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Quaternary of Wales

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The Quaternary of North Wales

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Introduction

Except for the Quaternary sediments exposed around the coasts of Anglesey and north-west Wales – see Chapter 7, North Wales is best known for its upland glacial and periglacial landforms. The glacial landforms of Snowdonia were amongst the first in Britain to be investigated in relation to the Glacial Theory (for example, Bowman 1841; Buckland 1842; Darwin 1842) and they have since featured in a number of important geomorphological studies (for example, Davis 1909; Seddon 1957; Unwin 1970; Gray 1982a; Gemmell *et al.* 1986). There is also evidence for the Pleistocene evolution of the region.

Deposits pre-dating the Ipswichian Stage

Evidence for environmental conditions prior to the Late Devensian is sparse in North Wales apart from Pontnewydd Cave in the Elwy Valley, where deposits have yielded a molar of early Neanderthal Man dated to *c.* 200,000 BP (Green *et al.* 1981; Green 1984). This suggests occupation of the cave during Oxygen Isotope Stage 7. In addition to the oldest known human evidence from Wales, the sequence provides a Middle Pleistocene sedimentary record. Stratigraphic, faunal, and dating evidence from Pontnewydd provides an important Pleistocene record and the only known Lower Palaeolithic finds from a stratified context. Work by H S Green of the National Museum of Wales has resulted in detailed descriptions and an interpretation of the Pontnewydd sequence.

The Ipswichian Stage

Evidence for conditions during the Ipswichian Stage in North Wales is sparse. The only documented North Wales sites with evidence are the caves at Pontnewydd and Cefn. Although Sutcliffe regarded some of the mammal remains from Pontnewydd as representing a typical Ipswichian assemblage, recent excavations have not confirmed the age of the fauna as Ipswichian (Currant *in* Green 1984). Indeed, there is considerable evidence to suggest that the cave entrance at Pontnewydd may have been closed during the Ipswichian (Green 1984). The best evidence so far available for this time is from the nearby Cefn Caves where a fauna including hippopotamus and straight-tusked elephant has been recorded (Falconer 1868; Neaverson 1942). Although the precise stratigraphical context of these finds is unknown, they provide palaeontological information which may be useful for elaborating longer term aspects of regional Pleistocene evolution (Bowen 1973a, 1974; Peake *et al.* 1973).

The Devensian Stage

Late Devensian deposits are widespread in North Wales and their broad distribution has been known for some time (Bowen 1974). In common with the coastlands of north-west Wales, it has long been recognised that the North Wales coast was subjected to complex fluctuations and interactions between ice flows moving outwards from the Welsh uplands and Irish Sea ice moving generally southward. Evidence for the interplay of these ice masses, in the form of superimposed tills of Welsh and Irish Sea origin, is common along the North Wales coast, particularly around Llandudno and Conway (Whittow and Ball 1970; Fishwick 1977). Whittow and Ball (1970) suggested these tills were formed during separate glaciations, but Fishwick (1977) argued there is no evidence to suggest that glacial deposits beneath the Irish Sea till along the coast are older than Late Devensian. It was therefore envisaged that till deposits along the north coast were related principally to the onshore movement of Late Devensian Irish Sea ice which incorporated deposits from an earlier Welsh glaciation as it moved south. This Irish Sea glaciation was powerful enough to penetrate the Vale of Clwyd to deposit shelly drift at *c.* 300m on Halkyn Mountain near Wrexham (Strahan 1886) and at over 300m on Gloppa Hill near Oswestry (Wedd *et al.* 1929). At the same time, it is generally believed that Welsh ice covered most of the Welsh uplands: for example, the Arenig region (Rowlands 1970), the Berwyns (Travis 1944), Montgomeryshire (Brown 1971) and the south Shropshire hill country (Rowlands 1966; Brown 1971). Studies of ice wastage phenomena in the region have also been provided by Embleton (1957, 1961, 1964a, 1964b, 1964c) in north-east Wales, and by Brown and Cook (1977) and Thomas (1984) in the Wheeler Valley and Mold areas.

The broad distribution and provenance of the glacial sediments of the region is known (Bowen 1974). A relative lack of good exposures and interglacial indicators, including weathering and biostratigraphic horizons, has hampered correlation and interpretation in the region. In many respects the debates about the age of the drifts in North Wales are similar to those in the north-west Wales coastlands; namely, is there evidence for a readvance of Late Devensian ice? In this context the cave site at Tremeirchion in the Vale of Clwyd could be important. Here, Rowlands (1971) obtained a radiocarbon date of *c.* 18,000 BP, from material apparently sealed within the cave by Irish Sea till. If correct, the date provides evidence to show Irish Sea glaciation after 18,000 BP, when ice moved southwards into the Vale of Clwyd to the limit marked by the Bodfari-Trefnant moraine

(Rowlands 1955). Although correlation of this glacial phase with the Scottish Readvance (Pocock *et al.* 1938) is not now accepted, the evidence from Tremeirchion has been used to support a Late Devensian readvance (Bowen 1974), and it is consistent with evidence described from the Llŷn Peninsula (for example, Saunders 1968a, 1968b) – see Chapter 7. It is also interesting to note the close correspondence of the Tremeirchion date with those obtained from Dimlington in Yorkshire (Penny *et al.* 1969) which have been used to provide a maximum age for the principal advance of Late Devensian ice in eastern England, during the 'Dimlington Stadial' (Rose 1985).

North-east Wales is one of the potentially most rewarding areas for elaborating Late Pleistocene glacial history. This potential stems partly from its proximity to the Cheshire-Shropshire lowland, an area that has figured prominently in investigations of the Late Pleistocene. It is, however, beyond the scope of the present work to review such developments in that area, and reviews are available elsewhere (for example, Worsley 1970, 1977, 1985; Bowen 1974). It is important to note, however, that north-east Wales, and the Wrexham area in particular, forms an important link between the complex Cheshire-Shropshire lowland sequences and the more fragmentary records found elsewhere in North Wales. These important aspects of regional stratigraphy are more fully discussed in the introductory section to the GCR site at Vicarage Moss. Recent work in the Wrexham area (Dunkley 1981; Wilson *et al.* 1982; Thomas 1985) has demonstrated the complexity of the deposits there, with evidence for sequential wasting of Late Devensian ice, interrupted by brief ice advances at the margin of an oscillating ice-sheet (Thomas 1985). To some extent this evidence throws doubt on the more simplistic 'monoglacial' and 'tripartite' schemes erected by earlier workers in the area, and demonstrates a range of conditions at or near the margin of the Late Devensian ice-sheet – but see Chapter 2. Until better evidence is available to the contrary, it may be as well to regard multiple glacigenic sequences along the North Wales coastal margin in the same manner, namely as broadly Late Devensian in age, without sub-division.

The uplands

During the Late Devensian, local ice masses in Snowdonia and Arenig were subordinate to a major ice dispersal centre – the Merioneth ice cap (Greenly 1919; Foster 1968). This is believed to have contributed westerly and easterly flows from just east of Arenig Fawr and Rhobell Fawr (Foster 1968; Bowen 1974). Both Foster and Rowlands (1970) showed, as did Greenly, that the greatest thickness of ice occurred in the neighbourhood of Trawsfynydd. Foster (1968) demonstrated that the erratic content of tills in the Harlech Dome reflected deposition from different layers within the westerly moving limb of the Merioneth ice; with the upper portions of the ice crossing the Rhinog Mountains and entering Cardigan Bay, and the lower layers entering the Vale of Trawsfynydd and Afon Eden. Similarly, it was established (Rowlands 1970) that an easterly extension of the Merioneth ice cap overrode lower lying parts of the north-east Wales massif, being sufficiently powerful for a time to obstruct southward moving Irish Sea ice and prevent it from entering the Vale of Clwyd.

Exposures in glacial deposits occur widely within the network of selected GCR sites in Snowdonia, and these have been chosen primarily to represent three main aspects of the Quaternary for which the area has become nationally important.

First, three sites – Snowdon (Yr Wyddfa), Y Glyderau, Y Carneddau, represent an outstanding range of large-scale glacial erosional features. These spectacular upland landforms include classic examples of cirques, arêtes and troughs, all modified by glacial and periglacial processes. These three principal upland sites demonstrate a range of landforms which have resulted from varying conditions controlled by such factors as altitude, aspect, geological composition and structure. Snowdon, for example, demonstrates a classic 'Alpine' arrangement of cirques radiating from a horn and separated by precipitous arêtes. One cirque complex within this erosional assemblage also demonstrates a classic example of a 'cirque stairway'. The adjacent massif of Y Glyderau is a departure from this pattern, with a series of cirques, including Cwm Idwal, showing a marked structural alignment. These cirques fed ice into the spectacular Nant Ffrancon trough. In contrast, the easternmost part of the main Snowdonian massif is represented by landforms in the Carneddau range. Although cirque forms are also well represented here, for example Cwm Dulyn and Cwm Melynllyn, the landscape is far less rugged in nature and contains many broad-shouldered ridges. Y Carneddau exhibits an outstanding assemblage of fossil and contemporary periglacial landforms, for which the site has primarily been selected.

Second, although small and medium-scale features formed by the agencies of glacial erosion, particularly striae and roches moutonnées, are well represented within these three large upland sites, they are exceptionally well developed within the Snowdon site at Llyn Llyddaw (Gray and Lowe 1982) and in the Llanberis Valley at Llyn Peris. The latter site demonstrates an unparalleled range of small-scale erosional features including striae, friction cracks and forms associated with subglacial meltwater erosion.

Third, the selected upland sites of Snowdon, Y Glyderau and Y Carneddau contain an outstanding range and diversity of depositional landforms, formed largely during the Late Devensian late-glacial. Cirque glaciation during Younger Dryas times is by no means limited to these north Snowdonian sites, and landforms belonging to this phase are widely documented elsewhere in Wales – in the Arenig Mountains (Rowlands 1970), around Cadair Idris (for example, Watson 1977a); and in the Brecon Beacons (for example, Lewis 1970b; Ellis-Gruffydd 1972; Walker 1980, 1982a, 1982b).

The principal features of this late-glacial landform assemblage, the cirque moraines and protalus ramparts, however, are among the finest examples of their kind in Britain, and are well represented within the three main Snowdonian sites. These depositional landforms have long been known from the region (for example, Darwin 1842; Ramsay 1860; Daykins 1900), with Kendall's (1893) treatise *On a moraine-like mound near Snowdon* representing one of the first descriptions of a protalus rampart in Britain. The presence of both inner and outer moraine arcs in many of the Snowdonian cirques, and a mixture of 'sharp' and 'diffuse' moraine forms was noted by workers mapping their distribution (Seddon 1957; Unwin 1970). They concluded from this distribution and the morphology of the features that both protalus ramparts and moraines dated from two separate events. Analysis of pollen bearing sequences by Godwin (1955) and Seddon (1957, 1962) was fundamental in establishing this sequence of Late Devensian late-glacial vegetational events. This led to the suggestion that the outer and generally 'diffuse' moraines and protalus features might date from Pollen Zone I or to a recessive stage of the Late Devensian ice-sheet, with the inner 'fresh' features dating to the Younger Dryas (Pollen Zone III) (Seddon 1957, 1962; Unwin 1970).

More recently, Gray (1982a) has remapped these features, and provided evidence for thirty five Younger Dryas cirque glaciers in northern Snowdonia. Gray demonstrated that many of these small glaciers left complex depositional evidence to mark their maximum limits, including not only end-moraines but boulder limits and the down-valley extent of hummocky moraine – the Snowdon, Y Glyderau and Y Carneddau sites have, in part, been chosen to reflect the considerable variety of these depositional landforms. Gray further suggested that the highly variable evidence marking these glacier limits threw doubt on the widespread existence in the region of pre-Younger Dryas moraines (the 'Older Series' of Unwin (1970)). Palynological and radiocarbon dating evidence (Burrows 1974, 1975; Crabtree 1969, 1972; Ince 1981, 1983) from the region has also helped to place tighter constraints on the age of the final cirque glaciation of the uplands, and the majority of cirque moraines and protalus ramparts are now widely held to date from the short Younger Dryas, between *c.* 11,000-10,000 BP.

At Cwm Dwythwch, however, just north of the main Snowdon massif, Seddon (1962) described a typical full Late Devensian late-glacial sequence behind a large cirque moraine. This site, therefore, displays the only reliable relatively dated evidence from Wales for a cirque moraine of demonstrably pre-Younger Dryas age.

Late Devensian late-glacial and Holocene environmental history

Pollen analysis has been used in North Wales to reconstruct vegetational and environmental history during the Late Devensian late-glacial and Holocene. The network of selected pollen sites, some with radiocarbon calibration, provides evidence for conditions across North Wales from the wastage of the Late Devensian ice-sheet. In terms of the diversity of topography and climate in North Wales, both past and present, the range of sites illustrates both the broad patterns of environmental change and regional variations.

Evidence for palaeoenvironmental conditions during the late-glacial of the Late Devensian is recorded in the major upland GCR site at Nant Ffrancon in the Glyderau (Seddon 1962; Burrows 1974, 1975). It is supplemented by the sequences at Cwm Dwythwch, Clogwynygarreg and Cors Geuallt. Cwm Dwythwch provides evidence for ascribing a cirque moraine to a pre-Younger Dryas episode. Clogwynygarreg and Cors Geuallt also lie outside the mapped Younger Dryas limits of Gray (1982a), and place further limits on the possible age of the final cirque glaciation in the uplands. Clogwynygarreg records a near complete late-glacial sequence, including what appears, on the basis of the sediments, to be a single interstadial – the 'late-glacial interstadial' (Ince 1981). A minimum age for Late Devensian deglaciation in the area is indicated by a radiocarbon determination of 13,670 ± 280 BP (Birm 884) (Ince 1981). The pollen record shows a gradual improvement in conditions associated with the 'late-glacial interstadial'. A change from organic to clastic sedimentation, and a decline in *Juniperus* pollen mark the onset of the Younger Dryas (*c.* 11,000 BP) – a brief cold pulse when glaciers again occupied many of the upland cirques (Ince 1981).

This simple threefold lithology may represent the division of the pre-Allerød, Allerød and post-Allerød episodes of the Continental late-glacial (Moore 1977), which shows a single warm phase preceded and followed by colder climatic ones – but see Chapter 1. This is not recorded everywhere, which shows the need for a range of sites to reconstruct late-glacial conditions. At Glanllynnau – Chapter 7, for example, both Coope and Brophy (1972) and Simpkins (1974) suggested that what appeared to be a single 'late-glacial interstadial' might represent a combination of the Continental Bølling and Allerød Interstadials (Moore 1977). In Snowdonia, similar complexity has been recorded at Nant Ffrancon (Y Glyderau), where Burrows (1974, 1975) described what he interpreted as the Bølling 'oscillation'. A similar pre-Allerød climatic oscillation, possibly equivalent to the Bølling, has also been recorded from Cors Geuallt (Crabtree 1969, 1972). Moore (1975b, 1977) and Ince (1981), however, have questioned the validity of this evidence, particularly the radiocarbon dates from Nant Ffrancon. The network of GCR late-glacial sites represents these aspects of regional floral and environmental diversity which establish the relative timing of late-glacial climatic and environmental changes in Wales.

Within the principal upland sites of Snowdon, Y Glyderau and Y Carneddau, a number of pollen analytical sites with sequences from the beginning of the Holocene have been studied, which are the basis for environmental reconstruction in the uplands. These include the radiocarbon dated Holocene profiles at Cwm Cywion and Llyn Llyddaw (Ince 1981, 1983), and those at Cwm Idwal (Godwin 1955), Cwm Clyd (Evans and Walker 1977) and Cwm Melynllyn (Walker 1978). The last two sites also record detailed diatom evidence for changing Holocene environmental conditions.

The Holocene vegetation succession in North Wales reflects the development of temperate deciduous forest in response to climatic amelioration after the Younger Dryas. The early Holocene, *c.* 10,000 BP, is usually marked by expansion in *Juniperus* and *Betula* (Moore 1977) with a rise in *Corylus* very shortly after, although Moore (1972b) noted that the precise relationship between these rises varies both with altitude and latitude across western Britain. The mid Holocene sees a sharp expansion in *Betula* which at most Welsh sites declines again rapidly with the invasion of other trees. At Cwm Idwal, however, this *Betula* peak is more protracted. The birch and hazel woodlands are replaced eventually by forests of birch, oak, elm and alder (Ince 1983) and *Alnus* assumes a major, if not dominant, role in the pollen records of many Snowdonian profiles (Moore 1977). Deteriorating environmental conditions and human interference from about 5,000 years BP onwards resulted in the gradual decline of upland forests and the development of open-grassland and heathland which characterises the area today (Moore 1977; Ince 1981, 1983). The Holocene pollen profiles within the large upland GCR sites of Snowdon, Y Glyderau and Y Carneddau, and those from the selected pollen sites at Cwm Dwythwch, Cors Geuallt and Clogwynygarreg are important in establishing the timing of regional variations in these major vegetational and environmental changes.

Tufa

Tufa deposits in North Wales were mapped and described at an early stage (Maw 1866; Strahan 1890; Wedd and King 1924) and their potential for palaeoenvironmental reconstruction recognised (for example, Jackson 1922; McMillan 1947; Millot 1951; Bathurst 1956). A number of tufa localities has been recorded in the region, around Prestatyn and the Wheeler Valley (Neaverson 1941; McMillan 1947). Those at Caerwys and Ddol provide contrasting records: Caerwys represents the only known example of tufa formation from the Late Devensian late-glacial in Wales. The tufa and buried soils at these sites provide an exceptional biostratigraphic record (molluscs, leaf-beds and vertebrate faunas) recently re-examined by Preece (1978), Preece *et al.* (1982), McMillan and Zeissler (1985) and Pedley (1987). These accounts of the biostratigraphy and carbonate sedimentology of the tufa are complemented by radiocarbon calibration, and provide one of the most extensive and detailed records of environmental changes in Wales since the wastage of the Late Devensian ice-sheet.

Periglacial landforms

Upland North Wales is a classic area for periglacial landforms and processes. Many landforms, such as solifluction terraces and scree slopes, are widespread (Ball 1966; Ball and Goodier 1970), but other indicators of periglacial action, for example, patterned ground, are also well developed, although they are limited in extent. The network of GCR sites in the region reflects the considerable importance of non-glacial, cold-climate processes for landform evolution in North Wales during the Late Pleistocene and Holocene, even in historical and modern times. Although the major upland landform sites of Snowdon and Y Glyderau contain an impressive assemblage of periglacial features, including scree slopes, block screes (Pont-y-Gromlech), frost-shattered summits and tors (Y Glyderau) and a fine series of vegetated stripes (Y Garn), the scale and diversity of forms does not generally match that developed in the adjacent Carneddau massif. Many of the periglacial landforms in the Carneddau, including well developed screes, blockfields, tors and solifluction lobes and terraces, are classic examples of their kind. Although dating evidence is not yet available, it is believed that many features were formed during periglacial conditions following wastage of the Late Devensian ice-sheet and during the Younger Dryas (Ball 1966; Ball and Goodier 1970; Scoates 1973). Some features (patterned ground at Waun-y-Garnedd) are currently active and provide evidence for contemporary frost-assisted processes (Pearsall 1950; Tallis and Kershaw 1959; Ball and Goodier 1970; Scoates 1973). The factors influencing the distribution and maintenance of a range of landforms in the Carneddau associated with periglacial activity, have been discussed in detail by Scoates (1973).

Although the Carneddau provide a range of fossil and contemporary frost-assisted features in a compact area probably unparalleled elsewhere in Wales, three further sites in North Wales, at Moelwyn Mawr, Rhinog Fawr and Y Llethr, add a contrasting range of landforms, including for example, the only known occurrence in Wales of a fossil rock glacier (Lowe and Rose *in* Gray *et al.* 1981), and a fine series of unsorted vegetated stripes (Taylor 1975).

Sites in the Rhinog Mountains at Y Llethr and Rhinog Fawr also provide landform evidence for periglacial conditions and frost-assisted activity on a number of different occasions. Sorted stone stripes at Rhinog Fawr, thought to date from the

Late Devensian late-glacial (Ball and Goodier 1968, 1970), are the finest examples in Wales, and they are developed at a larger-scale than similar features elsewhere in Britain. In contrast, landforms at nearby Y Llethr may provide unique evidence in Wales for formation during a later cold period in historical times (Goodier and Ball 1969; Ball and Goodier 1970), perhaps during the climatic deterioration of the 'Little Ice Age' between *c.* 1550 and 1750 A.D. (Manley 1964; Lamb 1967).

This selected network of sites therefore provides substantial evidence for a wide range of landforms associated with periglacial conditions and frost-assisted processes from the Late Devensian late-glacial to the present day.

Pontnewydd Cave

Highlights

This is a site with a long Pleistocene rock and fossil record which has yielded the oldest human remains in Wales, artefacts and an associated 'warm' mammal fauna. This dated evidence indicates a pre-Ipswichian temperate interglacial.

