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Quaternary of Wales

S Campbell and D Q Bowen

W A Wimbledon
Editor in Chief

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The Quaternary of South Wales 5

Introduction

Studies of coastal and cave stratigraphic sequences particularly in Gower (Chapter 3) and south-west Wales (Chapter 4) have provided the most detailed evidence about the Middle and Late Pleistocene and its sub-division in southern Wales (for example, Bowen 1970a, 1973a, 1973b, 1974, 1984). Elsewhere in Dyfed, the Brecon Beacons, Black Mountains, the South Wales Coalfield and the Vale of Glamorgan particular details of the Late Pleistocene and Holocene history provide further complementary evidence. A prominent theme of past studies has been attempts to delimit the maximum extent of the Late Devensian ice-sheet. Another theme relates to the upland areas of South Wales, particularly the Brecon Beacons, which exhibit a range of glacial and periglacial landforms that provide evidence for Late Devensian and especially Devensian late-glacial environmental events and conditions. A number of sites within the region has also yielded important data for reconstructing Holocene palaeoenvironments.

Events pre-dating the Ipswichian Stage

With the exception of landforms such as erosion surfaces and tors, which have evolved in response to processes operating over long timescales (Brown 1960; George 1974; Battiau-Queney 1980, 1984), the oldest evidence for the Pleistocene in South Wales is generally held to be the deposits of the 'Older Drift' (Bowen 1970a, 1974). It has long been believed that glacial deposits of the 'Older Drift' were younger than the *Patella* Beach of Gower (George 1932), but in recent years it has been demonstrated that the raised beach in fact post-dates the 'Older Drift' (Bowen 1970a, 1973a, 1973b, 1974, 1984). Bowen (1973a, 1973b) argued that only derived, redistributed 'Older Drift' glacial sediments overlie the raised beach, having been reworked into this position by periglacial processes during the Devensian Stage.

'Older Drift' glacial deposits occur, for example, in west Gower and in the Vale of Glamorgan. These consist of both Irish Sea and Welsh glacial deposits, and they exist in areas outside the limit of the Late Devensian ('Newer Drift') glaciation (Charlesworth 1929; Bowen 1970a, 1973a, 1973b, 1981a, 1981b). They are sometimes characterised by considerable dissection in comparison with more coherent deposits of the Late Devensian, although those in west Gower cannot be distinguished in this way.

Much is owed to the work of the Geological Survey Officers (for example, Strahan and Gibson 1900; Strahan and Cantrill 1904; Strahan 1907a, 1907b, 1909; Strahan *et al.* 1907, 1909, 1914; Dixon 1921) who established the details of glaciation in South Wales. They showed that two ice-sheets had traversed the region: one from the Irish Sea Basin with erratics from as far afield as Scotland, the Lake District and North Wales, and another from the Welsh uplands. Strahan and his colleagues (and later T N George in Gower) demonstrated that 'Older Drift' ice crossed south-west Dyfed (Pembrokeshire) from the north-west, and moved in an easterly direction along the Bristol Channel, impinging on west Gower and parts of the Vale of Glamorgan. At Pencoed, in the Vale of Glamorgan, Strahan and Cantrill (1904) described shelly deposits with igneous Irish Sea erratics, underlying

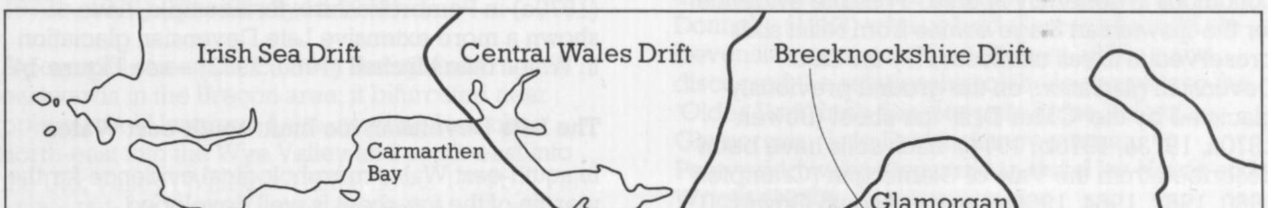

Figure 13 Drift provinces of South Wales (from Bowen 1970a)

Welsh glacial deposits. They demonstrated that this Irish Sea ice had carried erratic boulders to the Vale of Glamorgan as far east as Cowbridge and possibly beyond. Details of this extensive Irish Sea glaciation in the region were further elaborated by Griffiths (1937, 1939, 1940) who applied heavy mineral analyses and plotted erratics trains to ascertain the provenance of the drifts. He concluded that, over much of South Wales, the Irish Sea and Welsh ice masses had been coeval. Using similar evidence, Bowen (1970a) delimited six provinces of glacial drifts – Irish Sea, Central Wales, Brecknockshire, Glamorgan, mixed Irish Sea and Central Wales drift, and mixed Irish Sea and Glamorgan drift – see Figure 13. It is generally held that South Wales was entirely submerged beneath the Irish Sea and Welsh ice-sheets in 'Older Drift' times.

Bowen *et al.* (1985) and Bowen, Jenkins and Catt (unpublished) have shown that parts of the 'Older Drift' are of different ages in south-west Gower: with mixed provenance Irish Sea and Welsh drift succeeded by a Welsh drift delimited by a moraine at Paviland. Estimates of their ages in comparison with an oxygen isotope scale are made by Bowen *et al.* (1985).

Recent work in the Vale of Glamorgan and a re-examination of the 'Storrie erratic collection' from Pencoed (Strahan and Cantrill 1904) have confirmed the former presence of Irish Sea ice in the area (Donnelly 1988) – see also Chapter 2. Donnelly noted that the Irish Sea glacial sediments were probably extensively reworked by Welsh ice in the Late Devensian. Unfortunately, these drifts are no longer exposed in the Pencoed and Ewenny areas, although British Geological Survey boreholes record their presence.

The Ipswichian Stage

Other than for the coastal margins of South Wales, where raised marine and terrestrial cave sediments occur, evidence for temperate (interglacial) conditions is generally sparse. Possible evidence for the Ipswichian Stage comes from relict soils preserved in areas unaffected by the Late Devensian glaciation, on the ground previously glaciated by the 'Older Drift' ice-sheet (Bowen 1970a, 1973a, 1973b, 1974). Such soils have been described from the Vale of Glamorgan (Crampton 1960, 1961, 1964, 1966c), parts of south Gower (Ball 1960; Clayden 1977a, 1977b) and south Pembrokeshire. Such palaeosols are an important element of the coastal sequences around Gower, where they have been reworked as colluvial deposits, analogous to the 'limon rouges' of Mediterranean lands (Bowen 1966, 1970a). Where these palaeosols occur as surface features, they provide assistance in defining areas not glaciated by Devensian ice. They are represented in the GCR site coverage by the colluviated facies of the coastal sections – see Chapter 3.

The Devensian Stage

Evidence for Early and Middle Devensian conditions is also confined to areas beyond the limit of the Late Devensian ice-sheet, and it is only represented by colluvial and head deposits widely exposed around the coast and in cave sequences (for example, at Long Hole and Bacon Hole Caves, Gower). It is reasonable to assume that comparable head and colluvial sequences also exist inland, but they have not yet been recognised. The long sequence described by Bull (1975, 1976) from Agen Allwedd Cave near Llangattock may cover much of the Devensian.

The South Wales end-moraine

An incidental but pre-eminent theme in investigations of the Late Pleistocene in South Wales is the delimitation of the extent of Late Devensian ice. Since Charlesworth (1929) first defined the 'Newer Drift' limit, the South Wales ice margin has been the subject of several revisions (Charlesworth 1929; Griffiths 1940; Wirtz 1953; Mitchell 1960, 1972; Lewis 1966b; Bowen 1970a, 1973a, 1973b, 1974, 1981a, 1981b; George 1970; John 1971a) – see Figure 14.

The most significant differences between these reconstructions have arisen from different methodology. For example, Mitchell (1960, 1972) used an East Anglian stratigraphical model amplified by work in Ireland and argued that the raised beaches around Wales were principally of Hoxnian age, thus making it implicit that they were overlain by deposits of both Saalian and Devensian age. Mitchell (1960) and Synge (1963, 1964) concluded that the majority of glacial sediments in Wales were of Saalian age, with Late Devensian Welsh ice only forming a limited ice cap in the uplands, and Irish Sea ice only impinging along the North Wales coastal margin. In contrast, faunal (Bowen 1970a, 1973a, 1973b, 1974) and amino acid evidence (Bowen *et al.* 1985; Bowen and Sykes 1988) suggests that most of the raised beach outcrops are probably of Ipswichian age. Principally on the basis of coastal lithostratigraphy, Bowen (1970a, 1973a, 1973b, 1974) and John (1970a) in Pembrokeshire, for example, have shown a more extensive Late Devensian glaciation in Wales than Mitchell (1960, 1972) – see Figure 14.

The Late Devensian ice limit: south-east Wales

In south-east Wales morphological evidence for the margin of the ice-sheet is well developed. Prominent moraines and areas of hummocky terrain were widely deposited by ice from Mid Wales and Breconshire, and Charlesworth's (1929) limit, drawn to coincide with the southern limit of continuous drift mapped by the Geological Survey, has been relatively little modified by subsequent workers. Lewis (1966a, 1966b) argued for little more than a Late Devensian cirque glaciation in the South Wales uplands, extending to valley glaciation in parts of the Usk Valley (the 'Breconshire end-moraine'), but it was subsequently demonstrated

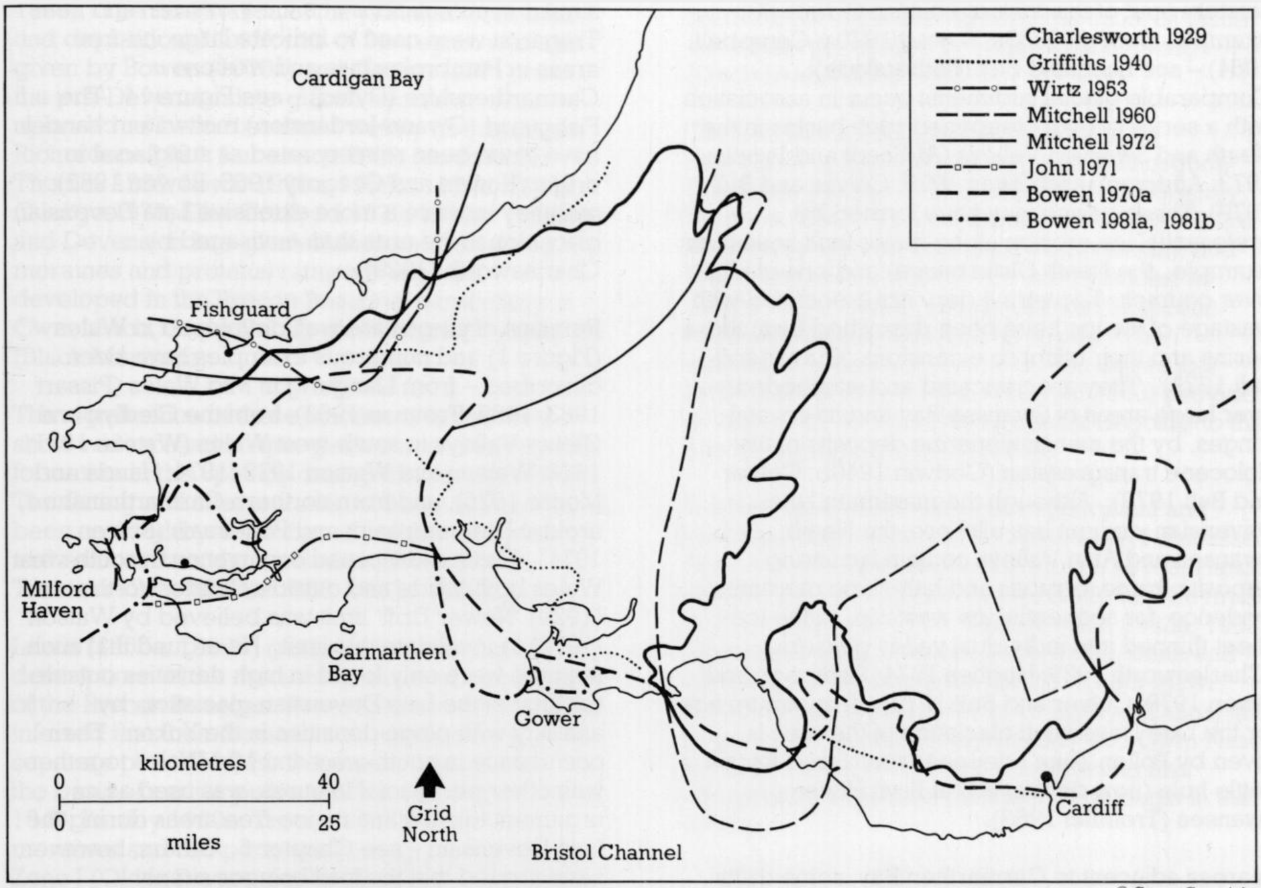

Figure 14 Some suggested Late Devensian ice limits in South Wales (from Bowen and Henry 1984; Campbell 1984)

that Late Devensian ice was extensive in the uplands. For example, Ellis-Gruffydd (1972, 1977) argued that glacial striae and erratics showed that the entire Old Red Sandstone escarpment had been submerged beneath the 'Breconshire ice-cap'. Ice from this dispersion centre flowed north into the Usk Valley (Williams 1968a); west through Cwm Dwr to join Mid Wales ice moving down the Tywi Valley; and south across the South Wales Coalfield, to the limits reconstructed by Bowen (1970a, 1973a, 1973b, 1974) (Ellis-Gruffydd 1977).

A powerful stream of ice from the uplands moved eastwards in the Brecon area; it bifurcated near present day Llangorse Lake, sending branches north-east into the Wye Valley and south-east into the Usk Valley (Williams 1968a; Lewis 1970b). Part of this Usk glacier probably coalesced with glaciers from the eastern Coalfield (Welch and Trotter 1961) to form a piedmont lobe extending offshore between Newport and Cardiff (Bowen 1970a). The relationship of Late Devensian ice to buried channels in the lower Usk region has been discussed by Williams (1968b). Ice moving north-east into the Wye Valley probably only over-topped the Black Mountains escarpment (Hay Bluff) locally, and the Usk glacier moved almost due east near Crickhowell to terminate near Llanfihangel-Crucorney where it formed a large moraine.

The Late Devensian ice limit: central South Wales

Farther west, a similar pattern is repeated, with Late Devensian Welsh ice from the Glamorgan uplands moving south and south-east into the Vale of Glamorgan. Although moraines associated with this ice were developed locally, the maximum limit is frequently marked in the Vale by extensive areas of hummocky terrain, for example, around Pyle, Margam and Llanilid (Bowen 1970a). Deposits in the Llanilid area were recently examined by Donnelly (1988) who upheld the established Late Devensian maximum limit (Bowen 1970a), and discussed the relationship of these deposits to the 'Older Drift' Irish Sea deposits of the Vale of Glamorgan. Late Devensian events near Pontypridd were discussed in detail by Harris and Wright (1980).

