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Quaternary of Wales

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The Quaternary of Mid Wales 6

Introduction

In this account, Mid Wales is broadly defined as lying between a line running approximately west to east through the Barmouth Estuary and a line from the Cardigan Bay coast at Newquay to the northern escarpment of Mynydd Eppynt. The area includes the uplands of Cadair Idris, the Cambrian Mountains (Mynydd Elenydd) and the Welsh Borderlands. It excludes the coastlands of west Mid Wales which are dealt with separately – see Chapter 4. Although Late Pleistocene landforms and deposits are widespread in Mid Wales, these have received relatively scant attention. Two main themes, however, are of major significance to an understanding of the Welsh Quaternary as a whole. First, there has been considerable disagreement about whether landform and sedimentary evidence in the region indicates extensive glaciation of the uplands during the Late Devensian or is indicative of generally ice-free conditions and protracted periglacial activity throughout the Devensian Stage. Second, the region has become an important focus of attention in studies of Late Devensian late-glacial and Holocene environmental change and pollen biostratigraphy.

Extensive Late Devensian glaciation or a periglacial landscape?

Although aspects of the regional glacial history were discussed by Keeping (1882), Reade (1892, 1896), Dwerryhouse and Miller (1930), Jones and Pugh (1935), Miller (1946), Coster and Gerard (1947) and Howe and Yates (1953), these isolated studies have not led to any great elaboration of the Late Pleistocene history of Mid Wales, particularly the uplands. Miller (1946) concluded that Cadair Idris had formed a local centre for ice dispersal, with its own system of small glaciers feeding into and exploiting pre-existing valleys such as the fault-guided Tal-y-llyn Valley. The dominant regional direction of ice movement appears to have been NNE to SSW in this area. Although Cadair Idris nourished its own ice (Reade 1896; Miller 1946) and contributed westerly flows to the coast, this ice was subordinate to an ice cap, a larger dispersal centre, farther north. Working in the Harlech Dome, Foster (1968) demonstrated that this Merioneth ice cap deposited till as high as 427m on Aran Fawddwy, and that the ice escaped westwards through cols to provide felsite erratics for the tills of the Dyfi Estuary (Jones and Pugh 1935).

It was not until the work of Watson (1960, 1962, 1965a, 1965b, 1966, 1967, 1968, 1969, 1970, 1976, 1977a) and Potts (1968, 1971), however, that the landforms and deposits of these Mid Wales uplands were described in any detail. Watson provided substantive accounts of the glacial landforms around Cadair Idris (Watson 1960), the glacial morphology of the Tal-y-llyn Valley (Watson 1962), stratified screes in the area (Watson 1965a), nivation cirques in the Ystwyth Valley (Watson 1966), and slope deposits in the Nant Iago Valley near Aberstwyth (Watson 1969). He has used this evidence together with that derived from studies of local coastal sections (for example, Watson and Watson 1967; Watson 1982) to argue for a dominantly periglacial evolution of the west and Mid Wales landscapes during the Devensian Stage (Watson 1967, 1968, 1970, 1976, 1977a). Fundamental to Watson's views was the demonstration, by use of clast fabric analyses, that most Pleistocene deposits in the region were slope deposits and that any glacial deposits were not in their original position, having undergone extensive reworking and mixing with the slope deposits (Watson and Watson 1967; Watson 1969, 1982). In combination with studies of the distribution of fossil pingos (Watson 1971, 1972; Watson and Watson 1972, 1974), the Watsons argued for restricted Late Devensian glaciation in Wales, agreeing with the views of Mitchell (1960, 1962, 1972), Synge (1963, 1964) and Wirtz (1953). Mitchell and Synge envisaged that Irish Sea ice only reached as far south as the North Wales coast in the Late Devensian, being marked on Llŷn by the Bryncir-Clynnog moraine – see Chapter 7. Watson in fact argued that this ice had reached slightly farther south, to Sarn y Bwch. Wirtz (1953) envisaged that a lobe of Late Weichselian (Late Devensian) Irish Sea ice also impinged on south Ceredigion and Preseli but that Mid Wales remained largely ice-free. These argued that Welsh ice was only locally present in the uplands, but did not specify where in the region. Therefore, repeated cold pulses during the Devensian Stage, when the region was believed to have been largely ice-free, were considered to account for the thick accumulations of slope deposits and reworked glacial sediments – the latter presumably from a pre-Devensian glacial phase.

The widespread development of periglacial landforms and deposits in Mid Wales is not disputed, although the interpretations of the Watsons and others have been considerably modified by subsequent workers (for example, Potts 1968, 1971; Bowen 1974; Macklin and Lewin 1986). Four principal lines of evidence mitigate against the proposition that much of Mid Wales remained ice-free in the Late Devensian.

1 Considerable lithostratigraphic data from coastal sections around Wales (for example, Bowen 1970a, 1973a, 1973b, 1974, 1977a, 1977b; John 1970a) indicate extensive Late Devensian glaciation by Irish Sea and Welsh ice

to the limits proposed across South Wales by Bowen (1970a, 1981a, 1981b). This alone implies the presence of an extensive Late Devensian ice cover in the Mid Wales uplands (Bowen 1974).

2 The prominent *sarnau* present along the Cardigan Bay coast (Sarn Badrig, Sarn Cynfelyn, Sarn y Bwch) are thought to prove an extensive westward flow of Late Devensian Welsh ice from the uplands (Foster 1970b; Bowen 1974), which in places may have prevented contemporaneous Irish Sea ice from impinging onto the Welsh mainland over much of the present day Cardigan Bay coastline. Although Foster (1970b) proposed that the *sarnau* represented medial moraines between the Welsh and Irish Sea ice-sheets, Bowen (1974) argued that Sarn Badrig (near Mochras) was co-extensive with the upper till on eastern Llyn (Llanystumdwy Till), deposited when Irish Sea ice is thought to have been absent from western Llyn. Unfortunately the precise dating of the *sarnau* to either the main Late Devensian ice-sheet or to its possible subsequent readvance – see Chapter 7, and their correlation with stratigraphic sequences elsewhere, remains insecure.

3 The landform evidence from the Welsh Borderlands also shows an extensive development and a major easterly component of flow from Late Devensian ice in Mid Wales (Dwerryhouse and Miller 1930; Pocock 1940; Cross 1966, 1968; Luckman 1966, 1970). Ice nourished from central Wales is generally thought to have escaped eastwards into Herefordshire and Shropshire where it was unimpeded by other ice masses (Luckman 1970). The Clun, Teme, Lugg, Hindwell and Arrow Valleys are all believed to have contained glaciers fed by ice from the west (Luckman 1970). Similarly, farther south, the Wye glacier spread over the Hereford basin in a large piedmont lobe (Luckman 1970). The maximum extent of this Mid Wales ice is usually taken as the limit of continuous drift of an undissected nature (Bowen 1974), and it is marked in many areas by prominent morainic accumulations. Although absolute dates are unavailable, this morainic belt is thought to represent the maximum limit of the Late Devensian ice-sheet (Bowen 1974), and in this region the limit corresponds closely to the 'Newer Drift' limit drawn by Charlesworth (1929). Highly dissected drift and remanié deposits outside this limit are believed to date from a pre-Devensian glacial episode (Luckman 1970).

4 Landforms and sediments within this proposed Late Devensian maximum limit in Mid Wales are commensurate with a thoroughly glaciated landscape (Wood 1959; Potts 1971; Bowen 1974), but with a significant subsequent periglacial modification. Such evidence includes valley moraines, kettle holes and kame terraces in Radnorshire and Herefordshire (Luckman, 1966), and extensive lacustrine deposits around Wigmore and Presteigne where Cross (1968) estimated the thickness of Late Devensian ice to have been in the region of 240m, extensive outwash deposits in the Builth-Llanwrtyd lowland (Potts 1968; Lewis 1970b), and an extensive system of moraines and outwash terraces in the Wye Valley (Pocock 1940). Moreover, in the uplands proper Potts (1968) has mapped extensive areas of till and outwash in the major valleys, which he considered to be Late Devensian in age. Potts (1968, 1971) argued that extensive reworking of these glacial sediments by solifluction occurred during the Late Devensian late-glacial; and, where slope conditions and lithology were suitable, head, stratified screes, blockfields and tors formed.

More recently, Macklin and Lewin (1986) confirmed that a number of valleys in the region contain locally thick successions of glacial and alluvial sediments, and referred to local (Welsh) till mantling slopes and interfluves, for example, in the Rheidol Valley. In reply, S Watson (1987) maintained that nowhere was this till *in situ*, having been widely reworked and incorporated into slope deposits. In response, Macklin and Lewin (1987) concluded that till in the Rheidol Valley exhibited fabric properties entirely consistent with deposition by a westerly moving glacier.

It is within the context of this background that the selected GCR sites should be viewed. Those at Cadair Idris and Cwm Ystwyth provide some of the best evidence currently documented from Mid Wales for Late Pleistocene glacial and periglacial conditions. Cadair Idris and Tal-y-llyn demonstrate an excellent range of large-scale glacial erosional features, including the outstanding cirque of Cwm Cau (Watson 1960, 1977a) and the over-deepened valley of Tal-y-llyn (Watson 1962, 1977a). The interest of these sites is enhanced by landforms and deposits thought to have formed largely as the result of periglacial activity. These include the massive landslide impounding Tal-y-llyn, a number of alluvial fans and blockstreams, scree slopes and protalus ramparts. The cirque moraines and protalus features of this massif provide the best evidence for cirque glacier and snowpatch development in Mid Wales during the Devensian late-glacial. As such, the site provides complementary landform evidence to selected sites in northern Snowdonia and the Brecon Beacons. Cadair Idris also provides important exposures through stratified screes (Grèzes Litées). These deposits are a widespread feature in the Mid Wales uplands and they reflect the susceptibility of local geological strata, particularly mudstones and shales, to frost-assisted weathering processes under periglacial conditions (Watson 1965a, 1977a). It is likely that they formed in the Devensian late-glacial (Potts 1968).