Introduction

Pontnewydd Cave (SJ015710) contains a sequence of deposits with faunal, artefact and human remains important for reconstructing late Middle and Late Pleistocene events in North Wales. Pontnewydd has yielded the oldest known human remains from Wales, at about 200,000 years old. The site was first mentioned by Stanley in 1832 and was studied by Dawkins (1871, 1874, 1880), Hughes and Thomas (1874), Mackintosh (1876) and Hughes (1885, 1887). More recently the site was studied by Kelly (1967), Valdemar (1970) and Molleson (1976). Excavations by the National Museum of Wales since 1978 have led to a number of detailed reports (Green 1981a, 1984; Green *et al.* 1981; Green and Currant 1982).

Description

Pontnewydd Cave is formed in the Carboniferous Limestone of the Elwy Valley, and it lies at *c.* 90m OD. The difference in level between the cave and the present day River Elwy is 50m, and the valley contains both glacial sediments and recent alluvium (Embleton 1984; Livingston 1986).

The cave comprises one major east-west trending chamber, with a west-facing entrance. This chamber terminates at the East Passage and is made up of a number of smaller, generally north-south trending subsidiary chambers – the North Passage, the North-East Fissure, the South Fissure, the Back Passage, South Passage and South-East Fissure (Green 1984).

Outside the main entrance lies a large spoil heap from Dawkins' excavations in the nineteenth century, overlain by waste from World War Two activities at the cave. Recent excavations by Green and his colleagues have been at a number of different locations within the cave, and details of the sediments and stratigraphy for these sites are given by Collcutt (1984). Although no reference section representing the whole of this sequence is available at any one point, the following

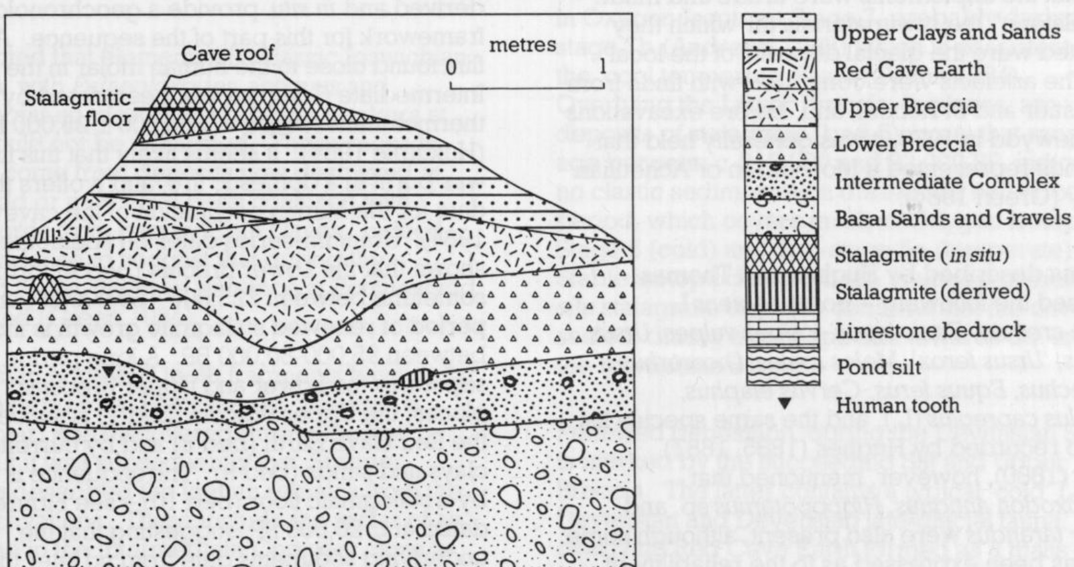

Figure 35 Quaternary sequence at Pontnewydd (after Green *et al.* 1981)

generalised sequence has been interpreted (Collcutt 1984), and is shown in Figure 35 –

11 Earthy unit*
10 Laminated Travertine*
9 Upper Clay and Sands*
8 Red Cave Earth*
7 Upper Breccia*
6 Silt*
5 Stalagmite*
4 Lower Breccia*
3 Intermediate Complex*
2 Upper Sands and Gravels**
1 Lower Sands and Gravels**

*Calcareous Member
**Siliceous Member (basal sands and gravels)

Interpretation

Pontnewydd Cave was first recorded by Stanley in 1832, who was then also working in nearby Cefn Caves. He noted that Pontnewydd Cave appeared choked with deposits and virtually unexplored. It seems that the cave remained in this condition until an excavation by Williams and Dawkins (Dawkins 1871, 1874, 1880) when only faunal remains were recovered. By the time the cave was next explored by Hughes and Thomas (1874) it was apparent that the earlier excavations had removed substantial deposits. Hughes and Thomas recorded a sequence of gravel, limestone breccia and cave earth beds in the main cave passage. Their investigation yielded both fauna and artefacts including a large human tooth (now lost). They noted that the implements were crude and made from 'felstone', the raw materials for which they suggested were the glacial deposits of the local area. The artefacts were compared with finds from Le Moustier and St Acheul, and, before excavations at Pontnewydd in 1978, it was generally held that these finds represented a Mousterian or Acheulian industry (Green 1984).

The fauna described by Hughes and Thomas comprised the following – *Homo sapiens* L., *Crocuta crocuta, Canis lupus, Vulpes vulpes, Ursus spelaeus, 'Ursus ferox', Meles meles, Dicerorhinus hemitoechus, Equus ferus, Cervus elaphus, Capreolus capreolus* (L.), and the same species list was also recorded by Hughes (1885, 1887). Hughes (1880), however, mentioned that *Palaeoloxodon antiquus, Hippopotamus* sp. and *Rangifer tarandus* were also present, although some doubt has been expressed as to the reliability of these latter records (Currant 1984). Mackintosh (1876) suggested that the sequence in Pontnewydd Cave comprised beds of marine, fluvial and glacial origin, and he attempted, admittedly unsuccessfully, to correlate the beds with the Pleistocene deposits of the local area. A summary of the earlier findings from Pontnewydd was given by Neaverson (1942). More recently, the cave was mentioned by Kelly (1967) who recovered only a few bones, supposedly of wolf and hare (Green 1984), and brief reviews of the earlier work have been given by Valdemar (1970) and Molleson (1976).

Green (1984) divided the sequence into eleven beds – see site description. These consist of two main elements, a basal siliceous member comprising beds 1 and 2, and a calcareous member consisting of the overlying beds. The basal siliceous member was interpreted as a mixture of fluvial and debris flow deposits (Bull 1984; Collcutt 1984) and it yielded neither artefacts nor fauna. Scanning Electron Microscopy (Bull 1984) and petrological analysis (Bevins 1984) revealed that the basal layers contained elements of redeposited till with erratics from north-west Wales and the Lake District. The sediments were deposited in a harsh environment when surface vegetation was locally absent. Selective cementation of these sediments may reflect, however, a milder climatic event during this phase of deposition.

Interpretation of the succeeding sediments which make up the Intermediate Complex and Upper and Lower Breccias, however, is more straightforward. These deposits have yielded not only artefacts and fauna, but human remains including a molar. The presence of limestone fragments in all these beds probably reflects the inclusion of typical cave entrance weathering products. The beds appear largely to be the product of debris flows, as shown by the apparent reworking of faunal elements through the sequence. Debris flow may have been interrupted by stalagmite growth on a number of occasions and ages for stalagmite fragments, both derived and *in situ*, provide a geochronological framework for this part of the sequence. A burnt flint found close to the human molar in the Intermediate Complex has been dated by thermoluminescence to 200,000 ± 25,000 BP (Huxtable 1984). It seems likely that this flint core was burnt in a domestic fire, and it offers the best date for the human occupation of the cave (Green 1984). Uranium-series dates on speleothem have shown that the Lower Breccia (bed 4) formed at sometime between 225,000-160,000 BP, and a period of renewed stalagmite growth is indicated between 95,000-80,000 BP. A long period thus separates the Lower and Upper Breccias. In places, the Upper Breccia (bed 7) is succeeded by the Red Cave Earth (bed 8) and by current bedded clays and sands (bed 9). The sequence is capped by a stalagmitic floor (bed 10) – see Figure 35, dated at *c.* 20,000 BP, suggesting that the underlying sediments date from no later than the Late Devensian late-glacial or early Holocene.

Currant (1984) recognised three mammal faunas of different ages from beds in the calcareous member. Most of the faunal material is not *in situ*; it has been substantially reworked by debris flows. Under such conditions, an increasingly derived faunal content could be expected in successive debris flows. Bones were grouped on the basis of their preservation: three different preservational states were identified and material assigned to these. The first occurs in the Intermediate Complex, and also as a derived component in the Lower Breccia. It is a 'warm' fauna and it includes beaver *Castor fiber* L., wood mouse *Apodemus* cf. *sylvaticus*, bear *Ursus* sp., roe deer and horse *Equus* sp., indicative of an open-woodland habitat. There is some evidence that the cave may have been used as a bear den during this period. According to Currant, this assemblage is probably post-Cromerian and has certain Hoxnian affinities. An Ipswichian age is ruled out on both faunal and stratigraphic grounds.

The second preservation group occurs mainly in the Lower Breccia, is dominated by bear *Ursus* sp., horse *Equus* sp. and extinct rhinoceros *Dicerorhinus hemitoechus*, and generally indicates an open-steppe environment. This second fauna appears close in age to the first, with only minor changes in species composition (Currant 1984).

The third mammal group occurs in the Silt (bed 6) and the Upper Breccia. It is a classic 'cold' fauna characteristic of the Arctic tundra today; it is the most readily placed of the faunal groups identified from Pontnewydd. A harsh environment with open, treeless vegetation and extensive seasonal snow cover is indicated. Much of the bone material is interpreted as the debris of a wolf den. This third fauna is readily assigned to the Late Devensian and Devensian late-glacial. It includes wolf *Canis lupus*, red fox *Vulpes vulpes*, reindeer *Rangifer tarandus*, arctic hare *Lepus cf. timidus* and brown bear *Ursus* cf. *arctos*, and entirely lacks extinct forms. Similar well dated faunas are known from numerous British cave sites.

Currant noted that elements of a classic Ipswichian type fauna, with *Palaeoloxodon antiquus* and *Hippopotamus* sp. described by early workers at the site, could not be confirmed. These records may have come from deposits now destroyed at Pontnewydd or may have been confused with faunal records from nearby Cefn Caves. Indeed, there is evidence to suggest that during the Ipswichian Stage, the cave entrance at Pontnewydd was blocked (Green 1984).

Seven human bone and tooth fragments have so far been recovered from Pontnewydd. The first, a human molar, was discovered during the last century but it was subsequently lost. Stringer (1984) has described the human remains from the recent excavations. These include the molar of an adult, found in the Intermediate Complex close to the burnt flint core with a thermoluminescence date of 200,000 ± 25,000 BP. Near this find, in the Upper Breccia, were recovered fragments of a juvenile upper jaw with two teeth. From an unknown bed within the cave have come further fragments of a child's mandible and a vertebra, and the 1983 season also yielded two pre-molars in the Lower Breccia. The two permanent upper molars are of great interest since they resemble early Neanderthal teeth and they compare closely with finds from Krapina in Yugoslavia (Stringer 1984).

Some 300 artefacts were recovered during the National Museum of Wales' excavations, mainly from the Intermediate Complex and the Lower and Upper Breccias. No evidence of settlement within the cave was found; all the artefacts appear to have been transported into the cave by mass-movement. The principal tools are handaxes of Acheulian types and Levallois tradition. The nature of these artefacts and the small size of the cave entrance suggests that Pontnewydd was probably used only as a temporary butchering site (Green 1981a, 1984).

The combination of stratigraphic, sedimentological, faunal, human and dating evidence from Pontnewydd provides the most extensive terrestrial Pleistocene record so far known in Wales. The earliest event recorded is deposition of the Lower and Upper Sands and Gravels, probably in a cold environment. These sediments contain erratics, presumably derived from an earlier glacial event. The succeeding Intermediate Complex contains mammal bones, artefacts and human remains. The recognition of a 'warm' mammal fauna (interglacial or interstadial) from these sediments (bed 3), together with a human tooth dated to *c.* 200,000 BP, provides evidence to suggest human activity at Pontnewydd during the temperate conditions in Oxygen Isotope Stage 7 (Green 1984). The earliest certain growth of stalagmite within the cave has been correlated with Oxygen Isotope Sub-stage 7c (*c.* 250,000-230,000 BP) and it seems reasonable that the human finds and associated artefacts could, in part, belong to this time. The evidence suggests that the succeeding Lower Breccia was also formed in Oxygen Isoptope Stage 7, probably during Sub-stage 7b (Andrews 1983) which is consistent with the 'cool temperate' fauna (Green 1984). Overlying the Lower Breccia, in places, are deposits of stalagmite (bed 5) *in situ* that range in age between *c.* 215,000 and 83,000 BP, indicating no clastic sedimentation during this extended period, which covers much of Oxygen Isotope Stage 6 (cold) and Sub-stage 5e (temperate). Stable isotope data from the youngest of these *in situ* stalagmite deposits confirms that the cave was sealed, during a cool episode towards the end of the Ipswichian Stage.

Renewed deposition, during the Devensian Stage, is marked by the succeeding Silt and Upper Breccia. The latter contains a typical 'cold' Late Devensian and Devensian late-glacial fauna. The overlying Red Cave Earth formed as a mass debris flow towards the end of the latter period, channelling into and incorporating older sediments. The Upper Clays and Sands and Laminated Travertine are complex waterlain deposits, containing the bones of modern mammals, and extending the record at Pontnewydd into the

Holocene.
Pontnewydd Cave contains the most extensive Pleistocene sequence in Wales and the only record of Middle Pleistocene conditions in North Wales. The sequence has been dated and correlated with the deep-sea oxygen isotope record. The human tooth is the earliest such find in Wales, and except for the Swanscombe fossil, the earliest in the British record. This probable early Neanderthal was associated with over 300 artefacts of Acheulian type. These are the only finds of Lower Palaeolithic antiquity from a stratified sequence in Wales, and they provide strong evidence for human activity probably in Oxygen Isotope Stage 7.

Conclusions

Pontnewydd Cave contains some of the oldest ice age rocks known in Wales. The latest methods of dating such rocks have been applied and they are known to be at least 200,000 years old. The human tooth dated to this time is the earliest evidence for Man in Wales.

Cefn and Galltfaenan Caves

Highlights

This is an important site yielding the only known 'warm' Ipswichian mammal fauna from North Wales, as well as a 'cold' mammal fauna from the rocks of the succeeding Devensian Stage.

Introduction

Cefn and Galltfaenan Caves (the Cefn Caves) are important for reconstructing the Late Pleistocene history of North Wales. Unlike South Wales, evidence for Pleistocene interglacial conditions in North Wales is strictly limited and a 'warm' mammal fauna from Cefn Caves, including hippopotamus and straight-tusked elephant, provides an important record of environmental conditions during the Ipswichian Stage. A 'cold' fauna associated with the Devensian Stage, is also present. The site has a long history of research commencing with Stanley (1832) and has also been described by Trimmer (1841), Falconer (1868), Mackintosh (1876), Hughes (1885, 1887) and Neaverson (1942). The place of the site with regard to the Late Pleistocene history of the region has been discussed by Bowen (1973a, 1974) and Peake *et al.* (1973). A more detailed account of its faunas and artefacts was given by Valdemar (1970), and the faunal evidence was also discussed by Currant (*in* Green 1984).

Description

Cefn Cave (SJ021705) occurs at approximately 76m OD in Carboniferous Limestone above the Elwy Valley, and consists of a number of interconnecting passages with multiple entrances. Galltfaenan Cave (SJ023702) is situated in a small ravine about 400m to the south-east. Reliable details of the stratigraphic sequences in these caves are not available, although Trimmer's (1841) account of Cefn Cave would appear to offer the best description thus far available. Trimmer recorded a sequence of –

4 Sand and silt containing marine shells
3 Calcareous loam containing bones and fragments of limestone
2 Stalagmite floor
1 Sediment containing smooth pebbles, bones and wood fragments

Unfortunately, the position of the faunas and artefacts within this sequence is not known, making dating and interpretation difficult. Significant deposits are thought to remain *in situ* at both caves.

Interpretation

A mammalian fauna was first discovered in the Cefn Caves by Stanley (1832). He gave an account of the caves and their contents, which included the remains of hyaena and rhinoceros. Trimmer (1841) interpreted beds 2 and 3 as terrestrial cave deposits and bed 1 as fluvial in origin. The overlying sand and silt with marine shells (bed 4) was considered to be a marine deposit formed during 'glacial submergence' of the land. This interpretation was largely followed by Mackintosh (1876).

In 1866, Moore excavated for a short time at Cefn; specimens from this time were placed in the Liverpool City Museum (Neaverson 1942). The site was also described by Hughes (1885, 1887), who unlike Trimmer and Mackintosh, believed that the 'shelly marl' (bed 4) had been washed in from the overlying boulder clay via fissures, and was not marine in origin.

The first detailed faunal list from the site was given by Falconer (1868) and later updated by Neaverson (1942), and now revised as follows –

Straight-tusked elephant *Palaeoloxodon antiquus*

Extinct rhinoceros *Dicerorhinus hemitoechus?*

Hippopotamus *Hippopotamus amphibius L.*

Horse *Equus ferus*

Reindeer *Rangifer tarandus*

Giant deer *Megaceros giganteus*

Red deer *Cervus elaphus*

Extinct bison *Bison priscus*

Lion *Panthera leo*

Spotted hyaena *Crocuta crocuta*

Cave bear *Ursus spelaeus*

Wolf *Canis lupus*

Red fox *Vulpes vulpes*

Brown bear *Ursus arctos*

Badger *Meles meles*

Human bones and artefacts were also recovered during early excavations at the site (Dawkins 1874). Both the human remains and tools were described as being of Neolithic type and they were apparently intermixed with the mammalian fauna. Dawkins (1871) also recorded finds of reindeer, bear and hyaena from Galltfaenan Cave.

More recently, Valdemar (1970) reassessed the faunas and artefacts from Cefn Cave, and discussed these in relation to those from Pontnewydd. He showed that the flint artefacts described by Dawkins as Neolithic, were probably Upper Palaeolithic in age, belonging to a Creswellian or Cheddarian culture. The stratigraphic context of these finds, however, was uncertain. Dawkins had identified the human remains as belonging to a brachycephalic race usually attributable to the Neolithic (Foulkes 1872). Valdemar therefore suggested that there must have been at least two phases of human occupation. He noted that, since Cefn Cave had yielded Upper Palaeolithic artefacts as well as human remains, it is possible that other caves excavated by Dawkins and earlier excavators also contained evidence from both the Upper Palaeolithic and Neolithic periods.

Elements of both a 'temperate' interglacial type mammal fauna, including hippotamus and straight-tusked elephant, and a 'cold' glacial type fauna, with woolly rhinoceros, mammoth and reindeer, have been described from the Cefn Caves. These records have been discussed by Bowen (1973a, 1974), Peake *et al.* (1973) and Stuart (1982) who have emphasised the difficulties of interpreting the assemblages without precise stratigraphic details. It has also been noted that early workers may even have confused faunal material from Cefn with specimens from Pontnewydd Cave (Currant 1984). Nevertheless, the fauna from Cefn Caves is of considerable importance in reconstructing Late Pleistocene events in North Wales, and it has been suggested that the 'temperate' fauna can be assigned to the Ipswichian Stage and the 'cold' fauna to the Devensian Stage (Bowen 1973a, 1974; Peake *et al.* 1973; Stuart 1982).

The fauna of proposed Ipswichian age at Cefn assumes considerable importance in view of the lack of evidence in North Wales for Pleistocene interglacial conditions. Cefn Caves, therefore, provide a contrasting record to nearby Pontnewydd where, although an extensive Middle Pleistocene sequence is present, sediments and fauna from the Ipswichian Stage are absent (Green 1984). Together they form important elements in a network of cave sites that demonstrates evidence for changing environmental conditions in North Wales in the Pleistocene.

The Cefn Caves have yielded the only mammalian fauna known in North Wales from the Ipswichian Stage. They also provide an important Devensian 'cold' fauna. Although the stratigraphic context of these finds has not been established, substantial deposits remain *in situ*, giving the site considerable potential for elaborating Late Pleistocene conditions in North Wales. Human and artefact evidence from here strongly suggests occupation during both the Upper Palaeolithic and Neolithic periods.

Conclusions

The Cefn Caves contain rocks which have yielded a prolific assemblage of fossils, including hippopotamus, which can be dated to some 125,000 years ago. This is important because it was the last time that Britain enjoyed conditions similar to the present. Evidence of this kind when assembled over a wide area may provide information on how interglacials like the present come to an end. The Cefn Caves were also occupied by Man during the Palaeolithic and Neolithic periods.

Tremeirchion (Cae Gwyn and Ffynnon Beuno) Caves

Highlights

Bone and human Palaeolithic implement-bearing deposits are found here beneath glacial sediments laid down during the last major Pleistocene cold phase in the Late Devensian. The 'cold' mammal fauna from the cave has been dated to about 18,000 BP, immediately before this glacial episode.

