Glanllynnau

Highlights

A complex site showing evidence for a fluctuating Devensian ice front. Its sediments, pollen, beetles and absolute dates have afforded one of the most detailed records of climatic change and, in particular, glacial retreat in Wales.

Introduction

Glanllynnau is a site of considerable importance for understanding glacial and late-glacial events in Wales. The glacial sediments have been interpreted as the product of two separate ice advances, but may also be explained as the result of a single glaciation. The deposits at Glanllynnau were first studied by Jehu (1909), and then by Matley (1936), Saunders (1963, 1967, 1968a, 1968b, 1968c, 1968d, 1973), Synge (1964, 1970) and Whittow and Ball (1970). Accounts of the Devensian late-glacial and Holocene successions were provided by Simpkins (1968, 1974) and Coope and Brophy (1972). The lithostratigraphy of the site was recently re-examined by Boulton (1977a, 1977b), and the succession has been discussed in a wider area by Bowen (1973a, 1973b, 1974, 1977b). It has also been referred to by Moore (1970, 1977), Shotton and Williams (1971) and Coope (1977).

Description

The coastal cliffs at Glanllynnau [SH 456 372] reveal a sequence of tills and fluvioglacial sediments, the latter displaying well developed glaciotectonic structures. The area inland is studded with kettle holes, some of which have been breached by coastal erosion to reveal a succession of Devensian late-glacial silty clay, peat and sand horizons.

Whittow and Ball (1970) described the following succession at Glanllynnau — see (Figure 33):

11 Hillwash

10 Peat

9 Grey silt with boulders

8 Organic pond clay

7 Lake mud

6 Stony solifluction clay

5 Brown stony till (Llanystumdwy Till)

4 Fluvioglacial sand and gravel (Mon Wen Formation)

3 Laminated stoneless clays, silts and sands (contorted)

2 Yellow-brown weathered surface of Criccieth Till

1 Blue-grey till disturbed by fossil ice-wedge casts (Criccieth Till)

Interpretation

The glacial sequence

When the exposures were described by Jehu in 1909, the lower till (bed 1) was not exposed. He recorded only one till (bed 5) lying above sands and gravels, and classified these as the upper two thirds of his tripartite sequence in Ll■n. He established that the deposits were of Welsh provenance. Matley (1936) suggested that the sequence had been trimmed into a terrace, which commonly occurred at about 50 feet (*c.* 15m) in southern Ll■n, formed either by marine agencies or at the margins of a glacially-impounded lake in 'Late-Glacial' times.

Saunders (1963, 1967) was the first to record the lower blue-grey till (bed 1) beneath the sand and gravel at Glanllynnau. Saunders (1968a, 1968b, 1968c, 1968d, 1973) also described additional lithological and till fabric evidence. He showed that the lower till was argillaceous with an erratic suite dominated by slate (over 85%) derived from the Nantlle–Bethesda slate belt; its fabric indicating deposition by ice moving from ENE to WSW. He suggested it was overlain by a thin band of weathered and soliflucted till (bed 2) of the same origin, which in places, filled well developed fossil ice-wedge casts in the surface of the lower till. The weathered horizon was succeeded by a thin bed of wavy laminated silts (bed 3), which sealed the top of the ice-wedge casts, and which he considered could have been caused by freeze-thaw activity or by subsequent overriding of the sediments by the ice of a later advance. The silts are overlain by the fluvioglacial sand and gravel (bed 4) described by earlier workers, and by the upper till (bed 5) which shows well developed cryoturbation structures. Saunders showed that, like the lower till, the upper till was also Welsh in origin and it contained erratics from the Vale of Ffestiniog, deposited by ice moving from east to west. On regional lithostratigraphic grounds he suggested that large areas of western Llyn were ice-free during the most recent glacial pulse (upper till at Glanllynnau). Saunders developed a framework for Late Pleistocene events in Ll■n using lithostratigraphical evidence supported by radiocarbon dating. He argued that the lower till (Criccieth Till) at Glanllynnau and elsewhere in southern Ll■n, for example at Morannedd, was deposited during the main pulse of the Late Devensian ice-sheet. He correlated it with the Trevor Till of northern Ll■n and Porth Neigwl. He suggested that the gravelly till (Llanystumdwy Till — Simpkins 1968) at Glanllynnau and at Morannedd had been deposited by a subsequent advance of Late Devensian Welsh ice. Saunders (1968a) reported a radiocarbon date of 11,740 ± 170 BP (I–3261) from peat collected at the base of a kettle hole developed in the fluvioglacial sands and gravels. Together with a determination of 16,830 + 970 –860 BP (I–2801) (Foster 1968, 1970a) from material disseminated in sands and gravels of an equivalent formation at Bryncir, these dates were used by Saunders as upper and lower limits for the last phase of glacial activity in Ll■n. He correlated this with the Scottish Readvance glaciation.

