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Quaternary of Wales

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Quaternary stratigraphy : west and south-west Wales

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Introduction

Stratigraphic sites around the west and south-west coasts of Wales have been the basis for a variety of reconstructions in the Quaternary history of Wales. Some sequences display important evidence for the interplay of the Welsh and Irish Sea ice-sheets, while others illustrate the importance of periglacial conditions and processes to regional landscape evolution. A number of sites shows evidence for changes in relative sea-level during the Late Pleistocene and Holocene. The network of selected stratigraphical sites is essential in distinguishing between those areas glaciated or unglaciated during the Late Devensian. In this respect, the area is significant in its proximity to the Late Devensian maximum ice limit and thus may be compared with Gower – see Chapter 3.

Early sub-division

The area is historically important for early attempts to sub-divide the Quaternary sequences. Interest was first stimulated by the rich fossil contents of certain local caves, especially the Caldey and Tenby caves, including Little Hoyle and Hoyle's Mouth. Some of the first known excavations were made by Jervis and Pugett as early as the 1840s at the Hoyle Caves, although no accounts were left of their discoveries (Leach 1931). A series of excavations initiated by the Reverend G N Smith in the 1860s stimulated continued interest in these caves, culminating in the excavations led by Green of the National Museum of Wales (Green *et al.* 1986).

Following early interest in the bone caves, attempts were made to sub-divide the Pleistocene sediments of the coastal sequences (for example, Keeping 1882; Prestwich 1892; Hicks 1894; Reade 1896). Particularly important was the work of Jehu (1904) in northern Pembrokeshire (Preseli) and Williams (1927) in western Cardiganshire (Ceredigion). They used a tripartite scheme and proposed a sequence of Lower Boulder Clay, Intermediate Gravels and Sands and Upper Boulder Clay. Jehu believed that this tripartite sequence was evidence for two glacial episodes separated by an interglacial, but Williams suggested that the deposits could simply have accumulated at the margin of an ice-sheet during a single glaciation. This work, together with other observations on drift deposits and raised beaches by Strahan *et al.* (1909), Leach (1910, 1911), Cantrill *et al.* (1916) and Dixon (1921), were important in the first elucidation of Quaternary events in the region. Collectively, they showed that parts of the west Wales coast had been glaciated by Welsh ice from the uplands, but that parts of Pembrokeshire and Cardiganshire had been inundated by ice from the north-west, that is, from the Irish Sea Basin.

The South Wales end-moraine

Following Wright's (1914) formal division of British glacial deposits into an 'Older Drift' and 'Newer Drift', Charlesworth (1929) traced what he considered was the maximum limit of the 'Newer Drift' ice-sheet of 'Magdalenian' age across South Wales. He distinguished between areas glaciated in 'Newer Drift' times and those previously glaciated during an 'Older Drift' glaciation. He established that south-west Wales had been glaciated on two occasions by ice from the Irish Sea Basin. Charlesworth used both stratigraphical and morphological evidence to delimit the extent of the 'Newer Drift' ice-sheet across Pembrokeshire (south-west Dyfed). With the tripartite division still much in vogue, he proposed that the maximum limit of the 'Newer Drift' coincided with the extent of the Upper Boulder Clay. Two other lines of evidence were also used to establish this limit. First, sands and gravels, forming hummocky topography, were regarded as terminal accumulations marking the maximum ice limit. Second, at the height of the 'Newer Drift' glaciation, he believed that Irish Sea ice in Cardigan Bay blocked the drainage from surrounding ice-free areas and resulted in the development of a series of extra-glacial lakes that were connected by ice marginal stream channels and 'direct' overflow channels. As the ice margin retreated, water spilled from one lake to another cutting a spectacular series of channels (the Gwaun-Jordanston system – see Figure 15, Chapter 5). The distribution of the sands and gravels, the Upper Boulder Clay and the meltwater channels was therefore used by Charlesworth to establish the area of south-west Wales affected by 'Newer Drift' ice. His hypothesis, relating the channels to overflows from glacial lakes, has since been shown to be partly untenable: the channels have now been interpreted as subglacial meltwater channels, indicating a far greater coverage of Late Devensian ice in the area than previously anticipated (Bowen and Gregory 1965; Gregory and Bowen 1966). The sand and gravel accumulations have also been reinterpreted to show that they did not accumulate at an ice margin (for example, Gregory and Bowen 1966; Bowen 1971b, 1981a, 1982a; Helm and Roberts 1975; Allen 1982; Bowen and Lear 1982).