Introduction

Tremeirchion comprises the caves of Cae Gwyn and Ffynnon Beuno. These have yielded rich mammalian faunas including the remains of mammoth, woolly rhinoceros, spotted hyaena, lion and reindeer, and they have provided some of the earliest clear evidence for the association of man-made stone tools with the remains of extinct mammals. The site is particularly significant in providing evidence that the last glaciation of the Vale of Clwyd took place during the Late Devensian. The site was first investigated by Hicks (1884, 1886a, 1887, 1888), and the evidence from these early excavations has been reviewed by Garrod (1926), Boswell (1932), Neaverson (1942), Embleton (1970) and Synge (1970). A radiocarbon date obtained from faunal material at the site (Rowlands 1971) has been discussed within the wider context of the Pleistocene history of North

Wales (Oakley 1971; Bowen 1973a, 1973b, 1974; Peake *et al.* 1973; Campbell 1977; Green 1984).

Description

Ffynnon Beuno and Cae Gwyn Caves (SJ085724) are situated close together at the base of the Carboniferous Limestone escarpment on the eastern side of the Vale of Clwyd. Cae Gwyn Cave consists of two entrances connected by a narrow single passage. One entrance faces south at *c.* 19m above the floor of the Ffynnon Beuno Valley. The other entrance faces west and was completely buried prior to its excavation (Campbell 1977). Ffynnon Beuno Cave, which lies at a slightly lower level, comprises three galleries and has two openings to the south (Garrod 1926).

The sequence found at the southern entrance to Cae Gwyn and inside the cave was as follows (Hicks 1886a) –

5	Reddish recent loam (0.60m)
4	Laminated clay with thin ferruginous and stalagmitic lenses (0.20m)
3	Reddish sandy clay with pebbles of felsite, granite, gneiss, quartz, quartzite, sandstone and limestone, with an early Upper Palaeolithic tool – partially disturbed (0.60m)
2	Unfossiliferous gravel mostly of local rock types (0.30m)
1	Carboniferous Limestone bedrock

Following a partial collapse in a field above the cave, a second section and entrance to the cave was exposed, showing the following sequence (Hicks 1886a; Garrod 1926; Campbell 1977) –

12	Surface soil (0.15m)
11	Brown till (0.85m)
10	Yellow clay with silt and sand (0.18m)
9	Stiff red till (0.70m)
8	Sand (0.05m)
7	Purple clay (0.25m)
6	Sand with boulders (0.50m)
5	Gravelly sand with boulders and lenses of purple clay (0.65m)
4	Sandy gravel (0.60m)
3	Sand lenses (0.40m)
2	Red laminated clay and 'bone earth' with angular limestone fragments and a few boulders (0.80m)
1	Carboniferous Limestone bedrock

From Ffynnon Beuno Cave, the following sequence was recognised (Hicks 1886a; Garrod 1926) –

6	Surface soil
5	Cemented breccia with charcoal
4	Red cave earth with bones and implements
3	Yellow band (ancient floor?)
2	Gravel with angular blocks of limestone
1	Carboniferous Limestone bedrock?

Cae Gwyn and Ffynnon Beuno Caves were first excavated by Hicks and Luxmoore between 1883-1887 (Hicks 1884, 1886a, 1887, 1888). Both contained a considerable mammalian fauna (Hicks 1886a; Garrod 1926) –

Lion *Panthera leo*
Wild cat *Felis sylvestris*
Spotted hyaena *Crocuta crocuta*
Wolf *Canis lupus*
Fox *Vulpes vulpes*
Bear *Ursus* sp.
Badger *Meles meles*
Wild boar *Sus scrofa*
Bovine *Bos*?
Giant deer *Megaceros giganteus*
Red deer *Cervus elaphus*
Roe deer *Capreolus capreolus*
Reindeer *Rangifer tarandus*
Horse *Equus* sp.
Woolly rhinoceros *Coelodonta antiquitatis*
Mammoth *Mammuthus primigenius*

Interpretation

Hicks considered that this fauna showed that the cave had been a hyaena den during the Pleistocene, and he noted that amongst the remains, the teeth of horse, rhinoceros, hyaena and reindeer were most numerous. Both caves also yielded human artefacts. He suggested that the evidence furnished from the bones and artefacts showed that Man had been contemporaneous with the mammals. His most significant claim, however, was that the caves had been sealed by undisturbed till. In places, the till contained marine shell fragments and erratics, indicative of a northern or Irish Sea origin. The sealing of the caves was considered by Hicks to demonstrate that the bones and artefacts were of 'pre-glacial' age. This suggestion was strongly refuted, especially by Hughes (1887) who argued that the glacial deposits were not *in situ*. Hughes was convinced that the Tremeirchion Cave deposits were 'post-glacial' in age. In the discussion (Hughes 1887), debate occurred concerning the antiquity of Man in relationship to the deposits, and it was noted that "......the interest attaching to the cave depends on the light which it throws on the relation of Palaeolithic Man to the glacial period". Hicks' view that the caves were sealed by till and that the fossiliferous remains pre-dated glaciation of the local area, however, prevailed (Garrod 1926; Boswell 1932; McBurney 1965; Embleton 1970; Synge 1970).

Garrod (1926) reviewed the earlier work at Tremeirchion and considered that the artefacts from the caves were of two principal types; Middle Aurignacian and Proto-Solutrean. Indeed, on the basis that the Irish Sea till at Tremeirchion post-dated the Aurignacian tools, Charlesworth (1929) established a Magdalenian (Creswellian-Cheddarian) age for the 'Newer Drift' (Devensian) glaciation of Wales and adjoining regions. Campbell (1977), however, observed that Garrod's sub-division of the artefacts was probably arbitrary, and assigned the finds more broadly to the Upper Palaeolithic. Neaverson (1942) also reviewed the early excavations at the site, providing useful details of the museums and establishments to which the finds had been dispersed.

Rowlands (1971) submitted a mammoth carpal collected by Hicks for radiocarbon dating. A date of 18,000 +1,400 -1,200 BP was obtained on the collagen, and this was used by Rowlands to demonstrate that the last glaciation of the area was Late Devensian in age, after *c.* 18,000 BP. He considered the date too young to provide an age for the Palaeolithic industry at the site. Oakley (1971), however, pointed out that although the dates of similar industries in France were in the region of 10,000 years older, a radiocarbon date on human bones at Paviland Cave in Gower, South Wales, showed a very close correspondence to Rowlands' Tremeirchion date. This indicated that human occupation may have occurred close to the peak of the Late Devensian glaciation.

The radiocarbon date from Tremeirchion demonstrates that the glacial deposits of the local area post-date *c.* 18,000 BP and are, therefore, Late Devensian in age. The exact significance of the date is, however, less clear: in discussing the evidence from Tremeirchion, Bowen (1973a, 1973b, 1974) suggested two main possibilities for interpreting the radiocarbon date. Either, the date indicates that the main thrust of Late Devensian Irish Sea ice in the region post-dated *c.* 18,000 BP, and a close similarity was noted between the Tremeirchion date and a radiocarbon date from Dimlington in Holderness (Penny *et al.* 1969) or, the date provides a maximum age for a readvance of the Late Devensian ice-sheet, rather than the main pulse of the glaciation. Although this remains unresolved, the Tremeirchion date shows that the fauna and human industries pre-date the last, Late Devensian, glaciation of the area (Peake *et al.* 1973; Campbell 1977; Green 1984). Historically, the site also provides some of the earliest evidence for the association of man-made stone tools with the remains of Pleistocene mammals. Although contemporary assessment of the mammal fauna from Tremeirchion is not available, it represents a generally 'cold' assemblage, and would appear to date, at least in part, from immediately before the Late Devensian glaciation.

Tremeirchion Caves provide an important record of Late Pleistocene conditions in North Wales, with a unique combination of faunal, archaeological, sedimentary and radiocarbon dating evidence. They provide a reference point for Late Pleistocene/Upper Palaeolithic tools which were apparently overlain by till from the last glaciation. The radiocarbon date from the site has shown that the glacial deposits post-date *c.* 18,000 BP and are, therefore, Late Devensian in age. Radiocarbon dates from Tremeirchion and Dimlington indicate that a substantial area of Britain was covered by glacier ice sometime after 18,000 BP.

Conclusions

The Tremeirchion Caves are among the most important archaeological sites in Europe. Because they contain a rich sequence of archaeological remains which are dated broadly to the period between 20,000 and 40,000 years ago, and because these were sealed inside the cave by glacial deposits of the last ice-sheet, they provide an important limiting date for that glaciation. A radiocarbon date of 18,000 years ago from a mammoth bone is one of only a few age determinations from this time in the British Isles.

Vicarage Moss

Highlights

This site shows one of the best developed kettle hole complexes in Wales. These depressions, formed by the melting of glacier ice caught up in glacial and fluvioglacial sediments, are typical of many developed towards the end of the Late Devensian glaciation in north-east Wales.

Introduction

Vicarage Moss is one of the best developed examples of a kettle hole complex in Wales. The features here are representative of many developed throughout the Wrexham area on the landform known as the 'Wrexham delta terrace'; they were probably formed towards the close of the Late Devensian glaciation by the melting of buried ice. The features have been described in numerous publications (for example, Wedd *et al.* 1928; Peake 1961; Poole and Whiteman 1961; Francis 1978; Dunkley 1981; Wilson *et al.* 1982; Thomas 1985). The features have been mapped and described in relationship to soil development in the Wrexham area by Lea and Thompson (1978).

Description

Kettle holes are depressions formed by the melting of ice masses which were formerly buried within glacial sediments. Those at Vicarage Moss (SJ360540) lie in the eastern part of the Wrexham delta terrace, an extensive area composed largely of sands, gravels and fine-grained diamicts. The site comprises one very large and two subsidiary kettle holes. The largest forms a deep basin occupied by mire vegetation and open-water which extend across the floor of the kettle hole for some 200m. Of the smaller subsidiary kettle holes, one contains a boggy floor but the other has no appreciable sediment infill. Other, even smaller, hollows with intervening ridges and mounds occur within the site. The main basin mire is exceptionally well defined by the junction of the surrounding steep, well drained gravel slopes. The vegetation of the main moss is dominated by bog moss, cotton grass and cranberry.

Interpretation

Wedd *et al.* (1928) showed that the Wrexham area had been affected by two major ice streams, one coming from the west (Welsh ice) and one from the north (Irish Sea ice). They divided the drift succession of the area into a tripartite sequence of Lower Boulder Clay, Middle Sands and Upper Boulder Clay. They argued that this sequence was formed in a single ice advance and retreat episode, during which the Middle Sands had been deposited by meltwater from the retreating Welsh ice draining eastwards into a large lake impounded by the Irish Sea ice to the north. According to Wedd *et al.*, this built the Wrexham delta terrace, and they noted that the complex kame and kettle topography on parts of its surface had been produced during the waning phase of the glacial episode, during 'Late-Glacial' conditions.

Peake (1961) argued that the terrace was built up by meltwater draining south from both the retreating Welsh ice and Irish sea ice margins, to form a 'composite prograding delta', on the edge of a lake occupying the Cheshire lowlands. She noted that the prominent series of large kettle holes and mounds south of Gresford, including Vicarage Moss, could represent a previous ice-stand. Peake (1961, 1979, 1981) has also argued that Irish Sea till overlying sands and gravels in the terrace in the Llay area of north-east Wrexham was distinct from the Upper Boulder Clay described by Wedd *et al.* (1928). This till, she suggested represented a separate ice advance, termed the Llay readvance.

Other workers, however, have suggested that the terrace was not in fact produced by deltaic processes. Poole and Whiteman (1961), for example, considered that the feature represented part of an end-moraine extending from Wrexham across the Cheshire-Shropshire lowland towards Ellesmere. The outer edge of the terrace was therefore seen as an ice-contact slope to the rear of Irish Sea outwash spreading westwards. This view has also been supported by Worsley (1970). Poole and Whiteman further suggested that the 'billowy, hummocky topography with occasional kettle-holes' was extremely characteristic of such morainic drift.

Similarly, Francis (1978) has suggested that the 'delta terrace' was not formed by deltaic processes, but as a subaerial fan supplied by glacial outwash. The well developed kettle-holed surface was believed to imply deposition in contact with ice; a view upheld by Dunkley (1981) and Wilson *et al.* (1982).

Most recently, however, Thomas (1985) has argued that the previous models do not explain adequately the variety of depositional conditions observed in the area in boreholes and in more recently exposed gravel workings such as those at Marford and Singret quarries. Thus, he considered that the Wrexham delta terrace could not be regarded as either a simple 'lake-delta' or as a simple 'alluvial fan', but rather as a much more complex and diachronous feature showing evidence for a variety of sedimentary environments, including ice-front, debris-flow, alluvial fan, sandur and proglacial and ice-contact lakes formed at the margin of the stagnating Irish Sea ice-sheet (Thomas 1985). He envisaged that the kettle holes south of Gresford and at Vicarage Moss had formed part of a complex dead ice topography at the retreating ice margin.

In demonstrating that considerable lateral and vertical variation occurs in the deposits of the terrace, Thomas concluded that the complexity was consistent with a period of oscillating ice-marginal conditions during the Late Devensian accompanied by the formation of ice-front outwash fans and short-lived lake basins.

Viewed against the extremely complex Late Pleistocene evolution of north-east Wales, the kettle holes at Vicarage Moss and elsewhere on the surface of the Wrexham delta terrace (see also Chapter 2) assume considerable importance in elaborating the nature and sequence of Late Pleistocene events in the area. The features at Vicarage Moss are representative of many developed in the sands and gravels of the Wrexham area and were probably formed towards the close of the Late Devensian glaciation by the melting of buried ice. They are classic examples of the kettle hole landform.

Conclusions

Vicarage Moss shows outstanding examples of kettle hole landforms. These are representative of numerous similar features in the Wrexham area. They contain peat deposits which can provide important information about climatic change at the end of the last ice age.

Snowdon (Yr Wyddfa)

Highlights

One of the first areas studied for its glacial features, this site shows numerous classic large, medium and small-scale examples of erosional and depositional landforms associated with glacial conditions, particularly in the Devensian Stage. Many moraines and protalus ramparts date from the last, Younger Dryas, cirque glaciation of Snowdonia.

Introduction

The mountain area of Snowdon contains a wide range of glacial and periglacial landforms of exceptional interest. The large spectacular features of glacial erosion (cirques, arêtes and troughs) were among the first in Britain to be described, and they have few parallels in Wales. Numerous fine examples of medium-scale, ice-sculptured features include rock steps and roches moutonnées. Further enhancing the interest of the area, particular around Llyn Llydaw, are many well developed, small-scale erosional features such as glacial striae and friction cracks. This assemblage of erosional forms is also accompanied by depositional landforms, particularly moraines and protalus ramparts. Although many of the latter have been assigned to the Younger Dryas, others may relate to wastage of the Late Devensian ice-sheet. Therefore, in addition to providing classic landform examples, the Snowdon area is important for interpreting patterns of mountain glaciation and deglaciation in north Wales.

The area was one of the first in Britain to be investigated with respect to the Glacial Theory, with studies by Bowman (1841), Buckland (1842), Darwin (1842) and Mackintosh (1845). It was not, however, until the work of Ramsay (1860, 1866, 1881) that the impact of glaciation in the area gained general acceptance (for example, Kidson 1888, 1890; Kendall 1893; Marr and Adie 1898; Daykins 1900; Jehu 1902; Davis 1909, 1920; Dewey 1918; and Carr and Lister 1948). Since these early studies, the area has become a classic ground for geomorphologists, with major studies by Seddon (1957), Embleton (1962, 1964a), Unwin (1970, 1973, 1975), Gray (1982a), Gray and Lowe (1982) and Gemmell *et al.* (1986). The area has also been described in texts by Williams (1927), Smith and George (1961), Johnson (1962) Ball *et al.* (1969) and Addison (1983, 1987). Ball and Goodier (1970) described the distribution of features associated with periglacial activity in Snowdonia, and Ince (1981, 1983) has reconstructed the late-glacial and Holocene vegetational history of the area using pollen analytical methods.

Description and interpretation

The Snowdon GCR site comprises a series of cirques radiating from the summit of Snowdon and representative sections of the spectacular glacial troughs in the Llanberis and Gwynant Valleys – see Figure 36.

Large-scale features of glacial erosion

Processes of glacial erosion have cut the Snowdon massif into a horn with large cirques radiating from a central point. The Crib Goch and Crib-y-ddysgl and Yr Wyddfa to Y Lliwedd arêtes are fine examples of the precipitous slopes developed in glaciated uplands. Indeed, probably only the broad-shouldered ridge extending north from Snowdon remains to give any impression of a pre-glacial land surface – see Figure 36.

The cirques within the site are generally complex in plan, with the concept of a cirque stairway clearly exemplified in Cwm Dyli (Embleton and King 1968). Here, the 'Snowdon Horseshoe' defines the eastern basin of the Snowdon massif; the arêtes of Crib Goch and Y Lliwedd encircling the largest glacial excavation of the massif (Addison 1983). Unwin (1970) recorded twenty five cirques in the Snowdon area, including Cwm Dwythwch to the north, although problems of definition may have led to an over-estimate of the total number. Many of the cirques are illustrative of the continuum of features described as cirque troughs and complexes (Gordon 1977). Little lithological control has been identified, although there is a significant orientation, probably climatically controlled, of secondary cirques (Unwin 1973).

Early in the development of the Glacial Theory, the Llanberis Pass was identified as a major glacial trough cut through the Snowdonian massif. Buckland (1842) described this as one of the finest examples of glacial erosion he had seen, comparable to landforms in the Alps. The GCR site includes part of the narrow trough extending from Pen-y-Pass to Llyn Peris GCR site, although the landform as a whole extends north-west as an 8 km long rock basin containing Llyn Peris and Llyn Padarn. The breaching of the Snowdonian uplands at Pen-y-Pass, the modern-day watershed, shows that the dispersal centres of North Wales ice-sheets, at various times in the Pleistocene, lay south of the Snowdon and Glyderau massifs (for example, Greenly 1919; Addison 1983).

The Gwynant Valley is a spectacular U-shaped trough (Johnson 1962), into which ice from the Snowdon Horseshoe flowed. This valley is separated from Cwm Dyli by an impressive rock lip, leaving what is perhaps best described as a 'hanging cwm' (Embleton 1962). The precipitous slopes of Gallt-y-Wenallt make this one of the most impressive features of glacial erosion in North Wales.

Small-scale features of glacial erosion

Small-scale features of glacial erosion are developed within the Snowdon massif. The widespread development of striated bedrock surfaces, particularly within the Llanberis Valley, led to Ramsay's (1860) early study of ice movement directions within the area. More recently, similar features have allowed a large-scale reconstruction of patterns of such movement over Snowdonia (Gemmell *et al.* 1986).

Small-scale glacial erosional features are, however,

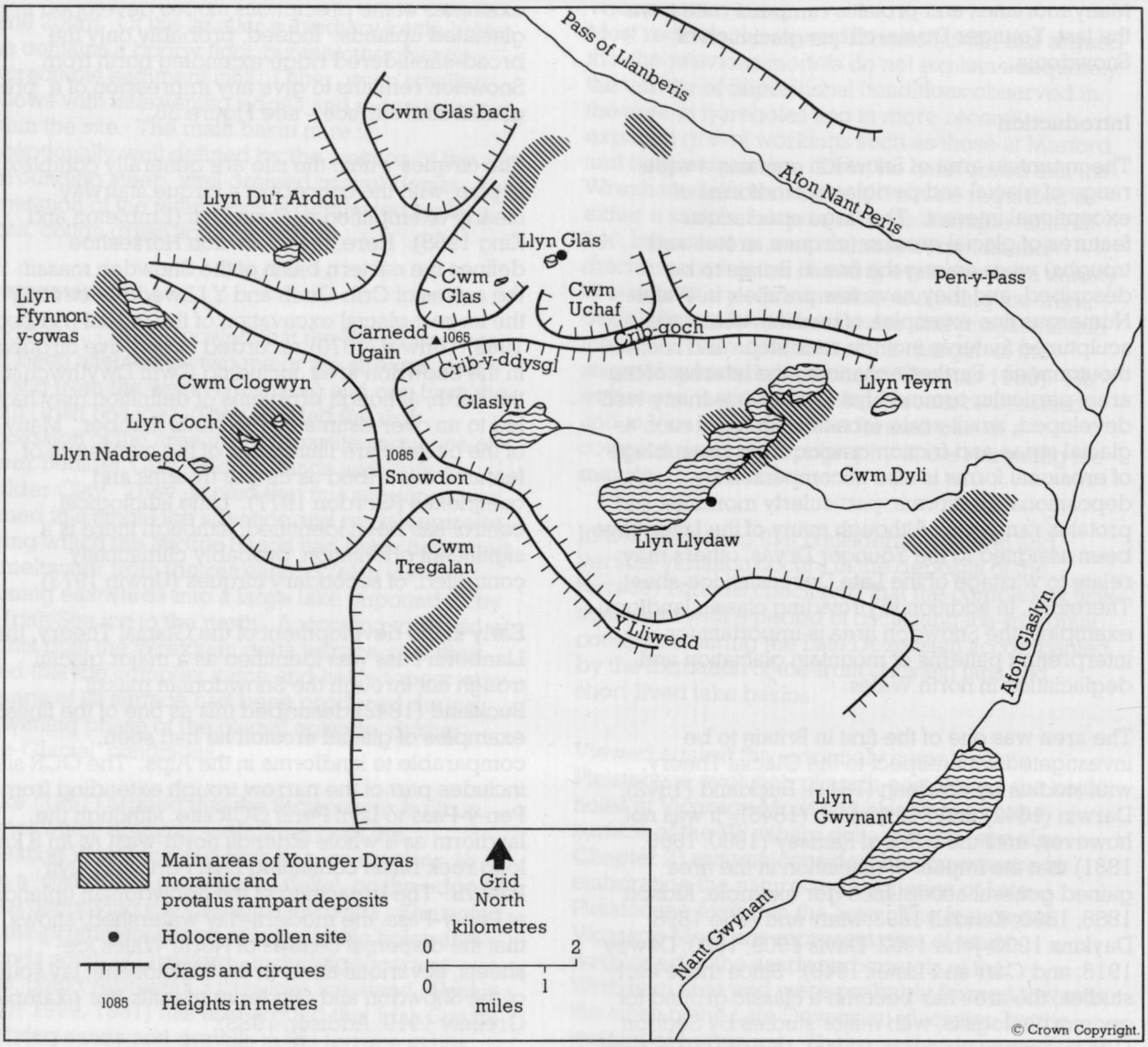

Figure 36 Snowdon (Yr Wyddfa): principal landforms

particularly well preserved in areas where bedrock surfaces have been protected from Holocene weathering, beneath for example, lake waters. Reductions in lake levels at Llyn Llydaw have revealed exceptionally fresh examples on the bedrock of ice erosion (Gray and Lowe 1982); excellent examples of abrasion and smoothing, with streamlined and striated bosses indicating a general easterly direction of former ice movement, can be examined. Roches moutonnées with clearly plucked facets are also visible. The importance of this particular area, however, lies in the small-scale features of subglacial erosion, including plastically-moulded forms (p-forms), well known from Scandinavia (Dahl 1965; Gjessing 1965) and North America (Gilbert 1906; Bernard 1971a, 1971b, 1972), but whose formation has yet to be adequately explained (Embleton and King 1975a). Other small-scale erosional features were noted (Gray and Lowe 1982), including grooves and channels and sichelwannen, possibly formed by subglacial meltwater, as well as friction cracks, gouges and striae. Gray *et al.* (1981) and Gray and Lowe (1982) have suggested that two dominant sets of crossing striae measured in Cwm Llydaw and adjacent areas can be related to different directions of ice movement: one set related to ice flow during the last recorded ice advance, during the Younger Dryas, the other to an earlier glacial event.