Evidence of Late Devensian glaciation in Swansea Bay is well established (for example, Strahan 1907a; Trueman 1924; Charlesworth 1929; Jones 1931a, 1931b; Griffiths 1939; Bowen 1970a; Al-Saadi and Brooks 1973; Culver 1976; Anderson 1977; Anderson and Owen 1979; Culver and Bull 1979). The Nedd (Neath), Tawe (Swansea) and Afan Valleys acted as major outlets for Welsh ice from the uplands. This ice coalesced to form a large piedmont lobe in Swansea Bay. Late

Devensian glacial sediments mark part of the western limit of this lobe in eastern Gower (for example, George 1933a; Bowen 1970a; Campbell 1984) – see Langland Bay (Rotherslade). Comparable glacial sediments occur in association with a series of over-deepened rock basins in the Neath and Swansea Valleys (Al-Saadi and Brooks 1973; Anderson and Owen 1979; Culver and Bull 1979). These basins may have formed by preferential ice erosion along major fault zones (for example, the Neath Disturbance) and pre-glacial river courses. Lacustrine deposits associated with wastage of the ice have been described from these basins and their offshore extensions (Culver and Bull 1979). They are truncated and succeeded, over large areas of Swansea Bay and its coastal fringes, by the marginal marine deposits of the Holocene transgression (Godwin 1940b; Culver and Bull 1979). Although the maximum Late Devensian ice limit lies offshore, the Neath, Swansea and Afan Valleys contain lacustrine deposits, kame terraces and halt-stage moraines; evidence for sequential ice wastage, as the ice-sheet thinned into individual valley glaciers (Charlesworth 1929; Hughes 1974; Anderson and Owen 1979; Culver and Bull 1979). A minimum age for the Late Devensian glaciation of the area is given by Pollen Zone I deposits recovered from a kettle hole (now destroyed) at Bryn House, Swansea (Trotman 1963).

In areas adjacent to Carmarthen Bay, some drifts contain both Irish Sea erratics and heavy minerals, but they are dominantly of Welsh origin (Griffiths 1940). Griffiths suggested that deposits in this region had lithological characteristics of the 'Older Drift' mixed Irish Sea and Welsh provinces, but had been substantially reshaped by 'Newer Drift' Welsh ice, which had only been weakly developed in the area. Subsequent workers (for instance, Bowen 1965, 1970a, 1980b; Campbell 1984) have discussed the evidence for Late Devensian ice streams moving into Carmarthen Bay from basal ice-sheds farther north, for example, in the Mynydd Sylen and Cross Hands areas (Cantrill *in* Strahan *et al.* 1907). This Welsh ice flowed along the valleys of the Tywi, Gwendraeth Fawr and Gwendraeth Fach. Upper layers of ice moved almost due south, providing important evidence for a considerable ice gradient and substantial central Wales ice cap in Late Devensian times (Strahan *et al.* 1907; Bowen 1970a; Campbell 1984). This evidence, together with important lithostratigraphic constraints provided by coastal sequences in west Gower (Chapter 3) and in the Carmarthen Bay coastlands (Chapter 4) have been used to revise Charlesworth's (1929) 'Newer Drift' limit in this area (Bowen 1970a) – see Figure 14.

The Late Devensian ice limit: south-west Wales

West of Carmarthen, the delimitation of the Late Devensian maximum ice limit has also been revised. Charlesworth (1929) restricted 'Newer Drift' Irish Sea ice to northern Pembrokeshire where he identified ice marginal overflow channels in the Fishguard district and end-moraine deposits between Newport and Cardigan. Morphologically similar accumulations at Banc-y-Warren and near Tregaron were used to indicate large ice-free areas in Pembrokeshire and western Carmarthenshire (Dyfed) – see Figure 14. The Fishguard (Gwaun-Jordanston) meltwater channels have since been reinterpreted as subglacial in origin (Bowen and Gregory 1965; Bowen 1967), and they indicate a more extensive Late Devensian glaciation in the area than envisaged by Charlesworth (1929).

Remains of pingos are well developed in Wales (Figure 1) and numerous examples have been described – from Llangurig in Mid Wales (Pissart 1963, 1965; Trotman 1963), from the Cledlyn and Cletwr Valleys in south-west Wales (Watson 1971, 1972; Watson and Watson 1972, 1974; Handa and Moore 1976), and from northern Carmarthenshire, around Llanpumpsaint and Pontarsais (Bowen 1974). Their widespread occurrence in south-west Wales both inside and outside Charlesworth's (1929) 'Newer Drift' limit was believed by Watson (1972) to invalidate this limit. He argued that such features were only found in high densities outside the limit of the Late Devensian glaciation, by analogy with pingo densities in the Yukon. Their occurrence in south-west and Mid Wales together with other periglacial features, was used as an argument to substantiate ice-free areas during the Late Devensian – see Chapter 6. Others, however, have argued that the fossil pingos simply demonstrate the occurrence of areas of former permafrost subsequent to deglaciation of Late Devensian ice (Bowen 1973a, 1973b, 1974; Handa and Moore 1976).

The area also provides important evidence for geomorphological conditions in south-west Wales during the Late Devensian. Significant periglacial modification to the tors of Preseli and the Trefgarn area is thought to have occurred (John 1970a, 1973) when they lay close to, but south of, the maximum ice limit. The Preseli Hills are thought to have formed a barrier to Irish Sea ice in the area (Bowen 1973a, 1980a, 1984). The survival of tors as significant landscape features, particularly in glaciated areas, has been a longstanding geomorphological problem. Tors and other indicators of periglacial conditions at the Stiperstones in Shropshire have also been used as evidence in the argument that locally elevated areas escaped engulfment by Late Devensian ice in the Borderlands (Rowlands and Shotton 1971; Goudie and Piggott 1981). Sites with tors and associated weathering products, may provide useful information regarding the long term, pre-glacial evolution of the landscape of south-west Wales (Battiau-Queney 1980, 1984).

Upland landforms

Striking examples of landforms associated with glacial erosion and deposition have long been known from the South Wales uplands (Symonds 1872; David 1883; Reade 1894; Howard and Small 1901), and accounts of these features were given by the Geological Survey (for example, Robertson 1933). The distribution of the principal erosional and depositional landforms of the region was also given by Bowen (1970a) and Groom (1971); and the pre-Devensian late-glacial evolution of the uplands has been discussed widely (for example, Richardson 1910; Robertson 1933; North 1955; Thomas 1959; Lewis 1966a, 1966b, 1970a, 1970b; George 1970; Ellis-Gruffydd 1972, 1977). Cirques and Devensian late-glacial landforms including moraines and protalus ramparts are well developed in the Brecon Beacons, particularly at Cwm Llwch, Craig Cerrig-gleisiad and Mynydd Du (Black Mountain).

The significance of these landforms is that they show widespread cirque glaciation and snowpatch formation in the uplands during the Younger Dryas. The dating and interpretation of these features have been assisted by a number of pollen stratigraphic and radiocarbon dating studies (for example, Trotman 1963; Walker 1980, 1982a, 1982b).

Lewis (1966a, 1966b) gave the first detailed descriptions of the moraines and protalus ramparts of the Brecon Beacons. From their morphology, he inferred that their formation occurred during two separate periods in the Devensian late-glacial. On the basis of earlier pollen work in the region (Hyde 1940; Bartley 1960a; Trotman 1963) the older moraines and ramparts were assigned to Pollen Zone I (Older Dryas), and the newer ones to Pollen Zone III (the Younger Dryas) (Lewis 1966a, 1966b). Later studies of the moraines and protalus features in the Brecon Beacons by Ellis-Gruffydd (1972, 1977) and Walker (1980, 1982a, 1982b) showed that most of the features had formed during the Younger Dryas.

Ellis-Gruffydd (1977) mapped 27 moraines and protalus features of varying morphological complexity at 23 locations along the Old Red Sandstone escarpment. Recent pollen analytical studies in the Brecon Beacons by Walker (1980, 1982a, 1982b) have provided evidence to support a recrudescence of glacier ice in the region during the Younger Dryas.

Devensian late-glacial and Holocene environmental history

A major theme in South Wales has been the use of pollen assemblage biostratigraphy to reconstruct Devensian late-glacial and Holocene environmental conditions. Hyde's (1940) study at Ffos Ton Cenglau (on the Pennant Measures escarpment) produced one of the first pollen diagrams in Wales. About the same time, Godwin (1940b) integrated the earlier observations of Strahan (1896), von Post (1933), Hyde (1936), George (1936) and George and Griffiths (1938) into a comprehensive account of marine and related sediments in the Swansea Bay area. He established that the Holocene transgression in the bay occurred during the later part of the Boreal (Pollen Zone VI) and was interrupted by minor regressive phases when peat beds formed. Many of these peat beds have been recorded at other sites around the coast as these were later correlated by radiocarbon dating (Godwin and Willis 1961).

The first Devensian late-glacial sequence described in South Wales was that at Rhosgoch Common (Bartley 1960a, 1960b). Subsequently, Trotman (1963) studied sequences at Bryn House (Swansea), Cwmllynfell (near Brynamman), and Waen Du (near Llangattock), and provided an outline of Devensian late-glacial and Holocene environmental history for the region. The sequence extending back to Pollen Zone I in a kettle hole at Bryn House (Trotman 1963) provided evidence for ascribing local glacial deposits to the Late Devensian (Bowen 1970a).

Further aspects of Holocene vegetational and environmental history have been widely discussed (for example, Seymour 1973; Moore 1975a; Handa and Moore 1976; Evans 1977a; Slater and Seymour 1977; Evans *et al.* 1978; Walker 1980, 1982a, 1982b; Chambers 1981, 1982a, 1982b, 1983; Smith and Cloutman 1984; Seymour 1985). Traeth Mawr, Craig Cerrig-gleisiad, Cwm yr Eglwys (Dinas) and Esgyrn Bottom, the Cledlyn Valley and Cwm Nash provide a framework for reconstructing and interpreting Holocene palaeoenvironments in the region.

Llanfihangel-Crucorney

Highlights

The finest example in South Wales of a terminal moraine formed at the extremity of the ice cap during the final (Devensian) phase of glaciation.

Introduction

The large arcuate moraine at Llanfihangel-Crucorney (SO316205), north of Abergavenny, provides some of the clearest evidence available for the terminus of the Late Devensian ice-sheet in South Wales. The moraine was formed by a branch of the Usk glacier. The site was first described by Strahan and Gibson (1900) who mapped the glacial deposits in the neighbourhood of Abergavenny. It was subsequently referred to by Grindley (1905) and Charlesworth (1929), and, more recently, Lewis (1970b) described the site in relation to the Late Pleistocene history of the region.

Description

The moraine runs west from Llanfihangel-Crucorney for about 1.5 km across the valley and rises about 20m on average above the general level of the valley floor. It has a steep, north-facing ice contact slope, best developed around Bridge Wood (SO320205). The moraine as a whole is characterised by the fine development of hummocky terrain, especially in its central portions. Sections through the moraine along a north-south railway line have been described (Strahan and Gibson 1900).

The site was first described by Strahan and Gibson (1900) who mapped an area of glacial sand and gravel (Abergavenny Sheet 232), extending some 1.2 km across the valley and for 1.6 km down its length. They noted that at Llangattoch, Llanfihangel and Clytha the gravels reached their northern and eastern margin, ending abruptly against a gently rising slope of Old Red Sandstone. The sand and gravel composition of these mounds was confirmed by exposures in the railway cutting at Llanfihangel. These exposures were also noted by Grindley (1905) who observed, in the deepest part of the cutting, solid rock capped by a considerable thickness of sand and what he considered to be coarse river drift. He noted that at its highest point the moraine lay about 127 ft (38m) above the level of the flood plain to the north, and that the feature was steep enough for it to be mistaken for an artificial embankment. To the south, the surface of the moraine sloped more gently, merging into an area of hummocky fluvioglacial terrain. Grindley considered that the moraine, the 'Llanfihangel dam', had caused a major diversion of Afon Honddu from a southerly course to its present north-east course, leaving the large valley south of the moraine occupied by a small misfit stream, the River Gavenny.

Interpretation

The Llanfihangel-Crucorney moraine was next referred to by Charlesworth (1929) who considered that during the 'Newer Drift' period a large glacier fed by ice from the Brecon Beacons had filled the Usk Valley. Part of this glacier had terminated near Llanfihangel, leaving extensive accumulations of outwash and morainic material.

More recently, Lewis (1966b, 1970b) concluded that, although a limited ice cap existed during the Late Devensian, the Usk Valley glacier was extensive. This bifurcated at Crickhowell, and the smaller of the two ice streams moved eastwards across the Lower Grwyne Fechan Valley to enter the Grwyne Fawr/Cwm Coed-y-cerrig trough at Llanbedr, and thence to the Vale of Ewyas where it formed the Llanfihangel-Crucorney terminal moraine (Lewis 1970b).

Charlesworth's (1929) 'Newer Drift' limit has been revised in many parts of Wales, but has been confirmed in south-east Wales (Bowen 1973b) where the morphological evidence of an ice-sheet terminus is well developed. The Llanfihangel moraine is probably the finest example of this morainic development in the area, and contrasts with that at Glais in the Swansea Valley, which is thought to represent a recessional rather than terminal feature of the Late Devensian ice-sheet. The moraine at Llanfihangel-Crucorney provides some of the finest evidence for an ice terminus in Wales and probably represents the maximum limit of the Late Devensian ice-sheet in the area. It was formed by a branch of the Usk glacier and has caused a major diversion of drainage, in deflecting Afon Honddu from a southerly course to its present north-easterly route.

Conclusions

The Llanfihangel-Crucorney moraine accumulated at the margin of the last major ice-sheet in south-east Wales. It is an exceptional example of its kind and is important because it provides data for reconstructing the dimensions and nature of this last major ice-sheet in Wales. As such it adds to the information about the south-westernmost extension of the North-West European ice-sheet complex.

Glais

Highlights

The largest and most impressive of the South Wales valley moraines formed by a short-lived readvance of Late Devensian ice as it wasted and retreated up the Swansea Valley.

Introduction

The most spectacular of the South Wales valley moraines occurs at Glais (SN697004) in the Tawe (Swansea) Valley. It is thought to mark a still-stand of the Late Devensian ice. The site was first described by Strahan (1907a) and has featured in studies by Trueman (1924), Charlesworth (1929), Jones (1931a, 1931b), Griffiths (1939), Bowen (1970a) and Anderson (1977). The most detailed account of the feature was given by Jones (1942).

Description

The moraine extends westwards for a mile across the Swansea Valley from the hillside at Glais to the former Garth Farm. It reaches a height of 59m OD and rises up to *c.* 150 ft (45m) above the general level of the alluvial flat to the south. The northern slope of the moraine is gentle, but at its southern margin forms a steep slope, seen to advantage from the west side of the valley (at SO704000). Hummocky terrain is well developed over much of the moraine, especially towards Cefn-y-Garth (SN697004). Stream exposures through the moraine are visible at the northern and western margins especially at SN689006, where glaciotectonic structures are well displayed. Recent road excavations through the western part of the moraine have revealed the internal composition and structure of the moraine.

Interpretation

The moraine at Glais was first described by Strahan (1907a) who referred to the remarkable development of 'gravels' and the 'dam' across the Tawe Valley at Glais. He remarked that the surface of the moraine was diversified by a number of small ridges running parallel to the main mass, and concluded that the moraine had been produced by the advance and retreat of a valley glacier over sediments 'extruded' from the ice-front. A gravel flat to the south of the moraine, ending abruptly some 15 ft (4.5m) above the general level of the valley floor was also thought by Strahan to be associated with the moraine which had subsequently caused a major diversion of the River Tawe.

Charlesworth (1929) referred to the moraine and noted that moraines at intervals across the Tawe and Nedd (Neath) Valleys were recessional deposits associated with the 'Newer Drift' ice-sheet; the features in these valleys having formed as the ice-sheet thinned into two distinct valley glaciers. The interpretation of the Glais moraine and similar features in neighbouring valleys as halt-stage moraines of 'Newer Drift' age was also supported by R O Jones (1931a, 1931b) and Griffiths (1939).

The most detailed account of the Glais moraine was given by O T Jones (1942). He mapped the extent of the feature and the distribution of other Late Pleistocene and Holocene deposits in its vicinity. Using borehole and sedimentary evidence, he showed that a large buried channel, as deep as 146 ft (44.5m) below OD, occurred to the south-west of the moraine. He considered this channel had been excavated in either 'Glacial' or 'pre-Glacial' times and had then been filled with proglacial outwash sands and gravels associated with the glacier which formed the Glais moraine in 'Late-Glacial' times. Subsequently, the channel was further filled with lacustrine and alluvial deposits, the upper part of the sequence being cliffed by the Tawe in 'Post-Glacial' times. Jones estimated that during formation of the buried channel, sea-level must have been about 200 ft (60m) lower than at present.

