988, figure 3), and as such is typical of the shoreline in the Firth of Lorn area. A cliffline 5–15 m high can be traced uninterrupted along virtually the whole length of the site, and a platform up to 100 m wide is also present, particularly in the south-west. Some of the classic features associated with the shoreline are also present at this site, including undercuts at the base of the cliffs (for example, around localities 14–17, Figure 10.5) and caves (such as Uamh na Cathaig – locality 18 – which is about 10 m deep; see Gray and Ivanovich, 1988, figure 4).

The presence and development of the shoreline on Lismore have been important factors in the evolution of ideas on the age and origin of the Main Rock Platform. In particular the sheltered

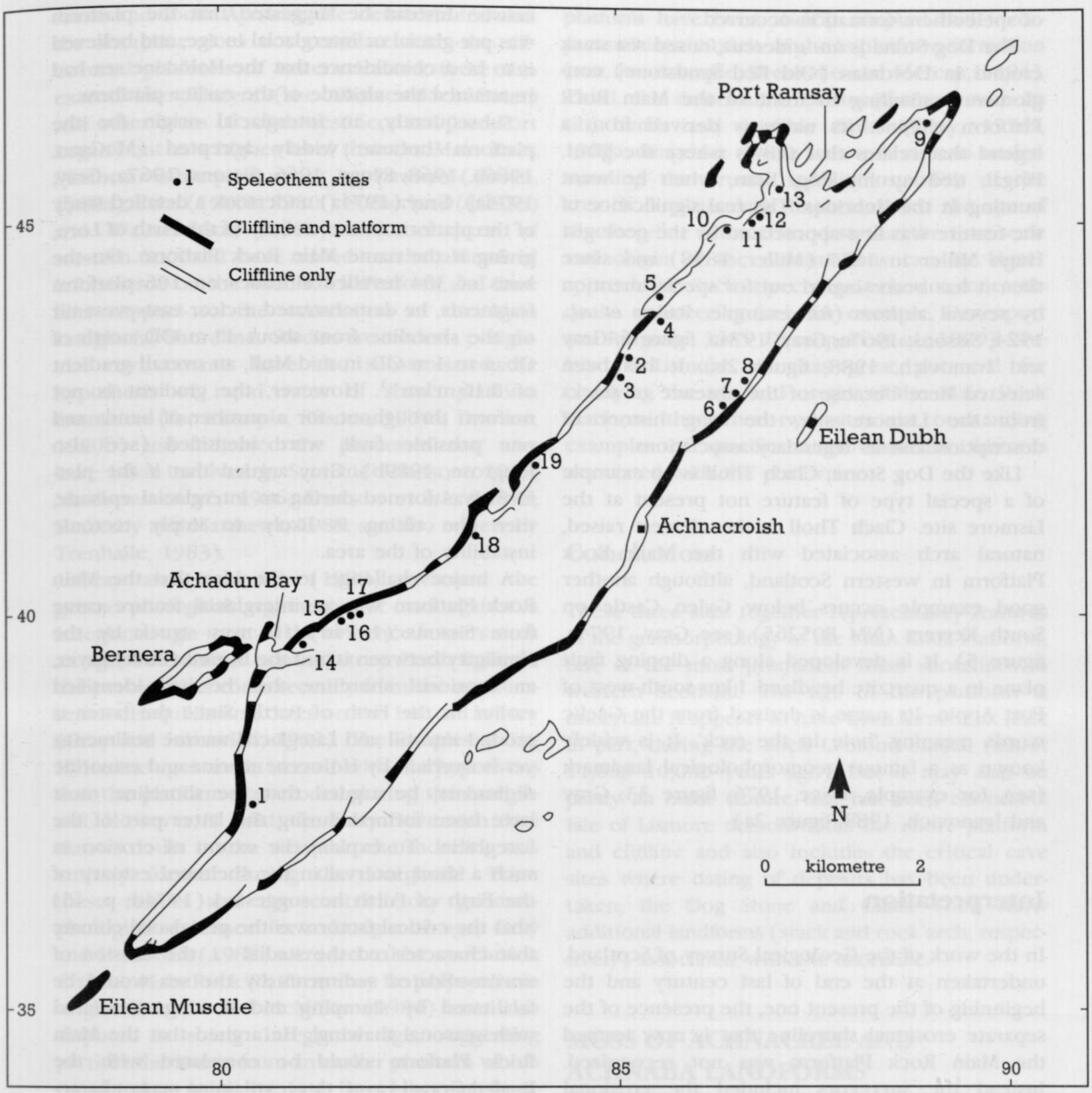


Figure 10.5 Distribution of the Main Rock Platform on the Isle of Lismore and localities mentioned in the text (from Gray and Ivanovich, 1988).

location of the island and its occurrence within the glacial trough of the Great Glen were both referred to by Sissons (1974d, p. 43) in his paper arguing for a Loch Lomond Stadial age for the shoreline.

Speleothem samples from four sites, undercuts and caves in the base of the cliffline, have been dated by uranium-series disequilibrium methods (Gray and Ivanovich, 1988). Five samples produced a range of ages: two from the Holocene, two from the Late Devensian and one from the Early Devensian. From analytical results, Gray and Ivanovich (1988) considered that the two samples that gave Late Devensian ages were unreliable and that they may actually be of Holocene age. However, the sample that gave the Early Devensian age (of 103.3 ka +28.4/−20.0 ka, HAR–3228) was considered reliable. Thus at least two periods of speleothem formation occurred.

The Dog Stone is an undercut, raised sea stack eroded in Devonian (Old Red Sandstone) conglomerate standing in front of the Main Rock Platform cliffline. Its name is derived from a legend that relates that this is where the giant, Fingal, tied up his dog, Bran, when he went hunting in the Hebrides. The real significance of the feature was first appreciated by the geologist Hugh Miller in 1857 (Miller, 1858) and since then it has been singled out for special mention by several authors (for example, Bailey *et al.*, 1924; Sissons, 1967a; Gray, 1974a, figure 6; Gray and Ivanovich, 1988, figure 2b). It has been selected here because of the absence of stacks from the Lismore site, the long history of description and its legendary associations.

Like the Dog Stone, Clach Tholl is an example of a special type of feature not present at the Lismore site. Clach Tholl is the clearest raised, natural arch associated with the Main Rock Platform in western Scotland, although another good example occurs below Gylen Castle on South Kerrera (NM 805265) (see Gray, 1974a, figure 5). It is developed along a dipping fault plane in a quartzite headland 1 km south-west of Port Appin. Its name is derived from the Gaelic words meaning 'hole in the rock'. It is widely known as a famous geomorphological landmark (see, for example, Price, 1976, figure 33; Gray and Ivanovich, 1988, figure 2a).

Interpretation

In the work of the Geological Survey of Scotland, undertaken at the end of last century and the beginning of the present one, the presence of the separate erosional shoreline that is now termed the Main Rock Platform was not recognized. Instead the surveyors included the erosional shoreline fragments with the '25 ft beach', of Holocene age (Kynaston and Hill, 1908; Bailey *et al.*, 1924), mainly due to the fact that the two sets of features broadly correspond in altitudinal range. Indeed, Wright (1928, p. 100) called the postglacial sea 'the cliff-maker *par excellence*'. McCallien (1937a), however, was not convinced that the rock platform and cliffs had been cut by the same sea that deposited the Holocene beach sediments. He believed (McCallien, 1937, p. 197) that 'since the Ice Age there has not been enough time for the cutting away of so much solid rock as is indicated in the raised platform around our coasts'. Instead he suggested that the platform was pre-glacial or interglacial in age, and believed it to be a coincidence that the Holocene sea had re-attained the altitude of the earlier platform.

Subsequently, an interglacial origin for the platform became widely accepted (McCann, 1966b, 1968; Synge, 1966; Sissons, 1967a; Gray, 1974a). Gray (1974a) undertook a detailed study of the platform in the vicinity of the Firth of Lorn, giving it the name Main Rock Platform. On the basis of 304 levelled altitudes on 106 platform fragments, he demonstrated a clear east–west tilt on the shoreline from about 11 m OD north of Oban to 4 m OD in mid-Mull, an overall gradient of 0.16 m km^{-1}. However, the gradient is not uniform throughout, for a number of bends and one possible fault were identified (see also Ringrose, 1989b). Gray argued that if the platform was formed during an interglacial episode, then the tilting is likely to imply tectonic instability of the area.

A major challenge to the idea that the Main Rock Platform was an interglacial feature came from Sissons (1974d). He was struck by the similarity between it and the Buried Gravel Layer, an erosional shoreline that he had identified earlier in the Firth of Forth. Since the latter is eroded into till and Lateglacial marine sediments, yet is overlain by Holocene marine and estuarine sediments, he argued that the shoreline must have been formed during the latter part of the Lateglacial. To explain the extent of erosion in such a short interval in the sheltered estuary of the Firth of Forth he suggested (1974d, p. 46) 'that the critical factor was the periglacial climate that characterized the stadial ... the erosion of unconsolidated sediments by the sea would be facilitated by slumping and flowing associated with seasonal thawing'. He argued that the Main Rock Platform could be correlated with the Buried Gravel Layer, thus explaining many characteristics of the former. For example, its tilt (due to differential glacio-isostatic rebound), its apparent lack of direct evidence of having been glaciated (due to its Lateglacial age), and its development in sheltered locations (due to periglacial frost shattering rather than wave action). Sissons used the term 'Main Lateglacial Shoreline' to refer to the correlation of the two features.

Fieldwork by Gray (1978a) in the area between the Firth of Lorn and the Firth of Clyde showed that the Main Rock Platform as well as having an east–west tilt also has a north–south tilt, reaching sea level in south Kintyre, south

Arran and south Ayrshire. He demonstrated that the shoreline does not correlate with the till-covered platforms of eastern Ireland; these also extend into Kintyre (see Glenacardoch Point) and other areas of south-west Scotland (see Port Logan) but at a higher level than the Main Rock Platform. Subsequent work by Dawson (1980b, 1988a), Rose (1980b, 1980f), Sutherland (1981b) and Wain-Hobson (1981) in other parts of western Scotland have added to the altitudinal information on the Main Rock Platform and have lent support to the correlation of the Main Lateglacial Shoreline. Studies in modern periglacial environments have also substantiated the hypothesis of rapid rates of shore platform formation (for example, Sissons, 1974a; Dawson, 1980b) and indicated the processes that may have been involved in Scotland (Hansom, 1983; Matthews *et al.*, 1986; Dawson *et al.*, 1987b; Shakesby and Matthews, 1987; see also review by Trenhaile, 1983).

Gray and Ivanovich (1988) reviewed the geomorphological arguments for and against a Lateglacial age: most of the evidence favours such an age, but some is contradictory. Fresh light on the problem has come recently from the uranium-series disequilibrium dates on the Isle of Lismore (Gray and Ivanovich, 1988). The samples giving Holocene ages are in accord with the hypothesis that the platform was eroded during the Lateglacial. However, if valid, the Early Devensian date throws doubt on the view that the shoreline was entirely formed during the Lateglacial. From these results and the contradictory geomorphological evidence for a Lateglacial age, Gray and Ivanovich (1988) were led to the conclusion that the Main Rock Platform may be polycyclic in origin. Browne and McMillan (1984) have also disputed a solely Lateglacial age, suggesting partial inheritance from an earlier platform which pre-dated at least the Late Devensian ice-sheet. Gray (1989) and Dawson (1989) have recently debated several aspects of the distribution and development of the Main Rock Platform in western Scotland.

The Main Rock Platform is important in several respects. First, it is one of the best-developed raised shorelines in Scotland and indeed in Europe. It is directly comparable with the 'Main Line' of northern Norway, also a rock-cut, glacio-isostatically tilted shoreline which was formed during the Younger Dryas (Marthinussen, 1960; Andersen, 1968; Sollid *et al.*, 1973). Second, recent ideas on rapid, periglacial formation of the platform have been widely adopted and incorporated into models of shore platform formation (see, for example, Trenhaile and Mercan, 1984). Third, the deformation of the platform with its tilt, bends and possible faults (Gray, 1974a, 1978a; Ringrose, 1989b) are relevant to understanding the crustal stability/instability of the area. It is particularly important that the age of the shoreline is understood so that the time-scale and origin of the deformations can be better appreciated. Such aspects are relevant to earthquake engineering (see, for example, Davenport and Ringrose, 1985; Davenport *et al.*, 1989). The Isle of Lismore site has great potential for clarifying the age and origin of the Main Rock Platform: the other two sites are outstanding examples of specific raised shoreline features associated with the platform.

Conclusion

These three sites together represent key features of the geomorphology of the Main Rock Platform, one of the most prominent fossil shorelines in western Scotland. The age of the platform is uncertain. It appears to have been formed, at least in part, during the Loch Lomond Stadial (about 11,000–10,000 years ago), but it may also be partly an older feature that has been reworked. Isle of Lismore demonstrates the shore platform and cliffline and also includes the critical cave sites where dating of deposits has been undertaken; the Dog Stone and Clach Tholl show additional landforms (stack and rock arch, respectively) associated with the shoreline.

MOSS OF ACHNACREE AND ACHNABA LANDFORMS

J. M. Gray

Highlights

This site demonstrates an outstanding assemblage of glaciofluvial landforms deposited by a Loch Lomond Readvance glacier.

Introduction

The site is located on the north side of Loch Etive and includes the major part (*c.* 4 km^2 in area) of an outwash plain underlying the Moss of Achnacree (NM 920358) and a 2.5 km length of adjoining kame terrace fragments and related glaciofluvial features to the east near Achnaba (NM 945365). It forms what is arguably the finest outwash and kame terrace system in Great Britain and its importance lies in the way that it is possible to demonstrate relationships between ice-marginal glaciofluvial features, and between ice-contact and proglacial drainage systems. Moss of Achnacree and Achnaba is also a particularly good representative of a landform assemblage associated with a number of Loch Lomond Readvance glaciers which terminated near to sea level in western Scotland. The area has been described by Kynaston and Hill (1908), McCann (1961b, 1966a), Synge (1966) and Gray (1972, 1975a).

Description

Moss of Achnacree

The Moss of Achnacree outwash plain (1, Figure 10.6) covers an area of almost 4 km^2. Most of the central part is covered by about 2 m of peat (the Moss of Achnacree), the edges having been cleared over the years for crofting and farming. Building construction and augering on these and other parts of the outwash plain have shown it to be underlain by sand and gravel. The feature forms a marked constriction at the entrance to Loch Etive. Here the loch is confined to a <0.5 km wide channel on the southern margin of the valley compared with a width of over 1.5 km a short distance to the east. When the outwash sediments were being deposited, the glacier snout lay immediately to the east and at that time the outwash plain would have been continuous across the valley. A large terrace behind Connel (NM 915342) is a likely remnant of the same outwash plain on the south side of the loch (Gray, 1972).

The outwash plain slopes from about 25 m OD near its eastern edge at Achnacairn (NM 927357) to about 12 m OD near the A828 Connel to Ballachullish road. This general gradient is, however, interrupted by a wide meltwater channel that runs westwards from Cairnbaan and by a number of deep, lochan-filled kettle holes (Figure 10.6). Bathymetric surveying of the three largest hollows has shown each to be complex. For example, Murray and Pullar (1910) noted that the Lochan na Beithe hollow consists of two major interlinked depressions. The deepest point lies 25 m below the terrace surface and 8 m below OD. Conacher (1932) found that Laga Beaga (NM 924357), west of Achnacairn, consists of four interconnected hollows with a deepest point 17 m below the terrace surface. The presence of these large kettle holes in the outwash plain has been seen by several authors as indicating that the glacier originally extended beyond Connel, and during retreat large blocks of ice were left behind, to be surrounded or covered by outwash sediments when the snout became stabilized at the eastern edge of the outwash plain.

As McCann (1961b) pointed out, the margins of the outwash plain have been modified by later marine action at a level of approximately 13 m OD. Along the eastern margin the ice-contact slope has been eroded so that there is a marked break of slope at this level. Westwards, along the southern edge of the terrace, the gradient of the outwash plain carries it down to the 13 m level at North Connel, and on the west side the sea has built a 2.5 km long north–south spit which rises to over 14 m OD. The sea level concerned is probably that of the Main Postglacial Shoreline. Because of the presence of this shoreline, it is difficult to decipher the relative sea level at the time the outwash plain was deposited, but it was certainly below the 13 m OD level. Following formation of the Main Postglacial Shoreline, relative sea level gradually fell to its present level and in doing so raised-beach sediments were deposited to the west of the spit around North Connel Airfield (NM 905353) and North Ledaig Caravan Site (NM 907369), as well as below the south-east corner of the outwash plain (around NM 928351).

Achnaba

The Moss of Achnacree outwash plain is continued eastwards by two main terrace fragments, one at Achnacreebeag (NM 933364) and the other 200 m to the south-east and partially built upon (2, Figure 10.6). At this locality the transition from a proglacial outwash plain to an ice-marginal kame terrace occurs. At its eastern end, where the kame terrace fragment rises to 26.4 m OD, it narrows into a short, sharp-crested ridge that is probably an esker. Thus it is possible to identify the locality at which a meltwater stream escaped from the ice and became an ice-

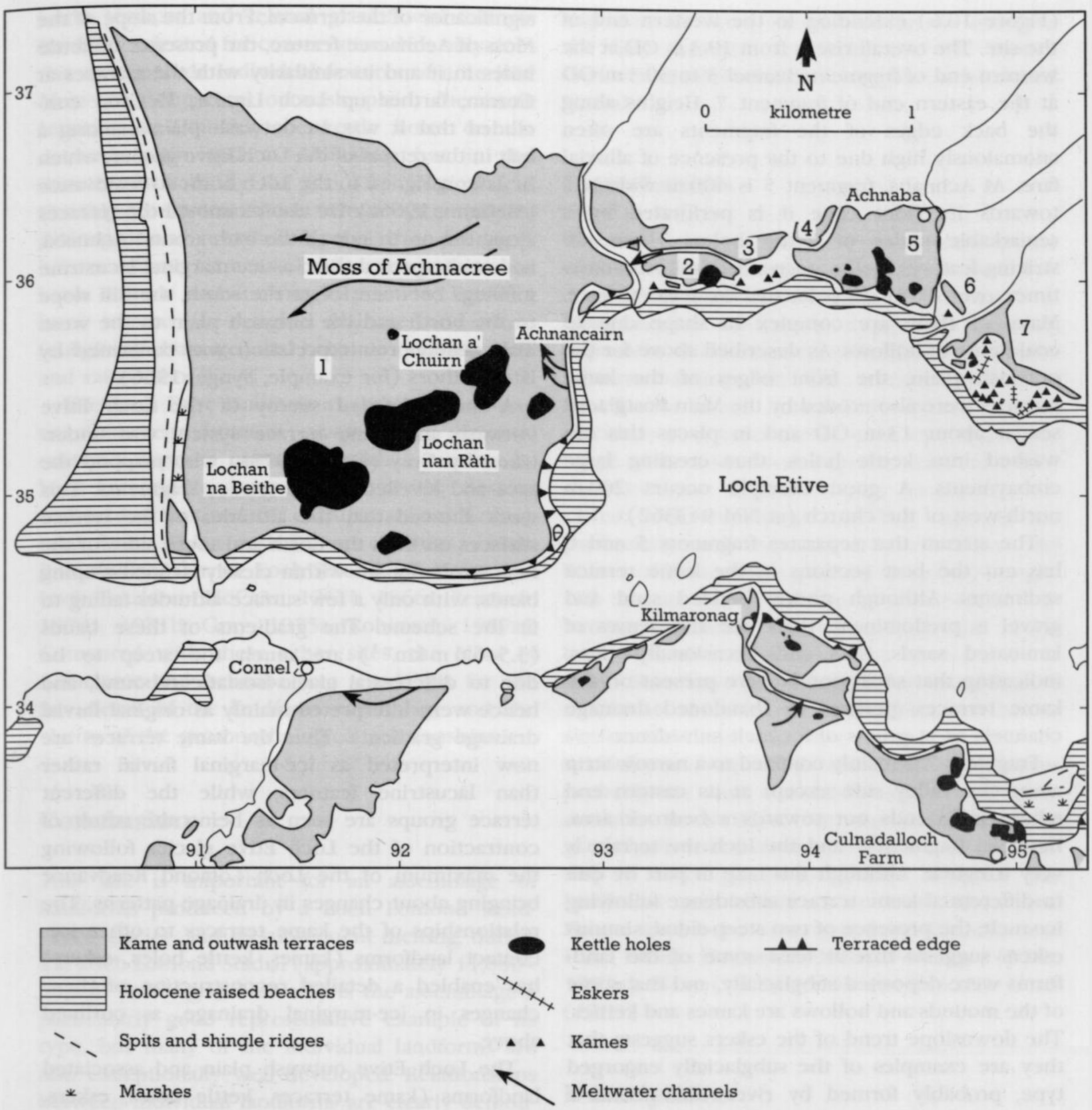


Figure 10.6 Geomorphology of Moss of Achnacree and Achnaba (from Gray, 1975a). See text for explanation of numbers.

marginal river contributing first to the deposition of the kame terrace and then to the outwash plain, west of Achnacreebeag.