Devensian late-glacial and Holocene environmental change

Although details of pre-Late Devensian late-glacial history are less well known in inland Mid Wales than in the coastal regions, the area is the most intensively studied in Wales for Devensian late-glacial and Holocene environmental history. Since Godwin and Mitchell's (1938) study at Tregaron, numerous profiles have been described and details of Devensian late-glacial and Holocene vegetational history established (for example, Moore 1966, 1968, 1970, 1972a, 1972b, 1973; Moore and Chater 1969a, 1969b; Smith and Taylor 1969; Hibbert and Switsur 1976; Lowe 1981; Lowe *et al.* 1988). Several studies have traced the course of vegetation development into historical and recent times (Turner 1964, 1965, 1977; Moore 1968, 1973; Moore and Chater 1969b), and Smith and Taylor (1969) have applied pollen biostratigraphic methods to soil profiles, enabling patterns of pedogenesis to be related to the established Holocene pollen zones, as well as documenting the influences of Bronze Age Man and his successors. Sites in the region have also featured in a number of nationwide studies which discuss aspects of regional floral diversity and diachroneity during major Devensian late-glacial and Holocene events (for example, Smith and Pilcher 1973; Taylor 1973; Deacon 1974; Birks *et al.* 1975). Sequences at Llyn Gwernan and the Elan Valley Bog provide the most extensive and complete Devensian late-glacial to Holocene sequences so far known in the region. Cors y Llyn (Llyn Mire), Tregaron Bog and the Elan Valley Bog represent the most detailed records of vegetation history during the Holocene for Mid Wales. Comprehensive radiocarbon calibration is available for the sequences at both Llyn Gwernan and Tregaron.

Cadair Idris

Highlights

This site provides one of the finest assemblages of large-scale glacial erosional features in Wales, showing a wide range of landforms formed by glacial and periglacial processes and mass-movement. This major dispersal centre for Welsh ice allows studies of cirque development in relation to substrate, aspect and relief.

Introduction

Cadair Idris and Tal-y-llyn are outstandingly important for glacial and periglacial landforms. Cadair Idris contains a number of glacial and nivation cirques, including Cwm Cau which was described by W V Lewis as the finest cirque in Britain. This shows a very clear relationship to geological structure and opens out on to the Tal-y-llyn Valley, a classic over-deepened valley developed along the line of the Bala Fault. In addition to large-scale features of glacial erosion, the area is also renowned for a range of depositional landforms associated with mass-movement and periglacial processes. Most spectacular of these is the bar impounding Tal-y-llyn, formed by a huge landslide from Graig Goch. The Tal-y-llyn Valley also contains very fine examples of stratified screes, well exposed near Maes-y-Pandy. Other periglacial interests include protalus ramparts, notably at Craig-y-llam, and a large debris fan or blockstream near Bwlch Llyn Bach. The glacial and periglacial geomorphology of the area has been described by Watson (1960, 1962, 1965a, 1967, 1968, 1970, 1976, 1977a), and has also been mentioned by Miller (1946), Lewis (1938, 1949), Howe and Yates (1953) and Cox (1983).

Description and interpretation

The main ridge of the Cadair Idris massif, which rises to *c.* 890m OD, runs south-west to north-east and is bounded to the south by the glaciated valley of Tal-y-llyn and to the north by the valley of the Mawddach. To the west is Cardigan Bay and to the east the Dulas Valley.

Despite the scale and range of Late Pleistocene geomorphological features around Cadair Idris and Tal-y-llyn, the area has received little attention from geomorphologists. Aspects of the regional glacial history were discussed by Reade (1896), Jones and Pugh (1935) and Miller (1946), and Cwm Cau was referred to in studies of cirque formation by Lewis (1938, 1949). A bathymetrical study of Llyn Cau was undertaken by Howe and Yates (1953). Miller (1946) concluded that the Cadair Idris massif acted as a centre of ice dispersal with its own system of small glaciers emanating from the cirques at, for example, Cwm Gadair and Cwm Cau. According to Miller, the regional direction of ice movement appears to have been from NNE to SSW exploiting pre-existing valleys developed along the lines of structural weakness such as that of Tal-y-llyn.

Cirques

The site contains a number of well developed glacial cirques and nivation cirques – see Figure 22. The Cadair Idris group of cirques is centred on Bwlch Cau to the south-west of the Cadair Idris summit. These demonstrate the relationship between cirque development and aspect and geological structure. In the group, magnificent cirques with precipitous head and side walls face north and east, with the more poorly developed south-facing Cwm Amarch (Watson 1960). The northern cirques are fashioned in a structural north-facing escarpment developed in a granophyre sill. Here, the steep back walls are formed by great joint blocks split from the sill: Cwm Gadair is a particularly fine example cut into this resistant igneous body. In contrast, the cirque of Cwm Amarch is cut in closely cleaved mudstones and acid volcanic rocks. The latter dip towards the cirque with the result that the back wall is much less precipitous.

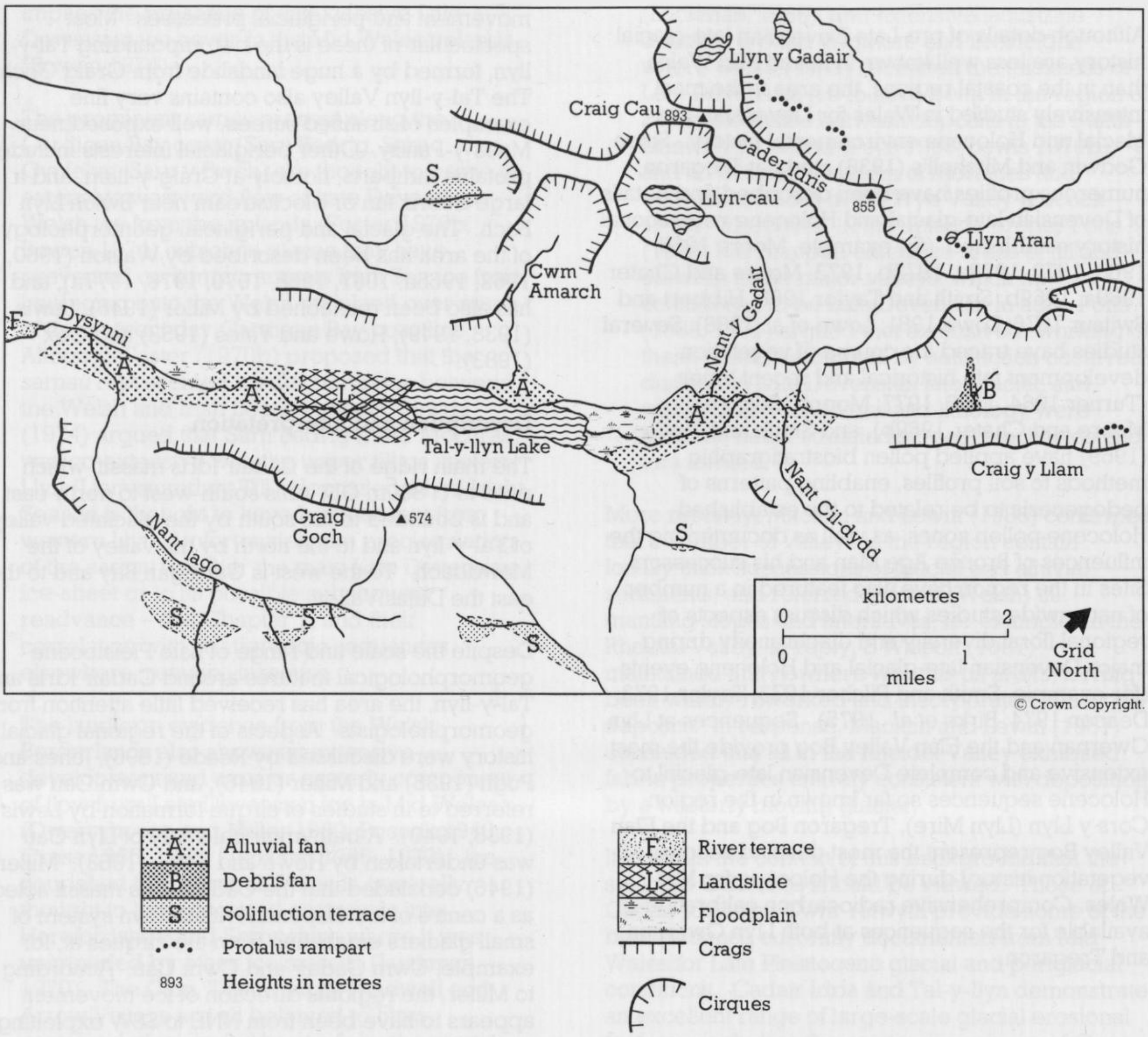

Figure 22 Cadair Idris: principal landforms (after Watson 1977a)

Of the Cadair group of cirques, Cwm Cau is undoubtedly the most impressive. It is surrounded on three sides by rock walls varying between 305-457m in height. The east-facing head wall and southern slopes are developed in highly resistant Ordovician igneous rocks, while softer mudstones occupy a line of weakness along which the cirque floor has been excavated. The head wall of Cwm Cau is exceptionally steep, rising *c.* 335m in a horizontal distance of some 200m. The present day lake is dammed by morainic material beyond which the valley floor falls in level via a series of roches moutonnées, many of which take the form of miniature steps (Cox 1983).

The Tal-y-llyn Valley

The glacial morphology of this valley was described in some detail by Watson (1962). It is a straight valley trending north-east to south-west. For most of its length it cuts through mudstones but nearer its head it is developed in volcanic rocks. The trough lacks spurs and has well developed cliffs below the valley shoulder. Tributary valleys all hang above the main trough, which their streams enter by spectacular falls (Watson 1960). The valley has many features, including an over-deepened profile, produced by glacial erosion (Watson 1962), and the pronounced straightness of the main valley is clearly a reflection of geological structure (Watson 1960). The Tal-y-llyn is a classic example of a glacial trough, but it has perhaps become better known for its wide range of depositional landforms associated with periglacial and mass-movement processes.

The Tal-y-llyn landslide

The bar impounding Tal-y-llyn lake is the most spectacular of the landforms in the valley. It is a massive feature some 24m above the level of the lake and it extends down the valley for almost 1 km.

Reade (1896) considered that this hummocky feature was a glacial moraine damming the lake; subsequent work (Watson 1960) showed that the feature was a rock bar. More detailed studies (Watson 1968, 1976, 1977a) have shown that the feature is a landslide of mudstones from the face of Graig Goch, where a scar demonstrates the source of the material. Watson (1977a) concluded that the landslide had occurred in several stages.

Stratified screes or Grèzes Litées

Much of the Tal-y-llyn Valley has been infilled with periglacial scree derived from the steep valley sides. The scree is stratified in places and consists of alternating thin beds of coarse and fine debris, the coarse beds generally being the thicker (Watson 1965a, 1977a). The finer beds are silty but the coarse beds frequently have an open texture (Watson 1965a). Classic examples of stratified screes or Grèzes Litées are well exposed in small quarries near Maes-y-Pandy in the southern part of the valley below the large landslide, and at the valley head where up to 18m of scree has been recorded (Watson 1968). A study of fourteen such sites in Mid Wales led Watson (1965a) to suggest that the stratified screes always rested on unsorted slope deposits. He considered that they had formed under periglacial conditions by freeze-thaw processes acting on the fine-grained mudstones of the region.