Details of the Quaternary evolution of the Tawe drainage system have not yet been established, but studies by Al-Saadi and Brooks (1973), Anderson and Owen (1979) and Culver and Bull (1979) have confirmed the presence of deep buried rock basins in the area. A geophysical study by Al-Saadi and Brooks (1973) showed that a series of Pleistocene buried valleys was present in the lower Swansea and Neath Valleys. These, they suggested, had been over-deepened by preferential ice erosion along major fault zones and pre-glacial river courses. Lacustrine deposits were described from these basins and their offshore extensions in Swansea Bay (Culver and Bull 1979). These sediments were considered to be Devensian late-glacial and early Holocene in age although the precise relationship of these buried valleys and associated sediments to the Glais moraine was not established.

The Glais moraine is a classic glacial landform. Its exact age and significance within the Quaternary evolution of the Swansea Valley area is still indeterminate, but it is generally considered to represent an advance of ice during general wastage of the Late Devensian ice-sheet (Bowen 1970a; Groom 1971; Anderson 1977). As such, the feature contrasts with the moraine at Llanfihangel-Crucorney in south-east Wales which probably marks the maximum extent of the Late Devensian ice-sheet.

Conclusions

The Glais moraine is a classic text-book example and is the best valley moraine in Wales. Its significance is not yet fully understood, but it may provide evidence for a minor and temporary readvance of a last ice age glacier as it wasted northwards.

Cwm yr Eglwys (Dinas) and Esgyrn Bottom

Highlights

This site shows fine examples of channels in one of the best and largest systems of meltwater channels in Wales. These features were formed by meltwater flowing under pressure beneath Late Pleistocene ice.

Introduction

Cwm yr Eglwys (Dinas) (SN010399) and Esgyrn Bottom (SM975346) are glacial meltwater channels in the well documented Gwaun-Jordanston system. This system is one of the largest and most spectacular in the British Isles, the interpretation of which has been important for determining the extent of Late Devensian ice in the area. The origin of the channels was first discussed by Charlesworth (1929). Since that time, numerous authors have investigated and described the features (for example, Jones 1946; Jones 1965; Bowen and Gregory 1965; Gregory and Bowen 1966; Bowen 1967, 1969a, 1971b, 1974, 1977a, 1981a, 1982, 1984; John 1965a; 1970a, 1971a, 1972, 1976; George 1970). The channels at Dinas and Esgyrn Bottom contain Devensian late-glacial and Holocene pollen sequences (Seymour 1973; Slater and Seymour 1977; Seymour 1985).

The Gwaun-Jordanston (Fishguard) meltwater channel system

The area to the north-west of Mynydd Preseli and immediately south of Fishguard contains a well developed network of glacial meltwater channels that has long been referred to as the Gwaun-Jordanston system. Detailed descriptions of the morphology and distribution of these features have been given, for example, by Bowen and Gregory (1965) and John (1970a) – see Figure 15. The largest channel is that of the modified Gwaun Valley, some 14 km long and passing between the Carn Ingli and Mynydd Preseli. Near its western end and its exit into Fishguard Bay, the Gwaun

Valley is joined from the north-east by the Cwmonnen Valley and, at this point, three major exits from the channel swing towards the south and west. This is the most complex part of the system comprising the spectacular channels of the Crinney Brook, Esgyrn Bottom, Nant-y-Bugail and numerous smaller and subsidiary channels. In addition to these interconnected channels, other examples have been described, particularly towards the west near Abermawr and Jordanston, and to the north-east where the Cwm yr Eglwys Channel all but separates Dinas Head from the mainland. The present day streams are small in relation to the channels they occupy; the Nant-y-Bugail, for example, is some 85m deep but contains a tiny stream (John 1970a). Some channels are cut through pre-existing watersheds, and they are steep-sided features with flat floors, the latter caused by substantial Devensian late-glacial and Holocene sedimentation and peat growth.

The Gwaun-Jordanston system was originally described by Charlesworth (1929). In defining his 'South Wales end-moraine' in Pembrokeshire, he interpreted the steep-sided channels as ice-marginal features produced by ice-dammed lake water overflow during the northward retreat of the Irish Sea ice-sheet – see Figure 15. These proglacial lakes were dammed by the Irish Sea ice margin in local valleys. Ice-marginal and direct overflow channels were formed as one lake spilled over into another. This glacial lake hypothesis was subsequently accepted, albeit with minor modifications, by Griffiths (1940), M Jones (1946), O T Jones (1965) and Pringle and George (1948).

From a detailed survey of the channels, Bowen and Gregory (1965) reinterpreted their mode of formation. First, they showed that evidence for former extensive proglacial lakes such as shoreline features, delta or lake deposits was generally lacking in the area. Only in the Teifi Valley at, for example, Llechryd did laminated lake clays exist (Jones 1965; Bowen 1967, 1984; Bowen and Lear 1982), and these are widespread between Cardigan and Pentre Cwrt (Bowen and Lear 1982; Lear 1986). Second, the Fishguard channels show a range of characteristics incompatible with an ice-marginal hypothesis. Bowen and Gregory (1965) noted that many of these channels showed 'humped' long-profiles, and, on some valley sides, channels with V-shaped profiles were sharply incised along the lines of the steepest slopes. Bowen and Gregory suggested that such an assemblage of features was most readily interpreted as the result of subglacial stream erosion. Humps on some long-profiles, for example, could not have formed at an ice margin because subaerial meltwater could not have flowed upslope: these features were more easily explained by subglacial meltwater flowing under considerable hydrostatic pressure. The steeply incised, superimposed valley side channels showed a close correspondence to features

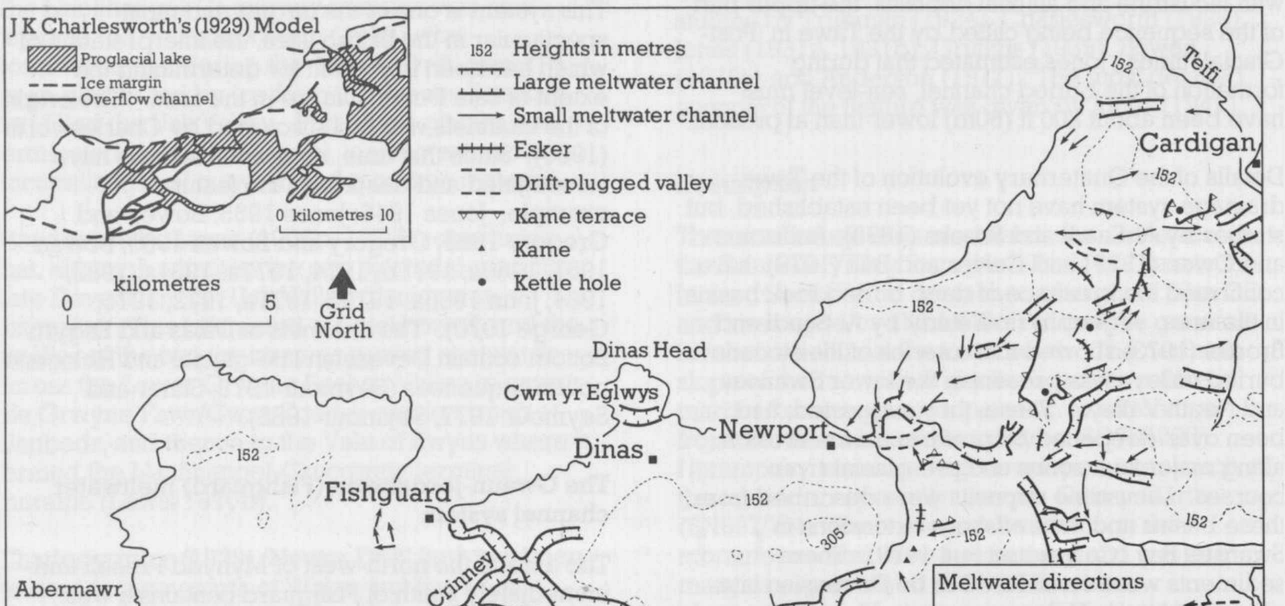

Figure 15 The Gwaun-Jordanston meltwater channel system (from Bowen and Henry 1984)

described as subglacial chutes by Mannerfelt (1945).

Thus, Bowen and Gregory and subsequently Gregory and Bowen (1966), and Bowen (1967, 1971b, 1974, 1977a, 1981a, 1982, 1984) have argued that the Gwaun-Jordanston system of channels had formed largely by processes of subglacial stream erosion, and that some channels may have developed following superimposition of englacial streams, and others as subglacial chutes. Bowen and Gregory also reconstructed a sequence of channel formation corresponding to various stages in the process of ice-sheet thinning – see Figure 15.

They considered that the fresh appearance of the channels probably indicated that they could be referred to glaciation in the Late Devensian, and observed that the re-evaluation of the channels as subglacial in origin necessitated a greater cover of ice than had been envisaged by Charlesworth (1929). This is consistent with the stratigraphic evidence from a wider area for Late Devensian glaciation (for example, Bowen 1973b, 1974).

The Gwaun-Jordanston channel system was also described and discussed by John (1970a, 1971a, 1972, 1976). He considered that the features had probably been cut by meltwater during a pre-Devensian (possibly Saalian) glaciation. Three main lines of evidence were put forward to support this contention –1) the large size of many of the channels; 2) many of the channels in Preseli are 'plugged' by thick sequences of periglacial and glacial sediments. These show that the channels existed prior to the depositional phase of the Late Devensian. Bowen (1966), however, argued that some of the tills were soliflucted, thus allowing for the possibility that both the channels and drift dated from the same (Late Devensian) glaciation. 3) The orientation of the channels was seen by John to have a bearing on their age, following the ideas of Mannerfelt (1945) who suggested that the orientation of subglacial meltwater channels, although influenced by bedrock relief, was controlled primarily by the direction of the ice surface gradient. Consequently, John observed that if the Gwaun-Jordanston channels dated from the Late Devensian, they would be expected to be aligned approximately north-west to south-east. In fact, the channels are generally oriented north-east to south-west; from which John concluded that it was more satisfactory to relate the channels to a pre-Devensian glaciation when there may have been a suitable ice gradient sloping from north-east to south-west on the flanks of Mynydd Preseli.

Such a conclusion is not, however, in keeping with prevailing opinion, which suggests that during the pre-Devensian glaciation of south-west Wales, Preseli was extensively invaded by north-west to south-east moving Irish Sea ice (for example, Griffiths 1940; Bowen 1973a, 1973b, 1974, 1977b). John (1970a) suggested that the 'fresh' appearance of the channels was satisfactorily explained if they had again been utilised by meltwater during the Late Devensian glaciation.

Esgyrn Bottom

Esgyrn Bottom (SM975346) is a steep-sided, generally north-east to south-west oriented valley, lying approximately 80m above sea-level in the central 'interconnected' part of the Gwaun-Jordanston system – see Figure 15. Near Llanwern Farm (SM977349) a smaller channel enters the Esgyrn Bottom Channel. This runs west for a distance of about 0.5 km before joining the larger Crinney Brook Channel. The steep sides of Esgyrn Bottom are densely wooded, providing a contrast with the bog vegetation on the floor of the channel. The channel reaches a maximum width of some 180m, and the main raised peat area is some 800m in length.

The peat deposits have been described in detail by Seymour (1973) and Slater and Seymour (1977) who recorded the following generalised sequence –

8 *Eriophorum, Sphagnum, Eriophorum* and *Molinia*, and *Eriophorum* and *Sphagnum* peats
7 Well humified sedge peat
6 Well humified wood peat with *Betula*, *Calluna* and *Eriophorum* remains
5 Wood peat with *Betula* remains
4 Humified peat with some *Phragmites* remains
3 Grey clay with peat
2 Blue lake clay with shale fragments
1 Blue lake clay

Slater and Seymour (1977) zoned the pollen assemblages collected from the sequence into the standard Godwin Pollen Zones IV-VIII, and local pollen assemblage zones were also recognised; no radiocarbon calibration was, however, provided. They proposed the following sequence of vegetational and environmental changes based on the pollen and plant macrofossil evidence. Organic deposits first began to accumulate in an early Holocene lake at Esgyrn Bottom towards the close of the pre-Boreal (Pollen Zone IV of Godwin). They considered that a fairly typical hydroseral succession took place at the site; that is a succession from non-productive open-water through a submerged macrophyte stage, a floating-leaved macrophyte stage, a reed swamp, a sedge and grass dominated fen and finally to bog with ericaceous species and *Sphagnum*.

The pollen record preserved at Esgyrn Bottom shows many of the classic features of the Holocene vegetation succession recorded at other sites in Wales. The well documented 'elm decline' is clear in the record as are the effects of forest clearance and the agricultural activities of early Man. Although the preserved record of vegetational changes is unexceptional in itself, the extreme westerly position of the site makes the record important in terms of interpreting regional variations in vegetation development throughout Wales.

Cwm yr Eglwys (Dinas)

The Cwm yr Eglwys Channel (SN010399) is some 1,300m long and opens onto the sea at both ends. The floor of the channel lies at *c.* 5m OD, and virtually isolates the Dinas headland from northern Preseli.

Both ends of the channel are 'plugged' by blown sand, while the area between is waterlogged, and it contains an infill of up to 11m of Devensian late-glacial and Holocene deposits. Seymour (1985) constructed a series of twenty local pollen assemblage zones from the profile and provided nine radiocarbon dates. The sequence was assigned to part of the Allerød (the Devensian late-glacial interstadial), the Younger Dryas and most of the Holocene.

A radiocarbon age of 11,700 ± 250 BP (GU - 1267) from the basal organic sediments provides a date for increased slope stability and improving conditions in the channel during the Allerød (Devensian late-glacial interstadial), as well as providing a date for the local expansion of *Corylus* and other shrub taxa (Seymour 1985). A sample from the top of the organic sediments, underlying a thin inorganic horizon, gave a radiocarbon age of 11,100 ± 140 BP (GU-1275), and provided a date for the marked climatic deterioration at the onset of the Younger Dryas. This return to colder conditions is evident in the lithological and pollen records.

The palynological data from Dinas and other sites in the Preseli region were used by Seymour (1985) to demonstrate that the presently distinctive climatic character of Preseli was probably established in Devensian late-glacial times. *Corylus,* for example, was locally present during the Allerød, and probably expanded from refugia lying to the south and west. In contrast, birch was relatively uncommon during the Devensian late-glacial and early Holocene, suggesting that its eastwards migration across the Cambrian uplands was inhibited. Seymour (1985) suggested that the pollen data also confirmed the early establishment of mixed oak forest along the coastal plain.

Glacial meltwater channels form an important element of the landscape of South and west Wales. The Gwaun-Jordanston system of channels is one of the finest of its type in the British Isles. Cwm yr Eglwys and Esgyrn Bottom are outstanding examples of channels in this extensive system. Although the channels were originally interpreted as overflow features from glacially impounded lakes (Charlesworth 1929), many are now believed to have been formed by subglacial meltwaters (Bowen and Gregory 1965). The interpretation of the Gwaun-Jordanston channels as subglacial in origin and of Late Devensian age (for example, Bowen and Gregory 1965; Bowen 1984) has important repercussions for the extent of the Late Devensian ice cover in south-west Wales and the manner of deglaciation: ice must have reached considerably farther south than envisaged by Charlesworth (1929), and ice wastage probably occurred by ice-thinning rather than by marginal retreat.

The channels are particularly noted for their large size and extent. This has led to some workers suggesting that they were occupied by meltwaters during more than one phase of ice wastage. As such, they contrast with the much more compact meltwater channel system near Carmarthen (at Maesyprior) of suggested Late Devensian age (Bowen 1967).

Cwm yr Eglwys and Esgyrn Bottom are both excellent and representative examples of glacial meltwater channels in the Gwaun-Jordanston system. This system is one of the largest and best documented in Britain, and is believed to have been formed largely by subglacial meltwaters. The scale and orientation of the channels are important factors in reconstructing and interpreting the sequence of Late Pleistocene events in south-west Wales; particularly for determining the extent of Late Devensian ice and the manner of ice wastage in the area. In addition, the channels at Cwm yr Eglwys and Esgyrn Bottom contain thick peat sequences with important Devensian late-glacial and Holocene pollen records.