As a glacier decays and contracts, the normal situation is for the earliest and highest kame terraces to occur along the valley sides and for later terraces to occur at lower elevations towards the valley centre. The situation at Achnacreebeag is different since fragment 2 is separated from the hill slope to the north by a channel/lower terrace (3, Figure 10.6) that is one of a slightly later group of kame terrace fragments. The explanation probably lies in the fact that in this case drainage was unable to flow along the front edge of fragment 2 because the glacier margin had not wasted away from it. Thus the drainage instead flowed along the back edge of the terrace and cut down into it.

The lower group of terraces is continued eastwards by terrace fragments 4, 5, 6 and 7

(Figure 10.6) extending to the western end of the site. The overall rise is from 19.3 m OD at the western end of fragment/channel 3 to 30.3 m OD at the eastern end of fragment 7. Heights along the back edges of the fragments are often anomalously high due to the presence of alluvial fans. At Achnaba, fragment 5 is 400 m wide and towards its front edge it is perforated by a remarkable series of kettle holes. These are striking features, being steep-sided hollows sometimes over 10 m deep located in a flat terrace. Many of them are complex in shape due to coalescing of hollows. As described above for the outwash plain, the front edges of the kame terraces were also eroded by the Main Postglacial sea at about 13 m OD and in places this sea washed into kettle holes, thus creating large embayments. A good example occurs 200 m north-west of the church (at NM 943362).

The stream that separates fragments 5 and 6 has cut the best sections in the kame terrace sediments. Although poorly bedded sand and gravel is predominant, there are also lenses of laminated sands, silts and occasionally clays, indicating that small ponds were present on the kame terraces, perhaps in abandoned drainage channels or at points of ice-melt subsidence.

Fragment 7 is mainly confined to a narrow strip along the valley side except at its eastern end where it extends out towards a bedrock area. Between fragment 7 and the loch the terrain is very irregular. Although this may in part be due to differential kame terrace subsidence following ice-melt, the presence of two steep-sided, sinuous eskers suggests that at least some of the landforms were deposited subglacially, and that some of the mounds and hollows are kames and kettles. The downslope trend of the eskers suggests that they are examples of the subglacially engorged type, probably formed by rivers that found a route down towards the valley floor from the kame terrace above.

Interpretation

The terraces at the entrance to Loch Etive and bordering the north and south sides of the lower part of the loch were originally interpreted as marine. Thus Kynaston and Hill (1908) described the Moss of Achnacree as resting on sands and gravels of the '50 ft beach' and assigned the terraces farther east to the '100 ft beach'.

McCann (1961b) was the first to appreciate the significance of the terraces. From the slope of the Moss of Achnacree feature, the presence of kettle holes in it and its similarity with the terraces at Corran, farther up Loch Linnhe, McCann concluded that it was an outwash plain marking a halt in the retreat of the Loch Etive glacier, which he later assigned to the Loch Lomond Readvance (McCann, 1966a). He also examined the terraces along the north side of the loch around Achnaba, and reinterpreted them as ice-marginal lacustrine infillings between ice to the south, the hill slope to the north and the outwash plain to the west. This general reinterpretation was confirmed by later authors (for example, Synge, 1966).

A more detailed survey of the Loch Etive outwash and kame terrace system was undertaken by Gray (1972, 1975a) who mapped the area and levelled all the terrace fragments. This work showed that the altitudes of the terrace surfaces on both the north and south sides of the loch generally fall within clearly defined sloping bands, with only a few surface altitudes failing to fit the scheme. The gradients of these bands (3.5–$6.0\ \mathrm{m\ km^{-1}}$) are much too steep to be due to differential glacio-isostatic rebound, and hence were interpreted mainly as original fluvial drainage gradients. Thus the kame terraces are now interpreted as ice-marginal fluvial rather than lacustrine features, while the different terrace groups are seen as being the result of contraction of the Loch Etive glacier following the maximum of the Loch Lomond Readvance bringing about changes in drainage patterns. The relationships of the kame terraces to other ice-contact landforms (kames, kettle holes, eskers) has enabled a detailed reconstruction of these changes in ice-marginal drainage, as outlined above.

The Loch Etive outwash plain and associated landforms (kame terraces, kettle holes, eskers, raised beaches) is arguably the finest such system in Britain. The system was formed during the early stages of wastage of the Loch Lomond Readvance glacier in the Loch Etive valley, and illustrates the meltwater drainage patterns and mode of ice decay at this time. Although individual outwash spreads and/or kame terraces are commonplace, it is the excellent development of the features at Loch Etive, the clarity of the relationships between features, and the size and completeness of the overall system that makes it exceptional. The system covers an area of 7 km by 4 km, but only part of this, including the outwash plain and adjoining 2.5 km stretch of kame terraces and related glaciofluvial features has been selected for conservation. Not only does this area include individual features of note (the Moss of Achnacree outwash plain, the kame terraces at Achnaba, the kettle holes on the outwash plain and at Achnaba), but it also demonstrates clearly the geomorphological relationships between kame terrace (ice-marginal drainage) and outwash (proglacial drainage), between kame terraces of different age, between kame terrace and ice-margin position, between kame terrace (ice-marginal drainage) and eskers (subglacial drainage) and between outwash plain and raised shorelines.

The Loch Etive landform assemblage is also an excellent representative example of a series of outwash deposits associated with a number of Loch Lomond Readvance glaciers on the western seaboard of Scotland, for example at Loch Creran, (see South Shian and Balure of Shian), Mull, Ballachulish, Corran, Loch Shiel, Loch Morar and Loch Torridon (McCann, 1961b, 1966a; Peacock, 1970a, 1971b; Gray, 1975a; Robinson, 1987a). Compared with these other sites, the Moss of Achnacree and Achnaba area stands out for the fine detail of the landform assemblage and the clarity of the geomorphological relationships.

Conclusion

This site is important for an assemblage of landforms produced by a Loch Lomond Readvance glacier, and its subsequent melting, during the Loch Lomond Stadial (approximately 11,000–10,000 years ago). Not only is the assemblage a particularly good representative example of its type, but many of the individual landforms are also exceptionally well developed. Relationships between individual landforms are clearly demonstrated and have allowed the pattern of glacier wastage to be reconstructed.

SOUTH SHIAN AND BALURE OF SHIAN

J. D. Peacock

Highlights

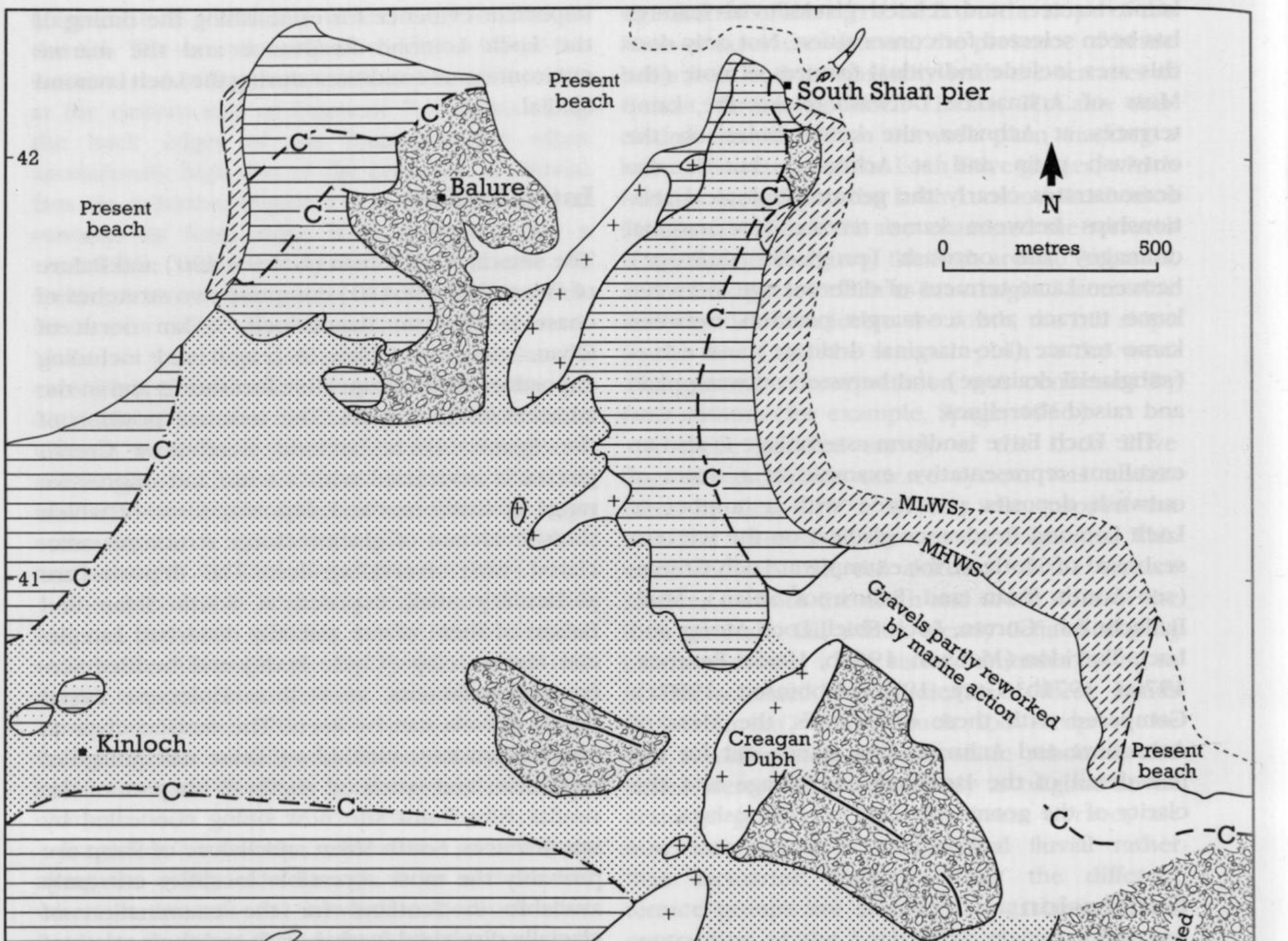
Deposits exposed in coastal sections at these two sites include fossiliferous marine sediments which have been deformed by glacier ice. These provide important evidence for establishing the timing of the Loch Lomond Readvance and the marine environmental conditions during the Loch Lomond Stadial.

Introduction

The sites at South Shian (NM 910420) and Balure of Shian (NM 896420) comprise two stretches of coast in western Banderloch, 13 km north of Oban, each *c.* 0.65 km in length and including exposures on the respective foreshores and in the adjacent backing cliffs. The terminal position of the former Loch Lomond Readvance Creran glacier is associated with a wide and impressive range of landforms and deposits, some of which show evidence of glaciotectonic structures associated with overriding ice. The deposits are particularly well exposed at South Shian and Balure of Shian where glacially disturbed Lateglacial marine clay (Clyde beds) and bedded ice-contact sediments, as well as Holocene raised beach gravels can be seen. The marine clays at South Shian have yielded a diverse assemblage of molluscan and ostracod shells. With part of the similar Rhu Point site now being concealed by sea defences, South Shian and Balure of Shian are probably the most accessible localities currently available in Scotland for the examination of glacially disturbed marine clays and their relationship to other glacial and marine deposits. The landforms and sediments at South Shian and Balure have been investigated by Kynaston and Hill (1908), McCann (1966a), Peacock (1971b, 1971c), Gray (1972, 1975) and Peacock *et al.* (1989).

Description

The deposits and landforms in Benderloch comprise end moraines, glaciofluvial outwash and mounds of ice-contact gravel, sand and silt: all have been modified by Holocene marine erosion and redeposition up to a level of about 13–14 m OD (Figure 10.7). At the west end of Loch Creran there is an arcuate end moraine which reaches over 30 m OD. It is formed chiefly of transported marine clay with minor sand and gravel (Peacock, 1971a and unpublished data). West and south of this ridge there is a peat-covered composite outwash fan that laps around rock ridges and mounds of ice-contact silt, sand and gravel (Gray,


Present beach
South Shian pier
Balure
Present beach
N
0 metres 500
42
41
40
39
90
91
MLWS
MHWS
Gravels partly reworked by marine action
Kinloch
Creagan Dubh
Present beach
Lochan Dubh
Cliff of Main Rock Platform partly or wholly buried
Present beach
Kiel Crofts
Holocene raised beach deposits
Lateglacial marine clay on foreshore
Proglacial outwash
Solid rock
Ice contact deposits
Dominantly silt & clay
Dominantly sand and gravel
Gravel ridge
Feature marking former coastline (cut in drift)

1972, 1975b). Moundy ice-contact gravels occupy a strip of country adjacent to the rock cliff of the Main Rock Platform east of Lochan Dubh and are terminated southwards by the back feature of the highest Holocene beach at about 12 m OD (Figure 10.7). Esker-like ridges formed of bedded gravel, which occur on both sides of the rock mound Creagan Dubh (NM 908407), were originally thought to have been produced by glacial disturbance within the outwash gravels (McCann, 1966a), but have been reinterpreted as the deposits of a subglacial stream (Peacock, 1971b). It is now considered that they could be minor end moraines. Peacock (1971b) concluded that, following the maximum of the readvance, the terminal part of the glacier stagnated while ice up-valley supplied material for deposition of outwash. This ice was probably that which formed the end moraines south of the site.

Immediately west of South Shian pier about 1.5 m of marine clay are exposed in a low cliff and are overlain by a small thickness of sand (Peacock, 1971b). The marine deposit is stiff, dark grey, brownish-weathering and silty and is streaked in places with black disseminated sulphide and organic matter. It is weakly laminated and contains scattered angular pebbles of red granite, black schist and phyllite. Similar clay crops out between tide-marks in the bay south of the pier southwards to, and beyond the southern limit of the site. Where lamination can be seen in the clay it is commonly contorted. Shells of about 40 species of mollusc have been recovered from the disturbed marine beds (Kynaston and Hill, 1908, p.168; Peacock, 1971b, p. 356 and revision in Table 10.1). These are chiefly cool-water taxa, but include the arctic bivalve *Portlandia arctica* (Gray), which in western Scotland is otherwise known only in beds attributed to the Loch Lomond Stadial (Peacock, 1977b). Radiocarbon dates on shells collected a few metres west of South Shian pier (calculated to $\delta^{14}C$) are as follows (Peacock, 1971c):

Chlamys islandica (Müller)	11,300 ± 300 BP (outer) 11,530 ± 210 BP (inner)	(IGS-C14/16)
Tridonta elliptica (Brown)	11,805 ± 190 BP	(IGS-C14/17)
Mixed shell debris	6705 ± 130 BP (outer) 11,430 ± 220 BP (inner)	(IGS-C14/18)

At Balure of Shian glacially disturbed Lateglacial marine clay with *Tridonta elliptica* (Brown) is exposed on the foreshore and in a low cliff, where it crops out below ice-contact silt, sand and clay as well as below glaciofluvial outwash gravel and storm beach gravel associated with the highest Holocene raised beach. In the sea cliff west of Balure, some 10 m of interbedded silt, clay and fine-grained sand capped by about 3 m of poorly sorted gravel were formerly to be seen in a temporary section exposed by marine erosion in the mound (NM 896418). Marine clay at the base of this section (McCann, 1966a) is folded up into the overlying beds (Peacock, 1971b). The clays contain entire hinged valves of *Portlandia arctica* (Gray) and small quantities of *Nuculoma belloti* (Adams) and *Yoldiella lenticula* (Müller) (Table 10.1). No microfauna was found (Peacock *et al.*, 1989).

Shells (*Portlandia arctica* (Gray)) from Balure of Shian have been radiocarbon dated using both conventional and accelerator methods. The results are as follows (Peacock *et al.*, 1989):

	Conventional age (^{14}C years BP ± 1σ)	Reservoir adjusted age (^{14}C years BP ± 1σ)
SRR–3182	10,510 ± 90 (outer)	10,105 ± 100
	10,320 ± 70 (inner)	9915 ± 80
SRR–3204	10,550 ± 100	10,145 ± 110
OxA–1345	10,960 ± 120	10,555 ± 130

Interpretation

Most of the glacial deposits in Benderloch were regarded as '100 ft Beach' sediments by the original geological surveyors (Kynaston and Hill, 1908) and are shown as 'Higher Beach' and 'Highest Beach' on the accompanying 'One-inch' map (Geological Survey of Scotland, 1907, Sheet 45). Charlesworth (1956) noted morainic deposits east of Lochan Dubh (NM 908400), but the

Figure 10.7 Quaternary deposits of the South Shian and Balure of Shian area, Benderloch (from Peacock, 1971a, unpublished data).

possibility that the landforms and sediments were laid down near the terminus of a Loch Lomond Readvance glacier was first put forward by McCann (1966a) and independently by Synge (1966). McCann suggested that the 'high raised beach' deposits were in fact glaciofluvial outwash post-dating the marine clay, and Synge described the arcuate ridge south of South Shian as a terminal moraine. Both authors were of the opinion that the glacier terminated at the west end of Loch Creran (*c.* NM 915425), but Peacock (1971b) put forward evidence that the ice had extended considerably farther west and south (by as much as 2 km), a view supported by Gray (1972, 1975b) and Peacock *et al.* (1989).

The radiocarbon dates from South Shian confirm that the dated molluscan fauna flourished in the latter half of the Lateglacial Interstadial and that the Loch Lomond Readvance glacier in Loch Creran reached its maximum later than about 11,400 BP. This is a similar picture to that obtained from radiocarbon dating of glacially disturbed marine clays at Rhu Point, Loch Spelve (Mull) and Menteith, west of Stirling (Sissons, 1967b; Gray and Brooks, 1972; Rose, 1980c; Sutherland, 1984a).

The Balure of Shian site provides clear evidence for the stratigraphic position of the Lateglacial marine clay, that is, it antedates deposits laid down by the Loch Lomond Readvance ice (when this was near its maximum extent). Further work (Peacock *et al.*, 1989) suggests that the marine clays at Balure are less deformed than those at South Shian and contain an arctic marine fauna typical of glaciomarine conditions. The low-diversity fauna dominated by *Portlandia arctica* (Gray), is typical of that found seaward of the mouths of glacial rivers and tidewater glaciers in east Greenland and Spitsbergen today (Odhner, 1915; Ockelmann, 1958). The marine clays would thus be expected to immediately antedate the arrival of the Creran glacier at its maximum position.