Depositional landforms

Glacial depositional landforms are well known (for example, Darwin 1842; Ramsay 1860; Kidson 1890; Kendall 1893; Marr and Adie 1898; Daykins 1900; Jehu 1902; Williams 1927). Recent work has elaborated the distribution of these landforms but it

has also raised questions concerning the processes responsible for their formation.
The first systematic mapping of moraines in Snowdonia was by Seddon (1957) who examined the palaeoclimatic factors responsible for their distribution. Pollen analyses made from cores in peat bogs both inside and outside the moraine arcs (Godwin 1955; Seddon 1962), led Seddon to argue that the moraines had formed during two separate phases – at some stage during the retreat of the Late Devensian ice-sheet and again during the Younger Dryas (*c.* 11,000 -10,000 BP). Unwin (1970) subsequently studied the distribution of cirques and cirque moraines using multi-variate analysis. He grouped the moraines into an older series of diffuse forms and a younger series of fresh forms; he further sub-divided both groups into glacial moraines and protalus ramparts. Unwin considered the older series features to have been formed during a readvance of ice in Pollen Zone I or during a recessive stage of the Late Devensian ice-sheet, and the younger series features during the Younger Dryas.

More recently, the depositional landforms of Snowdonia, including the Snowdon massif, were remapped and described in detail by Gray (1982a). In all, he mapped evidence for thirty five cirque glaciers, with glacial limits based on the distribution of end-moraines, boulder and drift limits and the down-valley extent of hummocky moraine. Detailed mapping in the region also indicated the presence of sixteen protalus ramparts, reflecting the former presence of semi-permanent snowbeds down to altitudes of 150m OD. Within the main Snowdon massif, Gray inferred the presence of six former cirque glaciers which he believed had formed during the Loch Lomond Stadial (Younger Dryas). Many of the landforms mapped by Gray cannot be classified simply as 'moraine' or 'protalus rampart'. Many limits are marked by diffuse bouldery or hummocky terrain, and several features are of complex origin; for example, the outer part of the large arcuate ridge in Cwm Tregalen (Figure 36) may be glacial in origin but the inner rim accumulated as a protalus feature by gravity sliding of debris (Gray 1982a).

Dating of moraines and protalus features

Relatively few of the glacial limits thus far identified (Unwin 1970; Gray 1982a) have been dated by radiocarbon and/or pollen analysis. Gray (1982a) suggested that a Loch Lomond Stadial age (Younger Dryas) is likely for the mapped cirque moraines in Snowdonia on the basis of stratigraphic and pollen investigations from the general area (for example, Godwin 1955; Seddon 1962; Burrows 1974, 1975; Crabtree 1970, 1972). However, only Ince's (1981, 1983) study from Cwm Llydaw provides confirmatory dating for moraines actually within the Snowdon GCR site. Radiocarbon dates and pollen analyses of basal samples inside the mapped cirque glacier limits at Cwm Llydaw (Gray 1982a) show that organic sedimentation commenced at *c.* 10,000 BP. This contrasts with sites at Clogwynygarreg and Llyn Goddionduon (Ince 1981) outside the mapped cirque glacier limit, where organic sedimentation began earlier, in the Devensian late-glacial. Collectively, these data provide strong constraints on the dating and extent of the last cirque glaciation of the uplands which occurred during the Younger Dryas. Such evidence is entirely consistent with recent studies in Scotland (for example, Sissons 1976, 1979; Gray and Lowe 1977).

Gray (1982a) generally doubted the widespread existence of pre-Loch Lomond Stadial (Younger Dryas) moraines (the older series of Unwin) in Snowdonia, but the nearby GCR site at Cwm Dwythwch provides evidence for such an 'older', large cirque moraine (Seddon 1962), with a typical late-glacial sequence behind.

Holocene environmental and vegetational history

Pollen studies at Cwm Llydaw (Ince 1981, 1983) provide a detailed record of vegetational and environmental changes during the Holocene. The record shows that after *c.* 10,000 BP the recently deglaciated uplands were colonised by grassland and open-habitat plant taxa. These early herbaceous communities were then invaded by juniper and birch, which were in turn replaced by birch and hazel woodland and, eventually, by forests of birch, pine, oak, elm and alder (Ince 1983). Altitudinal factors ensured the survival of many open-habitat taxa in the uplands throughout the Holocene. Deteriorating environmental conditions and human interference during mid to late Holocene times resulted in the gradual decline of forests in the uplands and the development of the open-grassland and heathland communities which characterise the area today (Ince 1981, 1983).

Periglacial landforms and features

Periglacial processes have been of major importance in shaping the Snowdonian landscape. Many landforms, types of patterned ground and other features attributable to frost-action, occur within the region. The range and scale of such features in the Snowdon site is not so great as in the Carneddau, but individual landforms and features are discussed by Ball and Goodier (1970) who mapped their morphology and distribution. These include widespread scree slopes of suggested late-glacial age (Ball 1966), a solifluction terrace and an indurated till horizon in Cwm y Llan (Fitzpatrick 1956; Ball and Goodier 1970), and impressive block screes in the Llanberis Valley near Pont-y-Gromlech where individual boulders the size of a small house occur.

Snowdon is important for a wide range of glacial and periglacial landforms. In particular, the site shows the best examples in Wales of large-scale landforms of glacial erosion, including a classic central horn surrounded by a group of radiating cirques abruptly divided by arêtes. This assemblage comprises some of the most spectacular glaciated topography in Wales, and indeed Britain, ranking favourably with parts of the Scottish Highlands in terms of intensity of erosion. In this respect, Snowdon contrasts markedly with the adjacent massif of Y Glyderau where the cirques show pronounced structural alignment, and to the Carneddau massif farther east where classic features of glaciation are less sharply defined and where the generally broad-shouldered landscape shows an unparalleled range of periglacial landforms and features. Of the Snowdon cirques, Cwm Dyli (the Snowdon Horseshoe) is a particularly fine example of a complex cirque with steep rock walls enclosing a series of lake basins and a varied assemblage of Younger Dryas moraines. These moraines indicate that the whole staircase from Glaslyn to the lip of Cwm Dyli was probably occupied by a single glacier – the largest Younger Dryas glacier in Snowdonia. The moraines also clearly demonstrate a recessional phase of this glacier as it retreated from Cwm Dyli towards Cwm Llydaw. Organic deposits from the site have helped in dating the moraines to the Younger Dryas, and the deposits also preserve an important record of vegetational changes in upland Wales during the Holocene. Cwm Dyli is also important for a wide range of well developed small-scale features of subglacial erosion, which help in determining the former directions of ice movement within the cirque during various glacial advances.

The spectacular large-scale landforms of glacial erosion here are some of the finest in Wales and were important for establishing the Glacial Theory in Great Britain. The site is also noted for a wide range of medium and small-scale glacial erosional forms as well as extremely varied depositional landforms. In particular, the site displays an outstanding assemblage of Younger Dryas moraines. The geomorphological interest of the site is enhanced by well developed periglacial landforms and by deposits which preserve important records of Holocene vegetational and environmental changes in upland North Wales.

Conclusions

Yr Wyddfa (Snowdon) displays internationally important landforms of glacial erosion and glacial deposition. These figured prominently in the debate and ultimate acceptance of the Glacial Theory in the British Isles a century and a half ago. Evidence for a glacier advance which only lasted for a thousand years, between 11,000 and 10,000 years ago, is important because it was caused by changes in the circulation in the North Atlantic Ocean. This information, together with cold-climate landforms and deposits, and evidence from pollen which shows climatic change, is important for reconstructing changes in climate over a wide area, and contributes to theories about future changes in climate.

Y Glyderau

Highlights

This major site shows outstanding examples of glacial landforms. Structurally controlled cirques, moraines and protalus ramparts combine to form some of the most spectacular glaciated scenery in Wales. Cwm Idwal, in particular, shows a diverse assemblage of features attributable to the final corrie glaciation of the region.

Introduction

Y Glyderau (the Glyders) are important for their assemblage of well developed glacial and periglacial landforms. The principal features include a series of impressive cirques, notably Cwm Idwal, and the classic glacial trough of Nant Ffrancon. Moraines are present in most of the cirques and some have been assigned on the basis of pollen analysis to the Younger Dryas. A number of the depositional landforms, for example in Cwm Idwal, are controversial in origin. The interest of the site is enhanced by well developed periglacial features, including a massive protalus rampart along the eastern flank of Nant Ffrancon, a fine series of vegetated periglacial stripes below Y Garn, numerous scree slopes, and the summit tors of Y Glyderau. The area was one of the first to be studied in Wales (for example, Darwin 1842; Mackintosh 1845; Ramsay 1860; Kidson 1888, 1890; Jehu 1902; Davis 1909) and has since featured in many geomorphological studies (Seddon 1957; Smith and George 1961; Embleton 1962, 1964a; Unwin 1970, 1973, 1975; Escritt 1971; Addison 1977, 1978, 1983, 1986, 1988; Watson 1977a; Gray *et al.* 1981; Campbell 1985b; Gemmell *et al.* 1986). Features in the area attributable to the Younger Dryas were recently described by Gray (1982a). The periglacial landforms of the site have been discussed by Ball and Goodier (1970). The area has featured in a number of studies of Devensian late-glacial and Holocene vegetational and environmental changes (Woodhead and Hodgson 1935; Godwin 1955; Seddon 1962; Switsur and West 1973; Burrows 1974, 1975; Evans and Walker 1977; Ince 1981, 1983).

Description and interpretation

The Glyderau lie east of the main Snowdon massif and west of the Carneddau. Bearing a similar range of large-scale features of glacial erosion to the Snowdon area (for example, cirques, arêtes, troughs), the Glyderau differ because the cirques show marked structural alignments (Unwin 1970, 1973): they show a preferred north-east orientation and open onto the trough of the Nant Ffrancon Valley. This striking glacial trough is enclosed at its upper end by a 'trough end', where a belt of grits and rhyolite crosses the valley (Watson 1977a). Examples of ice-smoothed bedrock and roches moutonnées are found in the area, especially to the north and east of Llyn Idwal. The Glyderau cirques and Nant Ffrancon were probably scoured by

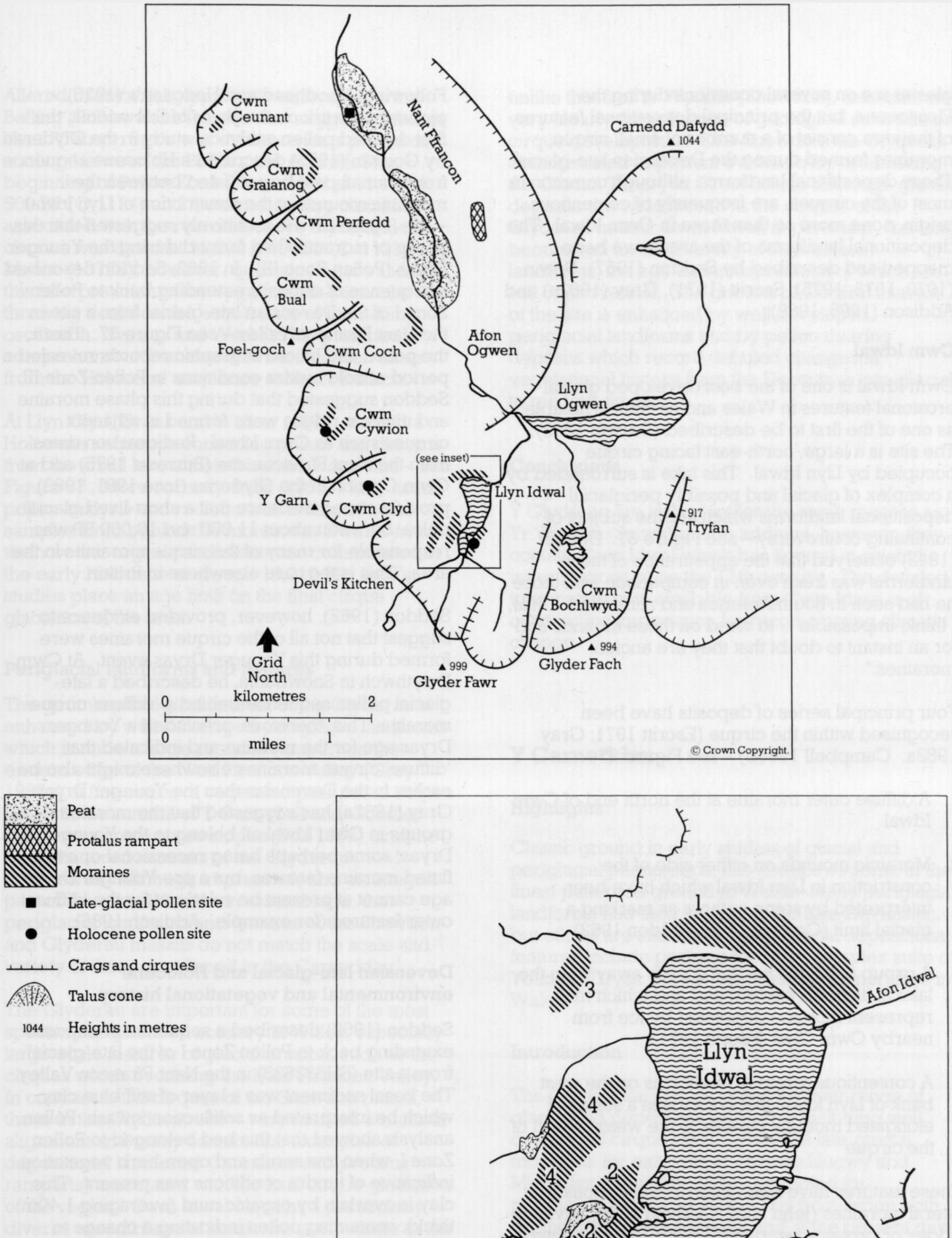

Figure 37 Y Glyderau: principal landforms (after Campbell 1985b)

glacier ice on several occasions during the Pleistocene, but the principal depositional features of the area consist of a number of small cirque moraines formed during the Devensian late-glacial. These depositional landforms, although common in most of the cirques, are frequently of contentious origin, none more so than those in Cwm Idwal. The depositional landforms of the area have been mapped and described by Seddon (1957), Unwin (1970, 1973, 1975), Escritt (1971), Gray (1982a) and Addison (1986, 1988).

Cwm Idwal

Cwm Idwal is one of the best developed glacial erosional features in Wales and as such is notable as one of the first to be described (Darwin 1842). The site is a large, north-east facing cirque occupied by Llyn Idwal. This lake is surrounded by a complex of glacial and possibly periglacial depositional landforms which are the subject of continuing controversy – see Figure 37. Darwin (1842) observed that the appearance of these landforms was fresh even in comparison with those he had seen in South America and remarked – "It is, I think, impossible ... to stand on these mounds and for an instant to doubt that they are ancient moraines."

Four principal series of deposits have been recognised within the cirque (Escritt 1971; Gray 1982a; Campbell 1985b) – see Figure 37 –

1 A diffuse outer moraine at the north end of Cwm Idwal

2 Morainic mounds on either side of the constriction in Llyn Idwal which have been interpreted by some authors as marking a glacial limit (Godwin 1955; Seddon 1962)

3 A group of landforms that curves away from the lake at its north-eastern end and which may represent moraine deposited by ice from nearby Cwm Clyd (Escritt 1971)

4 A contentious group of landforms on the west bank of Llyn Idwal that comprises a series of elongated mounds parallel to the western wall of the cirque

These features have been interpreted variously as lateral moraines (Jehu 1902; Godwin 1955), nivation ridges or protalus ramparts (Unwin 1970) or fluted moraine ridges (Gray *et al.* 1981). More recently, Addison (1986) mapped three further groups of features.

Dating the moraines

The traditional interpretation of landforms in Cwm Idwal is simply of an older series moraine at the lip of Cwm Idwal, and a younger series moraine (Younger Dryas) at the constriction half-way along Llyn Idwal (Seddon 1957, 1962; Unwin 1970, 1975). Despite pollen analyses and radiocarbon dating at a number of sites, the sequence of events is still unresolved.

Following Woodhead and Hodgson's (1935) pioneering work on the peats of Snowdonia, the first detailed pollen analytical study in the Glyderau by Godwin (1955) described a Holocene sequence from a small peat bog situated between the morainic mounds at the constriction of Llyn Idwal – see Figure 37. He tentatively suggested that this group of moraines had formed during the Younger Dryas (Pollen Zone III). In 1962, Seddon described a sequence of deposits extending back to Pollen Zone I of the Devensian late-glacial from a site in the Nant Ffrancon Valley – see Figure 37. There, the pollen and lithostratigraphic records revealed a period of cold tundra conditions in Pollen Zone III. Seddon suggested that during this phase moraine and nivation ridges were formed in adjacent cirques such as Cwm Idwal. Radiocarbon dates from the Nant Ffrancon site (Burrows 1975) and at Cwm Cywion in the Glyderau (Ince 1981, 1983) provide strong evidence that a short-lived glacial pulse, between about 11,000 and 10,000 BP was responsible for many of the cirque moraines in the area. This is the case elsewhere in Britain.

Seddon (1962), however, provided evidence to suggest that not all of the cirque moraines were formed during this Younger Dryas event. At Cwm Dwythwch in Snowdonia, he described a late-glacial pollen sequence behind a 'diffuse' cirque moraine. This, therefore, precluded a Younger Dryas age for the moraine and indicated that 'diffuse' cirque moraines elsewhere might also be earlier in the Devensian than the Younger Dryas. Gray (1982a) has suggested that the moraine groups in Cwm Idwal all belong to the Younger Dryas, some perhaps being recessional or even fluted moraine features, but a pre-Younger Dryas age cannot at present be ruled out for the 'diffuse' outer features (for example, Addison 1986).

Devensian late-glacial and Holocene environmental and vegetational history

Seddon (1962) described a sequence of deposits extending back to Pollen Zone I of the late-glacial from a site (SH632633) in the Nant Ffrancon Valley. The basal sediment was a layer of stiff blue clay, which he interpreted as solifluction inwash. Pollen analysis showed that this bed belonged to Pollen Zone I, when low scrub and open-herb vegetation indicative of tundra conditions was present. This clay is overlain by organic mud (averaging 1.40m thick), containing pollen indicating a change to open-birch woodland in Pollen Zone II. Above is a second solifluction clay in which a rapid decline in tree pollen shows a return to tundra conditions in Pollen Zone III. During this cold phase, moraine and nivation ridges (protalus ramparts) were formed in adjacent cirques. Overlying beds at Nant Ffrancon are wholly organic passing up into a modern raised *Sphagnum* and *Eriophorum* bog.