Thus, Saunders established a Late Devensian age for the Criccieth and Llanystumdwy Tills at Glanllynnau, the latter ascribed to an ice readvance later in the Late Devensian. The zone of weathering and frost-cracking on the surface of the Criccieth Till was ascribed to the time between deposition of the two tills. This was supported by Whittow and Ball (1970) and Bowen (1973a, 1973b, 1974, 1977b). Earlier, Synge (1964), suggested that the weathered till surface elsewhere in Ll■n was sufficiently deep and well developed to have formed under fully interglacial conditions, probably during the Ipswichian Stage. The tills were therefore considered by him to be Saalian in age. This view was also supported by Simpkins (1968) who argued that the deeply weathered Criccieth Till of southern Ll■n was older than the Trevor Till of the north Ll■n coast. In an alternative explanation, Synge (1970) suggested that the horizon of weathering was an iron-pan effect and the fossil ice-wedge casts were loading structures.

In contrast to earlier workers, Boulton (1977a, 1977b) suggested that the multiple till sequence at Glanllynnau was the result of a single glacial episode. The local landscape and sediments were seen to be evidence for a supraglacial landform system and sediment association. This model was developed from his studies of modern Arctic glaciers and their depositional sequences (Boulton 1972; Boulton and Paul 1976). He considered that the lower blue-grey massive till at Glanllynnau had been deposited beneath a glacier which contained a thick sequence of englacial debris. This glacier had moved from east to west as shown by Saunders' (1968b) fabric analyses and Boulton's determinations of magnetic anisotropy susceptibility. During ice wastage, englacial debris melted out onto the glacier surface and protected underlying ice from further ablation, when well defined ice-cored ridges developed. Flow till (released as a water-saturated fluid mass) accumulated on the surface of the dead ice, together with outwash from small streams and silts in surface ponds. Weathering of the exposed till and frost-cracking may also have occurred at this time. Any hiatus was only a brief interlude and not the result of protracted interstadial or even interglacial conditions as suggested by earlier workers. This was followed quickly by deposition of sands and gravels onto the lower till, the pattern being controlled by the positions of the ice-cored till ridges. The sands and gravels form large lenticular masses up to 15m in

thickness and show low angle cross-stratificiation, and scour and fill structures. These features are typical of braided stream deposits, and Boulton estimated the mean palaeocurrent direction to have been approximately north to south along the troughs between the ice-cored ridges.

The sands and gravels are overlain intermittently by an upper till whose internal structure and position on the surface of the hummocky landscape suggested to Boulton an origin as a flow till following cessation of outwash sedimentation. Boulton suggested that deposition of flow till and outwash was mutually exclusive, there being no upper till where the outwash gravels completely cover the lower till.

As the buried ice in the ridges began to melt, there was a complete reversal in topography with a warping of the supraglacial sequence. Faulting occurred in the gravels as kettle holes were formed at the sites of the former ice-cored ridges. These faults are developed as normal faults with downthrows of up to 0.5m towards the kettle hole depressions. Grey silty clay, derived from the flow till, was then washed into the kettle holes to form the base of the Devensian late-glacial and early Holocene sequence described in detail by Simpkins (1968, 1974) and Coope and Brophy (1972).