Conclusions

The Cwm yr Eglwys and Esgyrn Bottom glacial drainage channels are thought to have been fashioned underneath an ice-sheet. They were probably formed at an early stage during the wastage of the last ice-sheet which occupied St George's Channel and Cardigan Bay. Because the disappearance of that ice-sheet may have been catastrophic, it means that these channels may well have been fashioned over a timescale that is brief even by human standards. The channels also contain thick deposits of peat that have yielded pollen grains which have been used for reconstructing climatic change since the ice age up to the present day.

Maesyprior

Highlights

This locality shows excellent evidence for the sub-ice-sheet formation of South Wales glacial meltwater channels. They were formed by water under great hydrostatic pressure beneath the ice, rather than as subaerial streams draining ice impounded lakes.

Introduction

At Maesyprior (SN361195), west of Carmarthen, a number of glacial meltwater channels provides evidence for the Late Devensian deglaciation of central South Wales. The channels are a rare example in South Wales of a meltwater channel system, and have been used to reconstruct a sequence of glacial drainage events as ice-thinning occurred. The distribution of the channels was mapped and described by Bowen (1965, 1967, 1969a, 1970a).

Description

The Maesyprior channel system occupies an area some 2.5 km^2 lying to the north of the major east-west trending valley now occupied by Llanllwch Bog (Thomas 1965). The distribution of Late Pleistocene deposits in the area was mapped by Strahan *et al.* (1909), and Bowen (1970a) demonstrated the relationship between these deposits and the channels – see Figure 16. The channels are, for the most part, cut in Ordovician shales, and they are dry and have steep sides; several channels commence and end abruptly, and one example demonstrates a humped (irregular up and down) profile.

Interpretation

Channel features associated with glacial meltwater were first noted in the Carmarthen area by Strahan *et al.* (1909) who described a 'glacial overflow-valley' at Cwm-du-hen, near Merthyr and interpreted it as having been formed by northward flowing, subaerial meltwater issuing from the large valley to the south which was filled with ice. The Merthyr channel has since been reinterpreted as a subglacial chute (Bowen 1970a). Indeed, it was suggested for many years that meltwater channels in South Wales and elsewhere were associated with 'overflow' from postulated glacially impounded lakes. Workers, including Charlesworth (1929), Griffiths (1939), Driscoll (1953) and Crampton (1966c) have reconstructed such supposed ice-dammed lakes across South Wales, extrapolating Kendall's (1902) simple model.

Bowen (1967, 1970a) reviewed the evidence for such lakes in South Wales and observed that, in nearly all cases, shoreline features, bottom deposits and deltas – features that would normally be associated with such lakes – were conspicuously absent. Instead, he demonstrated that the majority of the channels had been formed by subglacial meltwater during ice-thinning, in the manner described by Flint (1929, 1942), Hoppe (1950, 1957) and Mannerfelt (1945). Bowen (1967) observed that patterns of meltwater channels, particularly around Carmarthen, confirmed this view. In all, he mapped some 370 such channels in central South Wales (Bowen 1965, 1980b), but noted that 'systems' of such channels were rare. One exception was the channel 'system' at Maesyprior, for which he reconstructed a sequence of channel development events.

First, the oldest channels at Maesyprior, which begin and end abruptly, were superimposed across the shale spurs by englacial streams flowing within the decaying ice. Alternatively, other channels demonstrating marked humped-profiles were cut later by subglacial meltwater flowing

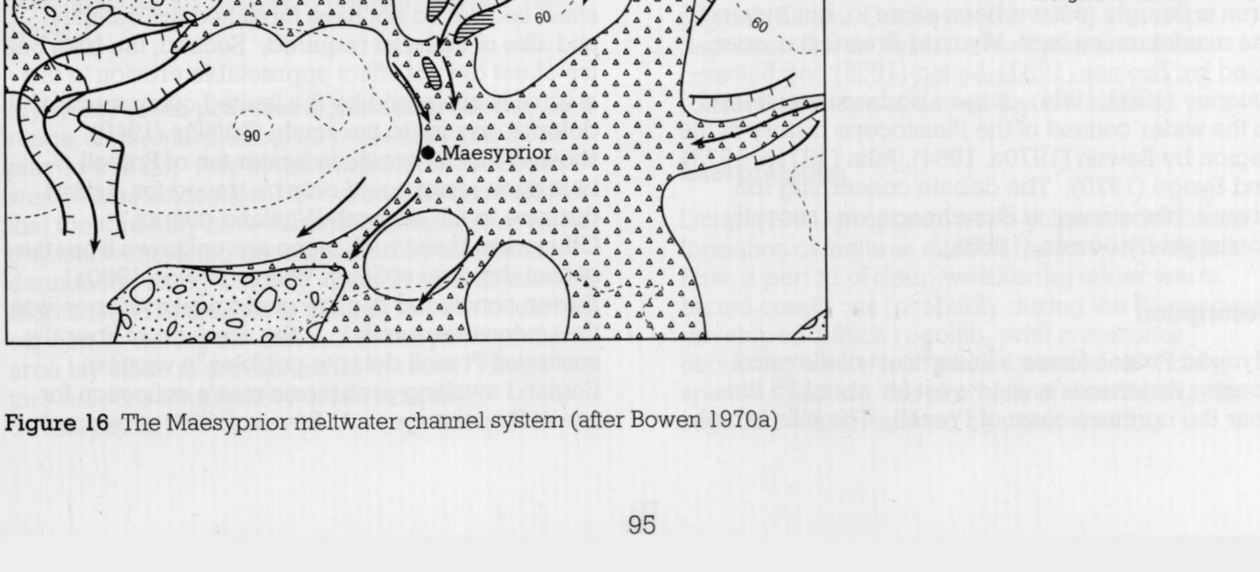

Figure 16 The Maesyprior meltwater channel system (after Bowen 1970a)

under considerable hydrostatic pressure. As the ice continued to thin, the channels became increasingly controlled by the underlying relief until, finally, meltwater flowed along the existing valley floor and sides. Bowen (1970a) considered that a Late Devensian age was likely in view of the freshness of the features.

The Maesyprior meltwater channels exhibit a number of features that cannot be reconciled with either an ice-marginal origin, nor an origin as direct overflow channels. The site therefore provides evidence to demonstrate the subglacial origin of the channels and to repudiate the long-held belief that similar channels throughout South Wales originated as overflows from major impounded glacial lakes.

Conclusions

The Maesyprior glacial drainage channels were probably fashioned underneath an ice-sheet. They are unusual because it is possible to infer stages in the process of ice-thinning from their mutual relationships. They also add to other evidence which shows that the last major ice-sheet to cover Wales extended at least as far south as this vicinity.

Mynydd Preseli

Highlights

One of the finest sets of tors in Britain, Mynydd Preseli shows evidence of tor formation in response to deep tropical weathering and later denudation during the Pleistocene. The balance between Devensian Stage periglacial action and earlier weathering has been the subject of controversy.

Introduction

Mynydd Preseli is important for an assemblage of summit and valley-side tors developed in Ordovician rhyolites and dolerites. The survival of tors as significant landscape features in the area is not fully understood, but the Preseli tors appear to have evolved, at least in part, under periglacial processes during the Late Devensian, when the area is thought to have been close to, but beyond, the maximum ice limit. Mynydd Preseli has been cited by Thomas (1923), Linton (1955) and Battiau-Queney (1980, 1984). It has also been mentioned in the wider context of the Pleistocene history of the region by Bowen (1970a, 1984), John (1971a, 1973) and Synge (1970). The debate concerning the Preseli 'bluestones' at Stonehenge was recently continued by Bowen (1980a).

Description

Mynydd Preseli forms a linear tract of elevated country that trends east to west for about 15 km near the northern coast of Preseli. The hills, which are the highest in south-west Wales, reach a maximum height of 536m OD, and rise above the adjacent plateaux, marking the outcrop of a series of Ordovician igneous rocks of a more resistant nature than the surrounding ancient sediments (Thomas 1923; Evans 1945). The most significant rocks in the range, from a geomorphological point of view, are the dolerites that form Marchogin and Carn Meini, and the rhyolites and felsites of Foel Trigarn and Carn Alw. The dolerites have been described as 'spotty' due to the occurrence of irregularly bounded white or pink patches of plagioclase feldspar (Thomas 1923), and they are quite distinctive. The generally smooth outline of the hills is punctuated by a series of summit and valley-side tors developed in these resistant intrusive and volcanic rocks.

Interpretation

The Preseli tors first attracted scientific attention in an archaeological context, as the possible source for the 'bluestones' at Stonehenge. Ramsay (1858) first alluded to the similarity of the 'Foreign Stones' at Stonehenge to certain igneous rocks in Pembrokeshire, and a possible Welsh source was also suggested by Moore (1865). It was not until the petrological study by Thomas (1923) that a conclusive geological connection was proved between Stonehenge and Mynydd Preseli.

In 1901, Judd put forward the theory that the 'Foreign Stones' of Stonehenge had been transported from Preseli to Salisbury Plain by ice. This mechanism found favour with subsequent workers, including, much later, Kellaway (1971) who proposed that the 'bluestones' had been transported eastwards up the Bristol Channel and onto Salisbury Plain by ice of Anglian age. Subsequently, Kellaway *et al.* (1975) used this hypothesis to invoke complete glaciation of southern England and the English Channel during an Anglian Stage glaciation, in marked contrast to the conventionally accepted extent of glacial limits proposed by other workers (for example, Kidson and Bowen 1976; West 1977; Bowen 1980a).

John (1976) also supported the agency of ice in transporting the 'bluestones' of Preseli, but Bowen (1980a) argued that the hypothesis is untenable for several reasons. First, the outcrops of dolerite are small and would not have furnished the quantity and size of material required. Second, the Irish Sea ice-sheet did not effect appreciable erosion in the area as is witnessed by the limited occurrence of dolerite erratics to the south: Griffiths (1940) showed that an erratic indicator fan of Preseli bluestone rocks could only be traced for a short distance to the Narbeth-Whitland district. Otherwise, these rock types are unknown from the glacial deposits of South Wales (Bowen 1980a). Bowen concluded that the geological evidence was thus inconsistent with "...... the scenario of liberally scattered Preseli dolerite pebbles in western England awaiting prehistoric man's collection for use at Stonehenge .....". Bowen (1984) proposed that during the Late Devensian, the Preselis formed a topographic barrier to ice from the Irish Sea Basin, whereas the previous 'Older Drift' glaciation had surmounted them, as shown by the train of dolerite erratics stretching south to Narbeth.

The question of the origin and survival of tors as significant landscape features has attracted considerable attention in the geomorphological literature. The Preseli tors were first described by Linton (1955). He proposed that tors were formed by a two-stage mechanism, involving deep tropical weathering (Tertiary) followed by mass wasting processes (probably during the Pleistocene) – see Trefgarn report. Others, however, have maintained that tors in Britain were formed principally under periglacial conditions (for example, Palmer and Radley 1961; Palmer and Nielson 1962), and in the case of the Preseli tors, John (1973) considered there could be no doubt that their present forms had evolved, above all, in response to periglacial processes. He noted that fossil scree slopes and lobate solifluction forms were widespread, citing large accumulations of scree and large frost-shattered blocks on the flanks of several of the upstanding summits at Carn Meini (Carnmenyn), Carngoedog and Carn Alw as examples (John 1973).

Battiau-Queney (1980, 1984) has recently suggested that tors in the Preseli and Trefgarn areas were, however, formed in response to two main factors. First, evidence, particularly from Trefgarn, showed that deep chemical weathering of the land surface had occurred in a hot humid environment (probably in Palaeogene times). Second, stripping of the weathered regolith and exhumation of the more resistant tors had occurred as the result of protracted uplift along old structural axes throughout the Cenozoic, and not solely as a result of changing climatic and environmental conditions. Therefore, Battiau-Queney suggested that the tors were formed in response to slow uplift where subaerial denudation had exceeded (perhaps only locally) the rate of chemical weathering. Consequently, a sharp deterioration of climate was not required to trigger stripping of the weathered regolith; rather a closely balanced relationship between persisting local uplift and erosion offered the most conducive conditions for tor formation (Battiau-Queney 1980, 1984).

Mynydd Preseli provides significant evidence for a range of geomorphological processes that have played a major role in the evolution of the south-west Wales landscape. Recent studies have shown that the tors may have formed in response to deep tropical weathering accompanied by subaerial denudation along a slowly uplifting axis. Significant modification of the tors is thought to have occurred especially during the Devensian Stage when the area lay close to the maximum ice limit. Hence the tors reflect a long history of landscape development.

Conclusions

The assemblage of tors on Mynydd Preseli is one of the finest in Britain. They provide important information about the history of landform evolution over long periods of time. Those at Carn Meini are famous because they provided the 'bluestones' for the Stonehenge monument.

Trefgarn

Highlights

Tors and profiles through weathered ancient bedrock and slope deposits have elucidated the processes behind tor formation. The site provides evidence for pre-Pleistocene deep tropical and Pleistocene periglacial weathering which combined to form the tors.

Introduction

Trefgarn is an important geomorphological site for the study of tors. It comprises two tors, Poll Carn and Maiden Castle, adjacent blockslopes and a quarry section showing deeply weathered bedrock overlain by superficial slope deposits. The site therefore displays several key elements that have featured in papers on the theory of tor formation. The tors were first investigated by Linton (1955) and the site has also featured in studies by Charlesworth (1929), Evans (*in* Jones 1965), George (1970) and John (1970a, 1971a, 1973). More recently, Battiau-Queney (1980, 1984) provided detailed accounts of the site.

Description

The site comprises three main geomorphological elements –1) the two spectacular low-level tors of Poll Carn (SM952245) and Maiden Castle (SM954248) developed in Precambrian rhyolite between 110m and 125m OD, with associated blockfield slopes; 2) the narrow gorge between Great Trefgarn and Little Trefgarn Rocks through which the modern Western Cleddau river runs at *c.* 25m OD and; 3) part of the disused quarry (SM958240) where deeply weathered Silurian andesites are truncated and overlain by possible alluvial (Battiau-Queney 1980, 1984) and slope deposits. The tor forms at Trefgarn are of the crestal type, but they are unusual in occurring on a rolling landscape at extremely low altitude.

Interpretation

Linton (1955) proposed a two-stage model for the formation of features such as the tors at Trefgarn. First, a period of deep weathering under warm humid conditions (probably during the Palaeogene) developed a thick regolith, with corestones occurring where joint planes were most widely-spaced. Second, the products of weathering (the regolith) were removed by mass-wasting processes, leaving the corestones as upstanding tors. Linton proposed that the tors had probably been exhumed under periglacial conditions during the Pleistocene when solifluction and meltwater would have been efficient agents in removing the regolith. During this period, periglacial activity may also have modified the tors (Linton 1955). Linton noted that at Trefgarn the rotting guided by joint planes had been so deep "as to produce masses of quite fantastic outline".

Since Linton's (1955) paper, however, others have maintained that tors elsewhere (Dartmoor and the Pennines) were formed essentially under Pleistocene periglacial conditions (Palmer and Radley 1961; Palmer and Nielson 1962). John (1971a) also noted that the present form of the tors at Trefgarn has evolved in response to periglacial processes. It is relevant to note that a considerable variety of tor morphology exists in both present and past periglacial regions (Embleton and King 1975b), and it would appear that no single hypothesis can satisfactorily cover all cases. Recent work in the Trefgarn area, however, has thrown additional light on the problem.