The Nant Ffrancon site was also investigated by Burrows (1974, 1975) who examined plant macrofossils and provided radiocarbon dates from the late-glacial sequence. Burrows revealed the occurrence of what he considered to be a pre-

Allerød interstadial, apparently equivalent to the Bølling (Pollen Zone Ib). He also suggested that at Nant Ffrancon there was evidence for a period of cooling between the Bølling and Allerød. The beginning of Pollen Zone II was dated at 11,900 ± 500 BP (Q-1124) and the deteriorating climate associated with the recrudescence of ice in local cirques was dated at 11,000 ± 400 BP (Q-1123). Moore (1975b), however, questioned the validity of this interpretation of the sequence, in particular throwing doubt on the occurrence of the Bølling oscillation. Switsur and West (1973) provided a comprehensive framework of radiocarbon dates from the Holocene sequence at Nant Ffrancon.

At Llyn Clyd, Evans and Walker (1977) studied a Holocene sequence containing pollen and diatoms from the small lake situated behind a moraine – see Figure 37. More recently, Ince (1981, 1983) used pollen analysis and radiocarbon dating of basal samples from behind the moraine at Cwm Cywion to show that organic sedimentation commenced in the early Holocene at around 10,000 BP. Ince's studies place an age limit on the final cirque glaciation of the area.

Periglacial landforms and features

The geomorphological interest of the Glyderau is enhanced by well developed periglacial landforms which include a large protalus rampart on the eastern edge of the Nant Ffrancon Valley (Gray 1982a), a fine series of vegetated periglacial stripes beneath the summit of Y Garn (Ball and Goodier 1970), numerous scree slopes (Ball 1966), and the frost-shattered summits of the Glyderau themselves. Although impressive, and an integral part of the overall landform assemblage, the periglacial landforms and features of the Snowdon and Glyderau massifs do not match the scale and variety of those developed in the Carneddau.

The Glyderau are important for some of the most spectacular glaciated scenery in Wales, especially large-scale features of glacial erosion, such as the cirques which overhang the Nant Ffrancon Valley. In contrast to the cirques of the Snowdon massif, those in the Glyderau show very marked structural alignment and many contain fine examples of depositional landforms (moraines and protalus ramparts) associated with the final cirque glaciation of the region. Cwm Idwal contains a particularly diverse assemblage of landforms attributable to the Younger Dryas. The controversial nature and age of some of these landforms make the site of considerable interest.

The Glyderau also contain important Devensian late-glacial and Holocene deposits which not only help to constrain the ages of moraines in the area, but also provide detailed records of vegetational and environmental changes in upland Wales. Many of these changes have been calibrated with radiocarbon dating.

The large-scale features of glacial erosion within Y Glyderau are some of the finest in Wales, and unlike those of Yr Wyddfa (Snowdon), demonstrate very clearly the influence of geological structure on cirque development. Like Snowdon, the Glyderau demonstrated important evidence for establishing the Glacial Theory in Great Britain. Although glacial deposits are widespread in the cirques of the Glyderau massif, Cwm Idwal, in particular, has long been noted for its diversity of depositional landforms, the age and interpretation of which are still controversial. The geomorphological interest of the site is enhanced by well developed periglacial landforms and by pollen bearing deposits which record detailed changes in vegetational history from the Devensian late-glacial to modern times.

Conclusions

Y Glyderau are important for the same reasons as Yr Wyddfa (Snowdon). In addition, however, they contain Cwm Idwal which has figured in scientific investigations since the 17th century. The detailed information now available from Cwm Idwal is of outstanding importance for reconstructing climatic change.

Y Carneddau

Highlights

Classic ground in early studies of glacial and periglacial phenomena, this site shows some of the finest patterned ground in Wales. Many periglacial landforms had their origins in the Late Devensian but others are still active. Late-glacial depositional features include perhaps the most complex suite of Younger Dryas, final cirque glaciation, moraines in Wales.

Introduction

The Carneddau are important for their range of glacial and periglacial landforms including well developed cirques and Devensian late-glacial moraines, for example at Ffynnon Llugwy and Melynllyn. The Carneddau are noted for periglacial landforms formed by frost-action both during the Late Pleistocene and at the present day (Pearsall 1950; Tallis and Kershaw 1959; Ball 1966; Ball and Goodier 1970; Scoates 1973). Like Snowdon and the Glyderau, the area was one of the first to be studied with respect to the Glacial Theory (for example, Buckland 1842; Mackintosh 1845; Ramsay 1860, 1881; Kidson 1898; Marr and Adie 1898; Jehu 1902). It has featured in geomorphological studies by Seddon (1957), Embleton (1962, 1964a), Unwin (1970, 1973, 1975) and Gray (1982a), and evidence from selected sites within the area provides the basis for reconstructing environmental and vegetational history (Woodhead and Hodgson 1935; Thomas 1972; Walker 1978).

Description and interpretation

The Carneddau lie east of the Glyderau and Snowdon massifs and form the largest area of upland Wales over 900m OD. To the west the range is bounded by the Nant Ffrancon trough, to the east by the Conway Valley and to the north by the coastal plain. The character of the landscape is markedly different to the Glyderau and Snowdon groups of the northern Snowdonian massif, being less highly dissected by large-scale features of glacial erosion. Nonetheless, Unwin (1975) recognised nineteen cirques within the Carneddau, including several examples such as Cwm Lloer and Cwm Ffynnon Llugwy with a convincing staircase of forms. Morphologically the cirques of this range vary considerably from large, semi-circular and over-deepened forms such as those at Dulyn and Melynllyn, to rounded and shallow hollows such as those at Moch and Bychans (Unwin 1975). In contrast to the Glyderau where the dominant cirque orientation is along the strike with the cirque floors excavated in less resistant strata, the Carneddau cirques show considerable variation in relationship to structure. The over-deepened form at Dulyn (Figure 38) is particularly exaggerated, with Jehu's (1902) soundings showing the cirque lake to be 57m deep.

The massif was probably occupied by ice and acted as a dispersal centre on a number of occasions during the Pleistocene, and it also displays significant evidence for a late phase of cirque glacier development. The cirque moraines of the area have been mapped and discussed by Seddon (1957), Unwin (1970, 1973, 1975) and Gray (1982a), and most are believed to have formed during the Younger Dryas (between *c.* 11,000-10,000 BP).

Of the cirque forms included within the GCR site, those at Melynllyn, Dulyn and Cwm Ffynnon Llugwy (Figure 38) are particularly notable, both as erosional forms, and for their unusually diverse range of associated depositional landforms of Younger Dryas age. A particularly fine example of a drift and boulder limit with several recessional moraines behind occurs in Cwm Ffynnon Llugwy (Gray 1982a). Here, Gray traced the limit of a former glacier for about 900m on the west side of the valley, although comparable evidence from the eastern side was absent. At *c.* 630m OD a lateral moraine complex, covered with boulders, occurs south of Craig-y-Llyn cliffs. Below about 530m OD the extent of the former glacier is marked by drift and boulders that run across the valley floor to reach Afon Llugwy. The river at this point is incised into what Gray interpreted as a small marginal glacial meltwater channel. Inside the glacial limit the ground appears to be a chaos of morainic undulations and boulder spreads. However, Gray was able to trace at least five ridges marking successive stages in ice recession. A sequence of recessional features associated with the retreating ice mass also occurs north of the reservoir. The depositional landforms in Cwm Ffynnon Llugwy were formed by the largest glacier of Younger Dryas age in the Carneddau range (Gray 1982a).

In contrast, the ice limit in the nearby Melynllyn cirque is marked by an unusual, straight and virtually boulder-free moraine (Gray 1982a). At Cwm Dulyn, however, the drift limit is again complex; there is a striking contrast between the mass of blocks and boulders inside the northern limit and the smooth, peat-covered slopes outside (Gray 1982a). Southwards, the limit grades into a series of low (<1m), boulder-covered, end-moraine ridges, from which at least three recessional positions can be recognised (Gray 1982a).

Periglacial landforms and features

The Carneddau Mountains contain a range of periglacial landforms and features probably unparalleled elsewhere in Wales, although the inaccessibility of the area has meant that relatively few studies have been carried out (Pearsall 1950; Tallis and Kershaw 1959; Ball 1966; Ball and Goodier 1970; Scoates 1973). The distribution of the main features is shown in Figure 38.

Pearsall (1950) was the first to record patterned ground in the Carneddau; on the broad saddle (Waun-y-Garnedd) connecting Foel Grach with Carnedd Llewellyn, where he described a series of stone polygons and stripes. These were later studied by Tallis and Kershaw (1959) who concluded that the polygonal patterns were unstable, showing rapid rearrangements because of fluctuating climatic conditions, particularly the erosive influence of wind and rain. Ball and Goodier (1970) recorded a graduated sequence of features ranging from well defined polygons, through elongated polygons to rather sinuous sorted stripes, in each case with a repeat distance of some 0.30-0.45m. They showed that over a number of seasons the patterns were less active than when observed by Tallis and Kershaw (1959). They also noted that such features were absent at lower altitudes in Snowdonia, and concluded that the present climate could only sustain patterned ground at the highest altitudes (that is above 900m). This was supported by a study of periglacial features throughout the Carneddau which confirmed that all polygons were found, without exception, above altitudes of 913m (3,000 ft), on volcanic rocks, and always in groups on flat or nearly flat areas (<2° of slope) (Scoates 1973).

Scoates also described sorted nets (patterned ground transitional between circles and polygons) on a number of other flat summit tops (for instance, Drosgl and Llwydmor) and low angle slopes (for instance, Foel Fras) at high altitude. Patterned ground in the form of stone stripes was also recorded, with good examples at Foel Fras and on the back wall of Cwm Ffynnon Llugwy. No conclusions were drawn about the distribution of these features with regard to altitude and aspect, although most of the stripes showed a north-west aspect above 770m (2,500 ft).

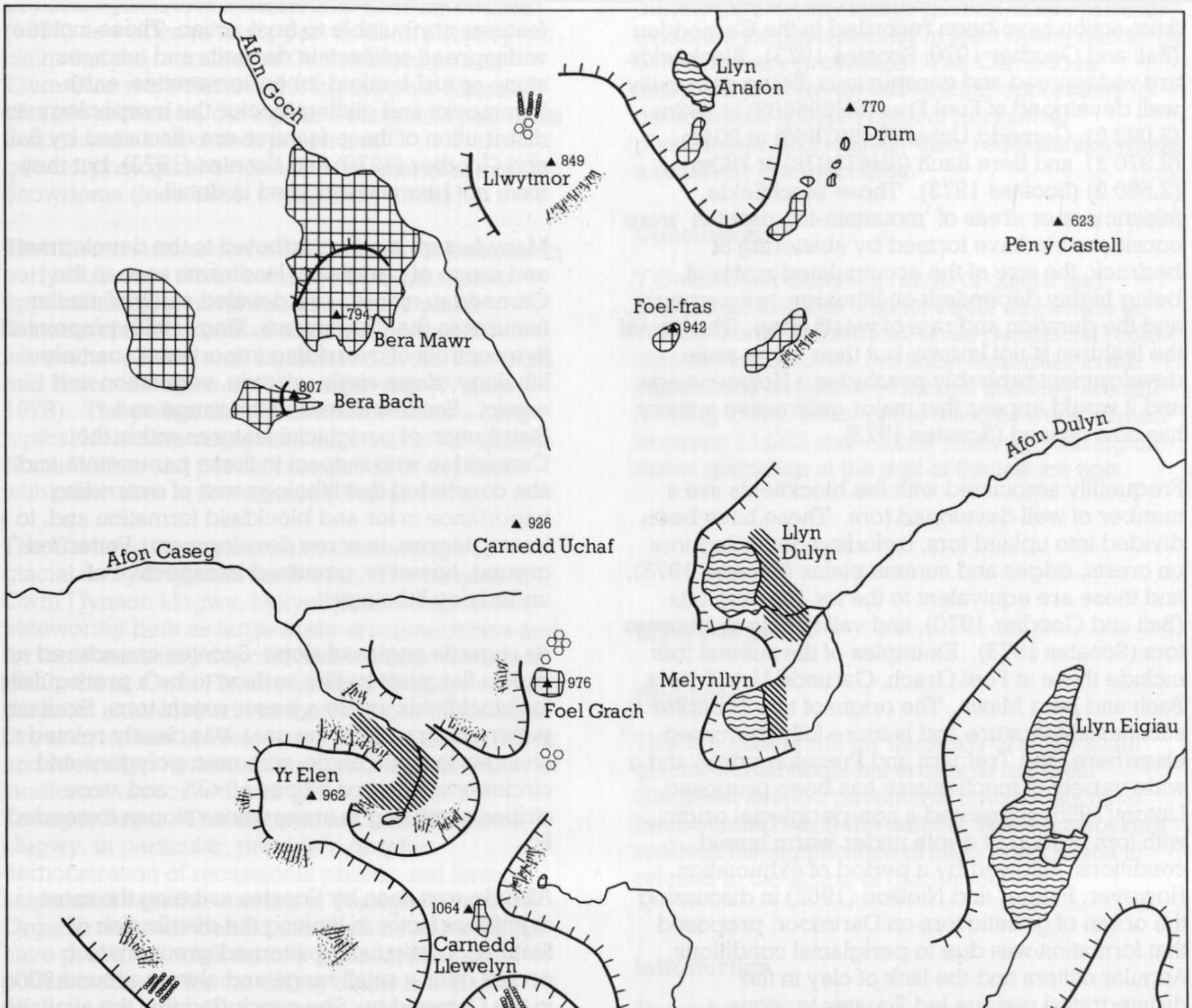

Figure 38 Y Carneddau: principal landforms

A wide range of other features associated with frost-action have been recorded in the Carneddau (Ball and Goodier 1970; Scoates 1973). Blockfields are widespread and conspicuous, being especially well developed at Foel Fras (SH696683) at 942m (3,092 ft), Garnedd Uchaf (SH687668) at 904m (2,970 ft), and Bera Bach (SH673678) at 780m (2,560 ft) (Scoates 1973). These blockfields, felsenmeer or areas of 'mountain-top detritus' were considered to have formed by shattering of bedrock, the size of the accumulated material being highly dependent on lithology, temperature and the duration and rate of weathering. The age of the features is not known, but their large-scale development probably precludes a Holocene age, and it would appear that major gelifractive activity has now ceased (Scoates 1973).

Frequently associated with the blockfields are a number of well developed tors. These have been divided into upland tors, including degraded tors on crests, ridges and summit plains (Scoates 1973), and these are equivalent to the tor-like summits (Ball and Goodier 1970), and valley side or buttress tors (Scoates 1973). Examples of the summit tors include those at Foel Grach, Garnedd Uchaf, Bera Bach and Bera Mawr. The origin of tors occupies a substantial literature and is more fully discussed elsewhere (see Trefgarn and Preseli reports) and a wide variety of mechanisms has been proposed. Linton (1955) suggested a non-periglacial origin; with tors formed at depth under warm humid conditions, followed by a period of exhumation. However, Palmer and Nielson (1962) in discussing the origin of granitic tors on Dartmoor, proposed that formation was due to periglacial conditions. Angular clitters and the lack of clay in the disintegrated residue led Scoates to argue a periglacial origin for features in the Carneddau. However, it is likely that weathering products from any chemical weathering phase would have been removed from the exposed watershed locations, although Ball (1964) described the weathering product gibbsite, a clay mineral from the feldspars of the microporphyritic granite on Y Llymllwyd (SH631609) in the Glyderau. Other workers (for example, Jahn 1962), however, have stressed the importance of rock structure rather than climatic factors in tor formation, and in this context Scoates (1973) noted that jointing had played an important role in the formation of the tors at Bera Mawr and Bera Bach.

One of the most extensive landforms associated with frost-action in the Carneddau is scree. Particularly extensive and well developed examples are found in Cwm Ffynnon Llugwy and around the slopes of Yr Elen. The characteristics of these features have been described in detail by Ball (1966), Ball and Goodier (1970) and Scoates (1973). Ball (1966) suggested that the Carneddau screes, in common with those elsewhere in Mid and North Wales, dated from Pollen Zones I and III of the Devensian late-glacial, and that re-sorting, rather than accretion of freshly shattered rock, was the dominant contemporary process.

The Carneddau also contain a wide range of other features attributable to frost-action. These include widespread solifluction deposits and terraces, stone or turf-banked lobes, terracettes, earth-hummocks and gliding blocks; the morphology and distribution of these features are discussed by Ball and Goodier (1970) and Scoates (1973), but they have not been investigated in detail.

Many factors have contributed to the development and range of periglacial landforms seen in the Carneddau massif. In a detailed study of similar features in the Cairngorms, King (1968) pinpointed five controls of overriding importance, namely lithology, slope angle, altitude, vegetation and aspect. Scoates assessed the range and distribution of periglacial features within the Carneddau with respect to these parameters and she concluded that lithology was of overriding importance in tor and blockfield formation and, to a lesser degree, in scree development. Patterned ground, however, occurred irrespective of underlying lithology.

As regards angles of slope, Scoates considered an almost flat, plateau-like surface to be a prerequisite for blockfields and to a lesser extent tors. Similarly, patterned ground in the area was clearly related to changes in slope angle, with nets, polygons and circles occurring on slopes of <3°, and stone stripes occurring in areas where slopes exceeded 5°.

Altitude was seen by Scoates as being the most significant factor in limiting the distribution of features, particularly patterned ground which occurs over a small range and always around 900m in the Carneddau. She concluded that the available evidence did not emphasise any particular correlation of periglacial features with aspect, save for the lack of westerly-facing phenomena. The effect of vegetation was also similarly difficult to assess.

Holocene environmental and vegetation history

With the exception of Woodhead and Hodgson's (1935) preliminary study of selected peats and Thomas' (1972) inventory of diatomaceous deposits, the Carneddau have received surprisingly scant attention in studies of vegetational change. Walker's (1978) study of diatoms and pollen from a sediment profile at Melynllyn provides the only detailed record of such changes in the Carneddau. She obtained pollen and diatoms from two cores from the bottom deposits of Cwm Melynllyn, situated behind the moraine. Also obtained from the profile were materials yielding six radiocarbon dates.
The stratigraphy of the sediments at Melynllyn compares closely with a profile described by Evans and Walker (1977) from Llyn Glas, in the Snowdon massif: at both sites the lowest deposit sampled is a clay with a typical post-Allerød (post Devensian late-glacial interstadial) pollen assemblage. The apparent absence of any earlier

deposits within these basins was used by Walker (1978) as evidence to support Seddon's (1957) claim that the moraines at Cwm Melynllyn and Cwm Glas were formed during the post-Allerød climatic recession, during the Younger Dryas. This is consistent with dated, pollen and geomorphological evidence from elsewhere in Snowdonia (Ince 1981, 1983; Gray 1982a).

The diatom succession at Melynllyn indicates that in early Holocene times a change from alkaline to approximately neutral conditions took place. Diatoms characteristic of acidic, oligotrophic waters have been well established in the lake from mid Holocene times to the present day (Walker 1978). The pollen data from the site show a fairly typical Holocene vegetation succession for upland North Wales, and permit correlation of deposits with other sites in Snowdonia (Walker 1978).

The Carneddau demonstrate a wide range of glacial and periglacial landforms. The cirques at Cwm Ffynnon Llugwy, Melynllyn and Dulyn are noteworthy both as large-scale erosional forms and for the contrasting depositional features contained within them: Cwm Ffynnon Llugwy displays one of the most extensive and complex suites of Younger Dryas moraines in Wales, and the features at Dulyn and Melynllyn further serve to show the diversity of landforms associated with glacial limits of the Younger Dryas. The features at Cwm Ffynnon Llugwy, in particular, provide a graphic demonstration of recessional phases and limits associated with the wasting of Younger Dryas ice. Organic deposits behind the moraine at Melynllyn have provided confirmatory radiocarbon and pollen evidence for the dating of this last glacial phase in the area. The deposits at Melynllyn also provide an important record of vegetational changes in this part of upland Wales during the Holocene.

The Carneddau are perhaps of the greatest interest for the wide range and fine development of landforms associated with frost-action and former periglacial conditions. Stone polygons developed at Waen-y-Garnedd are the finest features of their kind in Wales. Blockfields, tors, scree slopes, and a variety of patterned ground and related forms are also well developed, providing an unparalleled assemblage in Wales. Their dating, however, is problematical and although many may have formed during the Devensian late-glacial, others, such as stone polygons, are still active. The site provides a complementary range of features to those described in the Rhinog Mountains and at Moelwyn Mawr.

Cwm Ffynnon Llugwy contains one of the most impressive and diverse assemblages of landform features and moraines formed in the Younger Dryas. However, the Carneddau area is most important for a wide range of periglacial landforms unparalleled elsewhere in Wales. Small sorted stone polygons at the site are one of the finest examples in Great Britain. Although many of the periglacial landforms were probably formed during the Devensian late-glacial, others provide evidence for formation, or at least maintenance, by contemporary processes. The Carneddau therefore provide an outstanding opportunity to demonstrate a wide range of periglacial phenomena, and to study their relationships within a relatively compact area.

Conclusions

Y Carneddau contain a range of glacial and periglacial features without equal elsewhere in Wales. Some of the small-scale periglacial (cold-climate) features are the finest examples in the British Isles and show evidence that they are still forming today. Many of the features were formed between 11,000 and 10,000 years ago during the minor glaciation at the end of the last ice age.

Llyn Peris

Highlights

This is a classic site for the study of small-scale glacial and fluvioglacial erosional features. Glaciated striated pavements hereabouts have been studied since the earliest Victorian workers realised the significance of such phenomena in relation to the action of glacier ice.