Boulton's model serves also to explain observed textural and lithological differences between the two tills at Glanllynnau. Saunders (1968b) claimed that the lower till contained an erratic suite derived from the Nantlle-Bethesda slate belt but that the upper till contained erratics from the Vale of Ffestiniog. Boulton's work, however, showed that the change in erratic suite took place in the upper part of the lower till, rather than between the two tills. This, he considered, was likely to reflect vertical differentiation in the englacial debris content of the glacier: namely that the vertical sequence of englacial debris in a glacier often reflects in reverse order the lithologies over which the glacier has moved; giving a sequence in which the farther-travelled debris is at the top. Therefore, the lower, fine-grained till may have been derived subglacially, although the upper till may have originated from coarser-textured supraglacial material.

The Devensian late-glacial and early Holocene sequence

Above the glacial succession, Jehu (1909) recorded two peat beds containing *Sphagnum, Potamogeton* fruits, scraps of birch bark and wood and other floral remains, and separated from the glacial succession by a rootletted blue-grey clay. He did not discuss the significance of the peat beds. The detailed analysis of the late-glacial and early Holocene pollen sequence was by Simpkins (1968, 1974). Coope and Brophy (1972) dealt with coleopteran (beetle) faunas.

Description

Devensian late-glacial and early Holocene deposits were recorded by Simpkins from borings in an unbreached inland kettle hole at Glanllynnau Marsh and from a single kettle hole in Glanllynnau Cliff. This consisted of two basins of deposition linked behind the cliff, suggesting that the original plan of the kettle hole was kidney-shaped. Simpkins described the following sequence of deposits overlying iron-stained and cryoturbated fluvioglacial gravels of the Mon Wen Formation:

8 Modern soil developed on blown sand

7 Dark brown, highly humified and oxidised peat with some sand

6 Black, fibrous highly humified peat

5 Grey-brown clay-mud with leaves of *Salix herbacea* L.

4 Dark grey-brown mud with some clay

3 Dark brown fine mud with many *Potamogeton* fruitstones, *Menyanthes* seeds and *Carex* nutlets

2 Grey-brown clay-mud

1 Grey silty clay

Interpretation

Pollen

The palynology of the sequences shown in Glanllynnau Cliff and Marsh was used by Simpkins (1968, 1974) to divide the terrestrial vegetation history at Glanllynnau into four main pollen zones. Zone I was represented by pollen assemblages found in bed 1, and was termed the 'pre-interstadial' period, roughly equivalent to the Older Dryas. The grey silty clay contained a low overall pollen concentration comprising mainly species from environments of disturbed ground and open-habitats. A dominance of grass and sedge pollen, and pollen from plants which today have a mainly northern montane distribution, indicated that this was a dominantly cold period. Simpkins suggested that the dominance of *Artemisia* pollen probably reflected the importance of solifluction processes at this time. This early cold phase was succeeded by a warm 'interstadial' period represented in the rock record by beds 2–4. This phase was characterised by a dominance of *Rumex* and *Juniperus* pollen, and was marked in the early interstadial period by a rapid change to biogenic sedimentation and a cessation of solifluction into the kettle holes. The latter part of this warm interstadial phase was characterised by a *Betula–Filipendula* assemblage. The 'post-interstadial' period (Pollen Zone III/Younger Dryas) was marked by an overall decline in pollen production. A decline in *Betula* and increased percentages of pollen from open and disturbed habitats — for example, *Artemisia* and *Rumex* — characterise this period and bear witness to a deterioration in climate and a return to solifluction in the kettle holes (bed 5). Macrofossil evidence shows that least willow *Salix herbacea* may have grown in close proximity to the cliff kettle hole at that time (Simpkins 1974).

The early Holocene (pre-Boreal) is represented at Glanllynnau by beds 6 and 7, and is characterised by a cessation of solifluction and a rapid increase in pollen concentration. During this period, thickets of juniper may have become quickly shaded out by the expansion of birch woodlands, although a number of herbs characteristic of the late-glacial were also slow to disappear. It is of interest that the expansion of *Juniperus* at Glanllynnau during the interstadial and at the beginning of the Holocene is not as marked as at other Welsh late-glacial and Holocene sites, for example, at Cors Geuallt (Crabtree 1972) and the Elan Valley (Moore 1970). It has been suggested that the lower juniper values cannot be explained in terms of simple altitudinal differences between these sites, and it is possible that peaks in juniper pollen may reflect localised stands of this shrub during these periods (Moore 1977).