Moraines and protalus ramparts

Fine examples of cirque moraines and protalus ramparts occur within the area – see Figure 22. Watson (1960) demonstrated that the pattern of moraines within the cirques, as well as the cirques themselves, show the strong influence of aspect. For example, the relatively poorly developed western cirque has no recognisable moraines, but those in Cwm Cau and Cwm Gadair, the north and north-east facing cirques, are well developed. Those in Cwm Gadair are symmetrically arranged across the lower end of the lake which usually drains by seepage through the boulder moraine (Watson 1960). In Cwm Cau the moraines are hummocky and similarly impound the cirque lake. They are thickest and rise highest on its south side. In both cirques, the moraines occur at a considerable distance from the back walls.

Well developed examples of protalus ramparts also occur within the area, both in the Tal-y-llyn Valley, below Craig-y-Llam, and near Cadair Idris, at Llyn Aran and beneath Twr Du – see Figure 22. Watson (1967) considered that four protalus moraines occurred along the northern face of Cadair Idris, the easternmost forming the southern shore of Llyn Aran. He observed that, like the nivation cirque and protalus moraine described from Cwm Tinwen near Aberystwyth, none of the Cadair Idris examples occupied true glacial cirques. Rather, the protalus moraines occur in slight embayments or recessions within the steep ridge. Unlike the glacial moraines described at Cwm Cau and Cwm Gadair, these protalus features occur close against the ridge or back wall, indicating that they probably originated as rockfall accumulations downslope from perennial snow patches.

Perhaps the most impressive protalus rampart is that at Llyn Bach beneath Craig-y-Llam (Watson 1977a). Here, the rampart rises more than 20m above the surrounding surface, and its external width is some 200m. The rampart curves at both ends into the slight embayment within the steep valley side. The narrow basin which the rampart should typically enclose had been infilled with head.

The cirque moraines and protalus ramparts within the Cadair Idris area have not been dated precisely. However, in view of the detailed palynological and geomorphological evidence from northern Snowdonia (for example, Ince 1981, 1983; Gray 1982a), and from the Brecon Beacons, South Wales (for example, Walker 1980, 1982a, 1982b), a Younger Dryas age would seem probable. This interpretation is corroborated by palynological and radiocarbon evidence from Llyn Gwernan to the north of Cadair Idris where the Younger Dryas is represented (Lowe 1981).

Alluvial fans and blockstreams

Alluvial fans are a common feature of the Tal-y-llyn Valley, covering large areas of the valley floor at the discordant junctions of the tributary valleys – see Figure 22. Watson (1977a) noted that the fans which spread across the valley floor are composed of mudstone gravel bedded at low angles. On the other hand, fans of coarse blocky igneous rock debris stand at higher angles. Fine examples of such fans occur at the junction of the Tal-y-llyn Valley with the tributary Nant Iago, below Cwm Amarch and at the exit of Nant y Gadair from Llyn Cau. They are believed to be associated with a periglacial régime (Watson 1977a). Watson (1968, 1977a) also described what he called an avalanche fan or blockstream some 3.5 km north-east of Tal-y-llyn lake.

The Cadair Idris and Tal-y-llyn area contains an outstanding range of glacial and periglacial landforms which are important for reconstructing the Late Pleistocene history of the region. The area contains some of the finest glacial and nivation cirques in Wales and one of the most impressive glacial troughs. The landslide impounding Tal-y-llyn lake is also a remarkable geomorphological feature, as are the exposures of stratified scree in the Tal-y-llyn Valley. Together with the mountains of northern Snowdonia and the Brecon Beacons in South Wales, Cadair Idris provides an important example of large-scale glacial erosional features. The widespread development and range of periglacial landforms also makes the area of exceptional interest. The interpretation of this range of landforms is crucial to the understanding and reconstruction of Late Pleistocene events in the region as a whole.

The cirques of the Cadair massif demonstrate a close relationship between cirque development, aspect and relief, and provide, in a compact area, the best range of glacial landforms associated with a dispersal centre for Welsh ice in the Mid Wales uplands. The area is also noted for the wide range and fine development of landforms formed by mass-movement and periglacial processes; of these, the large landslide which impounds Tal-y-llyn lake, and the stratified screes, which are a characteristic feature of the region, are particularly impressive. Well developed cirque moraines and protalus ramparts demonstrate important evidence for cirque glacier and snow patch development during the Devensian late-glacial. The glacial and periglacial landforms are central to the discussion over whether or not the region was extensively glaciated during the Late Devensian.

Conclusions

Cadair Idris contains one of the finest assemblages of landforms caused by glacial erosion anywhere in Wales. It includes the cirque described as the most perfectly formed in the British Isles. The area also contains a wide range of periglacial landforms and deposits. Together the glacial and periglacial features combine to form one of the best teaching areas in the British Isles.

Cwm Ystwyth

Highlights

Features occur here which have been interpreted as nivation cirques, formed by persistent snow patches during the Late Devensian. The features show little evidence of glacial erosion typical of cirques elsewhere in upland Wales.

Introduction

Cwm Ystwyth is an important site with two features interpreted by Watson as nivation cirques, Cwm Du (SN811740) and Cwm Tinwen (SN832748). These features occur at much lower altitudes than would normally be expected for glacial cirques in the area. They are not thought to be associated with glacial erosion and are believed to have originated from nivation processes during the Devensian Stage. The site was first described by Keeping (1882) and has been studied in some detail by Watson (1966, 1968, 1970, 1976) and Watson and Watson (1977).

Description

The two cirque forms, Cwm Du and Cwm Tinwen (Figure 23) are developed in the north-facing slope of the Ystwyth Valley. According to Watson and Watson (1977), they are smaller and lie *c.* 180m lower than typical glacial cirques in the area (for instance, Cwm Cau, Cadair Idris). They possess steep rocky back walls, but apparently show none of the features often associated with glacial erosion, such as the typical rock basin with an enclosing rock lip.

Mapping at Cwm Tinwen (Watson 1966), showed a moraine-like ridge up to 17m thick, enclosing a boggy flat against the back wall. This ridge is highest in the centre, but west of a small gully that bisects the ridge, the drift accumulation becomes narrower. Where this narrowing occurs, there is some suggestion of a double ridge – a small ridge superimposed on a larger one. The material in the ridge is highly variable, comprising a mixture of loose yellow-grey head with lenses of sand, silt and gravel. Larger blocks up to 1.5m are also present (Watson 1966). The deposits show downslope stratification.

Cwm Du is larger than Cwm Tinwen, but in contrast is not simply occupied by just a 'moraine-like' ridge (Watson 1966). Instead, the basin is fronted by a steep bank of drift, some 18m high in the centre, which forms a smooth, generally concave, slope rising up to the back wall. This smooth slope is interrupted near the back wall by a small ridge of stony clay which fills the south-west corner of the cirque – see Figure 23. The main expanse of deposits at Cwm Du forms a fan that is stepped in profile. Gully exposures through the fan show that it consists of stony clays with bedded silts and gravels.

Interpretation

Keeping (1882) considered that the deposits at Cwm Du formed a terminal moraine "heaped up at the end of the melting glaciers". In contrast, Watson (1966, 1968, 1970, 1976) and Watson and Watson (1977) showed that the landform and its associated deposits may be the product of nivation rather than glacial processes. Watson proposed that Cwm Du and Cwm Tinwen had formed in response to the accumulation of two quite different types of perennial snow patch; one gently sloping, the other steeply sloping. At Cwm Tinwen, the steep moraine-like ridge located close to the back wall was interpreted by Watson (1966) as a protalus rampart formed at the foot of a steep perennial snow patch. He thought that the hollow enclosed by the ridge was narrow because the snow had been banked steeply against the valley side, giving a pronounced gradient down which frost-shattered debris could glissade eventually to accumate as a ridge at the foot. The curved back wall may have produced a convergence of debris towards the centre where the rampart is thickest. Where it shows a double ridge structure, a later rampart is probably resting on a larger, older one. The age of these features is uncertain, but Watson (1966) argued that they had probably formed during the Devensian late-glacial when ice is thought to have persisted in nearby but more elevated cirques such as Cwm Cau, Cadair Idris.

The debris fan at Cwm Du, however, was attributed (Watson 1966) to an entirely different set of circumstances and processes. It was thought to have accumulated beneath a large but gently

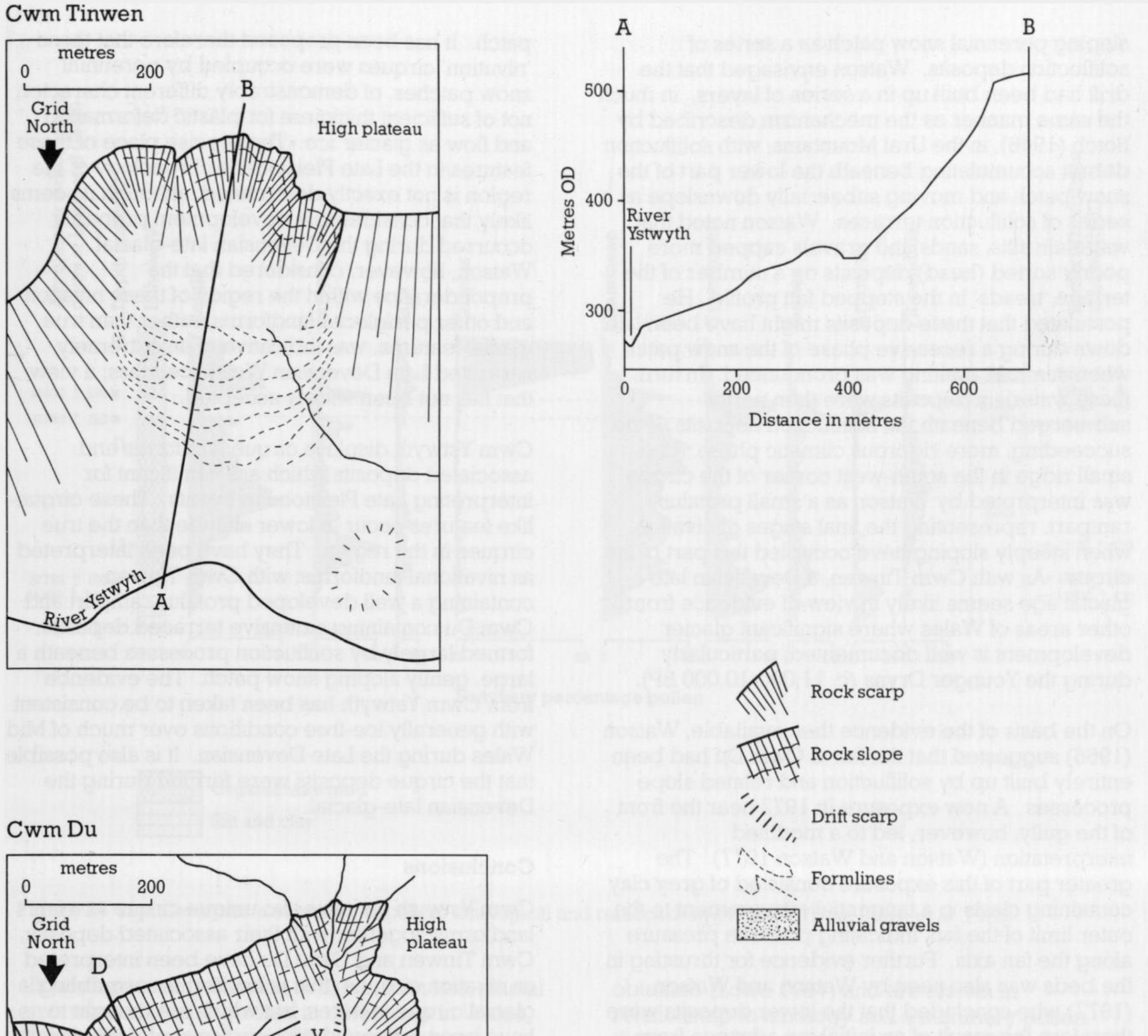

Figure 23 Cwm Ystwyth: principal landforms (after Watson 1966; Watson and Watson 1977)