Battiau-Queney (1980, 1984) included Trefgarn in a study of the 'pre-glacial' evolution of Wales. She described exposures in a disused quarry downslope from the tors; the Silurian andesite (at SM959240) was weathered to a depth of several metres. This weathering profile was truncated and overlain by poorly sorted and weathered deposits of alluvial origin. She considered that the weathering horizon (saprolite) was of Tertiary age on the basis of both physical and chemical properties which included – the depth of weathering (several metres), the fine texture of the material with a high percentage of particles < 50 microns, the clay mineralogy of the deposits which included a high percentage of newly crystallised clay minerals in the profile, the appearance of quartz 'particles' and the massive loss of silica. She argued it was unlikely that the saprolite had developed during Pleistocene interglacial conditions because the weathering products were generally located on interfluves, indicating that their formation had preceded incision of the valley; and because the presence of kaolinite, produced by the hydrolysis of silicates and the solution of quartz, indicated that the chemical processes had been operative for a considerable duration – conditions most readily facilitated by a protracted hot and wet climate. She considered that the poorly sorted and weathered alluvial deposit capping the weathered profile had been laid down by a palaeo-Cleddau river flowing in a larger and higher valley than the present one. Detailed evidence to support the latter interpretation, however, was not presented, and the sediments can equally well be interpreted as slope deposits.

Battiau-Queney argued that the Trefgarn tors had formed in response to slow but prolonged uplift along an old structural axis developed in the Precambrian rocks. Where subaerial denudation had exceeded the rate of chemical weathering, corestones were exhumed leaving tors at the land surface. Thus, a sharp deterioration of climate was not required to trigger the exposure of the tors (Battiau-Queney 1980, 1984). It is pertinent to note that the products of this 'tropical weathering', described at Trefgarn by Battiau-Queney, have survived in an area thought by most authors (for example, Griffiths 1940; John 1971a; Bowen 1974) to have been glaciated. This, Battiau-Queney suggested, indicated that Trefgarn had not been glaciated.

Trefgarn is also notable for the spectacular, deep, rocky gorge between Little and Great Trefgarn Rocks. Charlesworth (1929) considered that the Western Cleddau river had carried meltwater from a series of proglacial lakes impounded in north Pembrokeshire by the 'Newer Drift' ice-sheet, implying that the gorge had been used as a subaerial meltwater channel. This assertion was upheld by Evans (*in* Jones 1965) who suggested that quarrying operations within the gorge had revealed a complete lack of glacial sediments, therefore indicating that the gorge had probably been cut by large volumes of meltwater, a conclusion followed by John (1971a).

The geomorphological evolution of the landform assemblage at Trefgarn is the subject of some debate, but the site provides evidence for a range of geomorphological processes that have played an important role in the shaping of the south-west Wales landscape. In particular, the site exhibits several key elements that have featured in theories of tor formation, and the site shows evidence for probably pre-Pleistocene and Pleistocene geomorphological events and processes.

Conclusions

The landforms at Trefgarn provide evidence for the wide range of the erosional and weathering processes which have shaped the landscape of south-west Wales. The upstanding rock outcrops (tors) have been used as examples in developing theories on the formation of such landforms.

The Cledlyn Valley

Highlights

A locality showing the finest suite of fossil pingo features in Wales and some of the best examples in Britain. Formed in permafrost areas by the freezing of groundwater and the subsequent melting of sediment buried ice masses, their formation in relation to former ice-sheet limits has been the subject of controversy.

Introduction

Pingos are dome-shaped hills that occur in permafrost regions as a result of uplift of frozen ground by the growth of large convex masses of ground-ice in the substrate. Melting of the ice lens leads to a central depression or crater surrounded by a characteristic rampart of displaced substrate. Where permafrost conditions have ceased, the craters and surrounding ramparts are known as fossil pingos. The Cledlyn Valley contains probably the best preserved examples of pingo scars in Wales. The common occurrence of such features in northern Dyfed has been used as evidence for ice-free conditions in west Wales during the Late Devensian. The pingos were first described and mapped by Watson (1971) and the stratigraphy of the basin deposits investigated by Watson and Watson (1972). A detailed account of the Holocene pollen biostratigraphy from deposits infilling the pingo central depressions was provided by Handa and Moore (1976), and radiocarbon dates on the basal organic sediments by Shotton and Williams (1973) and Shotton *et al.* (1975). The site has also been referred to by Watson (1976, 1977c, 1982), Watson and Watson (1974, 1977) and Bowen (1977a).

Description

Widespread evidence for pingo development in the form of pronounced ramparts enclosing marshy tracts can be found in west Wales. The most notable groups of these features are near Llangurig (Pissart 1963, 1965; Trotman 1963), in the Cletwr Valley (Watson and Watson 1974; Handa and Moore 1976; Watson 1977c) and in the Cledlyn Valley (for example, Watson 1971; Watson and Watson 1972; Handa and Moore 1976).

The Cledlyn group of pingos – see Figure 17, is best developed in the more open part of the valley between 0.5 to 2.0 km above Cwrt Newydd. The features lie between 165m and 215m OD, particularly on long, low-angled north-facing slopes. They do not occur on slopes in excess of 8°. The altitude of the features rises with the valley since they are essentially valley bottom and valley side landforms (Watson 1971).

Characteristically, the tops of the ramparts are level and few of them completely surround the basins. Even in the case of isolated pingos, the upslope side of the rampart is frequently missing. Such 'mutually interfering' pingos (Watson 1971) show a range of forms; some are completely round or oval, others are more elongated with ramparts forming distinct linear ridges.

Although the steepest upper parts of some of the ramparts reach 23.5°, others have been ploughed and are therefore more subdued than they would have been in their natural state. The largest feature has a diameter of *c.* 200m, with ramparts up to 6m high enclosing a basin mire which is some 135m across.

The ramparts are formed in solifluction deposits consisting largely of unsorted gravelly clay (Watson 1971). The succession of deposits enclosed by the ramparts (up to 11m deep) appears to be consistent across the group, comprising a series of organic deposits and grey clay and silt overlying the gravelly clay of the ramparts (Watson and Watson 1972). Full details of the morphology and distribution of the features, their precise dimensions, relationship to slopes and the local drifts can be found in Watson (1971), and details of the basin deposits, their stratigraphy and textural characteristics are to be found in Watson and Watson (1972).

Interpretation

Fossil pingos were first recognised in Britain by Pissart (1963, 1965) near Llangurig. A preliminary pollen study (Trotman 1963) established that the basin deposits they enclosed were of Holocene age. Subsequently, similar structures were described in the Cledlyn and Cletwr Valleys of west Wales (Watson 1971; Watson and Watson 1972, 1974; Handa and Moore 1976), in Ireland (Mitchell 1971, 1973), and in the Isle of Man (Watson 1971); and all were interpreted as fossil pingos. Comparable structures have also been described in East Anglia at, for example, East Walton Common (Bell 1969; Sparks *et al.* 1972). Sparks *et al.* (1972), however, preferred to describe the features using the non-committal term 'ground-ice depressions'.

The Cledlyn pingo remains are the most studied in Britain. Watson (1971) compared them with contemporary pingos in the Yukon and Alaska. The modern examples were considered to be of the 'open-system' type, formed by water under pressure coming from strata beneath the permafrost. He argued that ice lenses were formed repeatedly causing a complex pattern of intersecting ramparts from which it is difficult to distinguish individual pingos. Watson and Watson (1972) considered that the 'mutually interfering' form of the features in the Cledlyn Valley was highly indicative of the open-system type of pingo. Similarly, ramparts which were open on their upslope sides, were also extremely characteristic of this type of pingo. The restricted distribution of the features, to valley side and valley bottom locations on gentle slopes, reflected the requirements for the growth of open-system pingos stressed by Müller (1959), Sinclair (1963) and Holmes *et al.* (1968): namely, that the water flowing below or within the permafrost should be small in amount as well as close to freezing point.

Watson (1972) argued that pingos were widespread in west Wales, both inside and outside the maximum limit of the 'Newer Drift' (Late Devensian) ice-sheet mapped by Charlesworth (1929). He observed that because pingos in the Yukon were only found in high densities outside the limit of the last (Late Wisconsinian) glaciation, and that they required a long time to develop, Charlesworth's reconstructed ice limit in south-west Wales was therefore incorrect. More recent work around the coast of Wales (for example, Bowen 1974) has shown that this area of south-west Wales was glaciated during the Late Devensian.

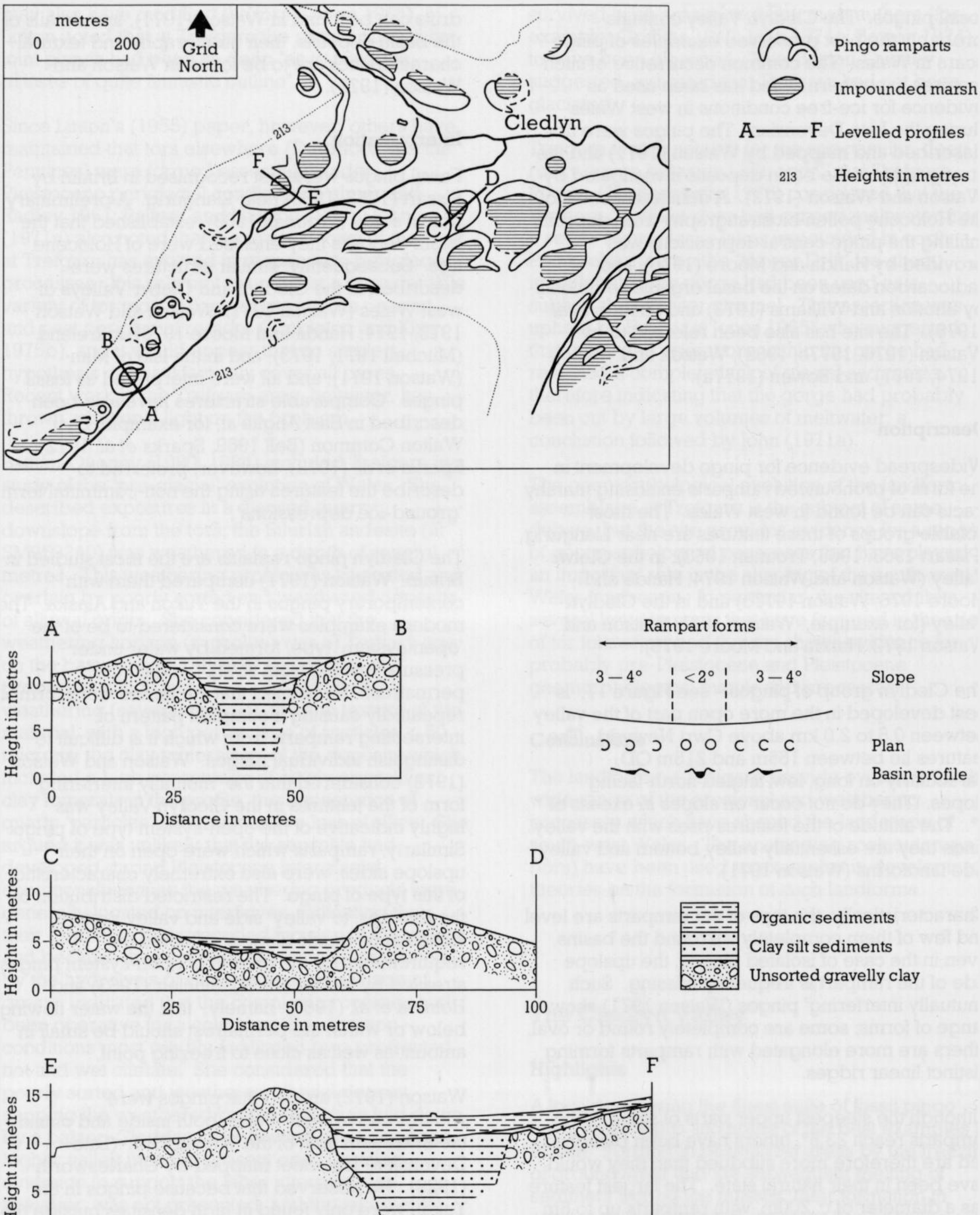

Figure 17 The Cledlyn Valley pingos (after Watson 1971; Watson and Watson 1972)

Moreover, other studies using radiometric techniques (for example, Handa and Moore 1976) indicate that the Cledlyn and Cletwr pingos formed at some time during the Devensian late-glacial. This has thrown considerable doubt on Watson's use of fossil pingos as indicators of glacier ice-free conditions in south-west Wales during the earlier Late Devensian. Moreover, open-system pingos have now been mapped in considerable densities *inside* the Late Wisconsinian limit in North America.

Radiocarbon dates are available for muds at the base of selected pingos from both the Cledlyn and Cletwr Valleys (Shotton and Williams 1973; Shotton *et al.* 1975). The small sample size resulted in large standard errors, but it appears that organic sedimentation commenced in the pingo basins between *c.* 10,300 and 9,000 BP (Handa and Moore 1976). These determinations show that the pingos had formed and that some sedimentation had occurred prior to the rise of *Juniperus* pollen at the close of Godwin's Pollen Zone III. Handa and Moore (1976) considered that this placed the date of pingo formation during the Younger Dryas. To some extent this is supported by Trotman's (1963) preliminary study of the Llangurig pingos which showed that organic sedimentation commenced at the boundary between Pollen Zones III and IV. Pollen studies from the East Walton pingos (Bell 1969; Sparks *et al.* 1972), however, suggest the presence of Older Dryas and Allerød deposits, indicating an even earlier phase of formation, perhaps at the close of the Older Dryas (Godwin's Pollen Zone I). Similar Allerød sediments have been recorded from pingos in Belgium (Pissart 1963). This led Watson (1971) to suggest that the Welsh pingos formed in Pollen Zone I or earlier. Evidence from the Cledlyn pingos, however, suggests that this is unlikely (Handa and Moore 1976): because the temperature threshold for ice melt in the pingo cores was lower than that for juniper flowering, it seems probable that the threshold would have been crossed in Pollen Zone I. Moore (1970) showed that *Juniperus* flowered even in upland Mid Wales during the Allerød, suggesting that the pingos' ice could not have survived this warm phase. Handa and Moore (1976) concluded, therefore, that the Cledlyn and Cletwr pingos both formed and collapsed during the cold Younger Dryas, showing that conditions were severe enough to provide at least discontinuous permafrost in the lowlands of west Wales at this time.

Handa and Moore's (1976) pollen study of the basal sediments in selected pingos from the Cledlyn and Cletwr sites permitted a reconstruction of regional and local vegetation succession during the transition from Late Devensian to Holocene times. The basal deposits show that sedimentation began before woodland invasion and prior to the initial expansion of *Juniperus* at the beginning of the Holocene. The early Holocene pollen spectra closely resemble those obtained from the upland valley site at the Elan Valley Bog (Moore 1970), although several important differences were noted (Handa and Moore 1976). First, the pingo sites show very low frequencies of montane and arctic/alpine taxa in marked contrast to the record from the Elan Valley. Second, the records do not show the early rise of *Corylus* documented at other sites. Handa and Moore suggested that the invasion and spread of *Corylus* had probably been localised to what is now the Cardigan Bay area, and that although pollen from this area was carried to the exposed upland sites such as that at the Elan Valley, it did not penetrate south-east into the Teifi Valley area. The pollen evidence also indicated that *Pinus sylvestris* and *Alnus glutinosa* (L.) Gaertn became established in the Cledlyn Valley soon after the extinction of *Juniperus.*

Examples of fossil pingos are rare in Britain. Possible examples have been described from Cumbria (Bryant *et al.* 1985) and west Surrey (Carpenter and Woodcock 1981), but the classic areas for the study of such features are East Anglia and Wales. The Cledlyn Valley contains the best developed group in Wales. Organic sediments infilling the pingo basins provide an important record of vegetational changes in lowland west Wales during Devensian late-glacial to Holocene times. The pingos are most probably of the hydrostatic (open-system) type, having developed in an area of discontinuous permafrost; and pollen and radiocarbon evidence suggests that this development was probably during the Younger Dryas (Handa and Moore 1976). However, this should perhaps be regarded as a minimum age, since De Gans *et al.* (1979) have argued that pingo remnants on the Drenthe Plateau date from *c.* 18,000 BP, and Sparks *et al.* (1972) have suggested that there may have been two periods of formation in East Anglia; an initial period of development during the Late Devensian or early Devensian late-glacial (Pollen Zone I) and a subsequent phase during the Younger Dryas (Pollen Zone III). Borings in the Cledlyn pingos have not proved organic sediments dating from earlier than the Holocene. However, such deposits may exist, particularly in view of Watson's suggestion that the Cledlyn group comprises clusters of mutually interfering pingos of different ages. It follows that although the latest of these may have been formed during the Younger Dryas, others may prove to be older.