Simpkins' palynological analysis also allowed reconstruction of the aquatic vegetation history and palaeoecology at Glanllynnau. Pollen Zone I (pre-interstadial) was dominated by the development of marginal reed swamp, while lacustrine conditions were experienced during the warmer interstadial. Towards the end of the late-glacial there is evidence that reed swamp and/or fen developed, while the diminution of all aquatics at the beginning of the Holocene, with the change to peat at Glanllynnau Cliff, marks the displacement of lacustrine conditions. The peat was colonised by *Sphagnum,* ferns, herbs and shrubs capable of growing in damp and boggy situations. At Glanllynnnau Marsh, the early Holocene is marked by the widespread accumulation of fine mud, which records the continued existence of pond conditions in this particular kettle hole.

A timescale was based on a number of radiocarbon determinations (Simpkins 1974). A date of 12,050 ± 250 BP (Gak -1603) was considered to mark the beginning of the interstadial, and a date of 11,300 ± 300 BP (Gak -1602) the end of purely organic deposition marked by the close of the *Rumex* pollen zone and the beginning of the *Betula–Filipendula* zone.

The Devensian late-glacial pollen diagrams from Glanllynnau therefore indicate a continuous ecological succession from pre-interstadial time, where the pollen spectra represent local pioneer vegetation, through to the warm interstadial period beginning at about 12,000 BP, comprising the *Rumex, Juniperus* and *Betula-Fihpendula* zones. This climatic amelioration is also indicated by a lithological change from dominantly clastic to organic sedimentation. Evidence for vegetational recession and renewed solifluction in the post-interstadial period is suggested, and the early Holocene is shown by the immigration of thermophilous tree species and forest development in response to rapid climatic improvement.

Coleoptera (beetles)

Coope and Brophy's (1972) study was designed to compare the environmental inferences made from fossil beetles with those from Simpkins' (1968, 1974) palynological data. The Devensian late-glacial and early Holocene sequence described at Glanllynnau by Coope and Brophy was similar to that described by Simpkins, and contained four distinctive faunal units.

The oldest fauna, from bed 1, indicates an environment of bare ground with a thin patchy vegetation cover, possibly of short grasses and moss. Coope and Brophy considered that bed 1 had probably accumulated in a pool of standing water. The outstanding feature of this fauna was a high proportion of species which today have an entirely arctic or montane habitat. There was little doubt that the fauna indicated a rigorously cold climate with thermal conditions at least as cold as those in the alpine zones of Scandinavia today. Coope and Brophy estimated the average July temperature at least as low as 10°C, and several species suggested that the climate at this time may have been distinctly continental. The constancy of specific composition suggests that there was no deviation from this arctic climate during deposition of the lower layers of bed 1.

A second fauna characterises the upper part of bed 1 and part of the more organic sequence above (beds 2–4). This fauna proves a gradual improvement in environmental conditions, although vegetation was still sparse until the uppermost sample of this bed. Near the top of the bed, species occur which suggest a meadow-like vegetation, with no evidence of trees. Many species lived in a pool which may also have supported *Potamogeton natans* L. The beetle specimens collected also provided evidence for a rich flora developed around the edges of the pool, where there may have been bush willows. Coope and Brophy suggested that there could be no doubt of the thermophilous character of this fauna; all the stenothermic species of the preceding fauna were absent. There was, however, no evidence for a gradual transition from fauna 1 to fauna 2, and the sharp faunal break occurred at a level in bed 1 where no lithological break could be detected. Chemical investigations by Coope and Brophy revealed that sedimentation had probably been continuous and they concluded that the sharp faunal break was proof of a real change in climatic conditions. Average July temperatures during this warmer period were estimated at least as high as 17°C, and there was no evidence that the climate at that time was any more continental than today.