Introduction

The shores of Llyn Peris are important for exceptionally fine examples of glaciated bedrock surfaces and small-scale forms of glacial erosion. Although it is some 13,000 years at least since the area was last glaciated, features including glacial striae, friction cracks, sichelwannen and sinuous grooves and channels have been remarkably well preserved from subaerial weathering beneath the lake waters. Glacial striae were first described in the Llanberis Valley by Ramsay (1860, 1881), and the late-glacial and Holocene deposits of the Peris-Padarn area were described by Tinsley and Derbyshire (1976) and Derbyshire (1977). A detailed account of the glacial erosional forms at Llyn Peris was given by Gray (1982b) and similar features in adjacent areas were described by Gray and Lowe (1982). The site was mentioned by Addison (1983) in an account of the classic glacial landforms of Snowdonia, and has also featured in a study of ice movement directions (Gemmell *et al.* 1986).

Description

The existence of well developed glacial erosional features, including roches moutonnées and glacial striae, has long been known from the Llanberis Pass in Snowdonia. As long ago as 1860, Ramsay described the distribution of striae in the Llanberis Valley and interpreted the former directions of ice movement. Recent construction of the Dinorwic hydro-electric power scheme has afforded a rare opportunity to study unweathered glaciated bedrock. During construction work, the lake levels were lowered both in the upper lake of the storage scheme (Marchlyn Mawr) and in the lower reservoir at Llyn Peris. The small-scale erosional features exposed at these sites have been described by Gray and Lowe (1982) and Gray (1982b).

Llyn Peris and Llyn Padarn occupy an over-deepened basin towards the lower end of the Llanberis glacial trough. There was once one lake but this was divided by an alluvial fan near Pont-y-Bala. At both ends of Llyn Peris, boreholes reveal considerable depths of sediment – lake rhythmites, sands, gravels, organic lake muds, wood debris and peat (Tinsley and Derbyshire 1976; Derbyshire 1977). Cambrian slate and sandstone bedrock, preserving a wide range of glacial erosional features is exposed along the lake margins. Gray's (1982b) description of the site pertains to the low lake levels experienced during construction of the HEP scheme, although substantial areas of glaciated bedrock are still visible even at relatively high lake levels.

Three chief areas of exposed bedrock bear significant evidence for glacial and fluvioglacial erosion processes. The first lies on the north shore of Llyn Peris at the eastern end of the lake (SH599591); the only stretch of the north shore not obscured by slate spoil. The bedrock surface here is heavily abraded and striated. Large, steeply sloping slabs of slate up to 10m high show that ice moved upwards against these obstacles at angles of 5-10°, and abraded lee slopes in this area frequently show a conspicuously stepped appearance as a result of rapid changes in lithological composition. Smoothed cavities on lee slopes can also be seen, and these bear witness to fluvioglacial smoothing in cavities beneath the ice. The unusual feature of a trench following an igneous dyke occurs at this site. The trench, 1-1.5m deep, runs transverse to the valley and the main down-valley trend of the striae. The trench also carries striae parallel to its trend.

The second main glaciated bedrock area, bearing a similar range of features, stretches along the southern shore between SH597589 and SH589594, and a smaller area carrying comparable features occurs on the shores below Dolbadarn Castle (SH588597 to SH586599).

Interpretation

The Llanberis trough was probably last glaciated during the Late Devensian, and a series of radiocarbon dates from deposits at Pont-y-Bala and East Peris (Shotton *et al.* 1975; Tinsley and Derbyshire 1976) dates the thick sediment sequence to the Devensian late-glacial and the Holocene. The basin could not therefore have been glaciated during the Younger Dryas, and the erosional features described by Gray (1982b) from Llyn Peris were most probably caused by Late Devensian ice.

Gray (1982b) considered that abraded bedrock was the most striking feature of the floor of Llyn Peris, noting that the homogenous fine-grained slate was particularly susceptible to subglacial scratching and polishing. He measured the orientations of striae at a number of locations on flat bedrock surfaces, confirming the expected down-valley trend of ice movement. However, small deviations of movement were also recorded, showing that the ice had changed direction as it moved north-west along the trough. In particular, once the ice had passed the steep confining slopes below Gweithdy (SH593590), it appears to have swung into the bay on the south-west shore as it became less constricted, moving into the wider valley where Llanberis is now situated. Other smaller-scale features influencing striae trends were also noted, including the trench running transverse to the main trend of the striae (with striae in the trench running parallel to the orientation of the trench), and several linear joint-controlled grooves bearing curved striae. These features appear to have controlled locally the streaming of basal ice and debris layers. Differential erosion had occurred as a result of lithological changes and jointing, as well as in response to the local occurrence of iron pyrite crystals which had caused small-scale 'crag and tail' forms (Gray 1982b).

Gray also described irregularly-shaped transverse marks at Llyn Peris, which had given the rock surface at many localities a rough appearance perpendicular to ice movement, probably as the result of bedrock fracture or crushing. Other locations were described where fracturing and plucking had been facilitated by cleavage and jointing in the slate.

The role of meltwater in eroding the bedrock surface was discussed by Gray: many sharp edges had been rounded off, and smoothed 'lee' faces with small shallow bowls were also commonly displayed. Because such features resembled meltwater-produced forms observed in cavities beneath the glacier d'Argentière in the French Alps (Vivian and Bocquet 1973), Gray considered this was also probably the most likely mechanism for widespread smoothing of lee slopes at Llyn Peris.

Other erosional forms including features resembling sichelwannen (Sugden and John 1976, Figure 15.1) and sinuous channels and grooves with striated floors were described by Gray from Llyn Peris. The latter were likened to 'p-forms' studied by Gray (1981) on Mull, which he considered had resulted from meltwater corrasion and/or cavitation, with active ice later moving through the channels to striate them. The processes of till squeezing, the movement of till as a semi-saturated mass under pressure beneath the ice (Gjessing 1965), or direct glacial abrasion (Boulton 1974) were also considered as alternative explanations.

Llyn Peris shows some of the finest glaciated bedrock surfaces in Britain. Examples of abrasion, bedrock fracture, plucking and meltwater erosion are found at the site, including a great diversity of typical small-scale erosional features such as striae and friction cracks. The interest of the site is enhanced by the presence of possible sichelwannen features and sinuous grooves and channels, perhaps formed by subglacial meltwater. Recent studies of the assemblage of features at Llyn Peris have shown that the standard view of glacial bedrock erosion occurring by the twin processes of 'abrasion' and 'plucking' is an over-simplification. From evidence at Llyn Peris, it is clear that bedrock fracture, particularly in highly-cleaved rocks, and meltwater erosion are also important processes. The process of erosion by the squeezing of subglacial till may also have contributed to the formation of some features.

Conclusions

The wide range of small-scale erosional features displayed at Llyn Peris and their remarkable state of preservation, make the site probably the finest of its kind in Britain and of exceptional interest to geomorphologists. The site provides a unique opportunity, in a country that has no present-day glaciers, to study former glacial and fluvioglacial erosion processes and resultant bedrock forms.

Cwm Dwythwch

Highlights

A key site that provides evidence of Late Devensian glaciation prior to the last, Younger Dryas, glacial event; either during a readvance of the dwindling Devensian ice-sheet or as part of a separate glacial pulse.

Introduction

Cwm Dwythwch (SH570580) is a unique site in North Wales with evidence for a possible stadial early in the Devensian late-glacial. It is the most northerly cirque in the Snowdon (Yr Wyddfa) massif and is occupied by a large lake impounded behind an impressive moraine. The moraine is more subdued (rounded and indistinct) in appearance than many of the typically steep-sided Younger Dryas moraines in the region. Pollen analysis from an infilled part of the lake has revealed a late-glacial profile dating back to Pollen Zone I. This is the only moraine in Wales that has been shown, by pollen analysis, to date from the early part of the Devensian late-glacial. The site has been mapped and described by Seddon (1957) and Unwin (1970), and a detailed study of the pollen biostratigraphy was carried out by Seddon (1962).

Description

Cwm Dwythwch is a massive compound cirque with four subsidiary cirques, and a lake, Llyn Dwythwch, situated at about 280m OD (Seddon 1957). The subsidiary cirques with floors at approximately 450m OD, also contain possible morainic accumulations (Gray 1982a). The main and the subsidiary cirque forms show a strong orientation to the north-east, towards the Llanberis Valley. The compound cirque back wall is cut into the peaks of Moel Eilio (726m), Foel Gron (593m) and Foel Goch (605m). A broad tract of alluvium covered by *Sphagnum-Polytrichum* bog extends from the west side of the lake to the head of the cirque. Boulder strewn areas surround the lake, except on its east side, where the base of the massive terminal moraine impounds the lake (Seddon 1962).

From a borehole core, Seddon (1962) described an 8.4m thick sequence (at SH568580), commencing with a basal layer of stiff blue clay, overlain by the friable grey-buff mud, succeeded by a further clay layer; making up the three-fold sequence that Seddon suggested was typical of late-glacial sites elsewhere in North-West Europe. The upper clay was succeeded by a sequence of wholly organic muds derived from successive phases in the development of aquatic vegetation (Seddon 1962).

Interpretation

Seddon (1962) interpreted the basal blue clay at Cwm Dwythwch as material soliflucted from surrounding slopes during a relatively cold climatic phase. Pollen from this bed shows a dominance of herb vegetation with few trees, with sea buckthorn, juniper and dwarf birch forming a low scrub in the otherwise open swards of herbs. Seddon correlated this assemblage with conditions characteristic of Pollen Zone I of the Late Devensian late-glacial.

The succeeding highly organic muds showed pollen characteristic of climatic improvement in the Allerød (Pollen Zone II). The Cwm Dwythwch pollen shows a marked increase of tree birches at that time, perhaps to a state best described as 'park-tundra' rather than true birch woodland; with herb vegetation still predominant but with a notable increase in meadowsweet *Filipendula*, indicating warmer conditions.

The beginning of Pollen Zone III is marked by a rapid decline of *Betula* pollen and of the ratio of arboreal pollen to non-arboreal pollen. Seddon considered this indicated the onset of less favourable climatic conditions and a tundra environment, with trees perhaps surviving only in the most sheltered locations. The end of this zone is terminated abruptly by almost pollen-barren clastic sediments, reworked by solifluction into the

lake. Seddon argued that it was at this time that a recrudescence of glacier ice occurred in many of the cirques in Snowdonia. Pollen in the succeeding sediments shows an amelioration of climate and demonstrates the course of forest development through the Holocene (Seddon 1962).
The interpretation and relative dating of the landforms at Cwm Dwythwch are based entirely on pollen biostratigraphic and geomorphological evidence. No radiocarbon calibration is yet available for the sequence.

Although pollen analysis has revealed a detailed record of Devensian late-glacial and Holocene environmental changes in upland Wales, it is the geomorphological implications of these data that make the site particularly important. The palynological and stratigraphical evidence shows that the vegetation of the Devensian late-glacial first formed in a tundra environment (Pollen Zone I), with arctic-alpines, notably dwarf birch. This is followed by a period of park-tundra associated with warmer conditions in the Allerød. No evidence exists at Cwm Dwythwch in the late-glacial profile for the Bølling oscillation described from some Continental and British sites. A deterioration of climate in Pollen Zone III is clearly marked in the section.

The climatic deterioration associated with Pollen Zone III has been widely documented as a period of limited cirque glacier and perennial snow patch development in parts of upland Britain (*c.* 11,000-10,000 BP – Younger Dryas), and several cirque moraines in North Wales have been dated, both palynologically and by radiocarbon techniques, to this time (for example, Seddon 1962; Ince 1981, 1983). The full late-glacial succession accumulated at Cwm Dwythwch within the confines of the large outer moraine, and therefore provides evidence for a cirque moraine of pre-Younger Dryas age. A similar age cannot therefore be ruled out at other sites where large 'diffuse' cirque moraines also occur, for example, the outer moraine at Cwm Idwal (Campbell 1985b). Whether such moraines belong to a readvance of cirque ice in Devensian late-glacial Pollen Zone I, or simply to a recessive stage of the main Late Devensian ice-sheet, remains to be determined. The smaller morainic or nivational accumulations within the higher subsidiary cirques at Cwm Dwythwch, in all probability, date from Pollen Zone III, the Younger Dryas (Gray 1982a).

Cwm Dwythwch provides an important pollen biostratigraphic record of Late Devensian late-glacial and Holocene conditions in upland North Wales. The pollen record, which extends back to Pollen Zone I, clearly post-dates deposition of the large 'diffuse' cirque moraine at the site. It therefore shows important evidence to suggest that active glaciers possibly existed earlier in the Devensian late-glacial than the well documented Younger Dryas cirque glaciation at around 11,000-10,000 BP, when the majority of cirque moraines in the region was formed.

Conclusions

Cwm Dwythwch is one of only two sites in Wales which provide evidence for events between the disappearance of the last ice-sheet and the onset of the minor glaciation between 11,000 and 10,000 years ago. It is an important site for research on climatic change.

Clogwynygarreg

Highlights

A key site that provides a rare record of Late Devensian pollen, and thus vegetation changes, with independent radiocarbon dates. These confine precisely the dating of the wastage of the main Devensian ice-sheet and the onset of the last, Younger Dryas, glacial event.

Introduction

Clogwynygarreg (SH560538) is an important palynological site which yields evidence from the Late Devensian late-glacial and the Holocene. The site is one of very few in Wales where a detailed late-glacial pollen sequence has been calibrated with a radiocarbon timescale (Ince 1981).

Description

The site lies west of the main Snowdon (Yr Wyddfa) massif, in the lowlands to the east of the rocky outcrop of Clogwynygarreg, and immediately north of Llyn Dywarchen. It consists of an infilled lake basin covering approximately 4ha and occupies what has been interpreted as a glacial meltwater channel (Ince 1981). The site lies at an altitude of 235m, and is about 2 km outside the Younger Dryas ice limit mapped by Gray (1982a).

The following succession was recorded by Ince (1981) at SH560538 –

8	Peat and organic deposits (too wet to sample with piston corer)
7	Dark brown, wet peaty gyttja
6	Dark brown, coarse clastic gyttja
5	Compact, fine clastic gyttja
4	Compact grey clay with angular slate gravel
3	Compact, fine, clastic, grey-brown mottled gyttja with sporadic small angular stones
2	Dark grey lake mud, coarse sand fraction towards base
1	Compact grey clay with angular slate gravels

Detailed pollen analyses together with counts of deteriorated pollen and spores were carried out by Ince (1981), and four radiocarbon assays were provided for significant levels in the sequence. The results provide the basis for detailed interpretations of vegetational change in the Snowdonian foothills during the Late Devensian late-glacial and early Holocene. Ince (1981) also provided comparable data from a late-glacial to early Holocene sequence at Llyn Goddionduon (SH753583) and at two sites, Llyn Llydaw (SH632543) and Cwm Cywion (SH632604), with early to mid Holocene sequences – see Snowdon and Y Glyderau site reports respectively for details of these last two sites.

Interpretation

Prior to 13,670 ± 280 BP (Birm 884), clays and silts (with occasional small stones) were deposited at Clogwynygarreg as the Late Devensian ice-sheet wasted. Pollen assemblages from the basal clastic deposits show that sedimentation occurred in a sparsely vegetated landscape characterised by areas of unstable ground and perhaps stagnant ice wastage. The Late Devensian late-glacial at Clogwynygarreg was then characterised by a prolonged period of vegetation development commencing with pioneer herbaceous communities and culminating in the establishment of *Juniperus* scrub. During this development, the trend towards soil stability is marked by sedimentation of an increasingly organic character, with pollen spectra indicating changes from a mosaic of pioneer herbaceous communities to a dominantly grassland community. Further diversification of the pollen spectra and the establishment of juniper scrub, reflect a marked climatic improvement in this part of the sequence. Birch was also present at this time, but the evidence for establishment of birch woodland is doubtful (Ince 1981).

The succession of plant communities proved by the pollen record at Clogwynygarreg was taken by Ince to indicate a response to climatic amelioration following disappearance of the Late Devensian ice-sheet. This period, he termed the 'late-glacial interstadial'.

By *c.* 11,020 ± 150 BP (Birm 886), a marked decline in juniper pollen in the succeeding local pollen zone and a change in lithology, commencing with deposition of a stone layer, mark a regression in environmental conditions and vegetational development. This is correlated with the Younger Dryas, when glaciers reoccupied many of the highland cirques of Snowdonia (Gray 1982a). At that time, widespread solifluction and increasingly severe conditions led to the break up of existing plant communities and the proliferation of open-habitat and disturbed ground taxa; and the renewed inwashing of clays and silts containing an increase in degraded pollen grains (Ince 1981)

The vegetation of the Younger Dryas and early Holocene transition at Clogwynygarreg is marked by a change in lithology from clastic to organic sediment, accompanied by a sudden rise in *Juniperus* pollen. These changes mark the transition from periglacial conditions to the milder climate of the early Holocene. An early radiocarbon date of 10,760 ± 140 BP (Birm 887) at this lithological transition is believed to be too old because of hardwater error (Ince 1981).

Following development of an open-grassland community during the period of transition, tree birches became established, and extensive woodland developed around the site. A fall in juniper pollen, which has been interpreted as marking its shading out by larger trees such as birch, was followed by a sudden expansion of *Corylus* and *Myrica* pollen, which denotes the arrival and dispersal of hazel in the local woodlands. These taxa also displaced birch. Continued diversification of the woodland taxa marks progressive vegetational development through the Holocene (Ince 1981).

Subsequent to this stage of woodland development, Ince noted a change in the arboreal and non-arboreal pollen ratio, with an increase in degraded pollen grains showing changes in the vegetation resulting from disturbance or a change in hydrological conditions in the lake basin. At this time, *Ulmus* and *Betula* pollen declined and Ince speculated that this may have been caused by local human activity. The age of these sediments, however, is unknown and it is not possible to correlate the elm decline with Neolithic activities discussed widely elsewhere. Woodland recovery, however, was rapid with *Pinus* and *Quercus* becoming important elements. Continued changes in the woodland community are also reflected by the local arrival of *Alnus* and the development of damp woodland in which *Alnus, Corylus* and *Betula* formed the dominant components (Ince 1981).

Clogwynygarreg provides an important radiocarbon calibrated pollen record of late-glacial and early Holocene environmental changes in the Snowdonian foothills. Organic sedimentation began after about 13,670 BP, a date which provides a minimum age for wastage of Late Devensian ice in the area. The pollen record shows a gradual improvement in thermal and environmental conditions associated with the 'late-glacial interstadial'.

A later decline, particularly in *Juniperus* pollen, is thought to mark deteriorating conditions culminating in the Younger Dryas. During this period, small glaciers again occupied cirques in the Snowdon massif, and Clogwynygarreg lay in the periglacial zone. A change to organic sedimentation and a rapid expansion of *Juniperus* pollen marks the transition from this cold stadial period to milder environmental conditions in the early Holocene. The site provides a contrasting record to that of nearby upland cirques at Llyn Llydaw and Cwm Cywion, and thereby helps to place limits on the age of the final cirque glaciation of North Wales. Clogwynygarreg shows no evidence of the Bølling 'oscillation' which has been recorded at some Welsh sites in the early part of the late-glacial sections (for instance, Cors Geuallt and Nant Ffrancon).

The radiocarbon dated pollen sequence at Clogwynygarreg is one of the most extensive and detailed in Wales, and it provides important evidence for changing Late Devensian late-glacial and Holocene environmental conditions in North Wales. The site yielded radiocarbon dates which provide a minimum age for the wastage of the Late Devensian ice-sheet and for the onset of cold conditions in the Younger Dryas. Together with adjacent sites in the uplands which provide radiocarbon dates for the cessation of cold conditions in the Younger Dryas, Clogwynygarreg helps to constrain the duration and timing of the final cirque glaciation of North Wales.

Conclusions

The Clogwynygarreg site is important because it shows a sequence of climatic changes over the last 14,000 years which have been dated by radiocarbon. It is an important site in a network of complementary ones throughout the British Isles and Europe which demonstrate vegetation and climatic change.

Cors Geuallt

Highlights

A unique site showing controversial evidence of climatic fluctuations during the early Devensian late-glacial, a warmer interstadial oscillation, the Bølling Interstadial, during the otherwise cold Older Dryas.