The radiocarbon dates obtained at Balure of Shian allow a revised estimate of the age of the maximum extent of the Loch Lomond Readvance glacier in the Loch Creran Valley, to within, and possibly towards the end of, the period 10,500–10,000 BP (Peacock *et al.*, 1989). This agrees well with recent estimates of the age of the maximum extent of the Loch Lomond Readvance glaciers at Loch Lomond and in the Upper Forth Valley (see Croftamie and Western Forth Valley; Browne and Graham, 1981; Sissons, 1983a; Rose *et al.*, 1988), but contrasts with dates from organic lake sediments which suggest earlier deglaciation (see discussion for Croftamie).

The deposits and landforms in western Benderloch, including those at South Shian and Balure of Shian, provide a well-documented record of environmental changes during parts of the Late Devensian and during the Holocene. As such they are integral members of a national network of key sites demonstrating changing marine and terrestrial conditions during the latter part of the Quaternary. The disturbed marine clays contain faunas which can be confidently referred to both the cool water (interstadial) and cold water (arctic) parts of the Clyde beds (see Chapter 1 and Geilston). Deformation of these deposits by overriding Loch Lomond Readvance ice can be clearly demonstrated, as can their burial by glaciofluvial deposits attributed to the subsequent retreat of the Creran glacier from its nearby maximum position. The presence of erosional and depositional landforms associated with the high Holocene sea levels and their relationship to the deposits of the Loch Lomond Readvance lend additional significance, particularly to the Balure site. Further, the sites offer considerable potential for research into Lateglacial marine microfaunas, sedimentology and the physical properties of glacially deformed marine and glaciomarine deposits (see Peacock *et al.*, 1989). Finally, the radiocarbon dates from the site provide important evidence for interpreting the age of the maximum extent of Loch Lomond Readvance glaciers.

Conclusion

The deposits at South Shian and Balure of Shian provide important evidence for interpreting critical aspects concerning the geomorphology and timing of the resurgence of glacier ice associated with the Loch Lomond Readvance, and the prevailing environmental conditions. The sea formerly covered this area, and fossiliferous marine deposits were laid down under cool-water and then cold-water conditions; these were subsequently deformed as Loch Lomond Readvance glacier ice in the Creran valley advanced across them to its maximum position. Radiocarbon dates provide important age estimates for the timing of this event (between about 10,500 and 10,000 years ago). South Shian and Balure of Shian is therefore a key locality for studies of the Loch Lomond Readvance in western Scotland.

Table 10.1 Mollusca from South Shian and Balure of Shian

	1	2	3	4
Antalis entalis (L.)	**	*		
Boreotrophon clathratus (Ström)		*	*	
Boreotrophon truncatus (Ström)	**			
Buccinum undatum (L.)	*	*		
Gibbula cineria (L.)		*		
Lacuna parva (da Costa)			**	
Lacuna vincta (Montagu)	*			
Littorina sp	*			
Littorina saxatilis (Olivi)				*
Lora turricula (Montagu)		*	*	
Manzonia zetlandica (Montagu)	*			
Margarites costalis (Gould)	*			
Margarites helicinus (Fabricius)			*	
Moelleria costulata (Möller)	*			
Onoba aculeus (Gould)			**	
Onoba semicostata (Montagu)	*		**	
Polinices pallidus (Broderip and Sowerby)	*	*		
Puncturella noachina (L.)	*	*		
Rissoa interrupta (Adams)	*		**	
Skeneopsis planorbis (Fabricius)			**	
Tectonatica affinis (Gmelin)	*			
Velutina velutina (Müller)		*		
Abra sp.				
Abra alba (Wood)			**	
Acanthocardia echinata (L.)	*			
Arctica islandica (L.)	*	**		
Astarte sulcata (da Costa)		*		
Chlamys islandica (Müller)	***	***		
Heteranomia squamula (L.)	*			
Hiatella arctica (L.)	*	*		
Jupiteria minuta (Müller)	*		**	
Lyonsia arenosa (Möller)		*		
Macoma calcarea (Chemnitz)		*	**	
Mya truncata (L.)		*	**	
Nucula nucleus (L.)	*	*		
Nuculana pernula (Müller)	**	***	**	
Nuculoma sp.			**	
Nuculoma belloti (Adams)		*		**
Parvicardium ovale (Sowerby)	**	*		
Portlandia arctica (Gray)		*	*	****
Spisula subtruncata (da Costa)			*	
Thracia cf. *myopsis* (Möller)			*	
T. cf. *villosiuscula* (Macgillivray)	*			
Thyasira gouldi (Philippi)	*		**	
Tridonta elliptica (Brown)	***	***		
Tridonta montagui (Dillwyn)	**	**		
Yoldiella solidula (Warén)	**		***	
Yoldiella lenticula (Müller)	**	**	***	**

Continued overleaf

Table 10.1 *continued*

1. Shore 10 m west of South Shian pier (NM 90834228).
2. Shore 10 m west of South Shian pier (NM 90834228), British Geological Survey collection.
3. Shore east of shellfish factory (NM 908416).
4. Shore west of Balure of Shian (glaciomarine bed) (NM 8962 4216).
** rare*
*** common*
**** very common*
***** dominant*

GLEN ROY AND THE PARALLEL ROADS OF LOCHABER

J. E. Gordon

Highlights

The area of Glen Roy and adjacent parts of Glen Spean and Glen Gloy is one of outstanding international importance for geomorphology. It is best known for the Parallel Roads, a series of ice-dammed lake shorelines which developed during the Loch Lomond Stadial. These form part of a much wider assemblage of glacial, glaciofluvial and glaciolacustrine features which provide unique evidence for the dramatic impact of geomorphological processes on the landscape during the stadial.

Introduction

The interest of this site extends across an area *c.* 146 km² east of Fort William, in Lochaber, covering parts of Glen Roy, Glen Gloy and Glen Spean. Glen Roy is a long-recognized site of international importance for its former ice-dammed lake shorelines, the 'Parallel Roads', which are the most extensive and best developed examples in Britain. The Parallel Roads, first documented by Thomas Pennant in 1771, have been the subject of some 70 scientific papers, and the site is widely regarded as being a classic example of former lake shorelines in standard texts on geomorphology and physical geology. Much of the original research on the Parallel Roads, which also occur in Glen Gloy and Glen Spean, was carried out during the 19th century when the landforms of this area were found to provide significant evidence for the former existence of glaciers in Scotland (Agassiz, 1842). The Parallel Roads were first recognized as the shorelines of ice-dammed lakes by Agassiz (1841b, 1842), an interpretation later confirmed in the definitive work of Jamieson (1863, 1892). More recently, in a series of papers Sissons (1977e, 1978, 1979a, 1979b, 1979c, 1981c, 1981d) has elucidated the formation of the Parallel Roads through detailed field observations and mapping and by setting them into the wider geomorphological context of contemporaneous events in Glen Spean and the Great Glen; additional evidence and details have been considered by Sissons and Cornish (1982a, 1982b, 1983), Peacock (1986, 1989a) and Peacock and Cornish (1989).

Of outstanding interest in their own right, the Parallel Roads also form part of a remarkable system of glacial, glaciofluvial and glaciolacustrine landforms extending from Loch Laggan west to near Fort William and north to the Great Glen (Figure 10.8). The total system and many of its individual elements are of considerable geomorphological interest both intrinsically and in their relationships to the Parallel Roads and the sequence of later events in Glen Roy. The scientific interest of the area therefore extends well beyond Glen Roy, and the site boundary is drawn to include not only the Parallel Roads of Glen Roy but also the wider landform system of which they are part.

Description

The landform assemblage and key localities

The geomorphology of the Glen Roy–Glen Spean area, including the form and location of the Parallel Roads, have been described extensively in the literature; the principal references are by MacCulloch (1817), Dick (1823), Darwin (1839), Maclaren (1839), Agassiz (1841b, 1842), Milne Home (1847b, 1849, 1876, 1879), Chambers

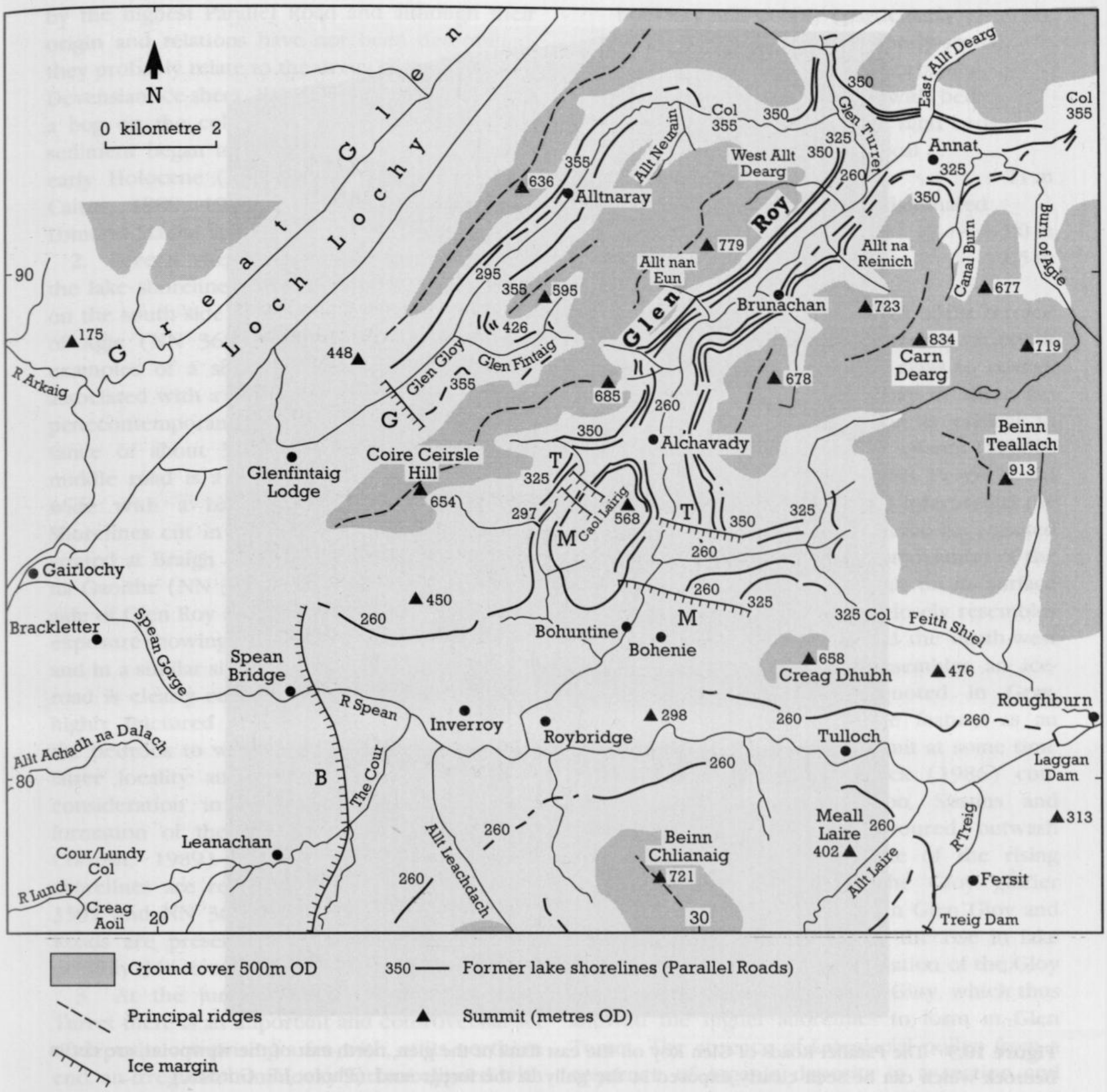


Figure 10.8 The Parallel Roads of Lochaber. The letters T, M, B and G identify the final positions of the ice-fronts damming the 355 m, 325 m, 260 m and Glen Gloy lakes respectively (from Peacock and Cornish, 1989).

(1848), Mackenzie (1848), Thomson (1848), Bryce (1855), Jamieson (1862, 1863, 1892), Rogers (1862), Mackie (1863), Watson (1866), Babbage (1868), Lubbock (1868), Nicol (1869, 1872), James (1874), Jolly (1873, 1880a, 1880b, 1886a, 1886b), Brown (1875), Campbell (1877), Dakyns (1879), Tyndall (1879), Livingston (1880, 1906), Prestwich (1880), Macfadzean (1883), Melvin (1887), Kinahan (1887), Wilson (1900), MacDonald (1903), Peacock (1970b) and Sissons (1978). The Parallel Roads are almost entirely former lake shorelines, although locally they occur as glaciofluvial terraces. Three main roads occur in Glen Roy at average altitudes of 350 m, 325 m and 260 m OD; one in Glen Gloy at 355 m and one in Glen Spean at 260 m OD (Figure 10.8). Typically they are cut in bedrock (Figure 10.9) and comprise an erosional floor and backslope and a depositional foreslope. Horizontal widths range from 1.6 to 63.6 m, and the backing cliff reaches a maximum height of 6 m (Sissons, 1978). To explain the formation of the

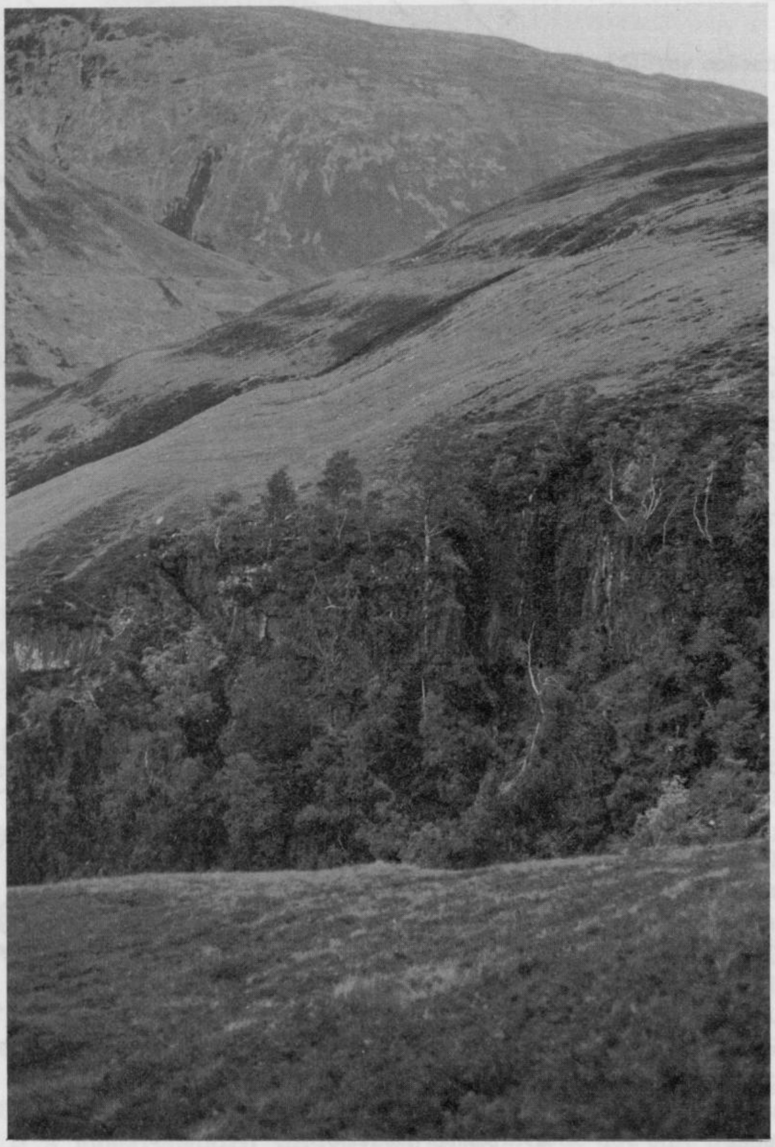


Figure 10.9 The Parallel Roads of Glen Roy on the east flank of the glen, north-east of the viewpoint, are cut in bedrock which can be seen clearly exposed in the gully in the foreground. (Photo: J.E. Gordon.)

features, Sissons (1978) invoked a combination of wave action and powerful frost disruption of the bedrock along each shoreline (see Matthews *et al.*, 1986; Dawson *et al.*, 1987b and Shakesby and Matthews, 1987 for discussion of possible modern analogues). Detailed levelling by Sissons and Cornish (1982a, 1982b) has shown that the shorelines are not uniformly tilted or warped, and that differential movements have occurred between blocks of the Earth's crust.

As noted above, the Quaternary landforms and deposits of the Glen Roy area are not only many and varied, but are also represented at a large number of key localities. Only the main features are summarized below, while additional details and sites are reported in Peacock (1989a).

Glen Roy

1. The important features in the uppermost part of Glen Roy are the Roy–Spey col (NN 410943) at 350 m, which controlled the level of the highest lake in the glen, and a suite of glacio-fluvial landforms extending from the Allt Chonnal across the lower valley slopes on the north side of the River Roy to the col. These deposits are crossed

by the highest Parallel Road and although their origin and relations have not been determined, they probably relate to the decay of the main Late Devensian ice-sheet. Palynological evidence from a bog on the col overflow channel shows that sediment began to accumulate there during the early Holocene (MacPherson, 1978; Lowe and Cairns, 1989, 1991), which supports a Loch Lomond Stadial age for the ice-dammed lakes.