sloping perennial snow patch as a series of solifluction deposits. Watson envisaged that the drift had been built up in a series of layers, in much the same manner as the mechanism described by Botch (1946), in the Ural Mountains, with solifluction debris accumulating beneath the lower part of the snow patch and moving subaerially downslope as a series of solifluction terraces. Watson noted that waterlain silts, sands and gravels capped more poorly sorted (head) deposits on a number of the terrace 'treads' in the stepped fan profile. He postulated that these deposits might have been laid down during a recessive phase of the snow patch when summer melting was pronounced. In turn, these waterlain deposits were then partly submerged beneath the solifluction deposits of the succeeding, more rigorous climatic phase. The small ridge in the south-west corner of the cirque was interpreted by Watson as a small protalus rampart, representing the final stages of nivation, when steeply sloping névé occupied this part of the cirque. As with Cwm Tinwen, a Devensian late-glacial age seems likely in view of evidence from other areas of Wales where significant glacier development is well documented, particularly during the Younger Dryas (*c.* 11,000-10,000 BP).

On the basis of the evidence then available, Watson (1966) suggested that the fan at Cwm Du had been entirely built up by solifluction and related slope processes. A new exposure in 1972 near the front of the gully, however, led to a modified interpretation (Watson and Watson 1977). The greater part of this exposure consisted of grey clay containing clasts in a tangential arrangement to the outer limit of the fan, indicating possible pressure along the fan axis. Further evidence for thrusting in the beds was also seen by Watson and Watson (1977) who concluded that the lower deposits were therefore the result of an initial ice advance from the cirque. This, they suggested, had been followed by a period of nivation responsible for the remainder of the fan form.

Cwm Ystwyth is important for a series of cirque landforms and associated deposits, the interpretation of which remains crucial to the understanding of Late Pleistocene events and processes in the area. Cwm Tinwen shows a fine example of a feature which is fairly common in upland Wales, a moraine-like ridge fronting a narrow basin elongated parallel to the ridge. Such features are found in strongly shaded positions and frequently below the level of more typical glacial cirques. The ridge at Cwm Tinwen is thought to be a protalus rampart developed at the base of a former, steeply sloping snow patch (Watson 1966). It contrasts with Cwm Du with its more open cirque-like basin floored by terraced superficial deposits. It has been proposed that this debris accumulated in Cwm Du as solifluction deposits beneath an inert mass of névé. Although there is also some evidence that glacier ice may have played a role in the formation of these deposits, the major part of the landform and sediment association is thought to have been derived from nivation processes beneath a relatively gently sloping snow patch. It has been proposed therefore that these 'nivation' cirques were occupied by perennial snow patches, of demonstrably different character, not of sufficient thickness for plastic deformation and flow as glacier ice. The precise place of these features in the Late Pleistocene chronology of the region is not exactly determined, although it seems likely that considerable development probably occurred during the Devensian late-glacial. Watson, however, considered that the preponderance within the region of these nivation and other periglacial landforms, rather than true glacial features, was indicative of an extremely restricted Late Devensian Welsh ice mass; a view that has not been widely accepted.

Cwm Ystwyth displays cirque landforms and associated deposits which are significant for interpreting Late Pleistocene events. These cirque-like features occur at lower altitude than the true cirques in the region. They have been interpreted as nivational landforms; with Cwm Tinwen containing a well developed protalus rampart and Cwm Du containing extensive terraced deposits, formed largely by solifluction processes beneath a large, gently sloping snow patch. The evidence from Cwm Ystwyth has been taken to be consistent with generally ice-free conditions over much of Mid Wales during the Late Devensian. It is also possible that the cirque deposits were formed during the Devensian late-glacial.

Conclusions

Cwm Ystwyth contains two unique cirque landforms, together with their associated deposits. Cwm Tinwen and Cwm Du have been interpreted as nivation cirques (that is landforms resembling glacial cirque features, but which are thought to have been fashioned by periglacial or cold climate and snow accumulation processes). The cirques and their deposits have been compared with similar features in the Ural Mountains of Russia and as such they are important in showing important variations in geomorphological processes towards the end of the last ice age.

Llyn Gwernan

Highlights

A key site where new radiocarbon dating techniques have been used to calibrate the Devensian late-glacial and Holocene rock record. Such dating allows accurate dates to be given for the onset of the last, Younger Dryas, glaciation in the Cadair Idris area, as well as for the wastage of this ice and the commencement of the Holocene.

Introduction

Llyn Gwernan contains an exceptional thickness of Devensian late-glacial deposits. Their biostratigraphy and radiocarbon dating have

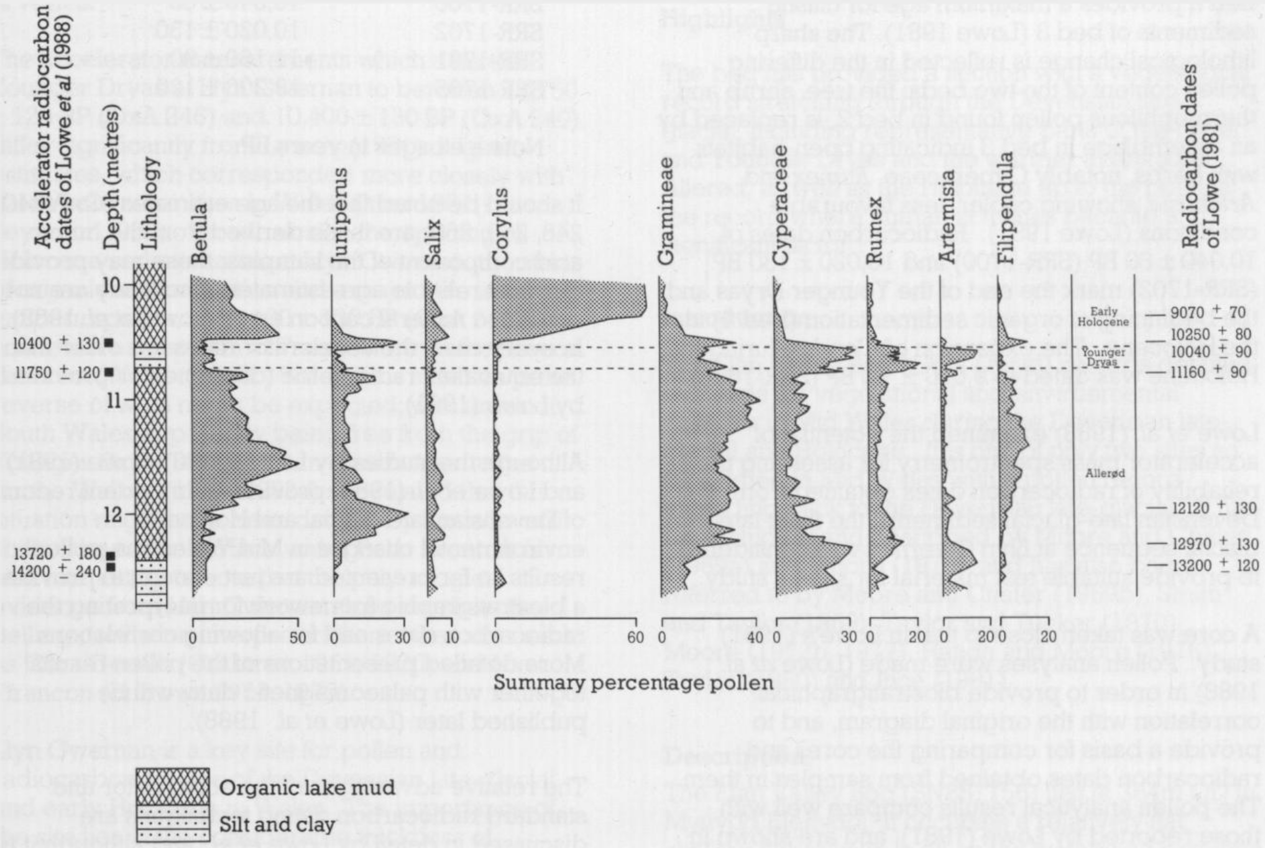

Figure 24 Llyn Gwernan: a summary of pollen, lithological and radiocarbon evidence (from Lowe *et al.* 1988)

allowed greater resolution of Devensian late-glacial environmental change than at other sites in Wales (Lowe 1981; Lowe *et al.* 1988). A preliminary investigation of the Holocene pollen biostratigraphy was undertaken by Laing (1980).

Description

Llyn Gwernan (SH703159) is a small freshwater lake on the northern flank of Cadair Idris. It occupies a steep-sided valley at *c.* 170m OD. Sediments, which include about 3.5m of Devensian late-glacial, and about 10m of Holocene deposits, have accumulated on the western edge of the lake, where a gradual succession of plant communities has raised the bog to a level higher than the adjacent lake. The following generalised late-glacial and early Holocene succession occurs (Lowe 1981; Lowe *et al.* 1988) –

4	Organic lake mud (0.75m)
3	Clay and silt with occasional stones (0.30m)
2	Organic lake mud (1.35m)
1	Clay and silt with some sand lenses and iron-rich (goethite) layers (>1.95m)

Organic material from comparable horizons was bulked from separate cores, and subjected to radiocarbon analyses. Eight dates were initially obtained (Lowe 1981) and are shown in relationship to lithology and a summary pollen diagram in Figure 24. Lowe *et al.* (1988) obtained accelerator mass spectrometry measurements of radiocarbon activity for comparison with the earlier radiometric dates – see Figure 24. The original samples for dating were bulked to minimise standard deviations from the assays (Lowe 1981).