A third fauna occurred in the upper part of bed 4 and bed 5 and was characterised by a loss of thermophilous species and their replacement by species whose distributions today are predominantly northern. This change at Glanllynnau, however, was overshadowed by a profound change in local conditions. The habitat became decidedly more acidic and substantially colder, and the kettle hole pond became choked by *Sphagnum.* Although Coope and Brophy noted the difficulty in assessing the average July temperature for this fauna, the beetles clearly indicated a considerable deterioration in the thermal environment, and this drop must have been rapid. It was estimated that the average July temperature may have been in the region of 14°C, and the climate was probably still no more continental than today.

The fourth fauna (bed 5) shows no abrupt change from the preceding one. Rather, a series of faunal changes reflected a more or less continuous deterioration in the thermal environment. A precise figure for the average July temperature was not established, but it was clear that temperatures were low.

A further and final fossil beetle assemblage was discerned from the overlying beds 6 and 7, although remains were sparse, and poorly preserved, and inadequate to make any detailed observations; the fauna from these beds, however, was thought to indicate climatic amelioration.

Both the sequences of beetle assemblages and the pollen spectra at Glanllynnau were, therefore, interpreted in terms of a single Devensian late-glacial climatic oscillation, although the possibility was noted that the interstadial floras and faunas at Glanllynnau represented a combination of the Continental Bølling and Allerød Interstadials (Moore 1977). However, the climatic events inferred from these separate suites of data differ from one another, both in their timing and in their intensity. Whereas the pollen indicates that the thermal maximum of this warm oscillation occurred during Pollen Zone II, the beetles suggest that the episode of greatest warmth was earlier than this, occurring during Pollen Zone I. Despite the pollen evidence, the beetles show that by Pollen Zone II times, the environment had deteriorated considerably.

Coope and Brophy identified a visible increase in pollen in the profile where the organic content of the sediment was dominant. The lithology therefore mirrored the expansion of the local flora at this time. The beetles show, however, a sharp improvement in the thermal climate at a level 0.200.25m lower in the section, where no consistent lithological break can be discerned in the grey silty clay (bed 1). Chemical investigations of this bed showed there was no evidence for a break in sedimentation during deposition of bed 1. The change in the thermal environment indicated by the beetles cannot therefore be attributed to a hiatus in deposition. Thus, the evidence points to a real and sudden shift in climate in which the mean July temperature rose from about 10°C to about 17°C. Coope and Brophy explained the anomaly between the palynological and beetle evidence in terms of the differential rate of plant and animal responses to rapid changes of climate.

Their study also provided new radiocarbon dates. First, a date of 14,468 ± 300 BP (Birm 212) was obtained from moss towards the base of bed 1, at the start of the Late Devensian late-glacial sequence — see (Figure 33). Second, dates of 12,050 ± 250 BP (Gak-1603) and 11,300 ± 300 (Gak-1602) were obtained by Simpkins (1974) from bulk samples from the basal 2cm and uppermost 2cm of bed 3. The possibility of contamination, however, was recognised in these samples, and a specially collected and prepared sample of seeds from the base of the mud was dated by Shotton and Williams (1971) to eliminate the possible sources of error. The date obtained, 12,556 ± 230 BP (Birm 276), was some 500 years older than the older of the two obtained by Simpkins. Third, samples were obtained from sparse plant remains from just above and just below the faunal break interpreted in bed 1. These samples yielded dates of 11,617 ± 270 BP (Birm 233) and 11,714 ± 255 BP (Birm 232), respectively (Shotton and Williams 1971). These samples, however, were obtained from plant debris made up largely of rootlets that penetrated the deposit from above. The dates, which are younger than those obtained 0.2–0.3m higher in the section, confirm the suspicion of rootlet contamination.

The estimated age of the faunal break, determined by calculations of average rates of sedimentation, and the onset of temperate conditions was placed at 12,850 ±250 BP (Coope and Brophy 1972). Further estimates suggest that the 5cm of grey silty clay (bed 1) during which the sudden climatic shift took place, must have accumulated in about 75 years. This indicates a dramatic rate of change in the average July temperature of about 1°C per decade. A summary of the beetle evidence from Glanllynnau and its significance was later given by Coope (1977).