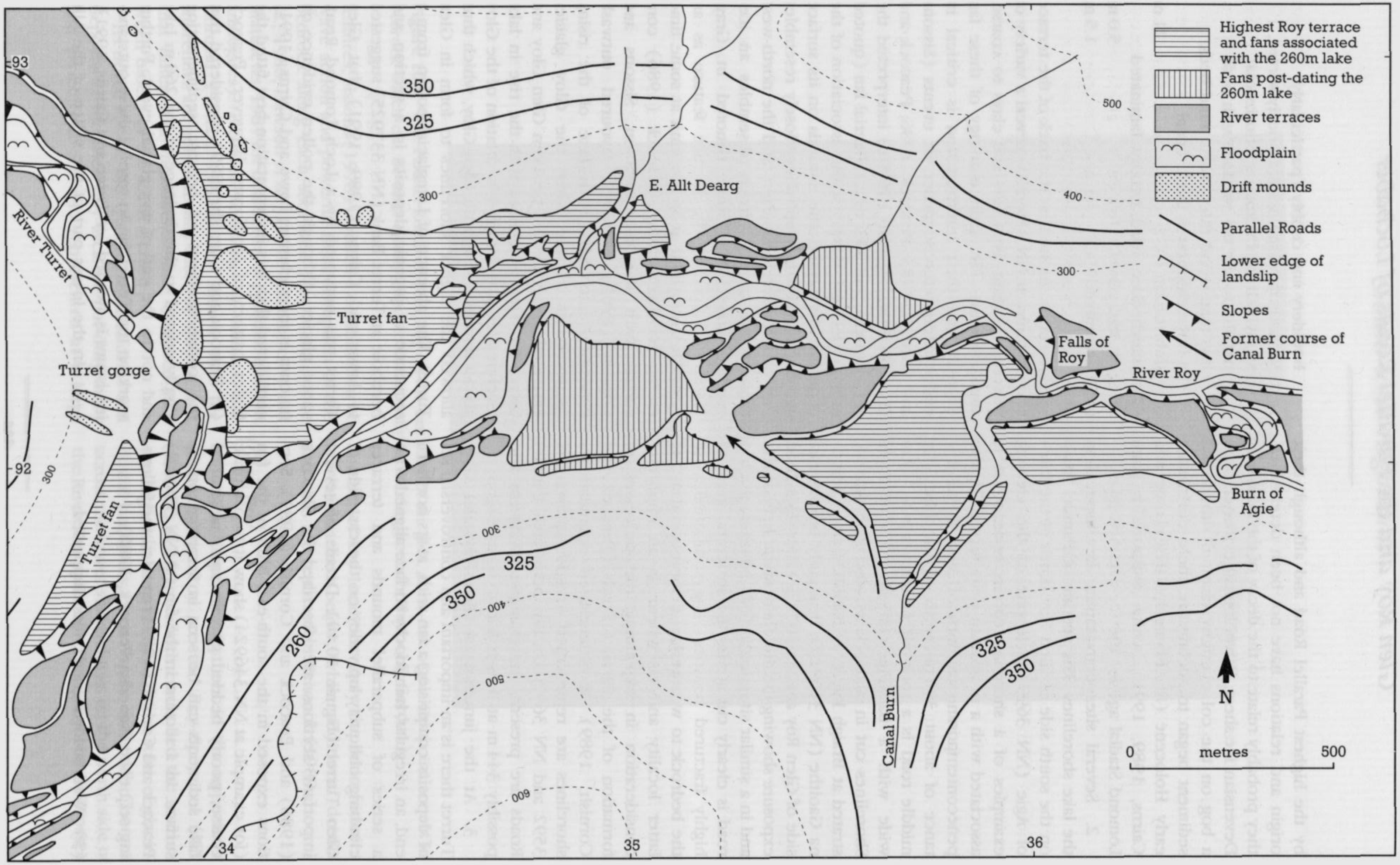
2. Several sites demonstrate key aspects of the lake shorelines. The section of Parallel Road on the south side of Glen Roy north of the Burn of Agie (NN 369920) is one of the clearest examples of a shoreline cut in bedrock. It is associated with a prominent delta formed by the penecontemporaneous Burn of Agie. For a distance of about 300 m north of the burn the middle road is a rock-cut platform up to 12 m wide with a backing cliff up to 5 m high. Shorelines cut in bedrock are also well demonstrated at Braigh Bac (NN 306882) and Creagan na Gaoithe (NN 370925). In a gully on the east side of Glen Roy at (NN 307877) there is a good exposure showing the middle road cut in bedrock, and in a similar situation at (NN 304868) the top road is clearly cut across the structural grain of highly fractured bedrock. The susceptibility of the bedrock to weathering, demonstrated at the latter locality and elsewhere, is an important consideration in explaining the processes of formation of the Parallel Roads (Peacock and Cornish, 1989). Well-developed aggradational shorelines are represented in grid squares NN 3592 and NN 3692. Locally, additional Parallel Roads are present, for example at 334 m and possibly 344 m at Braigh Bac.

3. At the junction of Glen Roy and Glen Turret there is an important and controversial set of deposits comprising a fan with, at its northern end, an irregular, hummocky surface aligned with a series of subparallel mounds and terraces climbing obliquely up-valley on the east side of Glen Turret (Figure 10.10). Details of several important sections are described by Peacock (1986) and Peacock and Cornish (1989). Sections exposed in the south-east bluff of the fan (for example at NN 346924) show it to comprise coarse, poorly bedded gravels, and fine-grained lake sediments can be seen in scrapings on its surface. In a section in the fan (at NN 338919) Peacock and Cornish (1989) reported the following sequence (see also Peacock, 1986):

(3)	Well-bedded gravel, clast-supported, bouldery and cobbly (particularly towards the top), with a poorly-sorted, sandy matrix. Bedding subhorizontal, parallel to the fan surface, with beds less than 0.3 m thick. Local sand beds a few centimetres thick. Local imbrication.	21 m
(2)	Interbedded, hard, pebbly, laminated silt, and gravel.	5.0 m
(1)	Gravelly till.	1.5 m

Sections in the mounds at the back of the terrace (for example, at NN 339928)) reveal a variety of materials ranging from silts and clays to coarse, angular debris. The sedimentology of these fan deposits and their interpretation is critical in understanding the sequence of events (Sissons and Cornish, 1983; Peacock, 1986; Peacock and Cornish, 1989). Sissons (1977e) interpreted the fan as a delta, and later as a subaerial fan (quoted in Gray, 1978b). However, the association of the deposits, the terrace, the mounds on its surface and the lateral ridges up-valley closely resembles that of a former ice margin, and the north-west flank of the terrace closely resembles an ice-contact slope. Thus Rose (quoted in Gray, 1978b) interpreted the terrace feature as an outwash fan formed at an ice limit at some time during ice-sheet decay. Peacock (1986) concurred with this interpretation. Sissons and Cornish (1983), however, favoured outwash deposition into the 260 m lake of the rising sequence, at a time when the Gloy glacier extended across the col between Glen Gloy and Glen Roy. They suggested that the rise in lake level in Glen Roy resulted in ablation of the Gloy glacier and its retreat into Glen Gloy, which thus allowed the higher shorelines to form in Glen Turret. The absence of Lateglacial pollen from a sequence of organic deposits in a section and borehole at Turret Bank (NN 337925) suggested to Lowe and Cairns (1989, 1991) that Glen Turret was occupied by a Loch Lomond Readvance glacier. Although the pollen evidence on its own is inconclusive, Lowe and Cairns (1991) considered that this interpretation best fitted the wider pattern of landforms. However, Peacock (in Peacock and Cornish, 1989) considered that the commencement of organic sedimentation simply related to the drainage of the 260 m lake and not to the end of any glacial event. Further work on the Turret fan to resolve these outstanding issues is awaited (cf. Lowe and Cairns, 1991).

4. In the lower part of the valley of the Allt


Highest Roy terrace and fans associated with the 260m lake
Fans post-dating the 260m lake
River terraces
Floodplain
Drift mounds
Parallel Roads
Lower edge of landslip
Slopes
Former course of Canal Burn
E. Allt Dearg
Turret fan
Turret gorge
River Turret
Falls of Roy
River Roy
Burn of Agie
Canal Burn
350
325
300
400
500
600
260
93
92
34
35
36
N
0
metres
500

a'Chomlain near its junction with Glen Turret (NN 330929) is a series of gravel mounds and deposits, with kettle holes, which have been terraced and dissected by the river. These were formed during the deglaciation of the area, although the precise details are unclear (Peacock and Cornish, 1989). Also in this area is a terrace which appears to be a delta of the 325 m lake (Peacock and Cornish, 1989).

5. Several superb examples of alluvial fans occur in Glen Roy (Sissons and Cornish, 1983; Peacock, 1986; Evans and Hansom, 1991, figures 1 and 2). On the east side (at NN 330907 and NN 318896) two large dissected fans extend across the valley floor from Coire na Reinich and Coire Dubh (the Reinich and Brunachan fans, respectively). Others are associated with the Burn of Agie, Canal Burn, the East Allt Dearg and the West Allt Dearg. Peacock (1986) described several sections in the fans, which principally comprise coarse gravels and sands, in places both overlain and underlain by laminated sediments. According to Sissons and Cornish (1983) these fans were deposited into the lowest lake of the rising sequence, but Peacock (1986) interpreted them as being older, subaerial features.

6. Thick drift deposits are present at the head of Glen Turret. In a gully section (NN 329944) there are up to 27 m of laminated silts, sands and gravels containing many angular clasts, which are overlain by up to 3 m of till. Sissons (1978) believed the source of the angular material to have been frost-riven debris transported from the lake shores by ice floes. Peacock (1986), however, considered the material to be waterlain till. East of the section a prominent fan appears to be graded to the level of the 325 m Parallel Road and may therefore be, in part, a delta (Peacock and Cornish, 1989).

7. In upper Glen Roy a particularly fine suite of river terraces, formed by the River Roy after drainage of the lowest lake, occurs on the south side of the River Roy between about NH 368920 and NH 345920 (Figure 10.10). Terraces also continue along the floor of the glen south-west from Braeroy Lodge.

8. Landslides are well represented (Sissons and Cornish, 1982a, 1982b; Holmes, 1984; Peacock and Cornish, 1989): a fine example occurs on the east side of Glen Roy (at NN 342915) and crosses the upper two roads (Figure 10.10). Another, which cuts across both the middle and lower roads, occurs 0.5 km down the valley from the viewpoint (at NN 295849). On the west side of Glen Roy, opposite Brunachan, Sissons and Cornish (1982a, 1982b) described a large landslide which they related to earthquake activity along a fault line activated by glacio-isostatic uplift. Ringrose (1987) (see also Davenport *et al.*, 1989; Peacock and Cornish, 1989), however, has suggested that the fault could have been activated by lateral movement along an adjacent fault line; it may therefore be only indirectly associated with glacio-isostatic uplift, if at all.

9. A series of interesting landforms and deposits are represented in the Allt Bhreac Achaidh area (NN 298875) (Peacock and Cornish, 1989). These include ridges of laminated silt and gravel with liquefaction and other deformation structures (Ringrose, 1987, 1989c), river terraces underlain by laminated silt, and glacial and paraglacial landforms and deposits.

10. The viewpoint (NN 297853) affords the classic view of the Parallel Roads, which are strikingly displayed on both the west and east hillsides of Glen Roy. On the hillside north of the viewpoint, the limit of the Loch Lomond Readvance ice in the glen occurs at, or a little beyond, the northern end of a massive, dissected drift plug up to 80 m thick (approximately NN 298864–NN 300850) (Sissons, 1979b). The former ice margin is probably marked by a clear drift limit, while on the east side of the glen there is a landslide and drift ridge at the ice limit. Older moraine ridges occur beyond the readvance limit. Roadside sections near the top of the infill reveal glaciofluvial sands and gravels, and lacustrine silts and sands with drop stones and slump structures (NN 296858). Various gully exposures (see Peacock and Cornish, 1989) reveal further sands and gravels, and till near the base. These deposits form a glaciolacustrine delta with foreset and bottomset beds. A sequence of river terraces extends from the southern end of the drift plug to Roy Bridge and merges with the Glen Spean terraces. The former relate to the dissection of the drift plug by the waters of a remnant lake impounded by the plug following the drainage of the 260 m lake (Sissons, 1979a).

11. The Caol Lairig is an important site where a variety of glacial, glaciofluvial and glaciolacustrine landforms are easily accessible. The Loch Lomond Readvance ice limit is marked by an

Figure 10.10 Geomorphology of the northern part of upper Glen Roy (from Sissons and Cornish, 1983).

arcuate moraine ridge 5 m high across the col (NN 288864) and its lateral extension can be traced along the hillslope to the west (NN 861276) as the upper limit of small meltwater channels (Sissons, 1979b). Four shorelines, in part lacustrine deltas, are present on the valley sides; the additional one at 297 m is related to the altitude of the Caol Lairig–Glen Roy col, and the lake overflow can be seen as a channel cut through the end moraine. Inside the latter, deltas and fans occur on the valley floor. Several sections occur in glaciolacustrine sediments (Peacock and Cornish, 1989), which include sedimentary structures that may relate to earthquake deformation (Ringrose, 1987, 1989c).

12. North of Bohuntine and Bohenie end moraine ridges on both sides of Glen Roy (at NN 291839 and NN 297836) mark the ice limit when the 325 m lake was formed.

13. Good sections in lake sediments are frequently exposed in cuttings along the public road in Glen Roy, and they provide a valuable source of sedimentary information. For example, Miller (1987) has identified two types of rhythmic deposit on the basis of their sediment characteristics and stratigraphic position. 'Group I laminates' (fine sands and silts) tend to cap major sediment bodies. They are typical of proximal glaciolacustrine deposits and they were probably deposited in the 350 m lake during the Loch Lomond Stadial. 'Group II laminates' (silts and clays) typically underlie major sediment bodies. They have characteristics of distal glaciolacustrine sediments, probably deposited during an early stage of the rising lake sequence.

Glen Gloy

1. Several mounds (at NN 280910) near Alltnaray are believed to mark the limit of the Loch Lomond Readvance ice in Glen Gloy (Peacock, 1970b; Sissons, 1979b), although this was not accepted by Sissons and Cornish (1983) (see also discussion of the Turret fan above). Inside this limit thick drift deposits are exposed along the forest road on the west side of the glen. They are attributed to debris flows and delta formation (Peacock and Cornish, 1989).

2. A second important site in Glen Gloy is the col at the head of the glen through which the waters of the 355 m lake spilled over into Glen Turret and Glen Roy. A small glaciofluvial terrace is present. Lowe and Cairns (1989, 1991) recorded 7.0 m of peat and lake sediments and showed that organic sedimentation began during the early Holocene.

3. At the Allt Neurlain (NN 303926) several features are of interest, including fault-controlled streams, possible recent movement along a fault (Ringrose, 1987), a delta at the 355 m road and sandy hummocks that possibly comprise a subglacial fan.

4. Glenfintaig (NN 265885) is important for an assemblage of landforms, comprising a sequence of up to eight shorelines (the clearest at 295 m, 355 m, 416 m and 426 m), a landslide, a drift limit possibly marking the maximum extent of the Loch Lomond Readvance glacier, and lake sediments and river terraces (Peacock and Cornish, 1989).

5. In addition to Glenfintaig, the main Parallel Road in Glen Gloy at 355 m is also well-developed at Allt Grianach (also 295 m road and delta) (NN 270905), Auchivarie (NN 287928) (partly cut in bedrock) and Allt Fearna (partly cut in bedrock) (NN 305935).

Glen Spean

1. The Roughburn area (Figure 10.11) is important for an assemblage of glacial and glaciolacustrine deposits. To the north of the A86 in the valley of the Feith Shiol a double end moraine marks the limit of the confluent Spean–Treig glacier, which impounded the 260 m lake in Glen Spean at the Loch Lomond Readvance maximum (Sissons, 1979b). The overflow from the 325 m lake in Glen Roy through the col at the head of Glen Glas Dhoire followed the valley of the Feith Shiol and breached the moraine ridges before entering the 260 m lake. At Roughburn a delta (NN 377813), comprising up to 10 m of coarse gravel in steeply dipping foreset beds on top of silty sands, records the torrential overspill into the lake (Jamieson, 1863; Peacock and Cornish, 1989). Eastwards along the north shore of Loch Laggan, fine-grained sediments of the distal part of the delta (bottomset or low-angle foreset beds) are well exposed (Peacock and Cornish, 1989).

2. The Inverlair–Fersit area north of Loch Treig (Figure 10.11) is important in several respects. It demonstrates an excellent example of a partly kettled delta formed in the 260 m lake as the Treig glacier receded back into the valley now occupied by Loch Treig (Peacock and Cornish, 1989). The delta extends from around Inverlair to south of the Treig dam and comprises an extensive area of sand and gravel, with

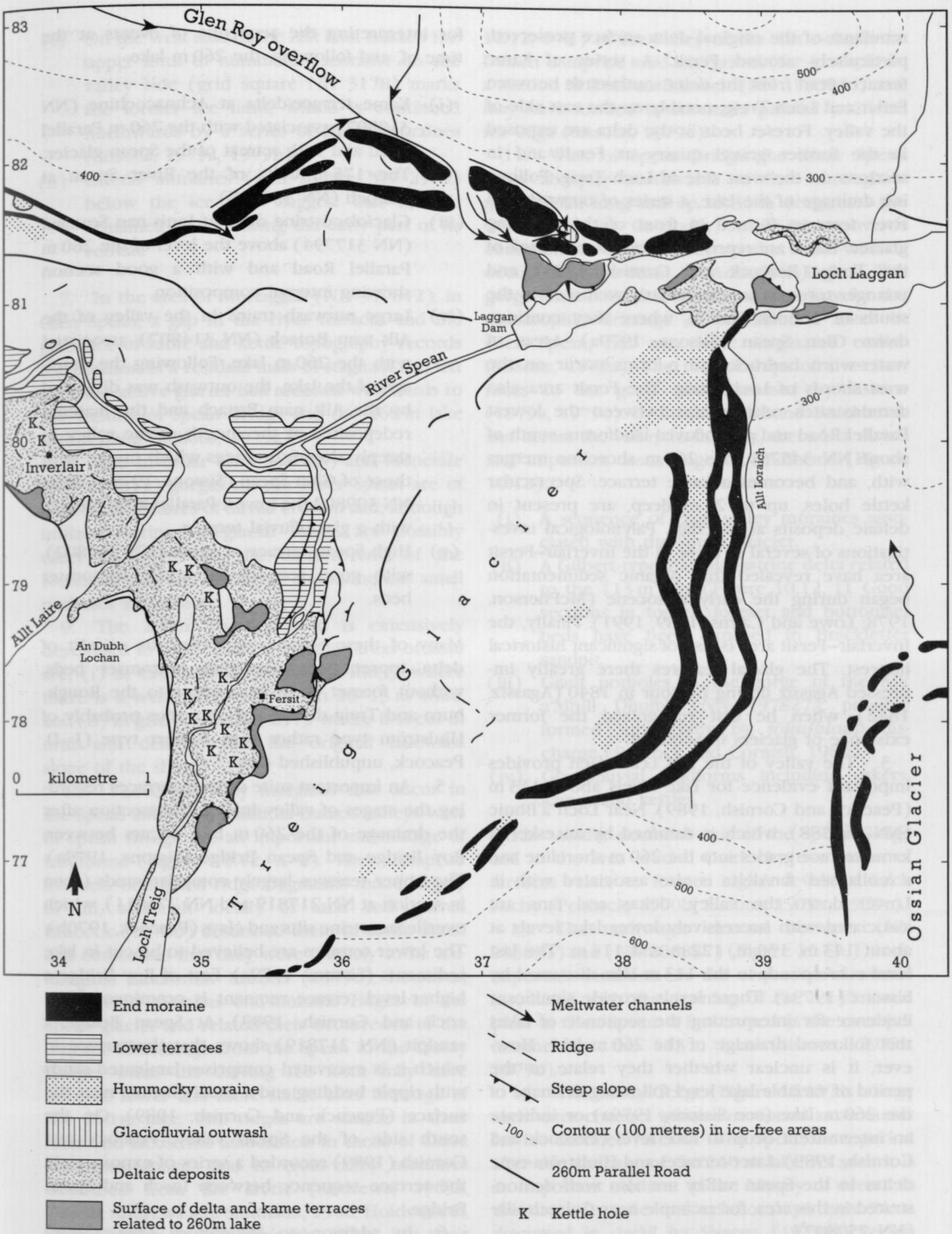


Figure 10.11 Landforms and deposits of the Treig–Laggan area (from Sissons, 1977c; Peacock and Cornish, 1989).

remnants of the original delta surface preserved, particularly around Fersit. A series of kame terraces lead from the delta southwards between Fersit and Loch Treig, notably on the east side of the valley. Foreset beds in the delta are exposed in the former gravel quarry at Fersit and in sections on the west side of Loch Treig. Following drainage of the lake, a series of outwash and river terraces formed in front of the receding glacier. These are represented on the east bank of the Treig (Peacock and Cornish, 1989), and younger terraces are particularly well seen to the south of Tulloch Station, where they continue down Glen Spean (Sissons, 1979a). Areas of water-worn bedrock and p-forms occur on the west shores of Loch Treig. The Fersit area also demonstrates relationships between the lowest Parallel Road and glaciofluvial landforms: south of about NN 345789, the 260 m shoreline merges with, and becomes a kame terrace. Spectacular kettle holes, up to 25 m deep, are present in deltaic deposits at Inverlair. Palynological investigations of several of these in the Inverlair–Fersit area have revealed that organic sedimentation began during the early Holocene (McPherson, 1978; Lowe and Cairns, 1989, 1991). Finally, the Inverlair–Fersit area is also of significant historical interest. The glacial features there greatly impressed Agassiz during his tour in 1840 (Agassiz, 1842), when he first recognized the former existence of glaciers in Scotland.