Interpretation

From detailed pollen and radiocarbon analyses, Lowe (1981) reconstructed a sequence of Devensian late-glacial and early Holocene events. Organic sedimentation in the basin began at *c.* 13,200 ± 120 BP (SRR-1705). The clay and silt (bed 1) contain pollen that suggests a generally open-grassland landscape prior to *c.* 13,200 BP. This date is thought to provide a minimum age for Late Devensian ice wastage at the site.

The rise of *Juniperus* (bed 2) is the first clear evidence at Llyn Gwernan of thermal improvement, and is dated to 12,970 ± 130 BP (SRR-1704). A date of 12,120 ± 130 BP (SRR-1703) from higher in bed 2 is believed to mark the beginning of climatic deterioration which eventually culminated in the Younger Dryas, about a thousand years later (Lowe 1981). At Llyn Gwernan, the onset of the Younger Dryas is marked by an abrupt lithological change from organic lake muds (bed 2) to clay-rich clastic sediments (bed 3). A radiocarbon date of 11,160 ± 90 BP (SRR-1701) from organic material at the top of bed 2 provides a maximum age for clastic sediments of bed 3 (Lowe 1981). The sharp lithological change is reflected in the differing pollen content of the two beds: the tree, shrub and thermophilous pollen found in bed 2, is replaced by an assemblage in bed 3 indicating open-habitats with herbs, notably Cyperaceae, *Rumex* and *Artemisia*, showing cooler, less favourable conditions (Lowe 1981). Radiocarbon dates of 10,040 ± 80 BP (SRR-1700) and 10,020 ± 130 BP (SRR-1702) mark the end of the Younger Dryas and the beginning of organic sedimentation (bed 4) in the Holocene. The expansion of *Corylus* during the Holocene was dated to 9,070 ± 70 BP (SRR-1698).

Lowe *et al.* (1988) examined the potential of accelerator mass spectrometry for assessing the reliability of radiocarbon dates obtained from Devensian late-glacial sediments: the thick late-glacial sequence at Llyn Gwernan was considered to provide suitable test material for such a study.

A core was taken close to that in Lowe's (1981) study. Pollen analyses were made (Lowe *et al.* 1988) in order to provide biostratigraphical correlation with the original diagram, and to provide a basis for comparing the cores and radiocarbon dates obtained from samples in them. The pollen analytical results compare well with those reported by Lowe (1981), and are shown in summary form in Figure 24. The overall pollen biostratigraphical sequence and the successive maxima and minima of *Betula, Juniperus, Rumex, Artemisia* and *Filipendula* match almost exactly, and make comparison of the accelerator and radiometric dates straightforward (Lowe *et al.* 1988).

An advantage of accelerator measurements is that residual radiocarbon can be determined from minute amounts of sample carbon, enabling various components of sedimentary organic matter, such as lipids, amino acids and humic acids to be assessed individually (Lowe *et al.* 1988). In theory, this aids the identification of contaminants such as older and younger compounds which may have been incorporated into the sediments through, for example, recycling of sediments, infiltration or sampling contamination.

Lowe *et al.* presented accelerator mass spectrometry data for four horizons which coincided with clearly defined lithostratigraphic boundaries. Three samples correspond directly with material dated by Lowe (1981), and an additional determination (OxA260) was presented from material at the base of bed 2 –

Accelerator dates (humic acid fraction) (Lowe *et al.*1988)

OxA240	10,400 ± 130
OxA246	11,750 ± 120
OxA253	13,720 ± 180
OxA260	14,200 ± 240

Radiometric (decay) dates (Lowe 1981)

SRR-1700	10,040 ± 80
SRR-1702	10,020 ± 130
SRR-1701	11,160 ± 90
SRR-1705	13,200 ± 120

Note – all ages in years BP.

It should be noted that the age estimates (OxA 240, 246, 253, 260) are those derived from the humic acid component of the samples; these may provide the most reliable age estimates, since they are not subject to mineral carbon error (Lowe *et al.* 1988). In every case, the accelerator dates are older than the equivalent radiometric (decay) dates provided by Lowe (1981).

Although the studies by Laing (1980), Lowe (1981) and Lowe *et al.* (1988) provide an important record of Devensian late-glacial and Holocene environmental changes in Mid Wales, the pollen results so far presented are just enough to provide a biostratigraphic framework for interpreting the radiocarbon dates and for allowing correlations. More detailed presentations of the pollen results, together with palaeomagnetic data, will be published later (Lowe *et al.* 1988).

The relative advantages of the accelerator and standard radiocarbon dating techniques are discussed in detail by Lowe *et al.*, and although it is clear that the accelerator technique has certain clear advantages, such as pinpointing sources of error, it is not intended to replace the earlier method and dates. One of the main conclusions drawn in the study of Lowe *et al.* (1988), was that a degree of mineral carbon error appears to have affected all four of the stratigraphic horizons investigated. If the humic acid activity is compared with the earlier results, a systematic error of about 600 years is evident. The cause of this error is unclear: the fact that the two sets of dates (SRR and OxA) were obtained from different cores hampers direct comparisons. It is nonetheless clear that variations within the site in radiocarbon activity occur within contemporaneous sedimentary horizons (Lowe *et al.* 1988). Lowe *et al.* concluded that sediments will therefore vary in suitability for the application of accelerator radiocarbon techniques, and that, until the method has been more widely applied and evaluated, they recommend that radiometric measurements of bulk samples are still simultaneously undertaken for the same horizons.

A minimum age for Late Devensian ice-sheet wastage in the Cadair Idris region, and for the commencement of early late-glacial sedimentation is now indicated by a date of 14,200 ± 240 BP (OxA 260) from Llyn Gwernan. This date corresponds closely with dates from Glanllynnau and Clogwynygarreg of 14,468 ± 300 BP (Birm 212) and 13,670 ± 280 BP (Birm 884), respectively. Despite the inherent uncertainties associated with radiocarbon dates and their comparison, these dates probably confirm that the wastage of the Late Devensian ice-sheet was not uniform everywhere in Wales.

The accelerator measurements which date the Younger Dryas at Llyn Gwernan to between 11,750 ± 120 BP (OxA 246) and 10,400 ± 130 BP (OxA 240), differ significantly from Lowe's (1981) original estimates, which corresponded more closely with dates from other sites in Wales (Ince 1981; Seymour 1985). Paradoxically, the opening of Holocene sedimentation at Llyn Gwernan, the start of organic sedimentation and a major rise in *Juniperus* pollen, at 10,400 ± 130 BP (OxA 240) is now even earlier than at Traeth Mawr in the Brecon Beacons (Walker 1980, 1982a). This situation is the reverse of what might be expected; with areas of South Wales apparently being free from the grip of Younger Dryas ice later than sites farther to the north. Walker (1980, 1982a) speculated that this situation might have been caused by a southward shift of the ocean surface water Polar Front. It is also interesting to note that the palynological evidence from Llyn Gwernan does not show the Bølling oscillation interpreted from other sites such as Cors Geuallt (Crabtree 1969, 1970) and Nant Ffrancon (Burrows 1974, 1975).

Llyn Gwernan is a key site for pollen and radiocarbon studies of the Devensian late-glacial and early Holocene in Wales. The importance of the site lies in the considerable thickness of Devensian late-glacial organic deposits. These preserve a detailed pollen record that, together with radiocarbon dates, have allowed a far greater resolution of the Devensian late-glacial than elsewhere in Wales. The site is particularly important for the detailed radiocarbon timescale of Devensian late-glacial events: standard radiometric dates having recently been supplemented by accelerator derived dates. Llyn Gwernan is the first site in Wales where the newer method has been applied and is therefore important for methodological comparisons which have considerable implications for Devensian late-glacial and Holocene studies.

Conclusions

Llyn Gwernan contains an exceptional thickness of organic deposits which accumulated over the last 15,000 years or so. These contain fossil pollen grains and have been radiocarbon dated to give the most detailed timescale of climatic change over this period anywhere in Wales. This evidence has been recently supplemented by AMS (accelerator mass spectrometry) radiocarbon dates, the same technique as used to date the Turin Shroud.

The Elan Valley Bog

Highlights

The bog has provided a section with a vegetational record stretching through the Devensian late-glacial, including representative parts of the Older and Younger Dryas and the warmer interstadial Allerød, as well as the Holocene up to the point in the record where human activities became a significant factor.

Introduction

The Elan Valley Bog (Gors Llwyd) records detailed evidence for vegetational and environmental changes in Mid Wales during the Devensian late-glacial and Holocene. It is one of only two sites so far studied in Mid Wales with a pollen record extending back to the Devensian late-glacial. It has been studied and described by Moore and Chater (1969a) and Moore (1970), and has also been referred to by Moore and Chater (1969b), Smith and Taylor (1969), Taylor and Tucker (1970), Moore (1972b, 1977), Handa and Moore (1976), Taylor (1980) and Ince (1981).

Description

The Elan Valley Bog (SN857756) lies at 384m OD in Mynydd Elenydd. It occupies a relatively flat, shallow depression in till on the watershed between the rivers Elan and Ystwyth, which drain south-east and west, respectively. The bog has probably been drained by both rivers during its development (Moore 1970). Sections through the bog and underlying superficial sediments are exposed along Afon Elan.

A line of borings across the bog (from SN855753 to SN859754) was used to establish the stratigraphy of deposits within the basin (Moore and Chater 1969a). The detailed stratigraphy at SN858753 is –

6	Peats varying in composition and degree of humification (5.00m)
5	Brown organic gyttja (0.29m)
4	Grey silty gyttja (0.07m)
3	White soft clay gyttja (0.04m)
2	Grey silty gyttja (0.20m)
1	Stiff blue lake clay (bottom not seen)

A simplified stratigraphic section of the Elan Valley Bog deposits is shown in Figure 25. The sequence indicates initial occupation of the basin by a lake which became infilled with both organic and inorganic deposits. Later, the site was invaded by *Carex* and *Phragmites* and then by birch carr. This eventually gave way to ombrogenous bog, with *Eriophorum* and *Sphagnum*. No radiocarbon dates are available for the site.