Boulton (1977a) also made several observations about the Devensian late-glacial succession at Glanllynnau. First, faulting occurs in both the fluvioglacial gravels and in the lower part of the late-glacial succession. The basal silty clay has joints and faults throughout, while, in places, the overlying mud is also jointed and warped. This was considered as evidence for the melting of buried ice beneath the kettle hole after 14,468 ± 300 BP (Birm 212) — see (Figure 33). There is evidence that the melting of buried ice continued at least until the end of the Older Dryas (12,556 ± 230 BP (Birm 276)) and possibly into the Allerød and Younger Dryas periods. Second, the intensity of faulting is greatest in the silty clay but is substantially reduced in the overlying beds, which suggests that the greatest rates of ice melting occurred towards the end of the period of deposition of these silty clays. Evidence for jointing in the upper clays and the pattern and distribution of the peat bed suggests, however, that the buried ice may have survived even longer, into the warm interstadial period inferred from the palynological and beetle evidence.

Glanllynnau displays a representative section through the tripartite sequence of southern Ll■n. Whereas Morannedd has come to be regarded as a reference site for the Criccieth and Llanystumdwy Tills, the fluvioglacial sands and gravels of the Afon Wen Formation are best developed at Glanllynnau. The sequence of Welsh sediments provides information for interpreting patterns of ice movement across southern Ll■n. Before Boulton's (1977a) interpretation, the sequence was interpreted as the product of two glacial advances separated by ice-free conditions.

From evidence at Glanllynnau, however, Boulton argued that the beds of the traditional tripartite sequence could be explained in an alternative manner. He suggested that much of the surface topography at Glanllynnau represented a foundered sediment surface let down by the melting of buried ice. He considered that the sequence of deposits was evidence for only a single Late Devensian glacial episode. This model of sedimentation has regional stratigraphic implications. Sequences essentially similar to that at Glanllynnau occur elsewhere in Ll■n, for example at Forth Neigwl and Gwydir Bay, where large lenticular masses of sand and gravel lie above dense tills with an undulating surface. These outwash deposits are also overlain sporadically by a thin upper till. Although Boulton's model explains a number of observed stratigraphic, textural and lithological changes in the sequence at Glanllynnau, it does not satisfactorily account

for the deeply weathered surface of the Criccieth Till. Boulton argued that the Criccieth Till was subaerially weathered as the surface became transiently exposed in a supraglacial environment, prior to deposition of outwash and flow till. He concluded that the surface did not therefore mark a significant break in sedimentation. Others, including Bowen (1974, 1977b), have maintained that the scale of weathering at Glanllynnau, and particularly at Morannedd, indicates a protracted hiatus in deposition. The lack of an acceptable explanation for the weathering horizon in Boulton's sedimentation model is, therefore, a major impediment to applying the model to other sequences.