3. The valley of the Allt Leachdach provides important evidence for lake levels above 113 m (Peacock and Cornish, 1989). Near Loch a'Bhuic (NN 264788), which is dammed by an esker, a kame terrace grades into the 260 m shoreline and a 'collapsed' fan/delta is also associated with it. Lower down the valley, deltas and fans are associated with successively lower lake levels at about 143 m, 130 m, 122 m and 114 m. The last level corresponds to the 113 m lake discussed by Sissons (1979a). These levels provide significant evidence for interpreting the sequence of lakes that followed drainage of the 260 m lake. However, it is unclear whether they relate to the period of variable lake level following drainage of the 260 m lake (see Sissons, 1979a) or indicate an intermittent drop in lake level (Peacock and Cornish, 1989). Later terraces and Hjulström-type deltas in the Spean valley are also well demonstrated in this area, for example near Coirechoille (NN 250807).

4. Deltas, fans and high-level terraces elsewhere in Glen Spean provide important evidence for interpreting the sequence of events at the time of, and following, the 260 m lake:

(i) Kame terrace/delta at Achnacochine (NN 310807) associated with the 260 m Parallel Road and with retreat of the Spean glacier.
(ii) The 175 m delta of the River Spean at Tulloch (NN 330807).
(iii) Glaciolacustrine delta at Innis nan Seangan (NN 317794) above the level of the 260 m Parallel Road and with a good section showing internal composition.
(iv) Large outwash trains in the valley of the Allt nam Bruach (NN 314807), associated with the 260 m lake. Following the drainage of the lake, the outwash was dissected by the Allt nam Bruach and the material redeposited at the mouth of the valley as steeply sloping terraces which merge with those of Glen Spean (Sissons, 1979a). Near NN 309802 the lowest Parallel Road merges with a glaciofluvial terrace.
(v) High Spean terrace at Insch (NN 264802), with good sections in deltaic bottomset beds.

Many of these Spean valley deposits consist of delta topset beds overlying bottomset beds, without foreset beds, in contrast to the Roughburn and Treig deltas. They are thus probably of Hjulström type rather than Gilbert type (J. D. Peacock, unpublished data).

5. An important suite of river terraces recording the stages of valley infill and dissection after the drainage of the 260 m lake occurs between Roy Bridge and Spean Bridge (Sissons, 1979a). The upper terraces largely comprise sands (seen in section at NN 217819 and NN 274811), which overlie lacustrine silts and clays (Peacock, 1970b). The lower terraces are believed to be cut in lake sediments (Sissons, 1979a). East of Roy Bridge a higher-level terrace remnant is prominent (Peacock and Cornish, 1989). At Spean Bridge a sandpit (NN 217819) shows that the terrace in which it is excavated comprises laminated sands with ripple bedding and a small channel near the surface (Peacock and Cornish, 1989). On the south side of the Spean valley, Peacock and Cornish (1989) recorded a series of exposures in the terrace sequence between Insch and Spean Bridge.

6. In addition to Roughburn (see above) several sites are notable for landforms associated with the Loch Lomond Readvance limit:

(i) On the west side of the Allt nam Bruach the upper limit of hummocky moraine on the valley side (grid square NN 3178) marks the former ice limit, which is continued northwards by a series of lateral moraines (Sissons, 1979a, 1979b).

(ii) Lateral moraines (grid square NN 2979) below the ice limit suggest that the ice remained active during the early part of its retreat.

7. In the area of Murlaggan (NN 317812), in Glen Spean, a gap in the river terraces and the presence of kame and kettle topography records the position of a residual mass of stagnant ice, left after the active glacier had receded westwards to the vicinity of Spean Bridge and the 260 m lake had drained (Sissons, 1979a).

8. The Inverlair (NN 341806) and Monessie (NN 298811) gorges on the River Spean are of interest as features of fluvial erosion and, although utilized during Lateglacial times, are possibly older in origin. At the eastern end of the Monessie gorge several large and numerous small potholes are of note.

9. The 260 m Parallel Road is extensively developed in Glen Spean. Particular areas of note are: (i) at Creag Bhuidhe (NN 304803), where there is a well preserved stretch 10–13 m wide; and (ii) in grid square NN 2979 where it is cut in drift and demonstrates the original lakeward slope of the shore.

10. The cross-valley moraines that occur in the Spean and Allt Achadh na Dalach valleys west of Spean Bridge are an important assemblage of landforms (Figure 10.12, A–E). They comprise five sets of aligned ridge fragments made largely of till, although locally of sand and gravel. Peacock (1970b) described them in some detail and concluded that they were unlikely to be ice-marginal landforms. Sissons (1979c), however, interpreted them as end-moraine ridges of the Spean glacier and related their occurrence to the transfer of drainage from the Spean to the Lundy Gorge, when the calving ice front may have become lower and more stable after drainage of the 260 m lake. The ridges are similar in their form and lacustrine association to those of Coire Dho (see above) and to cross-valley moraines described from the arctic (Andrews, 1963a, 1963b; Andrews and Smithson, 1966; Holdsworth, 1973; Barnett and Holdsworth, 1974), but their processes of formation have not been fully investigated. The westernmost three ridges (Figure 10.12, F–H) in the valley of the Allt Achadh na Dalach comprise sand and gravel (for example in a section at Tom na Brataich (NN 179795)) and may have formed in crevasses parallel with the ice edge (Sissons, 1979c).

11. West of Spean Bridge the River Spean turns abruptly northwards to flow through a gorge, 3 km long and up to 30 m deep, into the Great Glen at Gairlochy, while the obvious continuation of the valley to the south-west is occupied by the misfit Allt Achadh na Dalach. The gorge functioned as a subglacial routeway for the catastrophic drainage of ice-dammed lakes in Glen Spean, but may have originated earlier (Sissons, 1979a). The relationships of river terraces to the gorge are discussed by Sissons (1979a, 1979c). In this area, around Brackletter and across the valley to the east, there is a varied and important assemblage of landforms (Figure 10.12):

(i) A sequence of cross-valley moraines associated with the Spean Glacier.

(ii) A Gilbert-type glaciolacustrine delta related to the 113 m lake (Figure 10.12, I). Good sections in topset, foreset and bottomset beds have been exposed in Brackletter sandpit.

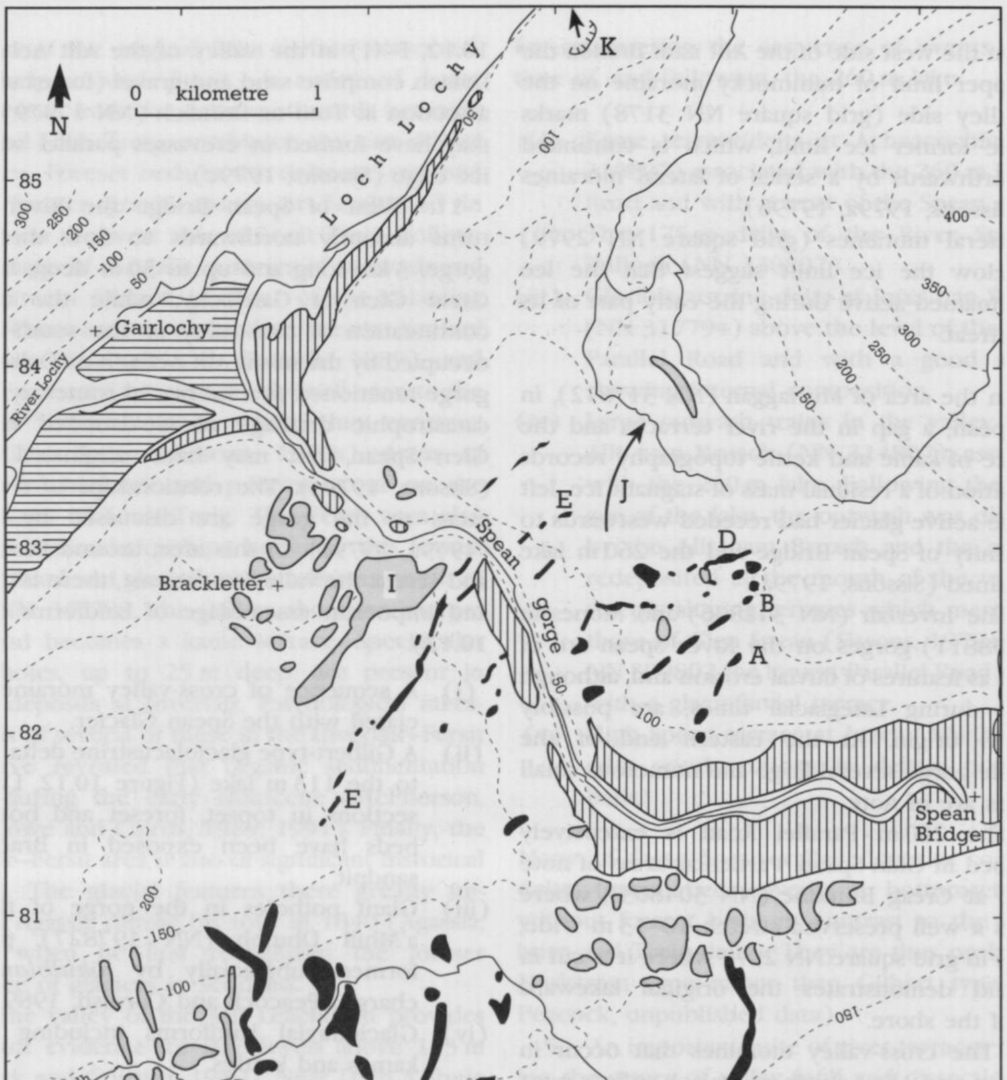
(iii) Giant potholes in the gorge of the Allt a'Mhill Dhuibh (NN 197827), possibly formed subglacially by *jökulhlaup* discharge (Peacock and Cornish, 1989).

(iv) Glaciofluvial landforms including eskers, kames and kettles.

12. At the northern exit of the Spean Gorge and in the area around Gairlochy two suites of terraces relate to former higher levels of Loch Lochy (Peacock, 1970b; Sissons, 1979a, 1979c).

13. The meltwater channel between (NN 203831) and (NN 205837) (Figure 10.12, J) is an important landform in the sequence of events associated with the draining of the ice-dammed lakes in Glen Spean: it functioned as the overspill channel for the 113 m lake (Sissons, 1979a, 1979c).

14. The Lundy Gorge (Figure 10.12) is a large meltwater channel which functioned as an outlet for ice-dammed lakes in Glen Spean for a period after the drainage of the 260 m lake. As such it is an important element in the history of events in the area. Its role and relationships have been discussed in detail by Sissons (1979c). Recent sand and gravel extraction has exposed the rock-cut north wall of the gorge from beneath the



N
0 kilometre 1
K
Loch Lochy
Gairlochy
River Lochy
Brackletter
I
Spean gorge
E
D
B
A
Spean Bridge
E
F
G
H
D
C
A
Leanachan Basin
Allt an Loin
Allt Achadh na Dalach
E
B
Lundy gorge
85
84
83
82
81
80
79
78
18
19
20
21
22
Lower terraces (Gairlochy)
Other terraces
Glaciofluvial deposits
End moraines
Meltwater channel
Cliff
200 Contour (metres)

kamiform sand and gravel deposits that extend to the north and north-east. There is a good section in these deposits at Tom na h-Iolaire.

15. An unusual, 'cirque-like' feature which leads into a meltwater channel on a hilltop south of Glenfintaig House (NN 201857) (Figure 10.12, K), has been interpreted by Sissons (1979c) as an abandoned waterfall site recording the final *jökulhlaup* of the ice-dammed lake in Glen Spean that had been periodically discharging through the Lundy Gorge.

Interpretation

The first published description of the Parallel Roads was by Thomas Pennant in 1771 in his work *A Tour in Scotland, 1769*. Although bad weather prevented him from visiting what he called the 'celebrated parallel roads', he noted the local belief that they had been constructed to facilitate hunting, a view later echoed by Rev. Thomas Ross in the *Old Statistical Account*. According to Ross (1796) the roads, or the 'Casan' as they were known locally, were 'one of the most stupendous monuments of human industry' (p. 549). Local tradition held that they were built either by the Kings of Scotland when they resided in the Castle at Inverlochy, or by the Gaelic mythical hero, Fingal, and his followers. In support of the latter explanation Ross noted that the features were locally called 'Fingalian roads'.

Historically Glen Roy played an important role in the development of geomorphological theories of landscape evolution. In addition, the search for a theory of formation of the Parallel Roads provides an instructive case study in the history and philosophy of science and the development of scientific ideas (Rudwick, 1974). In the 19th century various theories were proposed in the scientific literature to account for the origin of the Parallel Roads (Rudwick, 1974). These included aqueducts for irrigation (Playfair, cited by Jolly, 1880b), diluvial shorelines (Mackenzie, 1848; Rogers, 1862), lake shorelines (Greenough, 1805, cited by Rudwick, 1962; MacCulloch, 1817), marine shorelines (Darwin, 1839; Maclaren, 1839; Lyell, 1841b; Chambers, 1848; Watson, 1866; Nicol, 1869, 1872; Campbell, 1877; Macfadzean, 1883) and shorelines of debris-dammed (Dick, 1823; Milne Home, 1847b, 1849, 1876, 1879) or ice-dammed lakes (Agassiz, 1841b, 1842; Buckland, 1841b; Thomson, 1848; Jamieson, 1863, 1892; Lyell, 1863; Mackie, 1863; Geikie, 1865; Jolly, 1873, 1880a, 1880b, 1886a, 1886b; James, 1874; Brown, 1875; J. Geikie, 1877; Tyndall, 1879; Livingston, 1880; Prestwich, 1880). Several authors considered the shorelines to have formed by mass movements of slope debris (Jamieson, 1863; Lyell, 1863; MacCulloch, 1817; Babbage, 1868; Prestwich, 1880). Lubbock (1868) advocated redistribution of sediments by wave processes, while Melvin (1887) and Livingston (1906) believed that the roads were glacier-margin deposits. Dakyns (1879) made an important observation that the roads were locally cut in bedrock.

The marine school initially found strong proponents in both Charles Darwin and Charles Lyell. The former, in particular, was deeply impressed by Glen Roy. On 9 August 1838 he wrote to Lyell, 'I wandered over the mountains in all directions and examined that most extraordinary district. I think without any exception, not even the first volcanic island, the first elevated beach, or the passage of the Cordillera, was so interesting to me as this week. It is far the most remarkable area I ever examined. . . . I can assure you Glen Roy has astonished me' (Darwin, 1887, p. 293). At that time Darwin favoured a marine origin for the Parallel Roads. It was only 23 years later, in 1861, that he recanted in print this belief and accepted the fact that the roads represented the shores of a glacial lake (Barrett, 1973; Rudwick, 1974). However, it was Agassiz (1841b, 1842), a pre-eminent figure in the application of the glacial theory in Britain, who first identified the imprint of glacier ice and propounded the existence of former ice-dammed lakes in Glen Roy, following a visit there in 1840 with William Buckland. This idea was subsequently elaborated by Jamieson (1863, 1892). More recently, as outlined below, Sissons (1977e, 1978, 1979a, 1979b, 1979c, 1981c, 1981d) has refined the explanation of the Parallel Roads and established in some detail the sequence of events in their formation. His work also reveals the Parallel Roads to be part of a remarkable complex of glacial, glaciofluvial and glaciolacustrine landforms and sediments extending from Loch Laggan in the east through Glen Spean, Glen Roy and Glen Gloy, to near Fort William in the west, and north-

Figure 10.12 Geomorphology of the Spean Bridge–Gairlochy area (from Sissons, 1979c). See text for explanation of letters.

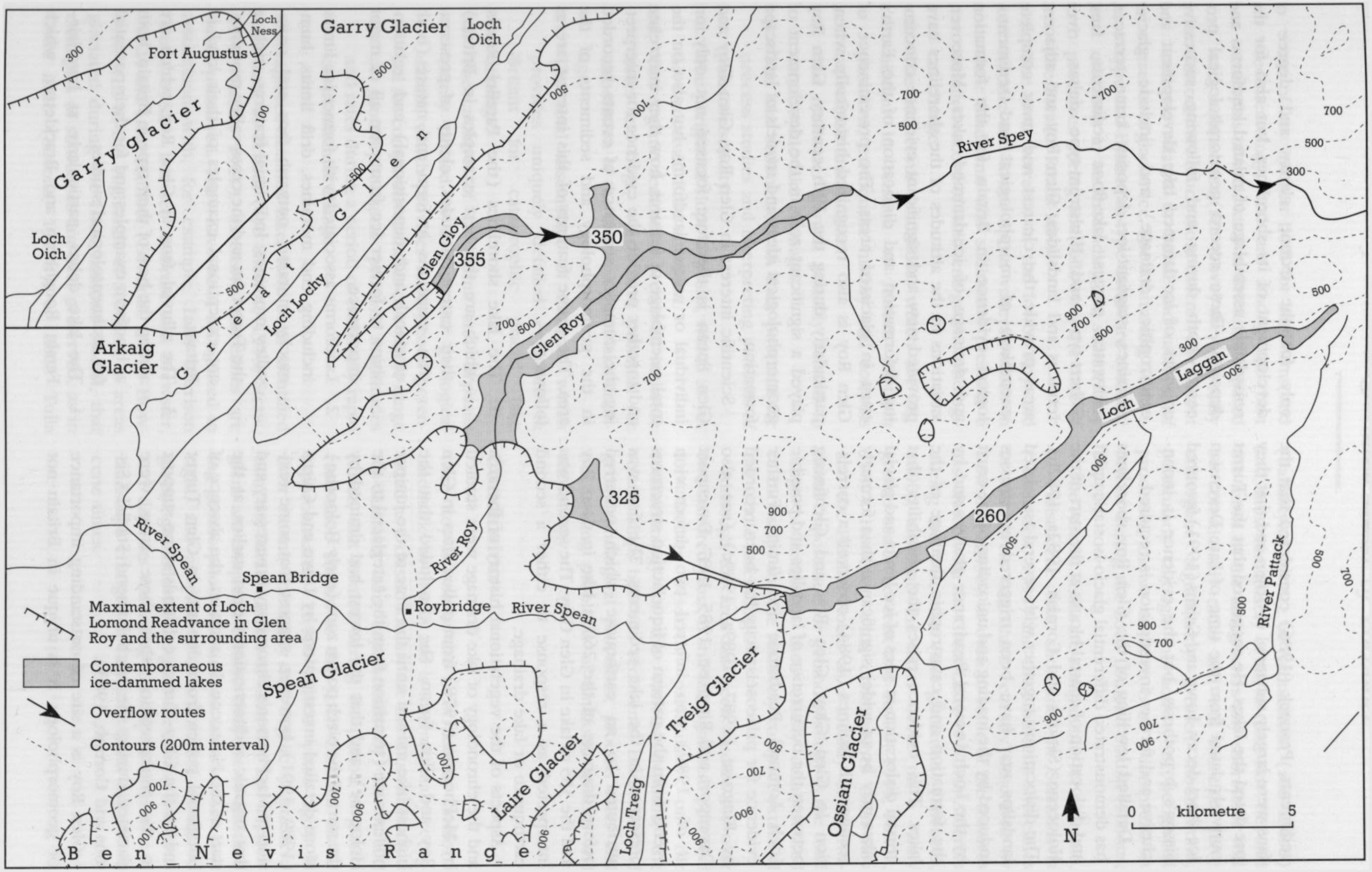
east to the Great Glen, Loch Ness and Inverness.