Together with comparable features at East Walton Common in East Anglia, the Cledlyn pingos are morphologically the best developed examples of these landforms in Britain. The clearly defined ramparts enclosing peat-filled basins are thought to be remains of open-system type pingos, formed by the collapse of melting ice lenses which had developed during permafrost conditions. Detailed stratigraphical, pollen and radiocarbon evidence shows that deposition in the basins began at the start of the Holocene (*c.* 10,000 BP), but the ramparts and basins may have formed during the Younger Dryas or even earlier. The basin deposits provide a valuable record of Holocene vegetational changes in lowland Dyfed.

Conclusions

The Cledlyn Valley contains the remains of pingos. Pingos are large circular mounds which contain a core of ice and are found in areas of permanently frozen ground (permafrost) in the Arctic today. The remains of such pingos consist of central depressions surrounded by ramparts. The Cledlyn pingos are some of the best developed examples of such landforms in the British Isles. Pollen and radiocarbon evidence shows that they were probably formed between 11,000 and 10,000 years ago. They are important because they show the former existence of permanently frozen ground in Wales at that time.

Cwm Llwch

Highlights

This site shows the finest glacial cirque and associated moraine in South Wales. The best of the Brecon Beacons cirques; it shows in addition to the final Devensian late-glacial moraine, possible evidence of pre-Younger Dryas ice occupying the cirque.

Introduction

Cwm Llwch in the Brecon Beacons (SO002220) is the finest example of a cirque and associated moraine in South Wales. The cirque is one of several on the Devonian (Old Red Sandstone) escarpment, and contains a semi-circular moraine of probable Younger Dryas age. The site has long attracted scientific interest being first described by Symonds in 1872. A description of the site was given by Reade (1894) and it has also been mentioned by Howard (1901), Richardson (1910), Robertson (1933), North (1955) and Thomas (1959). More recently, the significance and age of the morainic deposits at Cwm Llwch has been discussed by Lewis (1966a, 1966b, 1970a, 1970b) and Ellis-Gruffydd (1972, 1977).

Description

The valley head and cirque comprising Craig Cwm Llwch, Corn Dû and Pen-y-fan faces north-east, and contains a single broad arcuate moraine which encloses Llyn Cwm Llwch. The highest part of the moraine stands some 60 ft (18m) above the general level of the lake and valley floor. The feature has well developed lateral margins that climb the flanks of the back wall terminating 150 ft (46m) and 100 ft (30m) above the valley floor to the west and south-east, respectively (Ellis-Gruffydd 1972). Superimposed on the moraine are relatively minor ridges which run sub-parallel to its overall arcuate form. Towards the south-east end of the moraine two ridges are particularly conspicuous, and these are separated by a peat-flat from which a dry valley runs eastwards. A second peat-flat separates the back wall from the innermost ridge. The sides of the moraine are generally steep (20°-30°) and a small exposure, near the present lake outlet, suggests a composition of angular blocks in a sandy-silt matrix (Ellis-Gruffydd 1972). Thomas (1959) and Lewis (1966a) suggested that the lake, some 6-7m deep (Howard 1901), did not occupy a rock basin. The lower slopes of the cirque back wall are scree-covered and the upper limit of the back wall is defined by an extensive plateau remnant in the Old Red Sandstone, and the twin highest peaks in the Brecon Beacons, Pen-y-fan (886m) and Corn Dû (873m). An area of hummocky terrain outside the moraine may represent older morainic material, in part soliflucted (Lewis 1970b).

Interpretation

The moraine impounding Llyn Cwm Llwch was first noted by Symonds in 1872 and subsequently described by Reade (1894). Lewis (1966a, 1966b), on the basis of morphological evidence, concluded that at many sites in the Brecon Beacons there was evidence for two phases of moraine and protalus rampart formation. Preliminary pollen evidence from peat deposits behind the 'fresh' inner moraine at Cwm Llwch indicated a probable Younger Dryas age for this moraine (Lewis 1970b). An early Devensian late-glacial (Pollen Zone Ic) age was favoured by Lewis for the degraded morainic sediments outside the 'fresh' moraine by analogy with palynological results elsewhere in the region (Trotman 1963). Lewis also identified up to five distinct ridges which he considered marked successive retreat stages of the Cwm Llwch glacier.

In contrast, Ellis-Gruffydd (1972, 1977) considered that, with the exception of Craig Cerrig-gleisiad, only one phase of moraine formation was represented in the Brecon Beacons. At other sites in the region, this period of moraine formation has since been relatively dated palynologically and by radiocarbon to the Younger Dryas (Walker 1980, 1982a, 1982b); it seems likely that the moraine at Cwm Llwch also dates from this part of the Devensian late-glacial. Ellis-Gruffydd noted that the compound nature of the moraine at Cwm Llwch probably reflected oscillations of the glacier margin, and that the channel at the south-east end of the moraine marked the former position of a proglacial stream. He considered, however, that there was insufficient morphological and sedimentological evidence to invoke the existence of extensive pre-Younger Dryas moraines at the site.

Conclusions

The sharply defined cirque and associated glacial moraine at Cwm Llwch are the finest examples in South Wales. It seems probable that the moraine enclosing Llyn Cwm Llwch dates from the time when glaciers last formed in the South Wales uplands, but the significance of apparently earlier degraded moraines has still to be resolved.

Mynydd Du (Black Mountain)

Highlights

This site includes the escarpment and associated cirques of the western Brecon Beacons. Its suite of probable Younger Dryas (Devensian late-glacial) erosional and depositional features affords outstanding evidence of the last cirque glaciation.

Introduction

The north and east-facing escarpment of Mynydd Du (Black Mountain) is important for a range of glacial and periglacial features of the Devensian late-glacial. Protalus ramparts and moraines occur at the foot of the escarpment and its associated cirques in an almost continuous landform assemblage. The site has been studied by Howard (1901), Robertson (1933), North (1955) and Thomas (1959). Detailed descriptions were provided by Ellis-Gruffydd (1972, 1977).

Description and interpretation

The north and east-facing Old Red Sandstone escarpment of Mynydd Du reaches 781m and runs from Llyn-y-Fan Fach in the west to beyond Fan Hir in the east. The principal features of the landform assemblage associated with the escarpment are shown in Figure 18. Along its northern edge, the escarpment is dissected by a number of cirques including that which houses Llyn-y-Fan Fach. Along its eastern margin, the cirque forms are less well developed and the complex depositional landforms at Llyn-y-Fan Fawr and Gwal y Cadno occupy small embayments in the escarpment – see Figure 18.

Fan Hir

The most striking of the depositional landforms is the large ridge running along the foot of Fan Hir (Figure 18), between *c.* SN833207 and SN836197 (Ellis-Gruffydd 1972). Little can be added to the description given by Robertson (1933) – "At the foot of Fan Hir there is a fine example of a snow-scree moraine. It runs as a lofty, rampart-like ridge of debris, three-quarters of a mile long, parallel to the scarp, and separated by a fosse-like gully". It reaches some 30m above the surrounding land and its sides slope at 30° (Ellis-Gruffydd 1972). The stream draining the gully between the ridge and escarpment shows the ridge to be composed of angular and subangular fragments of Devonian sandstones in a loose sandy matrix (Ellis-Gruffydd 1972). Robertson (1933) further noted that "...We may suppose that after the Tawe Valley ice had disappeared a snow-slope lingered for many years under the great escarpment, and that the scree material which otherwise would have accumulated at the foot of the latter, was shot down at some distance in advance to form the ridge". Although the ridge beneath Fan Hir has been regarded as a classic protalus feature (for example, Robertson 1933; Ellis-Gruffydd 1972, 1977), the possible influence of structural control has also been commented upon (Thomas 1959).

Llyn-y-Fan Fawr and Gwal y Cadno

The moraines enclosing Llyn-y-Fan Fawr were first described by Howard (1901) and later by Robertson (1933) and North (1955). A ridge comprising a series of low mounds separated by cols and two northerly trending channels can be traced around the northern, eastern and part of the southern lake shores – see Figure 18 (Ellis-Gruffydd 1972). These mounds are strewn with large boulders and are partly peat covered. Sections near the lake outlet suggest that the mounds are composed of angular material with a subordinate proportion of subangular and subrounded clasts set in a coarse matrix. It is not known if the lake itself occupies a rock basin (Howard 1901). The interest of this part of the site is enhanced by a prominent debris cone located at the foot of a bedrock chute in the escarpment face (Ellis-Gruffydd 1972).

Farther north at Gwal y Cadno, a moraine or protalus rampart was described by Howard (1901) and Robertson (1933). It consists of a single arcuate ridge enclosing a peat-flat, although at its north-west end it bifurcates and is separated from the back wall by a dry channel (Ellis-Gruffydd 1972). The ridge rises about 9m above the outlying terrain, although only 1m above the enclosed peat-flat (Ellis-Gruffydd 1972). Prominent avalanche chutes are incised into the back wall beneath Fan Foel – see Figure 18, and scree erosion continues to form prominent debris cones at the foot of the scree banks and onto the peat-flat behind the enclosing ridge. According to Ellis-Gruffydd (1972), there can be little doubt that the well developed arcuate ridge, which lies well in front of the cirque back wall, is a moraine.

Sychlwch, Pwll yr Henllyn and Llyn-y-Fan Fach

The cirques and embayments of the north-facing escarpment also contain a wide range of depositional landforms. Ridges were recorded in Cwm Sychlwch beneath Fan Foel and Bannau Sir Gaer by Howard (1901) and Robertson (1933) – see Figure 18. The northernmost ridge is situated close to the foot of the western face of Fan Foel – see Figure 18, and was interpreted by Ellis-Gruffydd (1972) as a protalus rampart. The principal ridge is arcuate and encloses a small peat-flat in its central portion, and bifurcates at its south end (Ellis-Gruffydd 1972). It is separated from a prominent linear ridge to the south which encloses a more substantial peat-flat and rises about six metres above the surrounding area. The features are interpreted as a moraine and a protalus rampart, respectively (Ellis-Gruffydd 1972).

North-west of Bannau Sir Gaer a prominent arcuate ridge occurs, its crest standing 6m to 12m above the surrounding ground surface. The ridge slopes outwards at 20-27° and encloses a peat-flat. Although arcuate in form, the lateral margins of the

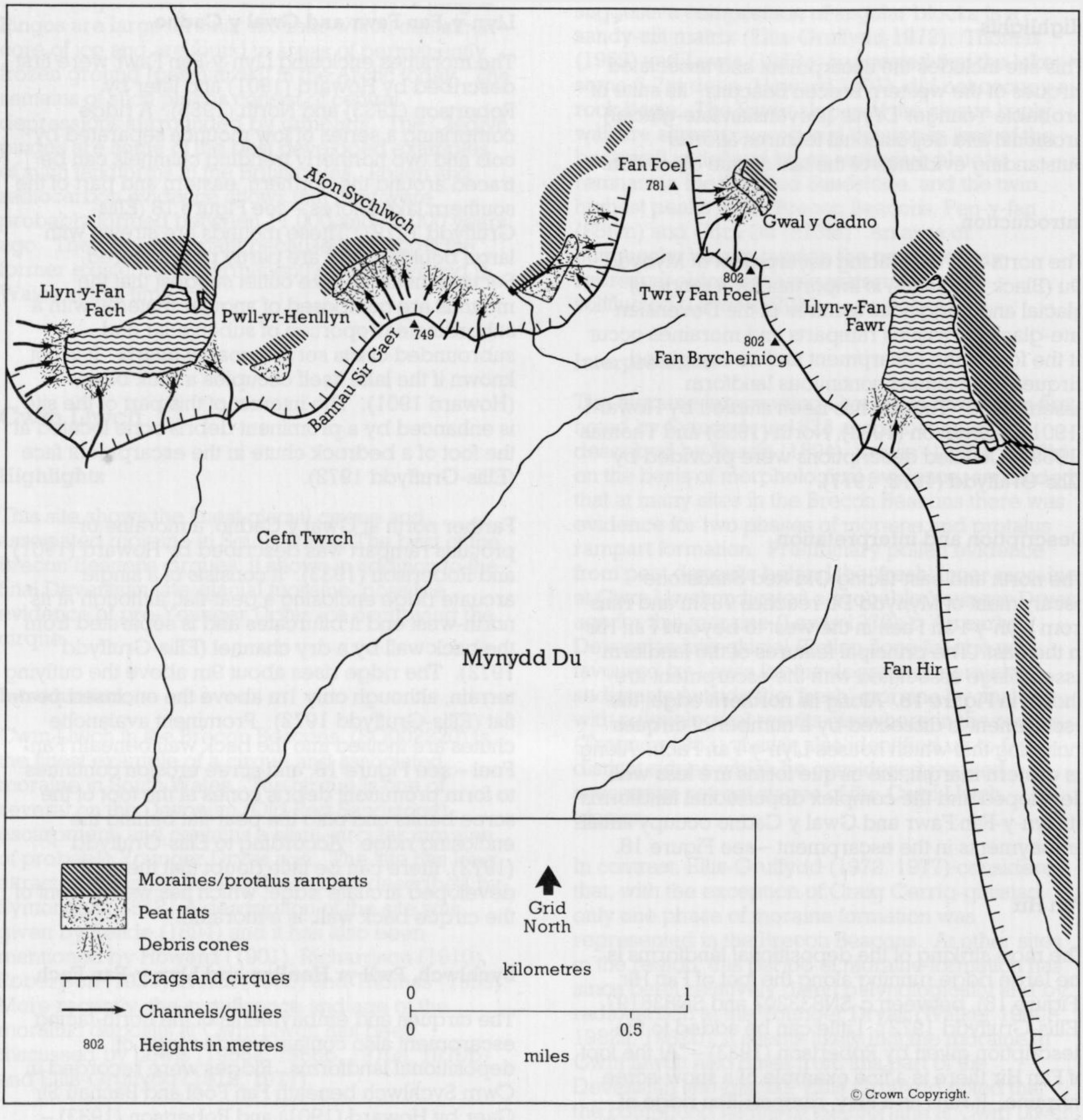

Figure 18 Mynydd Du: principal landforms (after Ellis-Gruffydd 1972; Statham 1976)

ridge are poorly developed and do not climb upslope. Ellis-Gruffydd (1972) suggested that the feature was probably a protalus rampart, built at the foot of a circular snow-patch. Large gullies are incised into the scree behind the moraine (Statham 1976).

A further feature interpreted as a protalus rampart occurs beneath an embayment in the escarpment at Pwll yr Henllyn – see Figure 18, (Ellis-Gruffydd 1972). This single, slightly sinuous ridge abuts the back wall at its eastern end, but near the western end is separated from the back wall by a channel enclosing a peat-flat. The back wall is mantled with scree which is extensively gullied.

Morainic accumulations have also been described around Llyn-y-Fan Fach (Howard 1901; Robertson 1933; Ellis-Gruffydd 1972) – see Figure 18. The feature is complex and is diversified by a series of smaller ridges, knolls and small enclosed depressions. Slope values along the length of the ridge vary between 15-25° and the form, extent and location of the ridge suggests that it is the product of glacial deposition (Ellis-Gruffydd 1972). To the south and south-west margins of Llyn-y-Fan Fach, the cirque back walls rise steeply by 160m. The lower slopes are extensively mantled with scree in which a number of spectacular gullies has been incised. Two particularly prominent chutes/avalanche couloirs cut the upper slopes of the back wall – see Figure 18, (Ellis-Gruffydd 1972).