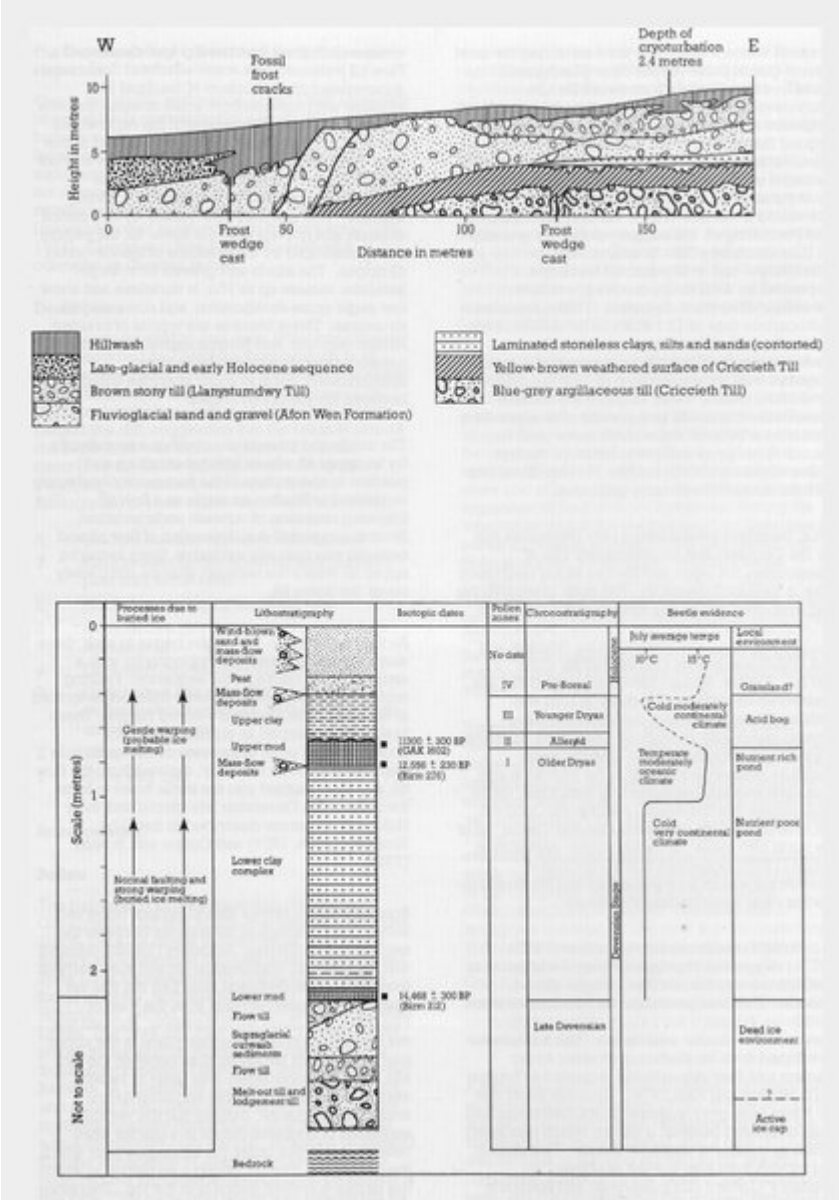
Whether the sequence at Glanllynnau was the product of one or two glacial advances, the composite age of the glacial sequence is clearly indicated by the evidence for melting of buried ice well into the Late Devensian late-glacial. This provides some of the strongest evidence in North and north-west Wales to confirm that widespread inundation of the region by ice occurred in the Late Devensian.The date of 14,468 ± 300 BP (Birm 212) from the base of the late-glacial succession is significant. It is one of the earliest radiocarbon dates for Late Devensian deglaciation in Wales. Glanllynnau also provides a record of late-glacial and early Holocene palaeoenvironmental conditions. It is the only sequence in Wales yielding both pollen and beetles that has been calibrated by radiocarbon methods. It gives one of the most detailed records of environmental changes in the late-glacial and early Holocene at any lowland site in North and north-west Wales. Together with sites in Snowdonia, the pollen record at Glanllynnau serves to demonstrate regional and altitudinal variations in vegetation history during these times.

Glanllynnau displays evidence for Late Pleistocene and early Holocene events in north-west Wales, and is perhaps the most intensively studied glacial to late-glacial sequence in Wales. Furthermore, it is the only late-glacial site in Wales where fossil beetle faunas have been investigated and is thus the only site where late-glacial palaeotemperature estimates have been possible. Although coastal erosion has removed part of the late-glacial and early Holocene sequence at Glanllynnau Cliff, the remaining kettle holes inland are likely to show comparable stratigraphic, pollen and faunal sequences, and this reference site therefore retains an outstanding potential for further research. Although some consider the glacigenic sequence to represent two ice advances, Boulton's work has shown that the sequence may have formed during a single Late Devensian glaciation. The site may, therefore, provide an important model for reevaluating multiple drift sequences elsewhere. Radiocarbon analysis and studies of pollen and beetles in the late-glacial sediments significantly enhance the interest for environmental reconstructions.

Conclusions

Glanllynnau is one of the most intensively studied glacial sites in the World. An on-going debate continues on the precise origin and age of the different deposits exposed here. Exposures also occur through the infill of kettle holes. These have provided evidence from pollen and fossil beetles which shows how the climate changed from the end of the ice age, to the present. A radiocarbon date of 14,468 years, obtained from the base of one of the kettle hole deposits, is one of the earliest known dates for the disappearance of the last major ice-sheet in Wales.

References



(Figure 33) Quaternary sequence at Glanllynnau (after Whittow and Ball 1970; Boulton 1977a)