Current understanding of the sequence of events in the formation of the ice-dammed lakes and their subsequent drainage was summarized by Sissons (1981d), drawing on the details of his earlier papers (Sissons, 1977e, 1979a, 1979b, 1979c). Lakes in Glen Roy, Glen Gloy and Glen Spean were impounded by ice of the Loch Lomond Readvance from west of the Great Glen, coalescing with glaciers from the Ben Nevis range and from the ground to the south via the Laire and Treig breached valleys (Figure 10.13). Wilson (1900) and Peacock (1970b) established ice-movement patterns from striations and the distribution of erratics, and Sissons (1979b) has mapped and discussed the ice limits and related landforms, which include spectacular lateral moraines, end moraines and hummocky moraine. At its maximum extent the ice reached the western end of the present Loch Laggan and penetrated up-valley into Glen Roy and Glen Gloy (Figure 10.13). As it advanced, the ice ponded back a series of ice-dammed lakes, successively at 260 m, 325 m and 350 m OD (the rising sequence). The levels of these were controlled by the altitudes of the lowest ice-free cols on their perimeters (Jamieson, 1863; Sissons, 1977e). At the maximum extent of the ice the Glen Gloy lake overflowed through the col at 355 m on the Gloy–Turret watershed into the Glen Roy lake which attained maximum dimensions of 16 km in length and 200 m in depth. The level of the Glen Roy lake was controlled by the 350 m col leading into Strathspey at the head of the glen. The waters of a contemporary lake in Glen Glas Dhoire escaped to the east through a col at 325 m into an extensive lake at 260 m controlled by the Feagour col at the eastern end of the present Loch Laggan. As the ice retreated, lakes were formed at successively lower levels (the falling sequence). First in Glen Roy, the 325 m col became available as an outlet for the Roy lake, and the latter fell to its second major level. Subsequent decay and westward retreat of the ice margin to the vicinity of Spean Bridge allowed the Roy lake to fall to the level of the 260 m lake in Glen Spean, which at its maximum extent was 35 km long. In Glen Gloy the level of the lake remained constant, as the col at the head of the glen is the lowest in the watershed.

Drainage of the 260 m lake may be inferred by analogy with modern ice-dammed lakes in many parts of the world, which drain periodically by catastrophic subglacial flow of the ponded water (for example, Liestøl, 1956; Stone, 1963; Mathews, 1973; Dawson, 1983c; Clement, 1984; Shakesby, 1985; Russell, 1989); the resulting floods are commonly described by the Icelandic term *'jökulhlaup'* (glacier burst). From his detailed investigation of the field evidence, Sissons (1979c) proposed that the 260 m lake was drained by catastrophic subglacial flow through the Spean Gorge and northwards along the Great Glen to the Moray Firth. At Fort Augustus (see above) an extensive spread of sand and gravel is thought to have been deposited by the *jökulhlaup*, as is a large gravel deposit in the Beauly Firth at Inverness (Sissons, 1981c). Very perceptively, Jamieson (1865) first raised the possibility that gravel deposits in the Inverness area might be related to the final catastrophic drainage of the Glen Roy and Glen Gloy lakes, although those he possibly had in mind are eskers and kames (see Torvean). Subsequently, there was a period of oscillating lake levels and smaller *jökulhlaup* events through the Spean Gorge and later through the Lundy Gorge. Upon the abandonment of the latter route, drainage shifted back to the north-east, first in the form of a *jökulhlaup* along a now-abandoned waterfall and channel near Glenfintaig House then via an overspill channel from a later lake in Glen Spean at 113 m. Considerable fluvial infill took place in Glen Roy and Glen Spean after the drainage of the 260 m lake, and a complex series of over twenty terraces has been identified (Sissons, 1979a), some of which relate to a variety of lower lake levels in Glen Spean and other, later, ones to higher levels of Loch Lochy. Failure of the ice dam in Glen Spean led to final drainage through the Spean Gorge, dissection of the valley infill and terrace deposition in the Gairlochy area.

In upper Glen Roy, Sissons and Cornish (1983) mapped extensive fans of coarse gravel deposited in the lowest lake in the sequence of rising lake levels. The largest feature is associated with outwash from a glacier in Glen Turret. Sissons and Cornish (1983) suggested this glacier had flowed over the col from Glen Gloy. As the lake level rose, the glacier retreated and the gravels were mantled with lake sediments (clays and silts). However, following a re-examination of the

Figure 10.13 Loch Lomond Readvance ice limits and associated ice-dammed lakes in the Glen Roy–Glen Spean area (from Sissons, 1981d).


Garry glacier
Fort Augustus
Loch Ness
Loch Oich
Garry Glacier
Loch Oich
Arkaig Glacier
Great Glen
Loch Lochy
Glen Gloy
355
350
Glen Roy
325
260
Loch Laggan
River Spey
River Pattack
River Spean
River Roy
Spean Bridge
Roybridge
Spean Glacier
Laire Glacier
Loch Treig
Treig Glacier
Ossian Glacier
Ben Nevis Range
N
0 kilometre 5
Maximal extent of Loch Lomond Readvance in Glen Roy and the surrounding area
Contemporaneous ice-dammed lakes
Overflow routes
Contours (200m interval)

sediments, Peacock (1986) considered that the fans were largely subaerial in origin and that they pre-dated the lakes. He suggested that the Turret outwash dated from the time of Late Devensian ice-sheet decay. Lowe and Cairns (1991) favoured Sisson's hypothesis, but the evidence is inconclusive and further investigation is required.

Detailed levelling of the Glen Roy shorelines has demonstrated differential glacio-isostatic uplift and dislocation of crustal blocks at the start of the Holocene (Sissons and Cornish, 1982a, 1982b). The dislocations, together with several associated landslips may have been triggered by stresses induced by the loading and unloading of the crust by the Loch Lomond Readvance glaciers and by the formation and catastrophic drainage of the lakes. This evidence raises the possibility that crustal dislocation at sites of ice limits and glacial lakes may be of wider significance than formerly recognized. Holmes (1984) observed a correlation in Glen Gloy, Glen Roy and Glenfintaig between the occurrence of landslips and possible Loch Lomond Readvance ice limits. Further evidence for palaeoseismicity has been recorded by Ringrose (1987, 1989a, 1989c) (see also Davenport and Ringrose, 1985, 1987; Davenport *et al.*, 1989) who inferred two deformation events from the pattern of liquefaction structures preserved in the lake sediments. The first was attributed to an earthquake which occurred before drainage of the 260 m lake in Glen Roy and the 355 m lake in Glen Gloy. The second was interpreted as a response to either a second earthquake or lake drainage.

Aspects of the vegetational history of the area and the chronology of lake drainage were studied by McPherson (1978) from pollen sites in Glen Roy and Glen Spean. She concluded that the highest lake existed until the time of the juniper pollen zone (transition from the Lateglacial to the Holocene), and that the lowest had drained by the start of the birch pollen zone (early Holocene). More detailed investigations by Lowe and Cairns (1989, 1991), however, suggest that some revision of MacPherson's chronology is necessary and that organic sedimentation began earlier, at the start of the Holocene. In addition, the absence of Lateglacial pollen from deposits in Glen Turret and on the Gloy–Turret col lends some support to the interpretation that these areas were glaciated during the Loch Lomond Stadial (Sissons and Cornish, 1983).

Glen Roy is a site of outstanding importance for geomorphology. It is unique in Britain not only for the extent, clarity and degree of development of its shorelines, but also for the remarkable assemblage of related landforms and deposits. These record geomorphological processes both during and following successive episodes of ice-dammed lake development and catastrophic drainage, and include glacier moraines, stagnant-ice deposits, kame terraces, meltwater gorges, lake-floor sediments, fans, Gilbert-type and Hjulström-type deltas, river terraces and landslides. Glen Roy and adjacent areas provide the clearest and most complete assemblage of morphological and sedimentological evidence in Britain for the formation and drainage of ice-dammed lakes. Moreover, variations in the altitudes of the shorelines have provided new and significant evidence concerning deformation and dislocation of the Earth's crust in glaciated areas. The pre-eminence of Glen Roy is also recognized historically when, particularly during the 19th century, Glen Roy played a significant role in the development of geomorphological ideas and models of landscape formation.

Scientific interest in Glen Roy, Glen Gloy and Glen Spean is therefore focused not only on individual or unique landforms, but also on the total assemblage of features, how they interrelate and together provide the evidence for interpreting the complex sequence of events recorded in the geomorphology and sediments of the area. The prime features of this interest are as follows:

1. The lake shorelines (the Parallel Roads, which are the best examples in Britain); their extent, altitudes, clarity of preservation, variations in form and nature (both erosional and depositional) and relationships to former ice fronts are all of major importance.
2. Landforms associated with former ice limits, including end moraines, drift limits, hummocky moraine, outwash fans and cross-valley moraines. Individual features, such as the Turret fan and the cross-valley moraines, are exceptional examples of their kind in Britain.
3. The alluvial fans in Glen Roy, which are among the best of their type in Britain, both as landform examples and for their potential for sedimentological studies.
4. The lake deltas, particularly at Inverlair–Fersit, Roughburn and Brackletter, which

are of key interest both for landforms and sedimentology, and are among the best examples of their kind in Britain; compared with Achnasheen (see above) they generally demonstrate much more extensive sediment collapse related to burial and melting of masses of glacier ice. The contrasting Gilbert-type and Hjulström-type deltas are essential elements in understanding the sedimentary processes during and following the time of the Parallel Roads lakes.

5. The river terraces in the lower Roy and middle and lower Spean valleys, which in their landforms and sediments preserve a detailed record of Holocene geomorphological change.
6. The numerous landslides, which are significant in relation to former ice-front positions, earthquake history and controls on release mechanisms.
7. The meltwater gorges, possibly related to catastrophic lake drainage.
8. The lake sediments with their potential for process studies and interpreting patterns of palaeoseismicity.
9. The periglacial slope deposits, which as yet have received little attention.
10. The organic sediments preserved in kettle holes and bogs, which have potential for elaboration of the chronology of lake drainage.
11. The total assemblage of features, which provides uniquely detailed evidence in Britain for catastrophic glacial lake drainage.
12. The archive of landforms and deposits clearly related to a particular geological datum, which provides unsurpassed potential for comparative studies of a whole range of geomorphological process magnitudes and rates during a period of extremely rapid environmental change.

Although ice-dammed lakes have been identified elsewhere in Britain (see Shotton, 1953; Straw, 1979; Gaunt, 1981), extensive shorelines are rarely preserved. They have been recognized in association with, for example, Lake Harrison (Dury, 1951 – but see Ambrose and Brewster, 1982) and Lake Humber (Edwards, 1937). However, it is in the Highlands of Scotland, in areas glaciated during the Loch Lomond Stadial, that examples of shorelines are best preserved, as in Coire Dho (Sissons, 1977b), at Loch Tulla (Ballantyne, 1979), at Achnasheen (see above) and, most remarkably of all, in Glen Roy. Beyond the limits of the last glaciers any shorelines will be considerably older and will therefore have undergone significantly greater modification, particularly through the activity of periglacial processes known to have been widespread in Britain during the Loch Lomond Stadial (Sissons, 1979e).

The Parallel Roads are comparable, for example, to Pleistocene lake shorelines in Scandinavia (Mannerfelt, 1945) and the Holocene shorelines in south-west Greenland recently described by Dawson (1983c); or even to some of the features associated with the Great Lakes of North America during the Wisconsin (last glaciation) (Spencer, 1890), although the latter occur on a vastly greater scale (Leverett and Taylor, 1915; Fulton, 1989). However, what distinguishes Glen Roy and the Parallel Roads as a locality of international importance for geomorphology is the total range of landforms, their clearly demonstrated relationships and the relatively compact extent of the whole assemblage.

Although the area has been studied for over two hundred years, it still has significant potential for further research, particularly on the sedimentology of the various deposits, the relationships between sediments, landforms and geomorphological processes, process rates and outstanding problems of landform genesis and chronology.

Conclusion

Glen Roy is one of the most famous landform landmarks in Britain and is internationally recognized as a classic locality for the shorelines of an ice-dammed lake, represented by the Parallel Roads, that formed during the period of glacier readvance known as the Loch Lomond Stadial (approximately 11,000–10,000 years ago). In their extent, continuity and degree of preservation, the Parallel Roads of Glen Roy and adjacent glens are unique in Britain. They are of outstanding geomorphological interest both in their own right, and as part of a remarkable system of glacial, glaciofluvial and glaciolacustrine landforms and deposits recording a complex sequence of landscape changes in Lateglacial and early Holocene times.

KINGSHOUSE

M. J. C. Walker

Highlights

Pollen preserved in the sediments that infill a topographic depression near Kingshouse provide an important record, supported by radiocarbon dating, of vegetational history and environmental changes during the early and middle Holocene. A radiocarbon date from the basal organic sediments provides a minimum date for the deglaciation of Rannoch Moor at the end of the Loch Lomond Readvance.

Introduction

The Kingshouse site (NN 282555) is situated in the north-western part of Rannoch Moor near the heads of Glen Etive and Glen Coe, and lies approximately 2.25 km north-east of the Kingshouse Hotel at an altitude of *c.* 340 m OD. It is the second of three sites in the Kingshouse area studied by Lowe and Walker (1976), and is known as Kingshouse 2. The importance of the site lies partly in the fact that it contains a detailed record of vegetational changes in the Rannoch Moor area of the west-central Grampian Highlands during the early and middle Holocene, but principally in the sequence of radiocarbon dates obtained from the lowermost sediments. The age determination on the basal organic sediments is one of the earliest from a site inside the Loch Lomond Readvance limits and, if correct, provides a minimum date for the deglaciation of Rannoch Moor. Details of the stratigraphy of the site can be found in Lowe and Walker (1976, 1980) and in Walker and Lowe (1977, 1980).

Description

The site is a small enclosed basin (maximum dimensions 40 m by 25 m) which has been buried beneath blanket peat. Almost 4.5 m of sediment have accumulated at the deepest point. The basal sediment sequence is complex (Figure 10.14): coarse gravels and sand are succeeded upwards by laminated silt and fine sand, clay, a thin band of gyttja, fine sand with abundant remains of the terrestrial moss *Rhacomitrium lanuginosum* and fine–medium-grained sand with occasional moss fragments. This sequence is overlain by over 4 m of limnic, telmatic and terrestrial organic sediments. The lower inorganic sediments are essentially barren of pollen, but a pollen diagram has been constructed for the lower 2.35 m of the overlying organic sediments, and a single pollen count was obtained from the thin gyttja layer near the base of the profile (Figure 10.14). The diagram was divided into local pollen assemblage zones and these were integrated with pollen data from the nearby sites at Kingshouse 1 and Kingshouse 3 to form a sequence of regional pollen asssemblage zones (R zones) for western Rannoch Moor (Walker and Lowe, 1977).

Three radiocarbon dates were obtained from the lowermost part of the Kingshouse 2 profile (Figure 10.14). The thin layer of gyttja within the basal sediments yielded a radiocarbon age of 10,520 ± 330 BP (Birm–723), and a date of 10,290 ± 180 BP (Birm–722) was obtained from fragments of moss, *Rhacomitrium lanuginosum*, in the fine sands above. The contact between these sands and the overlying organic sediments was dated at 9910 ± 200 BP (Birm–724) (Lowe and Walker, 1976).

Interpretation

The earliest vegetational records reflect a landscape immediately following deglaciation of *Empetrum* heath and juniper scrub with patches of ground covered by a moss carpet or by grasses. Indeed, the high *Empetrum* and *Juniperus* pollen frequencies, in conjunction with the macrofossil evidence of *Rhacomitrium lanuginosum*, suggest vegetational affinities with the '*Rhacomitreto–Empetretum*' (*Rhacomitrium–Empetrum* heath) and *Juniperetum nanae* (dwarf juniper scrub) associations which are common in parts of the western and northern Scottish Highlands today (McVean and Ratcliffe, 1962). Subsequently, the *Empetrum* heath communities were invaded by *Juniperus communis* and then by tree birch. Following the arrival of *Betula*, the landscape of the area appears to have been a mosaic of birch copses and heath and moorland communities, separated by areas of grassland on the steeper slopes around the Rannoch basin (see also Walker and Lowe, 1979, 1981). The juniper maximum in the Kingshouse 2 profile has been dated at 9910 ± 200 BP (Birm–724) and dates

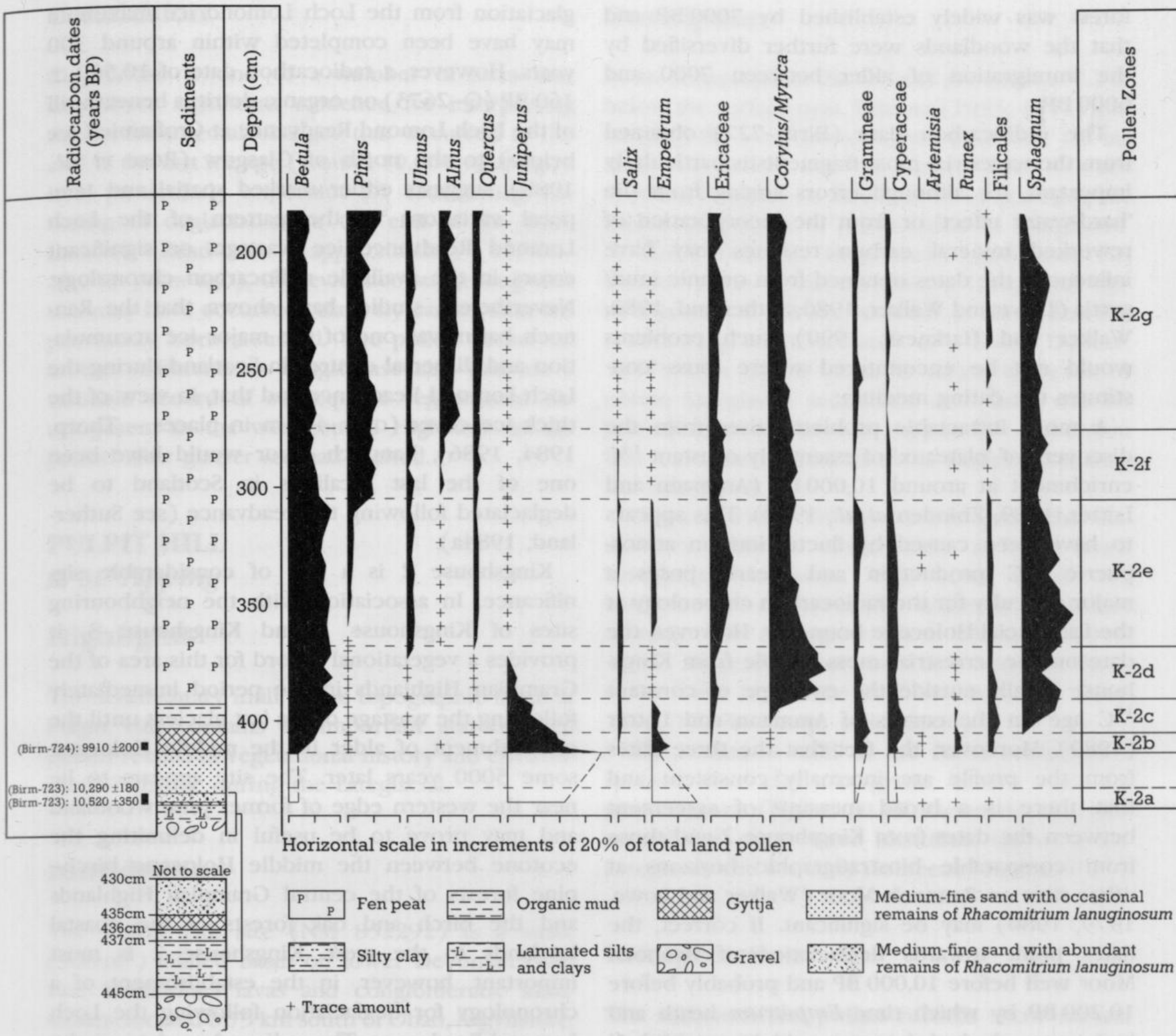


Figure 10.14 Kingshouse: relative pollen diagram showing selected taxa as percentages of total land pollen (from Walker and Lowe, 1977).

from other areas of Scotland suggest that tree birch would have been well established on western Rannoch Moor by 9000 BP (Birks, 1972b; Harkness and Wilson, 1979; O'Sullivan, 1976; Walker and Lowe, 1982, 1985).