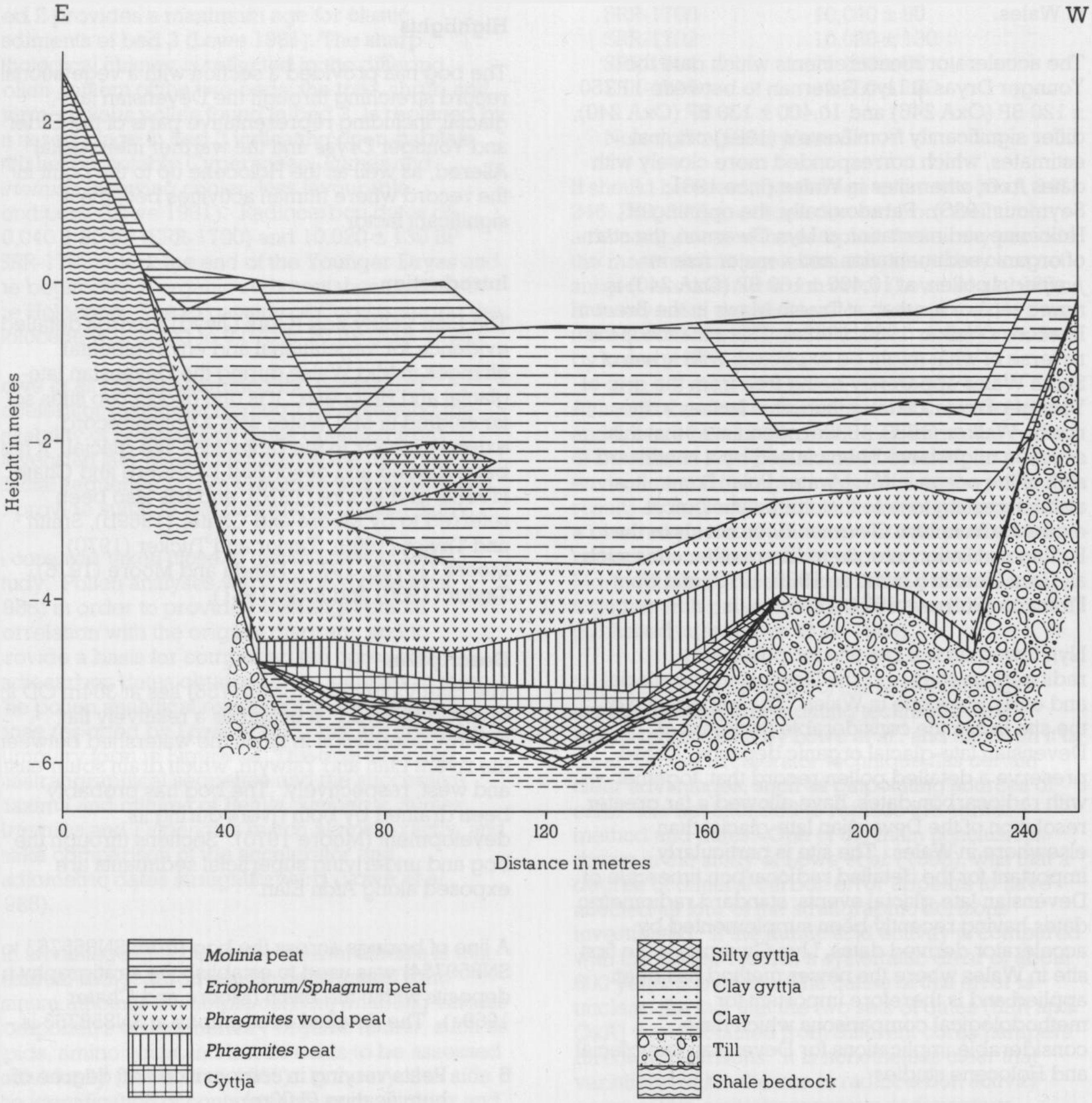

Figure 25 Elan Valley Bog: Devensian late-glacial and Holocene sequence (from Moore and Chater 1969a)

Interpretation

The pollen biostratigraphic data of Moore and Chater (1969a) and Moore (1970) allow the following sequence of vegetational changes to be reconstructed. The Devensian late-glacial was divided into Pollen Zones I-III. Intermediate pollen zones were also recognised.

The basal blue lake clay (bed 1) contained pollen characteristic of Pollen Zone I (Moore 1970), indicating a vegetation of dwarf shrub heath *(Betula nana* L. and *Dryas)* with tall herb communities. The assemblage shows a period of unstable environmental conditions with disturbed soils, and generally open-habitats. This phase was followed by increasingly shrubby vegetation in bed 2 (Pollen Zone I-II; Moore 1970) with birch carr and/or scrub birch. At this time, *Juniperus* also showed a marked rise. This period can be correlated with the change from periglacial conditions, following wastage of the Late Devensian ice-sheet, to warmer conditions associated with the Allerød.

The succeeding Pollen Zone II (bed 2), is characterised by a rise in tree birch pollen and a continued improvement in conditions, as demonstrated particularly by the occurrence of warmth-demanding taxa such as *Filipendula* and

Urtica. This assemblage was correlated with the Allerød represented at other sites in Britain and the Continent (Moore 1970).
A transitional zone (Pollen Zone II-III) was recognised by Moore (1970). During this period, birch declined but juniper was probably still present on local hillsides. Communities indicative of exposed montane grassland with some disturbed soils are present, and this transitional pollen zone appears to represent colder conditions than Pollen Zone II, but not cold enough to eliminate *Filipendula* and *Juniperus* (Moore 1970). A July mean of 10°C was estimated, on the basis that such a temperature would restrict *Betula* more severely than it would *Juniperus*.

During Pollen Zone III (upper bed 2 and bed 3) the exposed montane and alpine communities reached their greatest development. Taxa indicating disturbed soils and dwarf birch scrub became more prominent, and the assemblage indicates a return to colder conditions, with associated solifluction and the development of tundra vegetation. An accompanying change in lithology from largely organic to inorganic deposition (bed 2 to bed 3) also occurred at this time, and can be correlated with the Younger Dryas when glaciers occupied cirques in upland Wales (for example, Walker 1980; Ince 1981).

A further transitional pollen assemblage (Pollen Zone III-IV) represents a change from the cold Younger Dryas to milder conditions in the early Holocene. This pollen assemblage (bed 4) was marked by a return of *Filipendula* and the re-expansion of *Juniperus* scrub. Birch scrub and carr may also have begun to develop, but the succeeding Pollen Zone IV (bed 5) is marked by a much more rapid rise in birch pollen, although the presence of *Betula pubescens* Ehrh. fruits indicates that the local development of birch carr may have exaggerated this expansion. At this time, juniper probably gave way to birch. Later in Pollen Zone IV, juniper and dwarf birch virtually disappeared as birch woodland expanded. This pollen zone also records the arrival of *Corylus* and a decline in taxa which preferred open-ground.

The succeeding pollen zones all occur in bed 6 (peats). Pollen Zone V shows a sudden expansion of hazel which reaches its maximum in Pollen Zone VIa. This suggests that hazel favoured the maritime conditions of the west, and a similar expansion has been recorded at other sites in north and west Britain. Pine pollen increases sufficiently during this pollen zone, to indicate the local presence of pine trees.

Quercus and *Ulmus* pollen first occurs in Pollen Zone IV at Elan Valley, and it increases in Pollen Zone V and VIa. The latter pollen zone is associated with a decrease in *Betula*. Elm may initially have been more successful in colonising than oak, but by Pollen Zone VIb oak is dominant in the record, indicating the continued invasion of the shallow hillside soils by oak at the expense of hazel.

Pollen Zone VIa is characterised by a prominence of pine pollen (Moore and Chater 1969a). Oldfield (1965) suggested that *Pinus* invasion of upland deciduous woodland was in response to increased rainfall, but Moore and Chater suggested that locally at Elan Valley pine invaded the bog surface which was becoming progressively drier, prior to the beginning of Pollen Zone VIIa.

Pollen Zone VIIa is characterised by changes in the pollen curves and in stratigraphy. There is a sudden decline in pine, an increase in *Alnus* and *Quercus* pollen, and *Tilia* occurs for the first time. Birch declines still further from the preceding pollen zone. In addition, *Phragmites* (reed swamp) became dominant and *Phragmites* peat accumulated, perhaps indicating flooding of the bog surface. That this increased wetness was caused by climatic rather than local factors is suggested by an increase in alder. This period, as elsewhere in Britain, can be regarded as the time of maximum forest expansion (Moore and Chater 1969a).

The elm decline, frequently taken as denoting the onset of Pollen Zone VIIb, is well marked in the Elan Valley Bog pollen record, although the cause is not clear. Two distinct but conflicting lines of evidence can be deduced from the pollen spectra. First, there is evidence for climatic change involving an increase in the ratio of precipitation to evaporation. This is accompanied by a sudden increase in the rate of peat formation as shown by the stratigraphy and related pollen frequency index. This phase coincides with the initiation of blanket peat formation at several other sites in the area, and generally indicates wetter conditions (Moore 1966). Second, the pollen evidence suggests that human activity began to influence vegetation at the time of the elm decline: pollen of *Plantago lanceolata* L. (ribbed plantain) and an increase in *Pteridium* (fern) spores, suggests human interference by forest clearance and the grazing of domestic animals. Turner (1964) has suggested that *P. lanceolata* can be used as an indicator of grazing. Thus, although both climatic and human influences have been discerned in the record, it is not possible to attribute the changes to either of these mechanisms with certainty (Moore and Chater 1969a).

The Elan Valley Bog contains an important pollen biostratigraphic record of Devensian late-glacial and Holocene environmental and vegetational changes. The sub-division of the Devensian late-glacial sequence into a number of intermediate pollen assemblage zones as well as Pollen Zones I, II and III has allowed greater precision in interpreting the vegetational record (Moore 1970). The Devensian late-glacial record at Elan Valley shows that following the wastage of the Late Devensian ice-sheet a time of relatively severe conditions, dominated by broken, open-habitat vegetation with disturbed soils, occurred. This was followed by an improvement in conditions when birch and juniper flourished. A succeeding colder phase is then indicated, equivalent to the Younger

Dryas (*c.* 11,000-10,000 BP), when glaciers again occupied many cirques in upland Wales. At this time, large perennial snow patches and even glacier ice may have occupied the relatively low-level cirques at nearby Cwm Ystwyth (Watson 1966). The pattern of Devensian late-glacial events recorded at Elan Valley, closely follows the tripartite division comprising the Older Dryas, Allerød and Younger Dryas of the Continental Late Weichselian Stage (Late Devensian) – see Mangerud *et al.* 1974. It reflects a single warm phase equivalent to the period that Ince (1981) described at Clogwynygarreg as the 'late-glacial interstadial', preceded and followed by colder climatic phases. The site provides contrasting evidence, therefore, to sites at Nant Ffrancon and Cors Geuallt (Snowdonia) and Traeth Mawr (Brecon Beacons) which show evidence for a possibly more complex sequence of Devensian late-glacial events.

Conclusions

The Elan Valley Bog provides evidence for a continuous record of vegetational and environmental history for the last 14,000 years up until the time when human interference with the vegetation became a significant factor. It is an upland site for demonstrating important regional variations in the vegetational history of Wales.

Tregaron Bog (Cors Tregaron)

Highlights

This locality is one of the largest raised bogs in Britain. Its peats yield pollen making it possible to elucidate vegetational change through the Holocene. This, with close interval radiocarbon dating, has allowed the reconstruction of an accurate history of environmental change and later land use.