Introduction

Cors Geuallt is an important pollen site recording detailed vegetational changes in North Wales during the Devensian late-glacial and Holocene. It

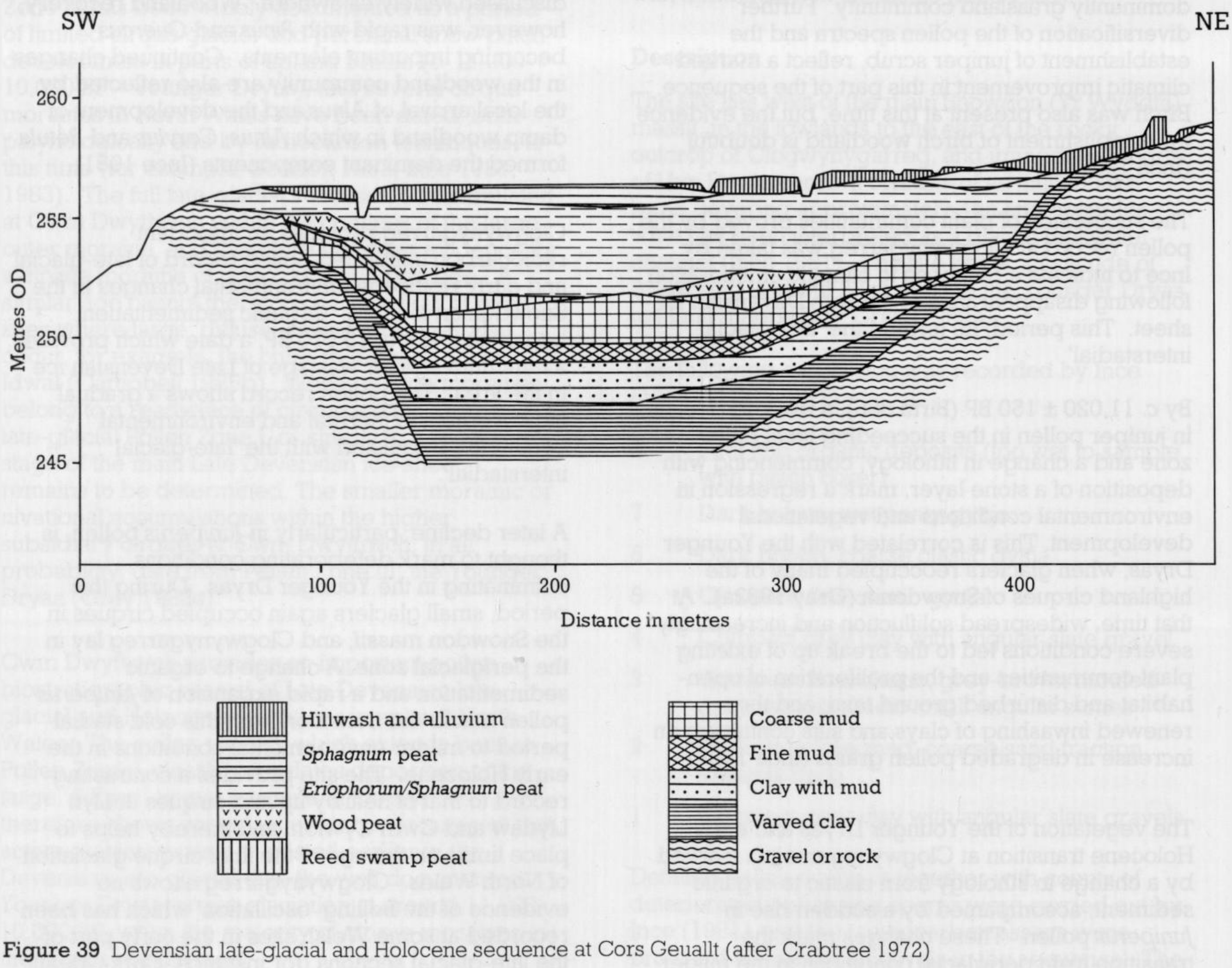

Figure 39 Devensian late-glacial and Holocene sequence at Cors Geuallt (after Crabtree 1972)

is one of a few sites in Britain that provide possible evidence for a pre-Allerød climatic oscillation during the Late Devensian, possibly equivalent to the Bølling Interstadial. Cors Geuallt is also the only site in Wales where a detailed record of diatoms extending back into the late-glacial has been studied. Detailed accounts of the pollen biostratigraphy and diatoms at the site have been provided by Crabtree (1969, 1970, 1972). The possible record of the Bølling Interstadial has also been discussed by Moore (1975b) and Ince (1981). Thomas (1972) referred to the site in a survey of diatomaceous deposits in Snowdonia.

Description

Cors Geuallt (SH734596) lies north-east of Capel Curig, in the foothills of the Carneddau. With dimensions of about 400m by 250m and lying at a height of some 255m OD, this former lake basin is now a mire. It has an irregular rocky floor generally not deeper than 4m, although in the central southern area, through which Nant-y-Geuallt flows, there is a deeper region (about 275m by 110m) which could not be bottomed with a 7.6m auger (Thomas 1972). Here, the mire is floating on a layer of water, and augering in this deeper area suggests the presence of a saucer-like deposit of mud, up to 2m thick, over an area of some 27,000 m^2 (Thomas 1972). The site lies well outside the ice limits of the last cirque glaciation in Snowdonia (Seddon 1957; Gray 1982a).

Levelling and boring was carried out at Cors Geuallt by Crabtree (1970, 1972) to determine the stratigraphy of the superficial deposits within the basin. The generalised sequence consists of –

6 Hillwash and alluvium

5 Reed swamp, wood, *Eriophorum* and *Sphagnum* peats

4 Coarse mud

3 Fine mud

2 Coarse mud and clay

1 Varved clays

The distribution and relative thicknesses of the beds are shown in Figure 39.

Two cores, referred to as the 1964 and 1969 cores, were taken by Crabtree (1969, 1970, 1972). These were analysed for their chemical, diatom and pollen characteristics. Crabtree (1970, 1972) zoned the pollen spectra in the standard manner (Pollen Zones I –VIII) but used additional local pollen sub-zones where appropriate. Detailed pollen diagrams for the two cores were presented, although these have no radiocarbon calibration.

Interpretation

Based on the relative frequency of *Betula* and herbaceous pollen types in the 1964 core, Crabtree (1970) assigned the lower pollen assemblages to the Late Devensian late-glacial, and the upper ones to the Holocene. Values of juniper pollen peak at the end of Pollen Zone II and again at the end of Pollen Zone III. Importantly, beneath sediments with a Pollen Zone II assemblage, Crabtree recorded a single organic band within the clastic, varved basal clays (bed 1). This band contained both rich pollen and diatom assemblages, which were tentatively ascribed to Pollen Zone Ib, with the implication that the bed had formed during the 'warm' Bølling Interstadial described from sites elsewhere in North-West Europe.

Pollen collected from the 1969 core made it possible to recognise a similar full Devensian late-glacial sequence, with a clearly defined Pollen Zone II flora (Allerød) and Pollen Zone I flora (pre-Allerød). Crabtree (1970) suggested that the pollen diagram constructed from work on the 1969 core showed the salient features proved in Devensian late-glacial sequences elsewhere in upland Britain. He noted that there was no correlative of the Pollen Zone Ib that had been identified in the other core. The core indicated a normal progression of vegetation without any such indication of a climatic oscillation. Crabtree (1972) suggested that the earlier identified Ib pollen assemblages might have been produced from a contaminated sample, although at the time there was every indication that the thin organic band, with its well developed pollen and diatom flora, was *in situ*.

With the pollen diagram constructed from work on the 1969 core largely in mind, Crabtree charted the following sequence of vegetational and environmental changes from the deposits at Cors Geuallt. First, the varved clays (bed 1) were deposited following wastage of the Late Devensian ice-sheet. The pollen spectra indicate development of open-grassland with many herb taxa, giving the overall impression of a restricted pioneer flora with a general absence of thermophilous taxa. Towards the end of this period, a gradual rise in *Juniperus* pollen occurs, indicating that juniper may have occupied areas with snow patches or formed an incomplete shrub cover.

The second main pollen zone (Pollen Zone II) was correlated by Crabtree with the Allerød, widely recognised in Britain and elsewhere in North-West Europe by a sequence of a juniper pollen maximum followed by a rise in birch, including tree birches. At this time, there is also an increase in thermophilous herb pollen types, such as *Filipendula*, and a decrease in shade intolerant taxa. The pollen spectra generally indicate an improvement over the preceding period: and this phase can be correlated with the phase described by Ince (1981) at nearby Clogwynygarreg as the 'late-glacial interstadial'.

Towards the end of Pollen Zone II at Cors Geuallt, *Betula* and *Filipendula* percentages fall markedly and a corresponding increase in taxa characteristic of open and disturbed ground habitats is also noted. These changes are accompanied by the change from organic sedimentation to deposition of clays. Both pollen and sedimentary evidence point to a period of intense cold with soil instability during Pollen Zone III, which may be correlated with the recrudescence of glacier ice in many of the upland cirques (Ince 1981; Gray 1982a). Towards the end of this event, the rapid decline in open and disturbed ground taxa suggests a very rapid change to the milder conditions of the Holocene (Crabtree 1972). However, many herb taxa persist into the early Holocene despite the increase in *Betula* pollen, and it is only with the rise of *Corylus*, in Pollen Zone V, that many of these heliophytic taxa disappear from the record.

The remaining record provides a clear picture of the infilling of the lake basin at Cors Geuallt. The pollen evidence shows a large amount of wood peat dating to the sub-Boreal and suggests that upland forest destruction began at this time. By the beginning of the sub-Atlantic, much of the uplands at this altitude had developed blanket or hill peat (Crabtree 1970).

Diatom counts were also made from samples taken from the Devensian late-glacial and Holocene deposits at Cors Geuallt, with samples chosen to cover the pollen zones already identified (Crabtree 1969, 1970). Peak diatom frequencies occurred in Pollen Zones II-III and in the Holocene. The organic band within the basal clays in the 1964 core also contained a well developed diatom flora (Crabtree 1970). The sequence shows rapidly changing diatom communities, both in terms of total numbers and in floral composition, during the late-glacial. The early Holocene is characterised by a period of *Fragilaria* dominance, and of peak diatom productivity. This peak was accompanied by a decline in base tolerant species, leading to a final stage where acid tolerant species dominate, but during which there was an overall decline in diatom numbers.

Cors Geuallt provides a pollen record of Late Devensian late-glacial and Holocene vegetational changes in North Wales. The site has also yielded a record of diatom floras extending back into late-glacial time, and, in this respect, the site is unique in Wales. The controversial organic band described from the early part of the late-glacial sequence may provide important evidence for a climatic oscillation, perhaps equivalent to the Bølling Interstadial. Indeed, Burrows (1974, 1975) published radiocarbon and fossil plant evidence, from a nearby late-glacial site in the Nant Ffrancon Valley, which he also claimed indicated a climatic oscillation at this time. Moore (1975b) and Ince (1981), however, believe these data to be equivocal and see no evidence for a Bølling Interstadial in these profiles. Cors Geuallt, therefore, may prove to be an important site for establishing a framework for early Late Devensian late-glacial events in Britain, and for the presence of an interstadial before the Allerød.
The sequence of Late Devensian late-glacial and Holocene deposits at Cors Geuallt preserves important pollen and diatom assemblages that record changing environmental conditions in upland North Wales. The site is important in establishing regional variations in Devensian late-glacial conditions, and in particular, demonstrates controversial evidence for a climatic oscillation in the early late-glacial, that has been correlated with the Bølling Interstadial. The pollen record therefore contrasts with other sites in Wales which show evidence for only one warm episode in late-glacial times.

Conclusions

Cors Geuallt is important because not only does it contain evidence for climatic change from pollen but also from diatom fossils in sediments dating from the end of the last ice age. As such it has unique qualities particularly because the evidence suggests a climatic variation (warming) not generally detected elsewhere in the Welsh upland.

Y Llethr

Highlights

A unique site showing periglacial features which are evidence of the 16th to 18th Century 'Little Ice Age'.

Introduction

Y Llethr is a unique geomorphological site in the Rhinog Mountains which exhibits an unusual range of periglacial landforms, some of which may be associated with the climatic deterioration of the 'Little Ice Age', *c.* 1550-1750 AD (Lamb 1967). Detailed accounts of the features at the site have been provided by Goodier and Ball (1969) and Ball and Goodier (1970).

Description

The site occurs on the north-facing slopes of Y Llethr (SH659261) between 600m and 754m OD, and the features, which include striped ground, terraced slopes, gliding blocks and stone-banked lobes, cover a total area of some 25ha. The generally smooth relief of the summit and flanks of Y Llethr is controlled by the underlying shales of Cambrian age. There is very little drift in the immediate area.

The partially-sorted stripes are of a small-scale pattern and occur on slopes between 15° and 30°; they comprise a series of prominent vegetated ridges and troughs orientated perpendicular to the local contours, with a repeat distance of *c.* 0.7-1.0m and an amplitude of *c.* 0.1-0.2 m (Goodier and Ball 1969). On the steeper slopes below, the stripes merge with well developed terracettes. Fine examples of 'gliding blocks' also occur, with frontal soil 'bow-waves' and pronounced upslope furrows, indicating movements of up to 13m. The most significant feature of the site, however, is an old stone wall built before 1815 (and possibly Mediaeval in age), which has become disrupted into a series of 'stone-banked lobes' by gelifluction processes (Goodier and Ball 1969).

Interpretation

Goodier and Ball considered that the displaced wall was important for assessing the period of formation for the features seen at Y Llethr. This wall runs along the northern slopes of the site at altitudes between 600m and 700m OD. It is a dry-stone wall and its independence from the later nineteenth century boundary system in the area, and its comparative state of collapse, indicate that it is of great age: local records indicate a probable Mediaeval age. The wall is down-thrown along its entire length, and its component boulders, which range in size from 30-50cm, have been rearranged differentially, so that stones occur in a lobate pattern towards the steeper slopes. An estimated maximum movement of some 9m downslope is indicated by the lobes; although, where the wall has become totally disrupted, downslope movement may have been as much as 30-40m (Goodier and Ball 1969).

Goodier and Ball considered that gelifluction and cryoturbation had played an important role in forming the stone lobes, and it seems extremely likely that frost-action was also involved in the formation of the adjacent stripes. There is little evidence to suggest that the features at Y Llethr are the result of contemporary frost-action: both the fossil stripes and gliding blocks appear stable at the present time and the stones in the wall show no signs of contemporary movement. Historical records confirm the presence of 'old' walls in the area during construction of newer walls in the nineteenth century, and there is no evidence that these later walls have in any way been disturbed by solifluction. This suggested to Goodier and Ball that the old wall had been disrupted by a period of gelifluction sometime between Mediaeval and nineteenth century times.

Both Manley (1964) and Lamb (1967) have shown that a period of extreme cold, the coldest in Britain in historic times, occurred between *c.* 1550 and 1750 AD - a period referred to by Lamb as the 'Little Ice Age'. It has been demonstrated that land and sea-ice in Britain during that period was at its most extensive since the end of the Younger Dryas at around 10,000 BP. Goodier and Ball (1969) considered that the historically dated evidence showed that periglacial conditions had probably formed all the Y Llethr features, and noted that stripes of a similar scale elsewhere in North Wales at Moelwyn Mawr, Yr Aran (Snowdon) and Y Garn (Y Glyderau) may also have been formed during the same 'Little Ice Age'.

Y Llethr provides the only documented occurrence of periglacial landforms in Wales that date from the 'Little Ice Age', and the site therefore provides contrasting evidence to that at nearby Rhinog Fawr, where large-scale stone stripes have been ascribed to the end of the Late Devensian, prior to the Younger Dryas. The features at Y Llethr also contrast with contemporary cold-climate landforms described from the Carneddau (Tallis and Kershaw 1959) and Moelwyn Mawr (Taylor 1975). These sites are important for demonstrating considerable diversity in the ages of periglacial landforms in the uplands of North Wales. In particular, the stone-banked lobes formed by collapse of the Mediaeval wall, may have important implications for interpreting small-scale periglacial features of unknown age found elsewhere. Although Goodier and Ball (1969) argued a strong case for ascribing the stone-banked lobes to the 'Little Ice Age', there is no clear evidence which dates the other periglacial features at the site to the same period.

Y Llethr is important for exhibiting an unusual range of periglacial landforms, including partially-sorted stone stripes, terracettes, 'gliding' (ploughing) blocks with prominent bow waves and furrows, and a stone wall deformed by gelifluction. Documentary records provide evidence to suggest that this wall is Mediaeval in age and that its collapse probably occurred in the climatic deterioration of the 'Little Ice Age' between *c.* 1550-1750 AD. This is the only known occurrence of periglacial activity in Wales from this period.

Conclusions

Y Llethr is a site of outstanding importance because it contains evidence for cold-climate processes during the 'Little Ice Age'. One of the most interesting features is the disturbance of a Mediaeval wall by periglacial slope processes. This site may well be the standard for similar, but as yet undiscovered, examples elsewhere in Britain.

Rhinog Fawr

Highlights

A key locality showing the largest stone stripes in Britain, evidence of periglacial activity on a large-scale during the Late Pleistocene.

Introduction

Rhinog Fawr (SH643286) is an important geomorphological site for a series of well developed large-scale stone stripes. The stripes are thought to be well preserved relics of Late Pleistocene periglacial conditions, and they occur at a larger-scale than sorted stone stripes described elsewhere in Britain. They were first noted by Ball and Goodier (1968), and their age and geomorphological significance was discussed by Foster (1970a). The site has also been mentioned in studies by Foster (1968), Goodier and Ball (1969), Ball and Goodier (1970), Whittow and Ball (1970) and Allen and Jackson (1985).

Description

Rhinog Fawr, in the Harlech Dome, consists of outcrops of Lower Cambrian Rhinog Grit (Matley and Wilson 1946) which reach 720m OD. The stripes occur on the south-west facing slopes at an altitude of 425-490m OD, lying at the margins of a drift-filled basin near the head of Cwm Nantcol. The stripes are visible over an area of about 10ha, occurring on slopes between 12° and 18° (Ball and Goodier 1968). There are two main elements in the stripe morphology –1) exposed stripes composed of sandstone and conglomerate (Rhinog Grit) boulders of a general size range between 0.60m and 1.50m, and a repeat distance between crests of 5-8m, 2) intervening vegetated zones composed largely of small shrubs dominated by *Calluna vulgaris* (L.) Hull. A trench across a typical pattern showed that the sub-surface boulder zone, was wider than that exposed on the surface, and that in the centre of the vegetated zone, fine earth was present to a depth of about 1m. At about 1.5m from the centre of the vegetated/fine earth zone, an area of large boulders occurred with a fine earth matrix, and in turn this was succeeded at a further 0.75m distance towards the exposed boulder stripe, by a change of matrix from fine earth to a non-stratified peaty humus. This zone extends for a further metre until the unvegetated, matrix-less stripe is reached. Dip and orientation measurements showed that only boulders in the central, unvegetated part of the stripes had a strongly preferred fabric, with steep dips and a marked downslope orientation between 213° and 252° – coincident with the direction of the ground slope at about 218° (Ball and Goodier 1968).

Interpretation

It is generally held that the processes of sorting by freeze and thaw coupled with solifluction movement on gentle or moderate slopes, can produce stone stripes (Ball and Goodier 1968; Washburn 1979). Patterned ground in Britain has been recorded from a number of localities, and it has been interpreted either as a relic of Pleistocene periglacial conditions or as the result of contemporary formation. Sorted stripes of *c.*2m pattern width, for example, were recorded by Galloway (1961) at 950m on Ben Wyvis, Scotland, and smaller contemporary stripe patterns of less than 1m repeat width have been described from Tinto Hill, Lanarkshire by Miller *et al.* (1954). In Wales the occurrence of small active polygons at 940m in the Carneddau (Snowdonia) was noted by Pearsall (1950) and Tallis and Kershaw (1959), and larger-scale, fossil sorted stone stripes (repeat width up to 6m) were described from the Stiperstones in Shropshire by Goudie and Piggott (1981). The features described by Ball and Goodier (1968) at Rhinog Fawr, however, are of a larger-scale than any of those previously reported in upland Britain, although similar scale features have been described in the Arctic (Sharp 1942) and in the Appalachians (Rapp 1967).

Ball and Goodier (1968) interpreted the Rhinog Fawr examples as 'fossil' features for the following reasons –1) the present climate of the area is too temperate to allow contemporary formation of the features at such altitudes, 2) the central vegetated zones are developed over mature podzols, 3) the exposed boulders possess weathered rinds and are covered by lichens, and finally, 4) nineteenth century walls beneath which the features pass are undisturbed. Ball and Goodier, however, suggested that a lack of detailed knowledge of the glacial history of the area prevented precise dating of the features. Although it has been shown that periglacial processes were important in the region during the Devensian late-glacial, especially during the Younger Dryas (for example, Seddon 1962; Ball 1966; Ince 1981; Gray 1982a), Ball and Goodier thought that the location, low altitude and large-scale of the Rhinog Fawr stripes indicated that they were formed at an earlier stage of ice retreat from the region. They further suggested that the drift cover in the higher areas of the Rhinog Mountains had been largely removed, probably by intense solifluction following glaciation, and that preservation of the stripes was due to an unusual combination of circumstances: the aspect of the south-facing hollow was conducive to producing numerous freeze-thaw cycles and the drift contained a suitable size range of frost-resistant boulders to allow sorting. They noted that indistinct patterning was present beneath the entire drift-filled basin, suggesting that the stripes were covered by peat and colluvium. They concluded that most of the Rhinog site had been similarly covered for much of the Holocene, with exhumation of the boulder stripes only occurring subsequent to woodland clearance, grazing and burning in the area. A series of post-Neolithic vegetation changes in the western Rhinogau has been confirmed by pollen analyses made by Walker and Taylor (1976).