The pollen records from the Kingshouse sites show that, following the period of open birch-woods, the landscape underwent further change with the arrival first of hazel (*Corylus avellana*) which expanded throughout Scotland early in the eighth millennium BP (Huntley and Birks, 1983), and subsequently with the immigration of woodland taxa including elm, oak, pine and, at a later date, alder. *Pinus sylvestris* and *Betula* appear to have formed the dominant elements of the woodland cover during the middle Holocene, whereas *Ulmus* and *Quercus* were more restricted in their distribution. The continuous representation of Ericaceae and Gramineae throughout the middle Holocene part of the Kingshouse 2 profile suggests that areas of heath and grassland communities may have existed between the woodland stands, and on the upper slopes and plateau surfaces above the regional treeline. Radiocarbon dates from the Cairngorms (Birks, 1970; O'Sullivan, 1975, 1976) and from north-west Scotland (Birks, 1972b; Birks and Williams, 1983; Pennington *et al.*, 1972; Williams, 1977) indicate that pine began to arrive in the Scottish Highlands soon after 8000 BP, that pine and birch forest was forest was widely established by 7000 BP and that the woodlands were further diversified by the immigration of alder between 7000 and 6000 BP.

The radiocarbon date (Birm–722) obtained from the terrestrial moss fragments is particularly important, for although errors arising from the 'hard-water effect' or from the incorporation of reworked mineral carbon residues may have influenced the dates obtained from organic mud/gyttja (Lowe and Walker, 1980; Sutherland, 1980; Walker and Harkness, 1990), such problems would not be encountered where moss constitutes the dating medium.

A more intractable problem arises from the discovery of 'plateaux' of essentially constant ^{14}C enrichment at around 10,000 BP (Ammann and Lotter, 1989; Zbinden *et al.*, 1989). This appears to have been caused by fluctuations in atmospheric ^{14}C production and clearly poses a major difficulty for the radiocarbon chronology at the Lateglacial/Holocene boundary. However, the date on the terrestrial moss sample from Kingshouse 2 falls outside the envelope of constant ^{14}C age on the curves of Ammann and Lotter (1989). Moreover, the fact that the three dates from the profile are internally consistent and that there is a broad measure of agreement between the dates from Kingshouse 2 and those from comparable biostratigraphic horizons at other sites on Rannoch Moor (Walker and Lowe, 1979, 1980) may be significant. If correct, the dates point towards deglaciation of Rannoch Moor well before 10,000 BP and probably before 10,200 BP by which time *Empetrum* heath and juniper scrub had become widely established locally.

The data from Kingshouse 2 are important in a wider context. The contrast between the dwarf-shrub-dominated pollen assemblage at the base of the profile and the largely herbaceous pollen assemblages found in the lowermost horizons of kettle hole basins in the valleys to the east of Rannoch Moor points towards a pattern of time-transgressive deglaciation following the Loch Lomond Readvance ice maximum (Lowe and Walker, 1981), although strictly the basal pollen relate only to the time of melting of buried ice and not necessarily to regional deglaciation. Basal organic sediments from a site located behind the Loch Lomond Readvance moraine at Callander (see Mollands) have been dated at 10,670 ± 85 BP (Lowe, 1978). If this age determination and those from Kingshouse 2 are correct, deglaciation from the Loch Lomond ice maximum may have been completed within around 300 years. However, a radiocarbon date of 10,560 ± 160 BP (Q–2673) on organic detritus beneath till of the Loch Lomond Readvance at Croftamie (see below) to the north of Glasgow (Rose *et al.*, 1988), suggests either marked spatial and temporal variations in the pattern of the Loch Lomond Readvance ice wastage, or significant errors in the available radiocarbon chronology. Nevertheless, studies have shown that the Rannoch basin was one of the major ice accumulation and dispersal centres in Scotland during the Loch Lomond Readvance and that, in view of the thick ice cover (over 400 m in places – Thorp, 1984, 1986), Rannoch Moor would have been one of the last localities in Scotland to be deglaciated following the readvance (see Sutherland, 1984a).

Kingshouse 2 is a site of considerable significance. In association with the neighbouring sites of Kingshouse 1 and Kingshouse 3, it provides a vegetational record for this area of the Grampian Highlands in the period immediately following the wastage of the last glaciers until the establishment of alder in the middle Holocene some 5000 years later. The site appears to lie near the western edge of former pine woodland and may prove to be useful in delimiting the ecotone between the middle Holocene birch–pine forests of the central Grampian Highlands and the birch and oak forests of the coastal lowlands to the west. Kingshouse 2 is most important, however, in the establishment of a chronology for deglaciation following the Loch Lomond Readvance. The radiocarbon date on the moss fragments is of particular significance and thus far is the only one obtained from plant macrofossil material from sites within the last glacier limits. In conjunction with the other age determinations from the site and from elsewhere on Rannoch Moor, it may imply much earlier deglaciation following the Loch Lomond Readvance than has previously been assumed (Sissons, 1979e).

The pollen stratigraphy indicates the complex and rapid vegetational changes that occurred following deglaciation, and suggests that the environmental changes associated with ice wastage were rapid and large. Nowhere else in north-west Europe is the evidence for rapid deglaciation and climatic change so clearly developed as on Rannoch Moor (H. J. B. Birks, unpublished data).

Conclusion

Kingshouse is one of a number of sites that contribute significant evidence for interpreting the environmental changes that occurred at the end of the last ice age (around 10,000 years ago). It is particularly important for establishing the timing of deglaciation at the end of the Loch Lomond Readvance (approximately 11,000–10,000 years ago), the evidence suggesting that this may have occurred relatively earlier than has previously been assumed. The pollen preserved in the sediments at Kingshouse also provide a valuable record of subsequent vegetational development in the west-central Highlands in the period after glacier ice had melted.

PULPIT HILL

R. M. Tipping

Highlights

The sedimentary infill in the topographic basin at Pulpit Hill contains an important and detailed pollen record of vegetational history and environmental change during the Lateglacial.

Introduction

The Pulpit Hill site (NM 852292) is a small (500 m^2) infilled basin on lower Devonian (Old Red Sandstone) lavas and conglomeratic sandstones, located 0.75 km south of Oban, Argyllshire. The basin contains a sequence of polleniferous, lacustrine sediments of Lateglacial and early Holocene age, important for its position in the historical development of Quaternary pollen studies in Scotland (Donner, 1955, 1957). Recent investigations (Tipping, 1984, 1991b) have demonstrated a number of environmental changes within the Lateglacial Interstadial, in particular, a climatic deterioration early in the interstadial and a later, but pre-Loch Lomond Stadial, climatic decline, which appear to have wider significance for the Scottish Quaternary, and which have also been reported from pollen sites on Skye (Walker and Lowe, 1990).

Description

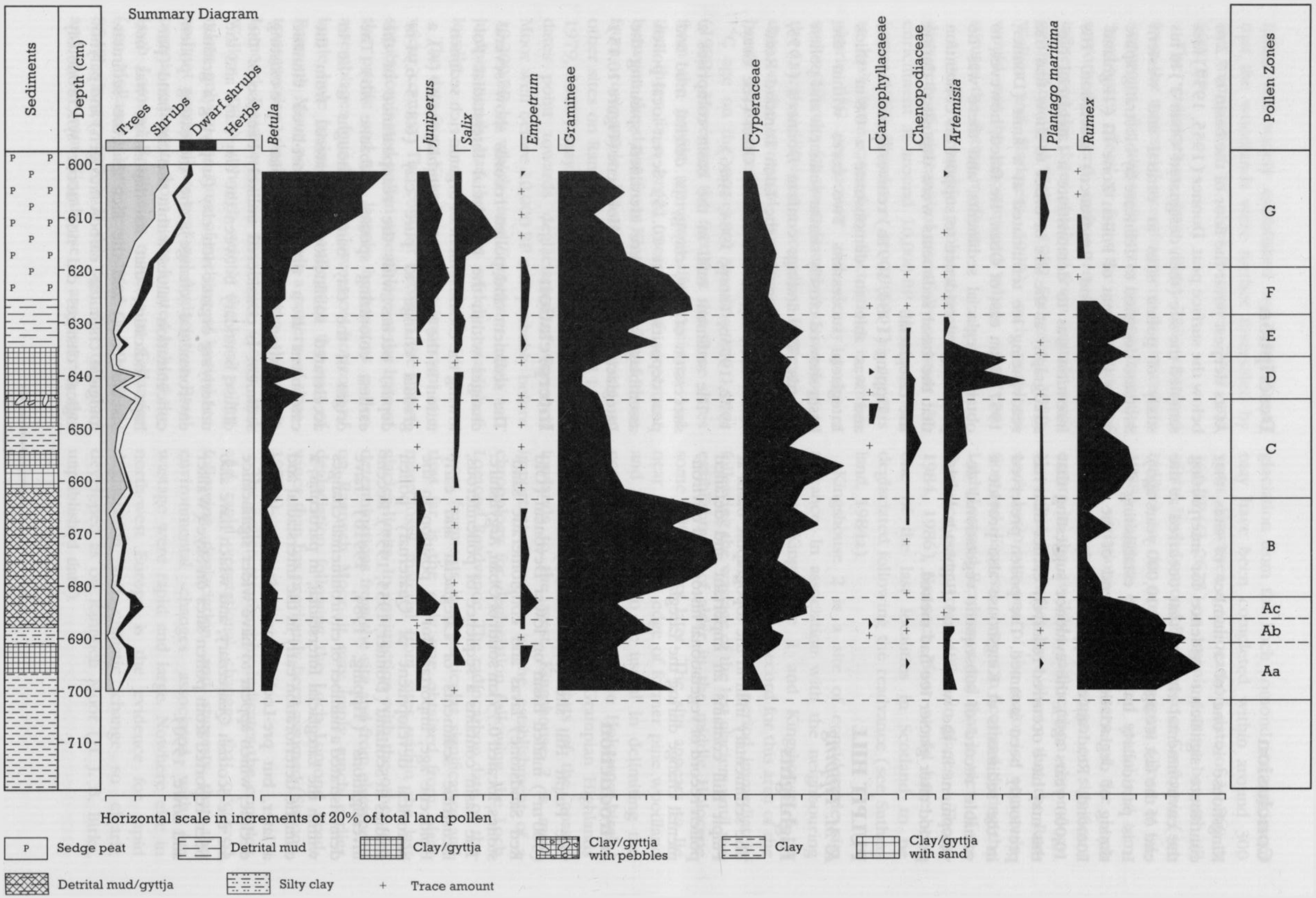
At its deepest point the floor of the basin is 7.2 m below the surface peat. Donner (1955, 1957) first sampled the site (then designated 'Oban 2') in his study of pollen sites in central and western Scotland designed to delineate by biostratigraphic means the extent of Pollen Zone III ('Highland' or Loch Lomond Readvance) glaciation. His intention was to demonstrate a Lateglacial biostratigraphy at the site in order to show that the readvancing ice terminated at a limit (Donner, 1957) 2 km east of Oban. He failed, however, to obtain Lateglacial sediments, and there was no palynological evidence to support his contention that the basal sediments were deposited during the Lateglacial.

Tipping (1984, 1991b) reinvestigated the site, and was able to demonstrate a 0.8 m thick Lateglacial succession. Two cores within the basin showed closely similar sediment and pollen records. The findings confirm Donner's (1955, 1957) suggestion that the Loch Lomond Readvance limit lay to the east of Oban (see Gray, 1972, 1975b; Thorp, 1984, 1986).

The sediment infill in the basin comprises a succession of clay, clay/gyttja, detrital mud and peat deposits (Figure 10.15). Seven local pollen assemblage zones were identified, spanning the Lateglacial and the early Holocene (Figure 10.15).

Interpretation

The sediment and pollen records show several changes within the Lateglacial Interstadial. Following the establishment of organic-rich sedimentation in the basal pollen assemblage zone (A), a gradual change to pure clay (6.875–6.91 m depth) occurs with the reappearance of the earliest colonizing species (subzone Ab). The origin of the clay band is thought to lie in accelerated solifluction of material from the catchment at a time of short-lived climatic deterioration. Basin-edge collapse of pre-existing sediment is considered unlikely because of the diffuse boundary between the clay band and the underlying organic-rich clay (implying a gradual environmental change), the increasing pollen concentration values within the clay band (perhaps indicating that its deposition was not instantaneous) and the fact that the sedimentological, chemical (carbon/nitrogen) and palynological changes did not occur synchronously



Sediments
Depth (cm)
Summary Diagram
Trees
Shrubs
Dwarf shrubs
Herbs
Betula
Juniperus
Salix
Empetrum
Gramineae
Cyperaceae
Caryophyllaceae
Chenopodiaceae
Artemisia
Plantago maritima
Rumex
Pollen Zones
600
610
620
630
640
650
660
670
680
690
700
710
G
F
E
D
C
B
Ac
Ab
Aa
Horizontal scale in increments of 20% of total land pollen
Sedge peat
Detrital mud
Clay/gyttja
Clay/gyttja with pebbles
Clay
Clay/gyttja with sand
Detrital mud/gyttja
Silty clay
Trace amount

(Tipping, 1984, 1991b).

The *Juniperus–Empetrum* subzone (Ac) represents the mildest climatic phase of the Lateglacial Interstadial, which, characteristically for the west coast of Scotland, has no arboreal pollen taxa at percentages high enough to imply local growth. The suppression of tree growth by westerly winds stronger than those of the present day was suggested by Tipping (1984, 1991b) as the reason for this vegetational pattern, which contrasts sharply with the birch parkland found during this period in eastern Scotland (Lowe and Walker, 1977).

The Gramineae–*Plantago maritima* pollen zone (B) is thought to indicate a second, but more sustained, climatic decline and with no amelioration until after the Loch Lomond Stadial. This is recognized in the pollen record through the displacement by grassland of *Juniperus* and *Empetrum* associations, and in the chemistry of the sediments by declining carbon and nitrogen values. This climatic decline has become increasingly widely recognized in western Scotland (Tipping, 1984, 1991b), the Inner Hebrides (Lowe and Walker, 1986a; Walker and Lowe, 1990) and Ireland (Craig, 1978), and is radiocarbon dated to *c.* 12,000 BP.

Clay-dominated sedimentation did not recommence, however, until the Loch Lomond Stadial, when solifluction again introduced minerogenic sediment from catchment soils and produced several inwashed moss bands (cf. Birks, 1970). The pollen assemblages (zones C and D) from the stadial sediments are typical of tundra communities at the present day, with *Artemisia* a prominent taxon; in this respect the pollen record at Pulpit Hill conforms with the pattern at a great number of Lateglacial pollen sites in Scotland (Walker, 1984b; Tipping, 1985).

Pulpit Hill is of importance to the history of Lateglacial climatic and glacial geological studies, in that the site was examined by Donner (1957) in the first attempt to identify his 'Highland Readvance' (synonymous with the Loch Lomond Readvance) with the climatic deterioration recorded in Godwin Pollen Zone III.

More recent palynological investigations (Tipping, 1984, 1991b) have succeeded in clarifying the Lateglacial stratigraphy and have shown that the site is of major significance for present understanding of the climatic changes during the Lateglacial, as well as in the clarity with which several climatic changes are shown. Recent syntheses (for example, Gray and Lowe, 1977b) have suggested that there were no climatic fluctuations during the interstadial comparable to those recognized in north-west Europe by Mangerud *et al.* (1974). This now seems to be incorrect and Pulpit Hill shows, in some detail, all the major climatic changes now recognized in the Lateglacial.

These changes principally are:

1. A short-lived climatic deterioration prior to *c.* 12,000 BP, probably of a similar character to the later Loch Lomond Stadial, though of apparent less severity or duration. This feature is now recognized at a number of sites in western Scotland (Walker *et al.*, 1988; Walker and Lowe, 1990), but is perhaps best exhibited at Pulpit Hill, in the clarity of the stratigraphy, the high temporal resolution of the pollen counts and the geochemical assays. These show that the changes in certain indicators were not synchronous. The decline in organic content occurred before the appearance of pollen types of a more disturbed-ground community. The latter also occurred prior to indications in the sediments of soil instability. This pattern is most easily interpreted as climatic in origin.

   This climatic deterioration appears to have correlatives at, for example, Loch Sionascaig, Loch Borralan and Lochan an Smuraich (Pennington *et al.*, 1972), Corrydon (Walker, 1977), Stormont Loch (Caseldine, 1980a) and Loch Ashik, Slioch Dubh, Elgol and Druim Loch on Skye (Walker and Lowe, 1990). Correlations are not constrained by reliable radiocarbon dates at these sites, and accordingly, the synchroneity of this event cannot be demonstrated. The suggestion that this is correlated with the Older Dryas in north-west Europe (Pennington, 1975b) may not be justified on present evidence (Tipping, 1991b).
2. A brief period of climatic amelioration occurred following this phase before a further, and seemingly sustained, climatic deterioration set in at *c.* 11,800–12,000 BP (by correlation with dated pollen sites on Mull (Lowe and Walker, 1986a) and south-west Ireland (Craig, 1978)). The evidence from carbon/nitrogen contents and pollen stratig-

Figure 10.15 Pulpit Hill: relative pollen diagram showing selected taxa as percentages of total land pollen (from Tipping, 1991b).

raphy at Pulpit Hill is that this decline continued without a break to the markedly more intense deterioration of the Loch Lomond Stadial, and so accords closely with coleopteran evidence for this time period (Atkinson *et al.*, 1987).

3. Within the Loch Lomond Stadial a trend to increasing aridity is clearly seen in the pollen record. This feature has been noted at only a few other sites in Scotland (MacPherson, 1980), due perhaps to inadequate resolution of pollen counts within the clay sediments of the stadial. Should it be confirmed at other sites it would have clear significance for the age of maximum glaciation of the Loch Lomond Readvance.

Finally, Pulpit Hill is important in that it remains one of only a few pollen sites to have been examined by the analysis of more than one pollen core. At Pulpit Hill, two cores were analysed, and the major vegetational and climatic changes discussed above replicated. This approach clearly indicates that the fluctuations recognized are not localized perturbations induced through sedimentological disturbance, nor are they statistical artefacts, but are real indications of the complexity of Lateglacial climatic evolution.

Conclusion

The deposits at Pulpit Hill provide a valuable record of environmental changes in the south-west Highland area during the Lateglacial (about 13,000–10,000 years ago). In particular, detailed study of the pollen and sediments has revealed two separate phases of climatic deterioration, the later one corresponding to the intensely cold Loch Lomond Stadial (about 11,000–10,000 years ago), together with the accompanying vegetation and soil changes. The detail of information available at Pulpit Hill makes it a valuable reference site and allows comparisons with the climatic records of sites in other areas.

LOCH CILL AN AONGHAIS

H. J. B. Birks

Highlights

Pollen preserved in the sediments that infill the floor of this loch provide a valuable record, supported by radiocarbon dates, of the vegetational history of the south-west Highland region during the Holocene. It is particularly important for understanding the woodland history of the area.