Introduction

Tregaron Bog is important for reconstructing Holocene environmental conditions in western Mid Wales. The stratigraphy and development of the raised bog at Tregaron were first studied in detail by Godwin and Mitchell (1938), and its ecology by Godwin and Conway (1939). The effect of human activity in the development of vegetation at the site, including forest clearance, was discussed by Turner (1964, 1965). Radiocarbon dates were given by Godwin and Willis (1960, 1962), Switsur and West (1972) and Hibbert and Switsur (1976). More general accounts of the Holocene history were given by Moore (1977) and Turner (1977), and the site has been widely discussed (for example, Turner 1962; Moore and Chater 1969b; Smith and Taylor 1969; George 1970; Moore 1972b; Deacon 1974; Taylor 1980; Walker 1980, 1982a, 1982b; Ince 1983).

Description

The site consists of three bogs known locally as Cors Goch Glan Teifi, developed upstream of a broad arcuate moraine near Tregaron. The moraine was regarded as the southern limit of Late Devensian ice in the Teifi Valley (Charlesworth 1929). The largest bog, usually referred to as the west bog (*c.* SN680630), lies on the west bank of the Teifi and is roughly oval in shape, measuring some 2,400m by 1,200m.

The other bogs lie to the east of the Teifi and are separated by a ridge of higher ground which runs towards the river from the valley side at Maes Llŷn. These bogs are referred to as the north-east and south-east bogs. Details of bog morphology and present vegetation are given by Godwin and Conway (1939). All three show marked raised profiles. The north-east bog has been extensively altered by drainage, but the west and south-east bogs are relatively intact, despite cutting at the margins.

The stratigraphy of the bogs at Tregaron was determined by Godwin and Mitchell (1938) and Hibbert and Switsur (1976), and consists over most of the valley centre of –

7 Fresh, light-coloured *Sphagnum* peat with remains of *Calluna* and *Eriophorum*

6 Thin (0.07-0.5m) highly humified peat, termed a retardation layer – see text

5 Light-coloured *Sphagnum* peat with remains of *Calluna* and *Eriophorum*

4 Highly humified *Sphagnum* peat with fibres and roots of *Eriophorum* and twigs of *Calluna*

3 *Phragmites* peat with scattered wood fragments, remains of *Cladium mariscus* (L.) Pohl and numerous seeds of *Menyanthes* and *Nuphar luta* (L.)

2 Pale brown mud with seeds of open-water plants and scattered fragments of wood

1 Stiff blue-grey (lacustrine) clay

Borings from the bog margins, however, show peats with a higher wood and silt content, overlying angular gravelly hillwash (Godwin and Mitchell 1938; Turner 1977).

The pollen biostratigraphy at Tregaron was first studied by Erdtman (1928), although a full pollen diagram was not published. Subsequently, the stratigraphy of the bogs was investigated by Godwin and Mitchell (1938) who described up to 5m of bog peat overlying *Phragmites* peat, mud peats and clays (beds 1-3). The bog peat was divided into a lower highly humified dark *Sphagnum* peat (bed 4) and an upper, light-coloured *Sphagnum* peat (beds 5 and 7). In all three bogs there is a well marked contact between the lower highly humified peat (bed 4) and the upper fresh peat (bed 5) termed the *Grenzhorizont* by Godwin and Mitchell (1938). A thin layer of

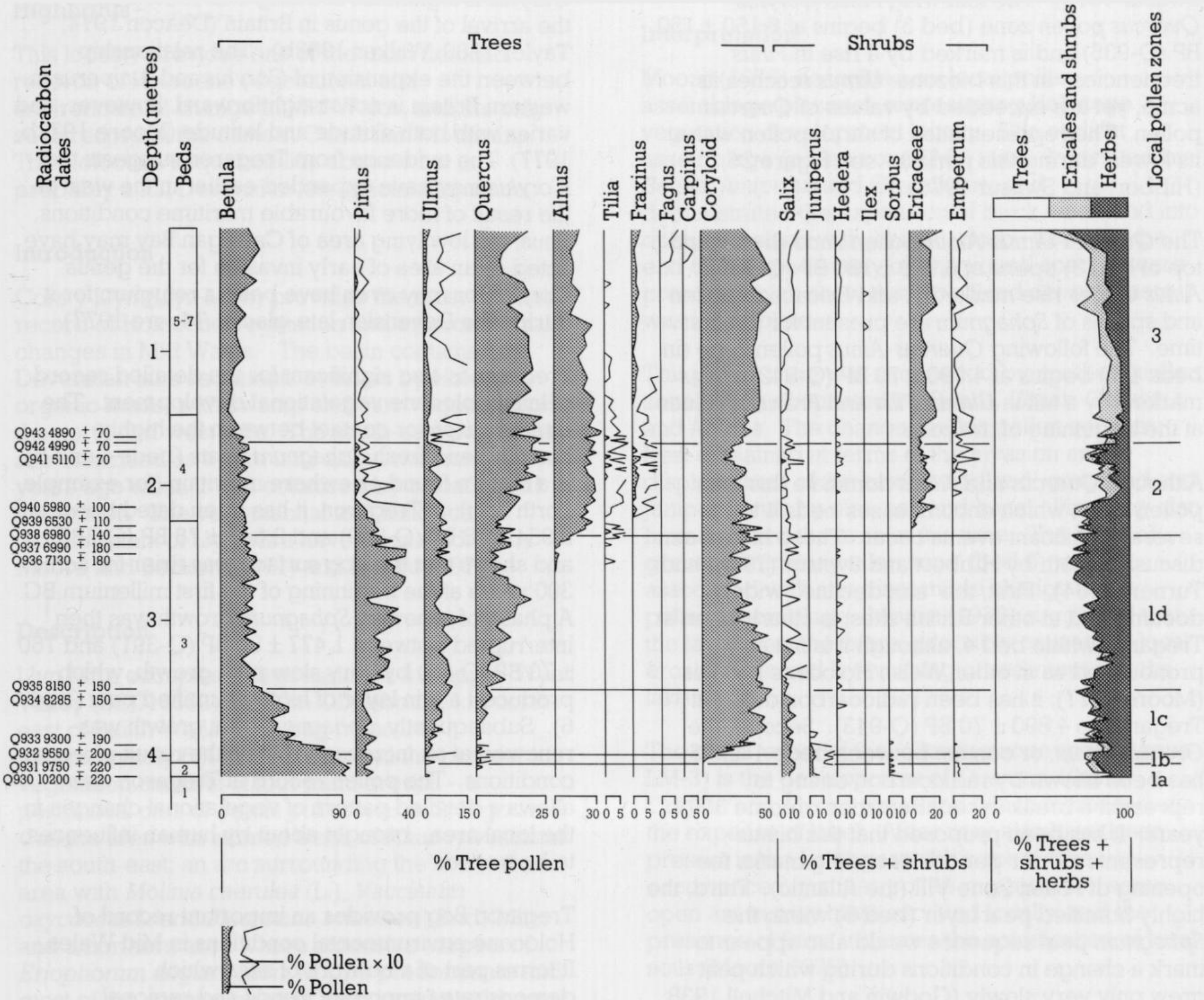

Figure 26 Tregaron Bog: a summary of pollen, lithological and radiocarbon evidence (from Hibbert and Switsur 1976)

highly humified peat (bed 6) occurs approximately mid-way between the *Grenzhorizont* and the upper surface of the fresh *Sphagnum* peat in bed 7; this was termed a 'retardation' layer (Godwin and Mitchell 1938).

In 1960, Godwin and Willis published radiocarbon dates from the south-east bog. These included dates of 760 ± 70 BP (Q-75) and 1,477 ± 90 BP (Q-391), between which the 'retardation' layer (bed 6) was believed to have formed. Dates of 2,954 ± 78 (Q-389) and 2,647 ± 78 BP (Q-388) were presented to show that the contact between beds 4 and 5 (the *Grenzhorizont)* represented a hiatus in deposition of about 300 years.

Interpretation

Godwin and Mitchell (1938) charted the course of vegetation development at Tregaron from the pre-Boreal to the sub-Atlantic using pollen analysis. Their interpretations were confirmed by Hibbert and Switsur (1976) who presented a detailed analysis of the pollen biostratigraphy with radiocarbon dates – see Figure 26. They showed that deposition began in the Holocene at Tregaron at 10,200 ± 200 BP (Q-930), marked by an abrupt lithological change from blue-grey clay (bed 1) to organic mud (bed 2). The first pollen assemblage zone (bed 2) shows *Betula* to be the dominant tree pollen, with pollen of *Juniperus* and *Salix*. *Pinus* pollen is also present in relatively low, yet constant, frequencies. The start of the succeeding pollen zone (bed 3), dominated by *Betula, Pinus* and *Corylus,* was dated to 9,750 ± 220 BP (Q-931). This zone shows the first continuous representation of *Corylus* in the profile.

The following pollen zone (also in bed 3) began at 9,300 ± 190 BP (Q-933), and is dominated by *Corylus* and *Pinus*. *Corylus* increased sharply at the start of this zone and maintained high values – see Figure 26. At this time, *Juniperus* declined, probably indicating shading-out by other woodland taxa such as *Ulmus* and *Quercus*, which first become continuously represented (Hibbert and Switsur 1976). The following *Pinus-Corylus-Quercus* pollen zone (bed 3) begins at 8,150 ± 150 BP (Q-935) and is marked by a rise in *Pinus* frequencies. In this biozone, *Ulmus* reaches its acme, yet it is exceeded by values of *Quercus* pollen. The representation of shrub pollen was at its lowest during this period – see Figure 26; (Hibbert and Switsur 1976).

The *Quercus-Ulmus-Alnus* pollen zone (bed 4 and top of bed 3) opens at 6,990 ± 180 BP (Q-937). *Alnus* values rise markedly, and Ericaceae pollen and spores of *Sphagnum* are present for the first time. The following *Quercus-Alnus* pollen zone (in beds 4-7) begins at 4,990 ± 70 BP (Q-942) and is marked by a fall in *Ulmus, Tilia* and *Fraxinus* values at the beginning of the zone.

Although *Quercus* and *Alnus* dominate this later pollen zone, which encompasses beds 4 to 7, several significant events occur. These have been discussed both by Hibbert and Switsur (1976) and Turner (1964). First, the 'elm decline', widely documented at other British sites, is clearly seen at Tregaron within bed 4, although it is not as pronounced as in other Welsh Holocene profiles (Moore 1977); it has been radiocarbon dated at Tregaron to 4,890 ± 70 BP (Q-943). Second, the *Grenzhorizont,* or contact between beds 4 and 5, has been shown by radiocarbon dating to represent a break in sedimentation of some 300 years. It has been proposed that this hiatus represents a drier period; its ending marks the opening of Pollen Zone VIII (the Atlantic). Third, the highly humified peat layer (bed 6) within the *Sphagnum* peat sequence would also appear to mark a change in conditions during which peat grew only very slowly (Godwin and Mitchell 1938; Turner 1977).