Foster (1970a) suggested that the large, sorted stone stripes were formed during periglacial conditions after the last major Late Devensian glaciation of the area, probably during the readvance of ice that formed the Bryncir-Clynnog moraine in northern Llŷn. This readvance has been radiocarbon dated at sometime after 16,830 +970 -860 BP (Foster 1968), although doubt has been expressed concerning the validity of this particular date (Simpkins 1968; Bowen 1974). Indeed, there is no firm evidence to confirm the association between this readvance of the ice and the formation of the Rhinog Fawr stripes, and a later Devensian, Younger Dryas age is equally, if not more, likely.

The sorted stone stripes at Rhinog Fawr are some of the finest in Wales, and are larger-scale examples than those elsewhere in Britain. Although the scale of the features makes them unique in Britain, they cannot be dated exactly. The features, however, are an important record of Late Devensian periglacial conditions and the site contrasts with those at Moelwyn Mawr and Y Carneddau, where there are periglacial landforms associated with contemporary processes of formation. In particular, the Rhinog Fawr examples contrast to the largely unsorted, vegetated and much smaller-scale stripes that are found elsewhere in Wales (for instance, Y Garn and Y Llethr).

Conclusions

Rhinog Fawr displays a series of well developed stone stripes. They are notable both as an uncommon landform and because their scale is greater than comparable features elsewhere in Britain. The age of the stripes is not known although they are believed to have formed during a periglacial phase in the last ice age, by sorting processes under exceptionally cold conditions.

Moelwyn Mawr

Highlights

Here are associated a probable Devensian late-glacial rock glacier and periglacial patterned ground. The latter is regarded as being still active.

Introduction

There are two controversial landforms at Moelwyn Mawr (SH660450). At Cwm Croesor a series of transverse boulder ridges and debris spreads have been interpreted as a fossil 'rock glacier'. Nearby, on the north-east flanks of Moelwyn Mawr, a series of well developed, apparently unsorted vegetated stripes occurs; some of the finest examples of their kind in Wales. The stripes have been studied by Taylor (1975), and preliminary studies of the fossil rock glacier were made by Lowe and Rose (*in* Gray *et al.* 1981)

Description

Patterned ground in the form of small-scale vegetated stripes occurs between 550m and 720m on Moelwyn Mawr (SH662452). The stripes occur on slopes between 15° and 30° and they cover an area of about 20ha. They overlie parent material of Ordovician Croesor Slate (Fearnsides and Davies 1944; Beavon 1963; Taylor 1975). The surface vegetation is a grassland community with a scattering of some heather. The patterned ground consists of a series of ridges and furrows, the corrugations having a wavelength of *c.* 0.8m and an amplitude of 0.2m. The stripes are completely vegetated, and there is little differentiation in vegetation type between the ridges and furrows. Some lineation downslope of large unvegetated stones was noted by Taylor (1975).

A feature interpreted as a fossil rock glacier has been described by Lowe and Rose (Gray *et al.* 1981) on the north face of Moelwyn Mawr (SH656453). The feature comprises a series of transverse boulder ridges with a steep scarp front and areas of pitted boulder strewn terrain. Well developed lateral ridges occur at the margins of the transverse ridges. The whole rock and morainic debris complex extends for about 300-400m NNW into Cwm Croesor from a small north-facing cirque-like feature. A shallow depression separates the rock accumulation from the head wall (Gray *et al.* 1981).

Interpretation

Patterned ground

Patterned ground was first described on the flanks of Moelwyn Mawr by Goodier and Ball (1969) and Ball and Goodier (1970). They noted that the stripes were on a similar scale to those found in the Rhinog Mountains at Y Llethr and at several other localities in Snowdonia. No dating or interpretation of the features were given, but it was suggested that the features were active, and were maintained by seasonal needle-ice (pipkrake) formation (Ball and Goodier 1970).

The stripes on Moelwyn Mawr were studied in greater detail by Taylor (1975). He described the vegetation and morphology of the features and constructed a map of a sample area of the stripes. Both mechanical and structural analyses of the soil were undertaken which showed particle sorting within the stripe pattern, but only within an extremely narrow size fraction (Taylor 1975). The high water content and low structural strength of the ridges was taken as evidence that they were probably maintained by active contemporary frost-assisted processes. He considered that in the absence of such processes, the ridges would probably have collapsed in response to heavy grazing and subaerial compaction. Taylor showed that although the stripes appeared superficially unsorted, mechanical analysis had proved there to be some sorting; and it seemed likely that wherever patterned ground occurs some sorting had taken place, even if this is not reflected in preferential growth of vegetation.
Together with sorted polygons in the Carneddau and similar scale vegetated stripes elsewhere in North Wales (Y Garn and Y Llethr), the stripes at Moelwyn Mawr provide evidence for formation, or at least maintenance, by contemporary frost-assisted processes. These features provide contrasting evidence to the larger-scale stripes at Rhinog Fawr and the Stiperstones which are believed to be fossil periglacial features.

Fossil rock glacier

Preliminary observations of this feature were made by Lowe and Rose – see Gray *et al.* (1981). The debris tongue extends into the Croesor Valley, well outside the confines of the cirque, and it appears to be flanked by distinctive lateral accumulations of postulated morainic material. This is the only documented occurrence of a fossil rock glacier in Wales, and little is known about its precise age and origin.

A possible analogue is the tongue-shaped postulated rock glacier described at Beinn Alligin, on the north side of Loch Torridon in Scotland (Sissons 1975, 1976). This is the largest such feature in Scotland, for which a variety of modes of formation has been suggested. Sissons (1975) considered that the feature had probably formed towards the end of the Loch Lomond Stadial (Younger Dryas) when a small decaying glacier was submerged by rockslide debris, which was subsequently reactivated as a rock glacier. In contrast, Whalley (1976) suggested that the feature was simply a rockslide. Further work at Moelwyn Mawr could provide a variety of hypotheses to explain the formation of the feature. At present it could be postulated that the so-called rock glacier was formed by unusually heavy rockfalls that submerged a small cirque glacier of Younger Dryas age; detailed pollen analytical and geomorphological studies elsewhere in Snowdonia have shown that this period was significant for widespread glacier growth within the region's cirques. As a result, numerous moraines and boulder limits of an extremely varied nature were developed, and it might be that specific local geomorphological and geological controls led to development of a rock glacier at Moelwyn Mawr.

Conclusions

The fossil rock glacier at Moelwyn Mawr is important as the only such feature so far described from Wales. As yet, its age and mode of formation are indeterminate. The well developed vegetated stripes enhance the interest of the site. They are some of the finest examples in Wales and provide important evidence for formation, or at least maintenance, by contemporary frost-assisted processes. These features may provide important evidence about climatic change and processes in upland regions.

Caerwys and Ddol

Highlights

One of the thickest and most complex tufa deposits in Britain occurs here. These limestones and their contained fossils record a history of sedimentary, hydrological and climatic change through the latest Devensian and the Holocene.

Introduction

Caerwys and Ddol provide some of the finest tufa deposits in Britain. The site contains buried soils and an exceptional fossil record (molluscs, leaf-beds and vertebrate faunas) recording environmental changes in the late-glacial and Holocene. The tufa at Ddol incorporates fossil groups including beetles and plant macrofossils not represented at Caerwys. The Wheeler Valley tufas were first described by Maw (1866) and some additional work was carried out by Hughes (1885) and Strahan (1890). Jackson (1922) provided a comprehensive list of molluscs from the site. Since then, Wedd and King (1924), McMillan (1947), Millott (1951) and Bathurst (1956) have all added data on the tufa, its flora and fauna. Detailed accounts of the tufas were given by Preece (1978), Preece *et al.* (1982), McMillan and Zeissler (1985) and Pedley (1987).

Description

The tufas at Caerwys (SJ129719) and Ddol (SJ142714) in the Wheeler Valley are the most extensive in Britain, occupying an estimated 80ha (Maw 1866). They occur in two small tributary valleys that enter the Wheeler Valley from the north. The tufa deposits contain leaf, twig, moss, liverwort and cyanobacterial tufas (Pedley 1987) and they overlie red sands and gravels – probably Late Devensian fluvioglacial deposits (Brown and Cooke 1977).

The Caerwys deposit extends downslope into the Wheeler Valley as a delta-shaped fan (Pedley 1987). The tufa is well exposed in both current and abandoned quarry sections. In the main quarried deposit, the tufa reaches a maximum depth of about 12m (Pedley 1987). In the centre of the quarry, a basal dark grey peat passes up into a transition zone of organic-rich carbonates overlain by reworked tufa (Pedley 1987). Away from the axis of the valley, however, the succession is more complex; the peat is absent and the tufa is interdigitated with red sands and gravels. This is well illustrated in the old disused quarry (SJ129717) where only a thin tufa layer is interbedded with substantial thicknesses of red sand. For the most part, the Caerwys succession can be generalised as follows (Preece 1978; Preece *et al.* 1982) –

6 Modern soil
5 Hillwash sediments
4 Main tufa deposit, devoid of organic material
3 Tufa with peat and soil horizons
2 Sandy tufa with two thin soil horizons
1 Fluvioglacial sands

However, it must be stressed that the sequence is highly variable both laterally and vertically. The distinction between each bed is not sharp, with beds grading imperceptibly into one another. The beds are frequently lenticular and sometimes interleaved. This complexity led Pedley (1987) to distinguish a number of lithological types, rather than to draw a stratigraphical sequence. He recognised five principal lithologies at Caerwys –

1 Tufa build-ups or encrustations on reeds, grass, mosses (phytoherms)

2 Oncoids (accretionary carbonate bodies, often oblate spheroids associated with pond sediments and frequently found in basal,

fluvial channel fills)

3 Wackestones and lime mudstones (often reworked deposits believed to have accumulated in relatively shallow ponds between raised tufa build-ups)

4 Subaerial slopewash

5 Palaeosols

The Ddol tufas (SJ142714) are less extensive and less well exposed; the formerly extensive quarry exposures are now overgrown, and the tufa is less than 6m thick (Pedley 1987). Small sections, however, are visible along Afon Pant-gwyn and in small ditch exposures near the old workings at Felin-gonglog. The deposits at Ddol are richer in organic horizons than those at Caerwys (Preece *et. al.* 1982), and consist largely of brown organic tufaceous silts alternating with white nodular tufa, and beds intermediate in character and composition between these two.

Interpretation

The Wheeler Valley tufas were first examined by Maw (1866) who established the distribution and broad sequence of deposits. He noted the impressions of marsh plants in the tufa and recorded 19 species of land snail. He considered that the tufa was deposited by carbonate-rich streams emanating from the Carboniferous Limestone to the north. Brief accounts of the deposits were also given by Hughes (1885) and Strahan (1890). Strahan commented that the land snail fauna appeared to be entirely modern.

Jackson (1922) recorded 43 species of non-marine mollusc at Caerwys. A variety of other finds, including the tusks of wild boar, ox molars, horse and human remains was noted (Jackson 1922), although their precise stratigraphical context is unknown. Jackson considered the tufas to be Holocene in age, and he emphasised the similarities of the deposits with those of Neolithic age at Blashenwell, Dorset. The human remains recovered by Jackson (1922) have since been radiocarbon dated (Barker *et al.* 1971). A date of 2,100 ± 140 BP (BM-255) confirms that the burial was recent and intrusive. The tufas of the Wheeler Valley were also mentioned briefly by Wedd and King (1924) and by McMillan (1947) and Millott (1951).

A preliminary study showed pollen from lime, alder, oak, pine and hazel to be present in one of the peat beds at Caerwys (Bathurst 1956). He concluded that such an assemblage of trees was not present in the British flora until early Pollen Zone VI (Holocene) (Godwin 1941). He also described the numerous tree leaf impressions in the tufa. These included hazel, willow, elm, oak, poplar, ivy and beech; the latter, he suggested, did not enter the British flora until the Holocene climatic optimum (Pollen Zone VII/early Neolithic times).

McMillan and Zeissler (1985) analysed the land snail fauna from the Caerwys tufa, recording a total of 54 species. Their study classified the molluscan assemblage in terms of environmental preferences (there were 22 woodland species, 11 catholic, 4 characteristic of short-turf grassland, 8 marsh species and 9 freshwater), and showed that most of the assemblage was therefore terrestrial with many obligatory marsh dwellers and species preferring marshy habitats. The snail fauna was used to demonstrate that freshwater habitats in the succession were restricted to only small bodies of water (McMillan and Zeissler 1985).

Recent investigations have attempted to interpret a sequence of palaeoenvironmental events and conditions from the molluscan evidence (Preece 1978; Preece *et al.* 1982) and the sedimentary evidence (Pedley 1987).

Preece (1978) and Preece *et al.* (1982) emphasised the difficulties of relating particular molluscan assemblages to individual beds within the highly complex and laterally and vertically changeable sequences at Caerwys and Ddol. However, detailed analysis of molluscs sampled from the beds at both sites allowed a number of molluscan assemblages to be recognised and the tufa to be zoned. The definition of the biozones was based principally on molluscan evidence from Holywell Combe, Kent (Kerney *et al.* 1980; Preece *et al.* 1982), where six molluscan biozones were recognised from the Holocene sequence. These principal zones were also recognised at Caerwys and Ddol, and although they cannot be related to specific beds, and traced throughout the quarries, the zones A, B and C broadly correspond with bed 3 at Caerwys, zone D with bed 4, and zones E and F with beds 5 and 6, respectively.

At Caerwys, molluscan zone A is dominated by terrestrial species. There is also an open-ground fauna, and a few species suggesting bare soil conditions. The assemblage indicates improving conditions in the early Holocene, following the cold conditions of the Younger Dryas. A radiocarbon date of 9,780 ± 200 (Q-2343), from organic material associated with a molluscan zone A type fauna at Ddol, supports the ascription of this molluscan assemblage to the early Holocene, and allows its correlation with Pollen Zone IV (Preece *et al.* 1982).

Molluscan zone B is characterised by a woodland fauna, demonstrating the development of woodland in the area. It is correlated with Pollen Zone V and the early part of Pollen Zone VI (Preece *et al.* 1982). Molluscan zone C also has a woodland assemblage and occurs largely within a prominent soil layer developed immediately above an erosion surface in the tufa succession (bed 3). The faunal boundary therefore corresponds with a change in lithology; there followed drier conditions in which the soil formed, and tufa formation temporarily ceased. The soil horizon has been radiocarbon dated to 7,880 ± 160 BP (BM 1736) (Preece *et al.* 1982).

The succeeding molluscan zone D is also

dominated by woodland species, and is thought to correlate with the later part of Pollen Zone VI and Pollen Zone VIIa. The implication is clearly that the bulk of the tufa deposit (bed 4) at Caerwys formed at this time. A radiocarbon date of 6,260 ± 120 BP (Q-1533) was obtained from sediments associated with a molluscan zone D fauna at Ddol, but this does little to establish the duration and timing of the phase as a whole.

Molluscan zones E and F at Caerwys show a clear change to open-ground conditions, with a decline in shade demanding species and an increase in grassland species (beds 5 and 6). In bed 5, horizontally bedded tufa has been weathered into small slabs and incorporated into a rubbly colluvium or hillwash. These hillwash sediments and the modern soil (beds 5 and 6) were correlated with Pollen Zones VIIb and VIII, respectively. The abrupt change in which woodland species of the tufa are replaced by open-country forms in the colluvium, is thought to have resulted from woodland clearance (Preece 1978; Preece *et al.* 1982).

In addition to the molluscan zones associated with Holocene tufa development at Caerwys, an additional trench cut into the floor of the main quarry (Preece 1978; Preece *et al.* 1982) revealed a thin lower sequence of tufa and soil horizons (bed 2) overlying fluvioglacial sand (bed 1). Molluscan analyses from bed 2 show a restricted fauna composed mainly of ecologically tolerant species, many of which have modern ranges that extend well into the Arctic Circle (Preece *et al.* 1982). Also, several Arctic-Alpine species were recorded which no longer live in Britain. The soil horizons within the bed were not marked by any faunal changes. The beds are devoid of identifiable pollen and their precise age is unknown. The molluscan evidence would appear, however, to indicate a Late Devensian late-glacial rather than a Holocene age (Preece 1978; Preece *et al.* 1982).

At Ddol, the entire exposed section of tufa and interbedded organic deposits contains a molluscan fauna of zone D type. Analyses of core samples show, however, that zone A, B and C type assemblages are also present in the sequence below. The exposed tufa is dominated by woodland species and by a freshwater fauna indicating a flooding event. In contrast with Caerwys, a heavily shaded stream environment is suggested, where local conditions favoured the preservation of much organic debris. Both at Caerwys and Ddol, pollen grains and ostracods were recorded (Preece 1978; Preece *et al.* 1982). Although certain pollen assemblages were recognised, there had been a very marked differential destruction of pollen grains in the strongly alkaline environment; the results are of little use for palaeoenvironmental reconstruction. Similarly, the limited ostracod fauna has proved extremely difficult to interpret (Preece 1978).

Pedley analysed the carbonate sedimentology of the tufa deposits at Caerwys, and recognised five main lithologies – see site description. In tracing the complex distribution of these elements, he was able to reconstruct the following sequence of events. Initially, the entire tributary valley at Caerwys formed the site of braided stream deposition, with oncoid and clastic tufa being formed, derived from upstream carbonate areas. Subsequently, ponding occurred as two tufa phytoherm barrages developed. Later, a single larger tufa barrier became established downstream causing ponding and flooding of the earlier tufa constructions. Ultimately, this led to the development of a single tufa marsh complex, upstream from the barrier. According to Pedley the phytoherms were sub-parallel, forming downstream-convex porous dams. The barrage-dammed ponds functioned as efficient sediment traps, perhaps even maintaining high upstream water-tables, while palaeosols developed in other downstream areas. Pedley envisaged that water from narrow ponds seeped through and trickled over the barrages sustaining the surficial colonies of mosses and liverworts. In doing so, the water descended via a series of plant-colonised gutters and micro-terraces and the principal barrage, and onto the clastic tufa facies. This promoted braided stream activity as well as the development of small reed phytoherms. Pedley noted that palaeosols and humus-rich levels are restricted to the downstream part of the Caerwys sequence. Finally, the last episode of the tufa succession was the breaching of the deposits by the River Wheeler tributary stream with a resultant lowering of the water-table. No tufa deposits are forming at Caerwys today.

An important characteristic of the Caerwys and Ddol deposits is their considerable vertical and lateral variability; the floral and faunal remains described in many of the earlier studies were thus not assigned to any particular bed or even lithology. The level of palaeoenvironmental reconstruction achieved was, therefore, limited. Recent studies at the site have redressed this situation, although the nature of the deposits has mitigated against a detailed stratigraphic interpretation of the sequence in the accepted sense.

The work of Preece (1978), Preece *et al.* (1982) and Pedley (1987), in particular, has helped to establish a clearer pattern of events. It has been shown that springs and seepages emanating from the Carboniferous Limestone, led to tufa formation over large areas of marsh. Calcium carbonate was precipitated around the stems and leaves of marsh and tree vegetation. In places at Caerwys, large encrustations of tufa (phytoherms) formed 'rims' and ponded back water in a series of small and larger barrages. The complex series of cascades, standing pools, marshes, and the drier land towards the margins, provided varied environments, each supporting a molluscan fauna. Evidence of the constantly changing pattern of tufa formation, as ponds developed, braided streams changed course and tufa was eroded and redeposited, is superimposed on the environmental framework of the Late Devensian late-glacial and Holocene. The Caerwys tufa, in particular, demonstrates the interrelationships between constructional and clastic sediments in an ancient barrage tufa complex.

Despite the problems outlined of correlating the beds and their fossil contents throughout the quarries, an environmental sequence has been detected from the land snail evidence (Preece 1978; Preece *et al.* 1982). The open-country assemblages of the late-glacial are replaced by more shade-demanding, woodland species in the early and middle Holocene. Eventually, a return to open-ground conditions with grassland communities is shown in the upper colluvial and soil horizons, and this is thought to be in direct response to Man's activities and his clearance of woodland from the local slopes. This record demonstrates that the tufa-forming ecosystem was extremely fragile; with increased run-off, the streams began to cut down, rather than trickle and seep through and over the vegetation, and tufa formation ceased (Preece *et al.* 1982).

It has not yet been possible to correlate the various organic horizons at Caerwys and Ddol precisely with the established record of Holocene vegetational changes in Britain. Nonetheless, a broad pattern of environmental changes based on molluscan zones has been established from the sites, and from a small number of tufa sites in Dorset, Somerset, Northamptonshire, Lincolnshire and Kent. The records from North Wales form an important element in this range of localities that have helped to establish regional patterns and variations in Holocene environmental conditions based on mollusc zonation.

The sequences at Caerwys and Ddol are also important for understanding the mechanisms and conditions required for tufa formation. There has been debate as to whether calcium carbonate precipitation is the result of biochemical reactions involving micro-organisms, algae and even mosses, or whether it is a straightforward chemical process in which plants play an indirect role. Lengthy ancient sequences such as those at Caerwys and Ddol, and sites where there is contemporary tufa formation (Cwm Nash and Matlock Bath), offer scope for elaborating the possible processes and mechanisms involved.

Studies of the leaf impressions and beetle faunas recovered offer considerable scope for further elaborating the nature and sequence of events at this site.

Conclusions

The Wheeler Valley tufas are the best exposed and most extensive of the documented tufas in the British Isles. The land snails in the tufa provide an important record of environmental and climatic changes over the past 14,000 years. Caerwys is the only accessible example of tufa formation in Britain from towards the end of the last ice age.