Introduction

Loch Cill an Aonghais (NR 776618) is situated at an altitude of about 25 m OD on the north side of West Loch Tarbert, 12 km south-west of Tarbert in southern Knapdale. It is a Quaternary site of considerable importance in the study and reconstruction of the Holocene vegetational history of western Scotland (Birks, 1977). Its detailed and extensively radiocarbon-dated pollen record, elucidated by Sylvia M. Peglar (unpublished data), documents the forest history of the area and clearly illustrates that pine never grew in this part of Scotland (Birks, 1989). The pollen stratigraphy demonstrates the history and development of the western oak-forest type, a type of woodland that is restricted to the high rainfall areas of western Britain, such as Knapdale (Ratcliffe, 1977). Summary pollen diagrams for the site have been published by Birks (1977, 1980).

Description

Loch Cill an Aonghais occupies a small hollow within till. The underlying bedrock is Dalradian schist and quartzite. The loch is about 130 m long and 90 m wide and is bordered by western bryophyte-rich oak and birch woods on its northern and western edges. An extensive fen has developed on the southern and eastern sides of the loch. A 9.5 m core was obtained from this fen. It consists of 0.24 m of *Phragmites* peat overlying 7.0 m of fine-detritus organic muds. Below these muds there are 2.26 m of silty clays and sulphide-rich clays (Figure 10.16). Eight radiocarbon dates (Q–1410 to Q–1417) were obtained from the organic muds to provide a detailed chronological framework for the Holocene pollen stratigraphy of the site.

The basal clays contain a fully marine macrofauna, indicative of cool water conditions, similar to that found at Lateglacial Interstadial sites elsewhere in western Scotland (D. K. Graham, unpublished data).

Interpretation

It is clear that the site was an arm of the sea at a time when relative sea level was higher than today owing to isostatic depression. The pollen record (Figure 10.16) indicates that a treeless landscape prevailed prior to about 10,000 BP. The vegetation was probably a mosaic of *Salix* scrub, *Empetrum* heath, and species-rich grassland. Between 10,000 and 9600 BP fern-rich juniper scrub expanded, presumably in response to climatic amelioration at the onset of the Holocene.

Betula was the first tree to migrate into the area at about 9600 BP, at the expense of the shrub, dwarf–shrub, and grassland communities that were prevalent before 9600 BP. *Corylus avellana* expanded very rapidly between 9400 BP and 9100 BP (Birks, 1989). Hazel was quickly followed by the arrival of elm at about 9000 BP and its subsequent expansion at about 8500 BP. *Quercus* appears to have expanded gradually from about 8500 BP, but it was not locally frequent near the site until about 8000 BP. *Alnus glutinosa* expanded locally at about 7500 BP (Bennett and Birks, 1990). By about 6000 BP the forests in this part of Scotland were probably dominated by oak and birch on poorer soils and by hazel and elm on the richer sites. Alder was locally abundant in moist areas around the loch and within the forests.

At 5100 BP *Ulmus* pollen values fell dramatically and there was a small increase in the frequency of herbaceous pollen, suggesting the presence of small clearings within the forest. Further forest clearance occurred between 4600 BP and 2100 BP. These clearance activities resulted in accelerated rates of erosion and inwashing of clastic material from the catchment of the loch. Extensive forest clearance occurred at about 1300 BP. Cereals and flax appear to have been cultivated locally from 800 BP to 250 BP. Local fen development at the coring site obscures the regional vegetational history for the last 250 years.

The pine pollen values at Loch Cill an Aonghais are very low throughout the Holocene part of the record, indicating that pine was absent from this area of Scotland (Birks, 1989). This conclusion is unexpected, as it contrasts with the undoubted presence of pine further north (see Kingshouse and Loch Maree) and further south in the Galloway Hills (see Loch Dungeon).

Loch Cill an Aonghais is a site of national importance because of its very detailed and well-dated Holocene pollen record. It provides critical evidence for the timing of the arrival and subsequent expansion of the major forest trees of western Scotland during the Holocene. It also demonstrates the absence of pine in the southern Knapdale area and the history of forest clearance and agricultural land use over the last 5000 years. It is particularly important in the context of regional Holocene vegetational history as it provides a geological perspective for an area of Scotland where internationally important woodland types occur today (Ratcliffe, 1977). The Lateglacial part of the sequence demonstrates the transition from a marine to a non-marine environment during the fall in relative sea level over this period.

Conclusion

Loch Cill an Aonghais is a key site in the network of localities representing the pattern of vegetational development in Scotland during the Holocene (the last 10,000 years). In particular, the pollen preserved in its sediments provide a detailed record of the vegetation history of the western oak forest area, showing the pattern of forest development and the notable absence of pine.

EAS NA BROIGE DEBRIS CONE

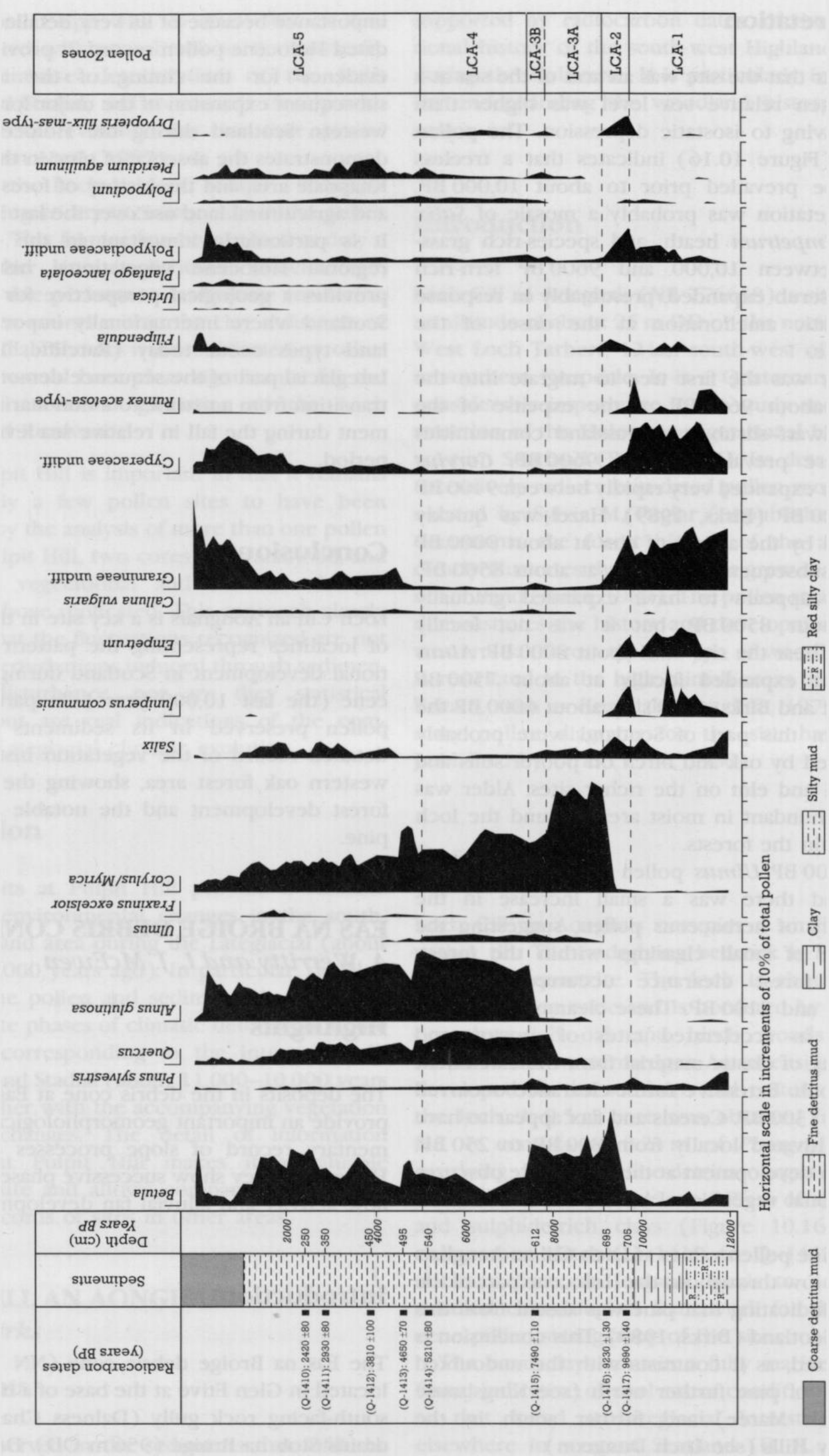
A. Werritty and L. J. McEwen

Highlights

The deposits in the debris cone at Eas na Broige provide an important geomorphological and sedimentary record of slope processes during the Holocene. They show successive phases of debris-flow activity and alluvial fan development.

Introduction

The Eas na Broige debris cone (NN 192598) is located in Glen Etive at the base of a near-vertical south-facing rock gully (Dalness Chasm) which drains Stob na Broige (956 m OD). Debris cones are fan-shaped accumulations of poorly-sorted


Radiocarbon dates (years BP)
Sediments
Depth (cm) Years BP
Betula
Pinus sylvestris
Quercus
Alnus glutinosa
Ulmus
Fraxinus excelsior
Corylus/Myrica
Salix
Juniperus communis
Empetrum
Calluna vulgaris
Gramineae undiff.
Cyperaceae undiff.
Rumex acetosa-type
Filipendula
Urtica
Plantago lanceolata
Polypodiaceae undiff.
Polypodium
Pteridium aquilinum
Dryopteris filix-mas-type
Pollen Zones
LCA-5
LCA-4
LCA-3B
LCA-3A
LCA-2
LCA-1
(Q-1410): 2420 ±80
(Q-1411): 2930 ±80
(Q-1412): 3810 ±100
(Q-1413): 4650 ±70
(Q-1414): 5210 ±80
(Q-1415): 7490 ±110
(Q-1416): 9230 ±130
(Q-1417): 9880 ±140
2000
250
350
450
4000
495
540
6000
612
8000
695
705
10000
12000
Horizontal scale increments of 10% of total pollen
Coarse detritus mud
Fine detritus mud
Clay
Silty mud
Red silty clay

debris formed by successive debris flows at the base of steep gullies. Such debris cones have developed extensively at the margins of valley floors in upland Scotland over the last 13,000 years and have formed in response to changes in sediment supply from adjacent gullies and slopes. Collectively these cones represent an important class of Lateglacial and Holocene landform found throughout upland Britain (Statham, 1976b; Harvey *et al.*, 1981; Innes, 1983b, 1985; Brazier *et al.*, 1988; Brazier and Ballantyne, 1989). The Eas na Broige cone is a particularly good example, and the deposits which comprise it have provided a detailed record of slope processes during the Holocene (Brazier *et al.*, 1988).

Description

The local bedrock comprises granite on the lower slopes with rhyolite lavas on the higher ground; the Dalness Chasm having been etched from a porphyritic dyke (Bailey and Maufe, 1916). During the Loch Lomond Stadial, glacier ice extended up to 650 m OD in upper Glen Etive (Thorp, 1981a, 1986). The debris cone is thus Holocene in age.

The Eas na Broige cone comprises two units: an upper debris cone with a concave long profile and mean gradient of 13.7°, and a lower alluvial fan with a mean gradient of 6.2°. Five discrete cone and fan surfaces can be identified within the lower alluvial surfaces which are inset into the steeper debris cone surfaces. The respective volumes of the debris cone and alluvial fan have been estimated at 170,000 m^3 and 100 m^3; the latter being entirely derived by incision and reworking of the former (Brazier, 1987).

The stratigraphy of much of the cone has been exposed by stream incision, and at two contrasting sites clearly distinguishable debris flow and fluvial sediments have been identified (Figure 10.17). At the apex of the alluvial fan (site 1) a coarse debris flow deposit lies beneath a distinctive and strongly podsolized palaeosol, radiocarbon dated at 550 ± 50 BP (SRR–2882). The overlying sediments comprise poorly-sorted alluvial gravels with only a weak soil development. Higher up the debris cone (site 2) a second palaeosol, radiocarbon dated at 4480 ± 300 BP (SRR–2884), separates two debris-flow units. The upper of these units is the continuation of the lower unit at site 1 and it appears to be the final debris flow unit which was deposited on this part of the cone (Brazier *et al.*, 1988). Pollen samples have been collected from site 1 in order to investigate possible vegetational changes associated with the onset of fluvial reworking. An initial cover of *Corylus*, *Alnus* and *Pinus* before 550 BP was replaced by Gramineae, *Plantago* and *Calluna* after that date. A strong presence of charcoal is also recorded in the unit above the palaeosol.

Figure 10.16 Loch Cill an Aonghais: relative pollen diagram showing selected taxa as percentages of total pollen (from Birks, 1980, after S. Peglar). Note that the data are plotted against a radiocarbon timescale.

Interpretation

Three major phases in the development of this fluvially modified debris cone can be identified. The debris cone initially developed during the first 6000 years of the Holocene, with aggradation ceasing about 4000 BP as a result of exhaustion of the sediment supply through the Dalness Chasm. A prolonged period of stability then ensued until 550 BP. This was followed by a final phase in which the incision into the debris cone produced the inset alluvial fan. The pollen evidence strongly suggests that fluvial activity was contemporaneous with changes in the vegetation cover caused by human interference. The removal of the tree cover destabilized the cone surface and triggered fluvial incision. This instability has continued until the present day.

This site has a potentially wider significance in terms of it being representative of the class of fluvially modified debris cones found throughout the Highlands (Brazier *et al.*, 1988) and other parts of upland Britain (Harvey *et al.*, 1981). First, the initial accumulation of debris-flow deposits involved the reworking of sediment deposited during deglaciation. This implies that this cone, like many others in upland Britain, is 'paraglacial' in origin (cf. Ryder, 1971; Church and Ryder, 1972), that is, its formation was dependent upon an abundant sediment supply following deglaciation. Once this was exhausted, aggradation on the cone ceased. Second, fluvial incision at this site is attributed to recent human

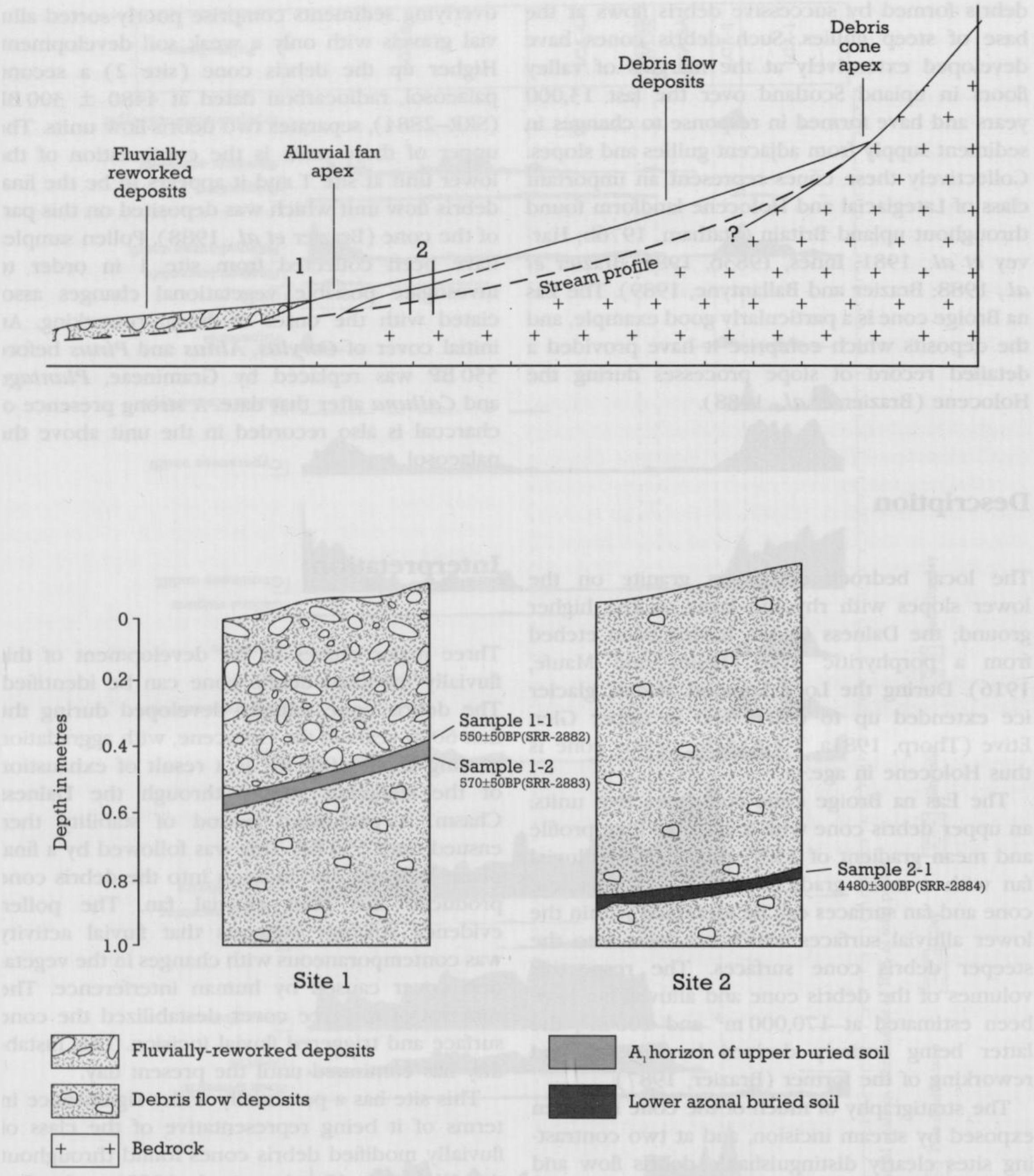


Figure 10.17 Top: schematic section along the length of the Eas na Broige debris cone. Bottom: detail of section at sampling sites (from Brazier *et al.*, 1988).

disturbance of the vegetation. There are many other fluvially modified debris cones in the Scottish Highlands and upland Britain where a similar anthropogenic trigger may have initiated the same change in the process regime on debris cones (see Statham, 1976b; Harvey *et al.*, 1981; Innes, 1983b). In this latter respect the Eas na Broige cone contrasts with those in Glen Feshie, where natural processes are considered to have been responsible for reactivation (Brazier and Ballantyne, 1989).

The Eas na Broige cone is a very good example of a Holocene debris cone that has been subject to fluvial modification. Although debris cones are ubiquitous throughout the Scottish Highlands, this site in Glen Etive is unique in that the date and extent of the fluvial reworking of the original cone have been precisely determined.

The Eas na Broige debris cone provides the most detailed record currently available of Holocene sedimentation at the margins of a major valley in Scotland. Following deglaciation at approximately 10,000 BP the debris cone developed over the next 4000 years. At this time the cone surface became stabilized until about 500 years ago, when fluvial reworking of the basal part of the cone arose in response to the removal of the forest cover by human activity. The cone thus represents a particularly good example of a fluvially modified debris cone in which the most recent phase of development has been in response to human settlement on the valley floor.

Conclusion

Eas na Broige debris cone is a fan-shaped accumulation of poorly sorted material (mixed particles of various sizes) formed by flows, from the slopes above, of rock and soil debris mixed with water. It provides an important record of slope processes during the Holocene and is representative of a type of landform and process system that occurs widely in the Highlands. In particular it shows two phases of development, the first reflecting high sediment supply following deglaciation (ice melting and retreat) and the second, the impact of forest clearance by Man. The site is not only a good landform example but has a well-documented history of development.