Finally, Turner (1964, 1965, 1977) studied the pollen biostratigraphy of the upper 2m of Holocene deposits at Tregaron (beds 5-7 and the top of bed 4), and inferred human influences in the later Holocene vegetational history of the site. She concluded that the area was well wooded with only small clearings during the Bronze Age. At about 400 BC, most of the woodland was replaced by grassland, perhaps as part of the pastoral economy of the Iron Age peoples who built a fort to the north-east end of the bog near Pontrhydfendigaid. This economy appears to have continued until the twelfth century when Cistercian monks founded an abbey at nearby Strata Florida (Ystrad Fflur) and established arable farming on their granges (Turner 1964, 1965, 1977).

Tregaron, therefore, provides an exceptionally detailed record of Holocene vegetational changes. Open-water conditions existed at the site until early Holocene times. The course of vegetation development can then be traced as open-ground conditions were replaced by woodland of increasing diversity. At Tregaron, the early Holocene is marked by a rise in *Juniperus* pollen followed closely by a rapid expansion of *Corylus*. A date of 9,750 ± 220 BP (Q-931) for the rise in *Corylus* is significant in being one of the earliest for the arrival of the genus in Britain (Deacon 1974; Taylor 1980; Walker 1982b). The relationship between the expansion of *Corylus* and *Juniperus* in western Britain is not straightforward, however, and varies with both altitude and latitude (Moore 1972b, 1977). The evidence from Tregaron suggests that *Corylus* may have expanded earlier in the west as the result of more favourable maritime conditions. Thus, the low lying area of Cardigan Bay may have acted as an area of early invasion for the genus *Corylus,* or may even have been a refugium for it during the Devensian late-glacial (Moore 1977).

Tregaron is also significant for the detailed record of later Holocene vegetational development. The *Grenzhorizont* or contact between the highly humified and fresh *Sphagnum* peats (beds 4 and 5) is a feature found elsewhere in Britain (for example, Borth Bog); at Tregaron, it has been dated between 2,954 ± 78 BP (Q-389) and 2,647 ± 78 BP (Q-388) and shows that the bog surface was drier for some 300 years at the beginning of the first millenium BC. A phase of renewed *Sphagnum* growth was then interrupted between 1,477 ± 90 BP (Q-391) and 760 ± 70 BP (Q-75) by very slow peat growth, which produced a thin layer of highly humified peat (bed 6). Subsequently, *Sphagnum* peat growth was renewed at an increased rate as the result of wetter conditions. The pollen record at Tregaron also allows a detailed pattern of vegetational changes in the local area, brought about by human influences, to be traced.

Tregaron Bog provides an important record of Holocene environmental conditions in Mid Wales. It forms part of a network of sites which demonstrates important trends and regional diversities in vegetational development during the Holocene. Its close interval radiocarbon timescale, together with pollen analysis and historical records have enabled a continuous pattern of changing environmental and land-use conditions to be reconstructed, from the early Holocene up to and beyond the establishment of the Forestry Commission in 1919.

Conclusions

Tregaron Bog is historically important because it was one of the earliest sites where pollen analysis was applied in the British Isles. It has yielded an important record of vegetational and environmental change over the past 10,000 years. These changes have been dated by radiocarbon methods and the detailed pollen evidence is sufficiently accurate to demonstrate the cereal growing activities of the Cistercian monks in the Middle Ages as well as the beginning of Forestry Commission activities in 1919. As such it is an exceptional example of the power of pollen analysis and radiocarbon dating in showing detailed climatic and other changes.

Cors y Llyn

Highlights

This locality provides one of the most detailed records of Holocene vegetational and environmental change in Mid Wales, and the only such record in the eastern Cambrian Mountains. The Holocene sequence lies above what is probably a full Devensian late-glacial sequence.

Introduction

Cors y Llyn (Llyn Mire) provides the most detailed record of Holocene vegetation and environmental changes in Mid Wales. The basin contains Late Devensian lake sediments overlain by Holocene organic muds, with swamp and carr vegetation on the north and west side. The south-east part of the site continued as a lake until about two hundred years ago when it was colonised by a floating raft of vegetation. The vegetational and historical development of Llyn Mire have been studied by Moore and Beckett (1971) and Moore (1978).

Description

Llyn Mire occupies a depression in the upper Wye Valley (SO016552) at 170m OD, about 6 km north-east of Builth Wells. The bog measures approximately 600m by 200m, and the present vegetation consists of four main groups – a peripheral carr of *Betula pubescens;* a *Sphagnum-Calluna* area with stunted trees of *Pinus sylvestris* in the south-east; an arc surrounding the south-east area with *Molinia caerulea* (L.), *Vaccinium oxycoccus* L. and *Pleurozina schreberi* (Brid) Mitt.; and a northern area where extensive carpets of *Eriophorum angustifolium* Hoppe predominate and most of the species already mentioned are absent (Moore 1978).

A series of borings shows that the mire occupies three basins formed on an undulating surface of glacial sediments (Moore and Beckett 1971). The stratigraphy at the deepest point of the south-east basin (Moore 1978) showed a 10.5m thick sequence of –

10	*Sphagnum* peat
9	*Phragmites* and/or *Carex* peat
8	Water
7	Mud
6	Gravel
5	Silty mud
4	Clay
3	Silty mud
2	Clay
1	Till

The lower beds (1-4) were not analysed in detail by Moore (1978) but were believed to represent a Devensian late-glacial sequence. The upper part of the sequence, some 8m, was analysed in detail for both pollen and macrofossils by Moore (1978). No radiocarbon dates are available for the site.

Interpretation

Moore (1978) described six local pollen assemblage biozones representing Holocene vegetation development locally. The earliest assemblage (pollen zone LM-1) was dominated by *Betula, Juniperus* and Gramineae, and demonstrated the expansion of birch woodland into open-grassland with juniper scrub. Towards the end of this zone, many open-ground species were present, which show that woodland development was incomplete.

This pollen zone was succeeded by another (pollen zone LM-2) dominated by *Betula, Ulmus, Corylus* and *Myrica.* The changes in this pollen zone are best explained in terms of the invasion and displacement of the birch woodland, grassland and juniper scrub by elm, oak and hazel. Pine may also have invaded the area at this time. The layer of gravel within this pollen zone (bed 6) was not associated with any discernible change in the pollen assemblage. Moore (1978) suggested that the layer was, therefore, probably caused by local erosion followed by washing of sediment into the lake basin.

The major event of the following zone (pollen zone LM-3) is the development of *Quercus, Ulmus, Corylus* and *Myrica* woodland which increased at the expense of birch. Alder may also have been present in the latter part of this zone. The occurrence of juniper pollen suggests that some open areas may have survived locally, and the presence of ferns indicates the acidification of local soils (Moore 1978).

The succeeding pollen zone (pollen zone LM-4), dominated by *Quercus, Alnus, Ulmus, Betula, Corylus* and *Myrica*, records, in particular, the attainment of dominance by oak and alder. The upper part of this zone is marked by pronounced changes in the ratio of non-arboreal to arboreal pollen, and Moore (1978) has suggested that the presence of ribbed plantain *Plantago lanceolata* and fumitory *Fumaria* is particularly indicative of disturbance to the vegetation cover at this time, perhaps by human agencies. This short-lived event, however, precedes the very marked elm decline of the next zone.

The following *Quercus, Alnus, Corylus* and *Myrica* dominated zone (pollen zone LM-5) records evidence for vegetation disturbance in the form of a rapid decline in elm, pine and lime pollen. Moore considered that there was strong circumstantial evidence to relate these changes to forest clearance and the cultivation of cereals. The pollen record from the upland site at the Elan Valley Bog to the north-west, however, suggests that increased climatic wetness at this time may also have been an important factor (Moore and Chater 1969a).

The major changes of the last recorded Llyn Mire pollen zone (pollen zone LM-6), characterised by *Pinus*, *Quercus* and Gramineae pollen, are best explained in terms of continued woodland clearance and the development of agriculture. At this time, *Betula* carr probably survived around the edge of the basin, and peat harvesting may have led to the invasion of *Pinus sylvestris* (Moore 1978).

Llyn Mire provides the only detailed record of Holocene vegetational and environmental changes from the upper Wye Valley. The site therefore provides information on the Holocene development of vegetation in a major valley on the eastern side of Mynydd Elenydd (Cambrian Mountains). In contrast, most other studies of vegetational changes in Mid Wales have been concerned with the ridge of Mynydd Elenydd itself and the land to the west (for instance, the Elan Valley Bog, Borth Bog, Tregaron Bog, Cledlyn Valley). The record from Llyn Mire shows vegetational development from the early Holocene (*c.* 10,000 BP) when birch woodland began to develop on the otherwise open-ground, grassland and juniper dominated landscape. The course of this development can be traced through the displacement of this early assemblage by elm, oak and hazel woodland, and the eventual attainment of dominance by oak and alder. The elm decline is very marked and is accompanied by evidence of cultivation; the first such evidence of cereal growing in early Neolithic times in Mid Wales (Moore 1978).

The lithological evidence shows that following the wastage of Late Devensian ice, sedimentation occurred in three basins on the till surface at Llyn Mire. A succession of clay, silty mud and clay (beds 2-4) was deposited on the surface of the till and is thought to be Devensian late-glacial in age; the threefold succession is characteristic of sequences elsewhere in Wales where the Older Dryas, Allerød and Younger Dryas are represented. The succeeding silty mud (bed 5) occurs in all three basins and shows deposition in open-water conditions in the early Holocene. The invasion of reed swamp and fen vegetation followed, and open-water conditions ceased in the northern and western basins. In the south-east basin the lake became enveloped by a floating mat of aquatic vegetation. This floating mat or *Schwingmoor* type of bog is rare in Britain, and Llyn Mire is an unusually fine example. The final vegetation invasion of the lake surface is believed to have occurred in historic times, during the post-Mediaeval period (Moore and Beckett 1971).

Llyn Mire contains an important Devensian late-glacial to Holocene sequence. Although the Devensian late-glacial sediments have not been studied in detail, the record of Holocene vegetational changes is one of the most detailed in Mid Wales, and the only such record on the eastern side of Mynydd Elenydd. The course of vegetation development can be traced from the early Holocene well into historic times. The pollen record shows clearly the 'elm decline' and provides the first evidence of cereal cultivation in early Neolithic times in Mid Wales. Part of the site was still a lake until two hundred years ago when it was colonised by floating vegetation.

Conclusions

Llyn Mire is the only site which provides a record of vegetational, environmental and climatic change on the eastern side of Mynydd Elenydd (Cambrian Mountains). It is important because it shows the first evidence of cereal cultivation in early Neolithic times in Mid Wales. Botanically, its floating vegetation *Schwingmoor* bog is one of the best examples in Britain.