Although cirque moraines and protalus ramparts have long been recognised in the Brecon Beacons (Symonds 1872; Reade 1894; Howard 1901; Richardson 1910; Robertson 1933), the first systematic interpretation of the features was made by Lewis (1966a, 1966b). He argued that the morphology of the moraines and protalus ramparts indicated two phases of formation during Pollen Zones Ic and III of the Devensian late-glacial. Preliminary pollen work in the region by Trotman (1963) was also used in support of this dating. Subsequent workers have, however, demonstrated sound evidence for only a single phase of moraine and protalus rampart formation in the South Wales uplands during the Devensian late-glacial (Ellis-Gruffydd 1972, 1977; Walker 1980, 1982a, 1982b).

Ellis-Gruffydd (1972, 1977) analysed the morphology, situation, aspect and altitude of moraines and protalus ramparts in the Brecon Beacons, including those of Mynydd Du. In total, 27 moraines and protalus ramparts of varying morphological complexity were identified at 23 locations along the escarpment. These included three moraines and five protalus ramparts around Mynydd Du. Morphological evidence indicated a single, synchronous phase of protalus rampart and moraine formation in the region (Ellis-Gruffydd 1977). The single exception to this rule was Craig Cerrig-gleisiad where, according to Ellis-Gruffydd (1977), possible evidence for more than one phase of moraine formation was present. Pollen, stratigraphic and radiocarbon evidence presented by Walker (1980, 1982a, 1982b) has since shown that a number of cirque moraines in the Brecon Beacons was formed during the Younger Dryas (*c.* 11,000-10,000 BP), and it is now widely held that the majority of cirque moraines and protalus features in the British Isles was formed at this time (for example, Ince 1981; Lowe 1981; Gray 1982a). Although the moraines and protalus ramparts around Mynydd Du have not been dated, it seems likely that they too were formed during the Younger Dryas.

Mynydd Du demonstrates a range of upland landforms with a significant bearing on attempts at reconstructing Devensian late-glacial palaeoenvironments. The relationship between the depositional landforms and the presence or absence of extensive plateaux surfaces in the Brecon Beacons is particularly striking, and is well illustrated around Mynydd Du: the cirques at Llyn-y-Fan Fach and Gwal y Cadno, for example, contain well developed moraines and lie at the north-east extremity of an extensive plateau. In these locations, specific meteorological conditions were conducive to the distribution and redistribution of snow, and ultimately the growth of glaciers. In contrast, an extensive plateau surface is absent west of the Fan Hir escarpment. In this location, circumstances favoured only the accumulation of a perennial snowpatch, at the foot of which formed the large protalus rampart (Ellis-Gruffydd 1972).

The moraines and protalus ramparts which stretch around the foot of Mynydd Du escarpment form an almost continuous landform assemblage. This assemblage contrasts with other upland areas where individual landforms are more isolated. The fresh and distinctive morphology of the features strongly suggests that they were formed during the Younger Dryas. Mynydd Du also exhibits exceptional examples of Devensian late-glacial scree slopes and talus cones. These deposits have been extensively gullied in recent times, leaving spectacular scars and unvegetated debris flows.

Conclusions

The drift ridges of this site form one of the finest assemblages of such landforms in the British Isles. They were formed between 11,000 and 10,000 years ago at the foot of either small glaciers or large snow patches. Spectacular evidence of recent erosion also occurs throughout the area.

Traeth Mawr

Highlights

This site shows a unique pollen record which stretches through the Devensian late-glacial with evidence for marked climatic fluctuations during the Allerød. Its long record is important for the calibration of pollen records in the floors of the Brecon cirques.

Introduction

Traeth Mawr is a pollen site important for reconstructing environmental history since the Late Devensian glaciation in South Wales. The bog at Traeth Mawr occupies a critical location for establishing the age of moraines and protalus ramparts in the Brecon Beacons to the south. The pollen record shows that the deposits are of Devensian late-glacial and early Holocene age. The site has been studied by Walker (1980, 1982a, 1984), following a preliminary pollen study at the site by Moore (*in* Lewis 1970b).

Description

Traeth Mawr (SN967257) occupies an area of about 1km^2 in a large depression on the plateau of Mynydd Illtydd. Few areas of open-water still remain and the bog is drained by two streams flowing north-west into Cwm Camlais and finally into the Usk. Walker (1982a) recorded 5m of infill comprising –

8 Poorly humified sedge peat
7 Humified peat

6 Fine peat grading down into brown amorphous organic mud
5 Organic mud with silt and clay lenses
4 Clay mud
3 Red homogenous silt and clay
2 Very fine brown organic mud with occasional silt and clay bands
1 Red silt and clay with some rhythmic bedding

This sequence is shown in simplified form in Figure 19, with the identified pollen assemblage zones and three radiocarbon dates.

Interpretation

Traeth Mawr was first investigated by J J Moore (*in* Lewis 1970b). Moore produced a pollen zonation which he interpreted as showing detailed evidence for vegetation changes in Pollen Zone I. He considered the data showed the presence of a British analogue of the Bølling Interstadial and claimed that at Traeth Mawr this event could further be divided into three minor oscillations. The interpretation and zonation of this diagram, however, has since been questioned (Ellis-Gruffydd 1972, 1977), and in view of the site's critical position adjacent to the cirque moraines of the Brecon Beacons, and because it is the only known Devensian late-glacial site from this part of South Wales, a re-investigation was carried out by Walker (1980, 1982a).

Walker's (1982a) pollen and radiocarbon analyses indicated the following sequence of palaeoecological and inferred geomorphological events. The lower red silts and clays (bed 1) are virtually barren of pollen and, in counting the rhythmites, Walker estimated that this inorganic sedimentation could have taken as little as 100 years in a proglacial environment, during wastage of the Late Devensian ice-sheet. Towards the end of this phase, patches of grass, sedges, pioneer herbs and dwarf shrubs probably existed around the site. The overall palaeoecological interpretation of this period, however, is a bleak hostile landscape with an open, generally pioneer-type vegetation, and perhaps disturbed soils.

The cessation of mineral inwash to the basin and the start of organic sedimentation (bed 2) was dated to 11,660 ± 140 BP (SRR-1562), a date which Walker considered too young by approximately 1000 years, certainly in comparison with other sites in upland Britain (for instance, Clogwynygarreg – see Ince 1981). After the change, the pollen indicates that the open-habitat conditions gave way to a landscape with shrubs and copses, dominated at first by juniper and willow, and later by birch. These stands were interspersed with tall herb communities and open-grassland. Thermophilous taxa such as *Filipendula*, also indicate an improvement in the thermal conditions. Improved soil stability is reflected in a reduced number of degraded pollen grains in the samples.

The remaining pollen assemblages representing this phase of largely organic sedimentation, however, pose problems of interpretation. Variations in the pollen percentages and concentration, and corresponding fluctuations in lithology are also apparent, with clay bands present in the organic sequence (bed 2). Walker considered it unlikely that local variations in the flowering of plants, or the influence of local site factors could account for the observed fluctuations. Rather, he suggested that they were probably indicative of major landscape changes around the basin caused by climatic conditions during the Allerød (Devensian late-glacial interstadial). The 'interstadial' record was therefore seen as a progression of three phases of vegetation development interspersed with two periods of climatic deterioration, in which woody taxa declined and more open conditions prevailed.

The change from gyttja (bed 2) to silt and clay (bed 3) is isolated to 10,620 ± 100 BP (SRR-1561). The latter phase of inorganic sedimentation represents the Younger Dryas when glaciers and snow patches occupied many cirques in upland Wales, including a number in the Brecon Beacons (Walker 1982b). During this period, the landscape around Traeth Mawr may well have resembled tundra; with few woody plants, and an open-vegetation with alpine communities and taxa characteristic of disturbed soils. The evidence of soil instability is consistent with the sediments of this phase having been deposited by solifluction and inwashing from a landscape with a reduced plant cover (Walker 1982a).

A reversion to organic sedimentation (bed 4 upwards), dated at 9,970 ± 115 BP (SRR-1560), denotes the onset of milder conditions in the Holocene. During this period, the tundra communities of the Younger Dryas were gradually displaced by more stable grassland with dwarf shrubs and heathland communities, although some soil instability may have persisted as witnessed by occasional silt and clay bands in the basin deposits. However, as thermal conditions improved, juniper began to colonise rapidly, and copses of willow and birch became established, culminating in the formation of a predominantly birch woodland. This latter development appears to have shaded out juniper, which finally disappeared with the arrival of *Corylus.* The later pollen zones reflect the establishment of a birch-hazel woodland and the arrival of the mixed forest genera with *Quercus and Populus.* By this time, open-water conditions in the basin may virtually have ended (Walker 1982a).

Traeth Mawr contains a record of Devensian late-glacial and early Holocene environmental changes in South Wales. Most Devensian late-glacial pollen profiles from Wales show an early phase of open habitats with pioneer vegetation, succeeded by more stable conditions accompanied by a change from inorganic to organic sedimentation. Renewed inwash or solifluction of sediments, together with a pollen record indicating more severe tundra-like

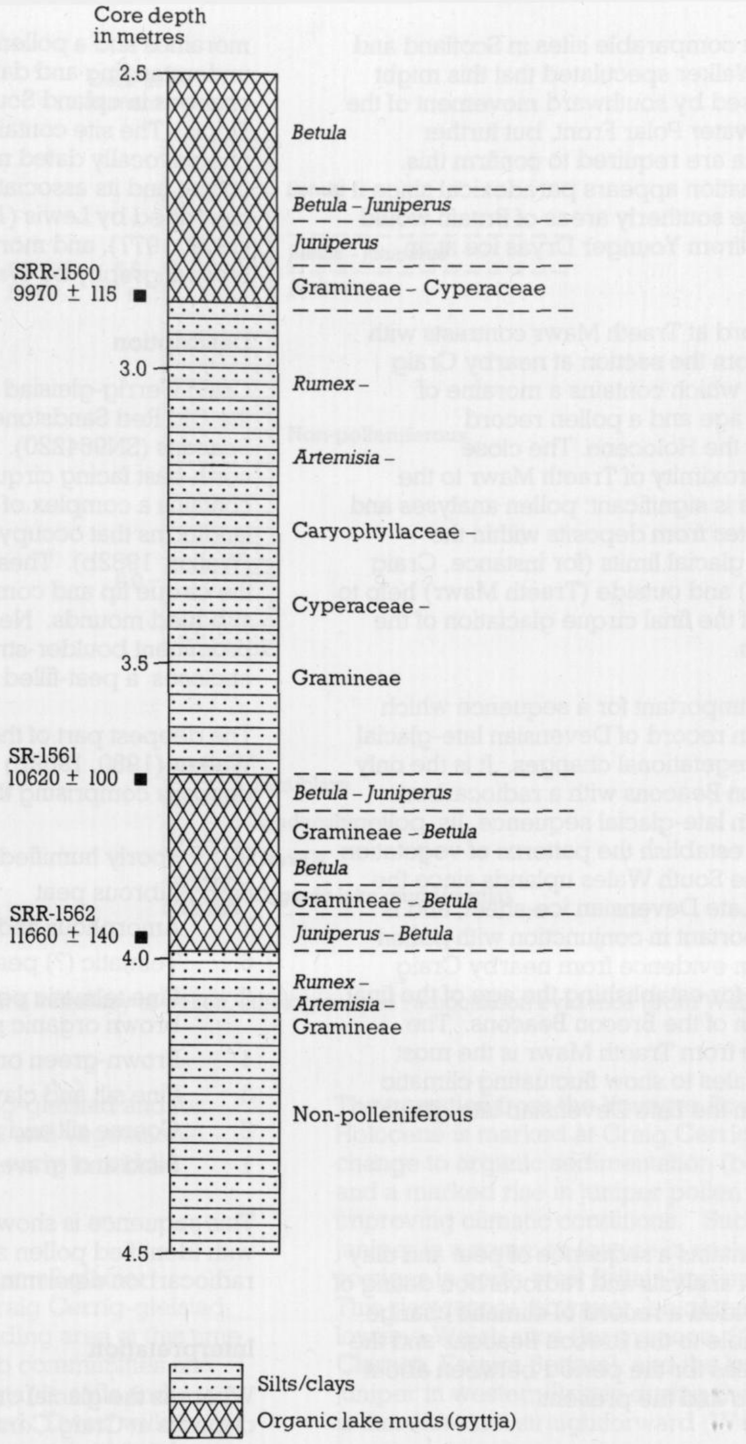

Figure 19 Traeth Mawr: a summary of pollen, lithological and radiocarbon evidence (from Walker 1984)

conditions, then characterise the change from interstadial conditions to the Younger Dryas. Both at Nant Ffrancon (Burrows 1974, 1975) and Cors Geuallt (Crabtree 1969, 1970, 1972) there is evidence for a more complex sequence, and at these sites it has been speculated that the equivalent of the Continental Bølling Interstadial may be present. However, Walker (1982a) observed that at Nant Ffrancon there were no pollen data to support Burrows' macrofossil evidence, and at Cors Geuallt there was also controversy about the status of the Bølling horizon (Moore 1975b). Traeth Mawr is therefore the only pollen profile so far described in Wales where there is unequivocal evidence for fluctuating climatic conditions within the Devensian late-glacial interstadial.

It is relevant to note that the radiocarbon dates for the Younger Dryas at Traeth Mawr are somewhat younger than at comparable sites in Scotland and North Wales. Walker speculated that this might have been caused by southward movement of the ocean surface water Polar Front, but further radiometric data are required to confirm this. Indeed, this situation appears paradoxical since it is logical that more southerly areas of Britain would have been free from Younger Dryas ice at an earlier stage.

The pollen record at Traeth Mawr contrasts with that obtained from the section at nearby Craig Cerrig-gleisiad which contains a moraine of Younger Dryas age and a pollen record commencing in the Holocene. The close geographical proximity of Traeth Mawr to the Brecon Beacons is significant: pollen analyses and radiocarbon dates from deposits within the Younger Dryas glacial limits (for instance, Craig Cerrig-gleisiad) and outside (Traeth Mawr) help to place the age of the final cirque glaciation of the Brecon Beacons.

Traeth Mawr is important for a sequence which contains a pollen record of Devensian late-glacial and Holocene vegetational changes. It is the only site in the Brecon Beacons with a radiocarbon dated Devensian late-glacial sequence. Its pollen record helps to establish the patterns of vegetation succession in the South Wales uplands since the wastage of the Late Devensian ice-sheet, and is particularly important in conjunction with pollen and radiocarbon evidence from nearby Craig Cerrig-gleisiad for establishing the age of the final cirque glaciation of the Brecon Beacons. The pollen evidence from Traeth Mawr is the most reliable from Wales to show fluctuating climatic conditions within the Late Devensian late-glacial interstadial.

Conclusions

Traeth Mawr contains a sequence of peat and clay deposits. Pollen analysis and radiocarbon dating of these have provided a record of climatic change which is applicable to the Brecon Beacons and the rest of south Wales for the period between about 14,000 years ago and the present.

Craig Cerrig-gleisiad

Highlights

This locality shows the best evidence, in the form of a pollen record and landforms, for the last cirque glaciation of the Brecon Beacons during the Younger Dryas (Late Devensian), and the climatic amelioration which followed in the early Holocene.

Introduction

Craig Cerrig-gleisiad, a fine example of a north-east facing cirque in the Brecon Beacons, contains moraines and a pollen record significant in understanding and dating climatic and vegetational changes in upland South Wales since the Younger Dryas. The site contains the best example of an unequivocally dated moraine in the region. The cirque and its associated moraines have been described by Lewis (1970b) and Ellis-Gruffydd (1972, 1977), and more recently the pollen biostratigraphy by Walker (1980, 1982b, 1984).

Description

Craig Cerrig-gleisiad occurs on the north flank of the Old Red Sandstone escarpment of the Brecon Beacons (SN964220). The steep back wall of the north-east facing cirque reaches 622m OD, and it contains a complex of glacial depositional landforms that occupy an area of nearly 1 km^2 (Walker 1982b). These deposits extend beyond the cirque lip and comprise a series of undulating, subdued mounds. Nearer to the back wall a more prominent boulder-strewn ridge, up to 5m high, encloses a peat-filled depression (Walker 1982b).

The deepest part of the bog was sampled by Walker (1980, 1982b) who proved about 6m of deposits comprising the following sequence –

9	Poorly humified *Molinia* and *Eriophorum* peat
8	Fibrous peat
7	Amorphous sedge peat with wood layers
6	Telmatic (?) peat
5	Fine telmatic peat grading down into dark brown organic mud
4	Brown-green organic mud
3	Fine silt and clay (with some laminae)
2	Coarse silt and sand
1	Sand and gravel

This sequence is shown in simplified form together with identified pollen assemblage zones and a radiocarbon determination in Figure 20.

Interpretation

Whereas the glacial origin of the cirque and its deposits at Craig Cerrig-gleisiad has long been accepted, their precise dating and interpretation have been debated. Following pollen studies by Trotman (1963) and J J Moore (see Lewis 1970b), it was suggested that separate cirque glaciers had existed in the Brecon Beacons in both Pollen Zones Ic and III of the Devensian late-glacial (Lewis 1970b). Lewis considered the more diffuse mounds at Craig Cerrig-gleisiad to belong to an 'older series' of moraines formed during Pollen Zone Ic, and the fresher inner ridge he believed to belong to Pollen Zone III (Younger Dryas). Ellis-Gruffydd (1972, 1977), however, suggested that many of the more diffuse forms could date from wastage of the main Late Devensian ice-sheet.

Recently, more detailed pollen work by Walker (1980, 1982b) has provided evidence for the dating

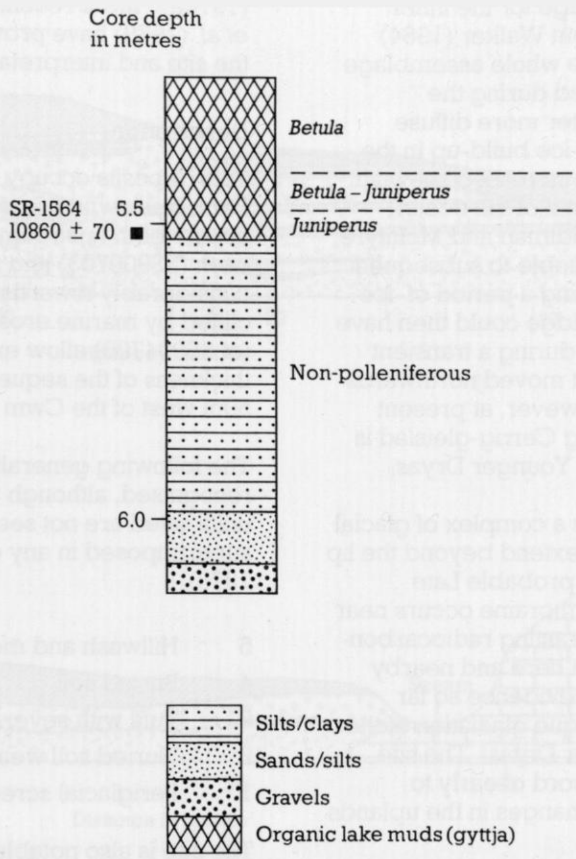

Figure 20 Craig Cerrig-gleisiad: a summary of pollen, lithological and radiocarbon evidence (from Walker 1984)

of the deposits at Craig Cerrig-gleisiad and for elucidating the environmental and vegetational history of the area during the early to middle Holocene.

During the Younger Dryas, a small glacier developed in the cirque at Craig Cerrig-gleisiad. The landscape of the surrounding area at this time was tundra, with pioneer herb communities and taxa indicating disturbed, unstable soils and extensive tracts of bare ground. Dwarf willow and occasional juniper and birch may also have been present in more sheltered locations. The deposits at this time reflect a severe periglacial environment, with solifluction and clastic inwash into the basin from poorly vegetated slopes. This phase of inorganic deposition (beds 1-3) is also recorded at Traeth Mawr, a few kilometres to the north, but at Craig Cerrig-gleisiad the renewed pulse of glacial activity during the Younger Dryas removed any evidence of earlier Allerød deposits. The radiocarbon date of 10,860 ± 70 BP (SRR-1564) marking the beginning of the Holocene (bottom of bed 4) at Craig Cerrig-gleisiad, has been considered (Walker 1982b) to be erroneously old, and the date of 10,030 ± 100 BP (SRR-1563) for the same boundary at nearby Craig-y-Fro to be more reasonable.

The transition from the Younger Dryas to the Holocene is marked at Craig Cerrig-gleisiad by a change to organic sedimentation (bed 4 upwards), and a marked rise in juniper pollen indicating improving climatic conditions. Such a peak of juniper is a common feature in early Holocene sections in north-west Britain and upland Wales. This rise cannot, however, be detected at certain lowland Welsh sites (for instance, Glanllynnau, Clarach, Esgyrn Bottom), and the behaviour of juniper in western Britain during the early Holocene is therefore not straightforward (Walker 1982b).

This early Holocene phase of *Juniperus* dominated scrub was followed by expansion of birch woodland over much of the area, and these forests were subsequently invaded by hazel *Corylus*. Mixed oak woodland then followed during the climatic optimum of the Holocene, with *Quercus* and *Pinus* on the hillsides and *Ulmus* in more sheltered base-rich sites on the valley floors (Walker 1982b, 1984). Increasing climatic wetness, commencing at *c.* 7,000 BP, was seen by Walker (1984) to have led to the decline of elm and birch, and the expansion of *Quercus* and *Alnus* throughout the woodlands of South Wales.

The interest of the site is enhanced by the apparent complexity of the depositional landforms. A Late

Devensian age for the diffuse outer mounds and ridges, and a Younger Dryas age for the inner ridge have been suggested, but Walker (1984) considered it plausible that the whole assemblage of landforms could have formed during the Younger Dryas alone. The outer more diffuse mounds might reflect an early ice build-up in the Younger Dryas in response to increased snowfall caused by southward movement of the ocean surface water Polar Front (Ruddiman and McIntyre 1981); their form being attributable to subsequent periglacial modification following a period of ice decay. The prominent inner ridge could then have developed later in the stadial, during a transient glacial pulse as the Polar Front moved northwards once again (Walker 1984). However, at present only the inner moraine at Craig Cerrig-gleisiad is dated with any certainty to the Younger Dryas.

Craig Cerrig-gleisiad contains a complex of glacial depositional landforms which extend beyond the lip of the cirque and which are of probable Late Devensian age. A small inner moraine occurs near the cirque back wall. The contrasting radiocarbon-calibrated pollen records from here and nearby Traeth Mawr provide the best evidence so far available for dating the last cirque glaciation of the Brecon Beacons to the Younger Dryas. The site also provides an important record of early to middle Holocene vegetation changes in the uplands of South Wales.

Conclusions

Craig Cerrig-gleisiad is a large cirque which was occupied by glacier ice during the last major ice age in Wales. The site's importance, however, stems from evidence which shows that the cirque was re-occupied by ice, certainly between 11,000 and 10,000 years ago, and possibly also somewhat earlier.

Cwm Nash

Highlights

This site uniquely shows screes of Devensian late-glacial age and tufas of Holocene age as well as contemporary tufa sedimentation. Its rock and land snail records allow insights into climatic change over at least the last 10,000 years.

Introduction

Cwm Nash (SS904700) is a unique site of great interest to the students of Devensian late-glacial and Holocene environmental history in South Wales. The common occurrence of land snails in a sequence of slope deposits comprising tufa, head and hillwash has allowed a detailed reconstruction of Devensian late-glacial and Holocene environmental change in South Wales that complements the available and more widespread pollen records. The site was first described by Driscoll (1953) and was later studied by Bowen (1970a). More recently, Evans (1977a) and Evans *et al.* (1978) have provided detailed descriptions of the site and interpretations of its interest.

Description

Tufa deposits occupy much of the small valley at Cwm Nash which is cut in Lias limestones. The tufa occurs both upstream and downstream of Blaen-y-cwm (SS909703) and it appears to thicken considerably towards the coast where it has been cliffed by marine erosion. The critical exposures (at SS904700) allow examination of the full (*c.* 4m) thickness of the sequence, which extends for about 50m west of the Cwm Nash stream.

The following generalised succession can be recognised, although the five main stratigraphical units listed are not seen to be directly superimposed in any one section (Evans *et al.* 1978) –

5	Hillwash and modern soil
4	Buried soil
3	Tufa with several intercalated buried soils
2	'Buried soil weathered into scree'
1	Periglacial scree and intercalated clay bands

The site is also notable for tufa which is forming at the present time along much of the valley. The stream bed is crossed at numerous points by rims of tufa and cemented tree litter, causing local ponding and the formation of a series of stepped cascades. Small exposures through the tufa occur in the banks of the stream at several locations within the valley. Full details of the stratigraphy and molluscan fauna at Cwm Nash are provided by Evans (1977a) and Evans *et al.* (1978), and a simplified section is shown in Figure 21.

Interpretation

Tufa occurs in a number of small valleys cut into the cliffed Lias along the Glamorgan coastline between Cardiff and Southerndown (Strahan and Cantrill 1904). Driscoll (1953) interpreted the deposits at Cwm Nash as a series of marine and estuarine sediments, but a more detailed study by Bowen (1970a) showed that the sequence was more readily explicable as a series of slope deposits. A preliminary investigation of the molluscan fauna by Kerney (*in* Bowen 1970a) showed that the faunas were terrestrial and that the upper layers of slopewash material were Holocene in age. This is particularly significant since it suggests a Holocene age for hillwash deposits capping Pleistocene sequences elsewhere around the South Wales coast (Bowen 1970a).

The molluscan faunas of Cwm Nash have been investigated in detail by Evans (1977a) and Evans *et al.* (1978), who interpreted the following sequence of events. The virtual absence of marsh

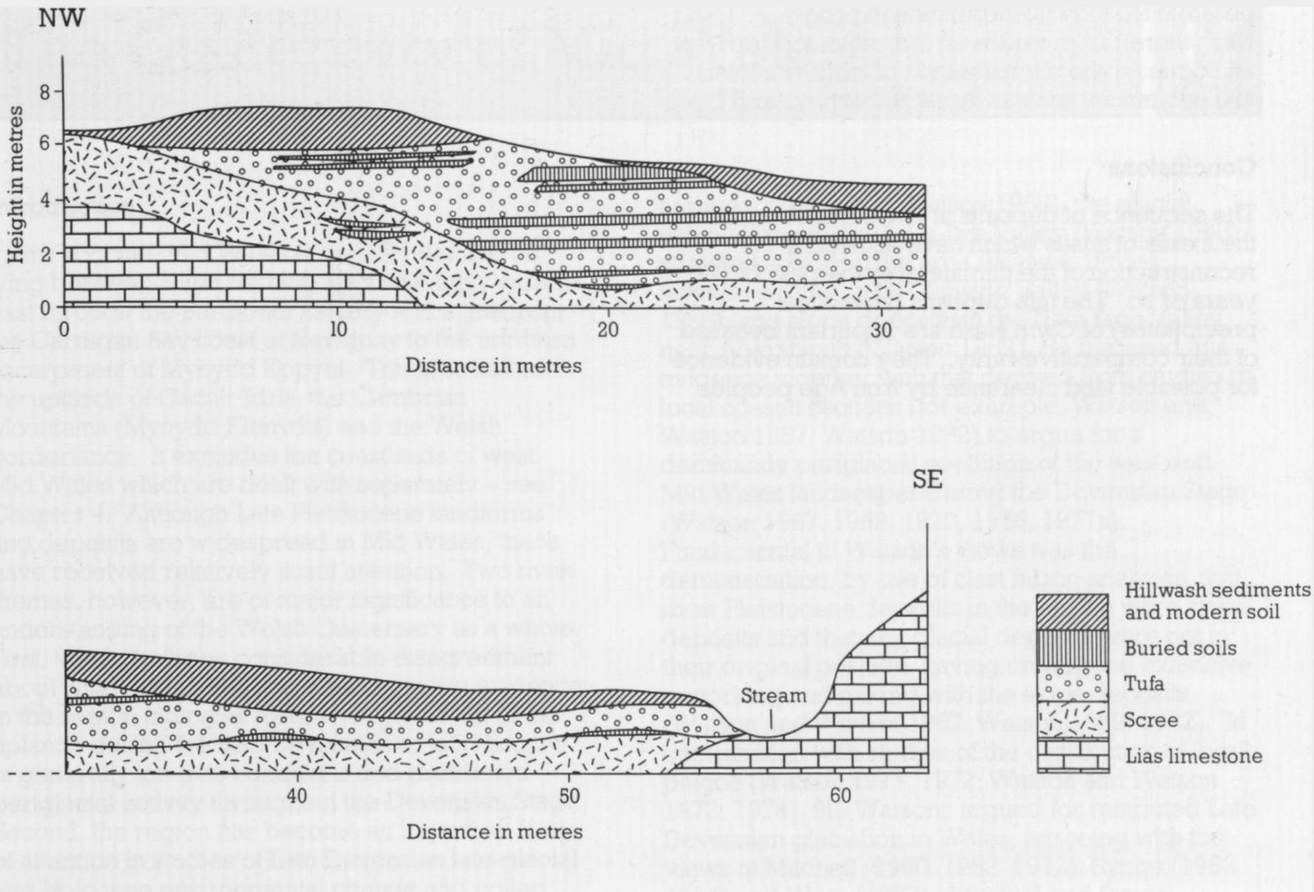

Figure 21 Quaternary sequence at Cwm Nash (after Evans *et al.* 1978)

snails indicated that the lower scree (bed 1) was deposited during fairly dry conditions, with the interstratified layers of finer material representing incipient soils. The restricted fauna suggested a Late Devensian age for these sediments, with the presence of *Helicella itala* (L.), in particular, implying a Pollen Zone II or Pollen Zone III age (Kerney 1963).

The overlying tufa (bed 3) marked a change from open-ground conditions in the Devensian late-glacial to shaded woodland with marshy conditions and perhaps pools of standing water, although true freshwater species were absent. Three distinct snail biozones have been recognised within the tufa (Evans *et al.* 1978), each reflecting an increase in the degree of tree cover, and being broadly equivalent to Pollen Zone IV, Pollen Zones V and VI combined, and Pollen Zone VIIa. Evans *et al.* (1978) stressed that this zonation was tentative. However, the extinction of *Discus ruderatus* (Férussac) and the appearance of a group of distinctively woodland snail species, probably mark a significant climatic change at the Boreal-Atlantic transition (Evans 1977a).
Soil layers within the tufa were considered by Evans *et al.* (1978) to represent periods of drier climate, including one possibly correlated with Pollen Zone VIc. A series of weakly developed soils within the upper layers of tufa was believed to mark oscillations within the Atlantic period, perhaps reflecting temporary drier conditions (Evans 1977a).

The soil horizon (bed 4) towards the base of the hillwash sediments (bed 5) marked the reappearance of open-country snail species, a corresponding reduction in woodland cover and a cessation of tufa formation. Man was probably responsible for this phase of forest clearance, because the horizon contains charcoal, marine molluscs and angular stones, indicative of human activity. A lack of archaeological material has so far made it impossible to date this clearance phase. The upper hillwash saw the virtual extinction of woodland snail species.

Cwm Nash has yielded the most detailed molluscan record of Devensian late-glacial and Holocene environmental changes in South Wales. The lower scree, with its fauna indicative of a Devensian late-glacial age, demonstrates a period of open-country and probably periglacial conditions. Land snails from the overlying tufa show a range of environments varying from marsh, open-woodland to closed-woodland, and they record detailed changes that may mark the Boreal-Atlantic transition. Land clearance, perhaps during the Iron Age, is indicated by the fauna of the overlying sediments.

The site is also of considerable geomorphological interest as one of the few places where it is possible to study tufa formation in progress. Cwm Nash therefore provides an important modern day analogue for the interpretation of lengthy ancient tufa sequences such as those at Caerwys and Ddol.

Conclusions

The sequence of deposits at Cwm Nash contains the fossils of snails which have allowed a reconstruction of the climate over the past 12,000 years or so. The tufa deposits (limestone precipitates) of Cwm Nash are important because of their comparative rarity. They contain evidence for possible land clearance by Iron Age peoples.