Stratigraphical correlations

In common with north-west Wales and Gower, the coastal Pleistocene deposits of west and south-west Wales have been important in regional stratigraphical syntheses. Following Wirtz's (1953) delimitation of the maximum extent of Late

Weichselian (Late Devensian) ice in north Pembrokeshire, Mitchell's (1960) reconstruction of a Pleistocene history for the Irish Sea provided a considerable stimulus for further work. Mitchell (1960, 1972) proposed a limited Late Devensian glaciation in Wales; with Welsh ice restricted to the Welsh uplands, and Irish Sea ice impinging only along the North Wales coast – delimited on Llŷn by the Bryncir-Clynnog moraine (Synge 1964). Most of the coastal glacial deposits exposed elsewhere around Wales were correlated with the Ballycroneen Till of south-east Ireland and the Fremington Till of North Devon, and all were believed to be Gippingian (Saalian) in age. This reconstruction stemmed from two fundamental lines of reasoning.

First, raised beaches around the Welsh coast, particularly on Gower, were considered to date from two separate interglacials. One beach was described by Mitchell as 'erratic-free' and was considered to be Hoxnian, the other was 'erratic-rich' and of Ipswichian age. According to Mitchell, glacial deposits *in situ* around the Welsh coast only overlie raised beaches of Hoxnian age; Ipswichian beaches are overlain by Devensian periglacial sediments. Bowen (1973a, 1973b) argued that where Ipswichian beaches are absent, Mitchell's model implied that they were lost in unconformity, for example, Gower. In support of his scheme, Mitchell (1960, 1962, 1972) cited the occurrence of an *in situ* interglacial soil of Ipswichian age in the coastal sections near Llan-non (the Llansantffraid Interglacial Soil). The pedological significance of this horizon has since, however, been disputed (for example, Stewart 1961; Rudeforth 1970; Bowen 1974). Secondly, large areas of Wales were believed to have remained free of Late Devensian ice because they show a widespread development of fossil periglacial features such as pingos and ice-wedge casts. (This aspect is more fully discussed in Chapter 5.) Coastal sections in west Wales, particularly those at Llan-non and Morfa-bychan, have figured in the debate over whether the region was glaciated during the Late Devensian, with workers such as Watson and Watson (1967) arguing for a periglacial origin for the drifts in the area, and others (for example, Wood 1959; Bowen 1973a, 1973b, 1974, 1977a, 1977b; Vincent 1976) arguing that substantial parts of the sequences are glacial in origin, albeit rearranged by solifluction.

Bowen (1977c) suggested that many studies (for example, Mitchell 1960, 1972) confused lithostratigraphy (rock stratigraphy) with chronostratigraphy (time-rock stratigraphy). For example, at Abermawr (Preseli), Synge (1963, 1964, 1969) ascribed three lithological units to three different glaciations. Others (for example, John 1970a; Bowen 1974) have ascribed the Abermawr deposits to the Devensian Stage, because no evidence of interglacial conditions is found.

Many of the GCR sites in west and south-west Wales were included in Mitchell's and Synge's reconstructions of Pleistocene events in the Irish Sea Basin. These sites were also used in later studies. During the 1960s and early 1970s, sites in south-west Wales were sampled for radiocarbon dating. However, the age determinations, particularly those on bulk shell samples, have not been universally regarded as reliable (for example, Bowen 1966; Shotton 1967; Boulton 1968). These age determinations, however, were used as definitive for a number of sites (for instance, Abermawr, Druidston, Banc-y-Warren) by John (1965a, 1965b, 1967, 1968c, 1970a), Brown *et al.* (1967) and John and Ellis-Gruffydd (1970). The results were used by John to support an extensive Late Devensian glaciation, covering most of Pembrokeshire. Most of the dates fall between 30,000-40,000 BP. In particular, it is interesting to note that finite dates were obtained only from material incorporated into highly permeable outwash deposits with an inherent potential for post-depositional contamination (Bowen 1974). In contrast, dates from relatively impermeable till facies at Abermawr and Druidston, yielded infinite ages (John 1970a) making the determinations of little value for elaborating Pleistocene chronology. Amino acid analysis of shells from these deposits have shown mixed populations ranging in age between the Early Pleistocene and the Devensian Stage, thus invalidating the use of bulk shell samples for radiocarbon dating (Bowen 1984).

Lithostratigraphy

Coastal exposures around west and south-west Wales were used in a series of lithostratigraphic studies by Bowen (1973a, 1973b, 1974, 1977a, 1977b). The basis of Bowen's classification was the proposal that the raised beach sediments are of Ipswichian age. By identifying sites where the Ipswichian raised beach was overlain by glacial deposits, in contrast to sites where the beach was overlain exclusively by non-glacial sediments, Bowen (1970a, 1973a, 1973b) was able to extrapolate between coastal sites and, using all available evidence, to delimit the extent of Late Devensian ice across south-west and South Wales. John (1970a, 1970b, 1973) also proposed an Ipswichian age for raised beach deposits around the south-west Wales coast (for instance, at Druidston, West Angle Bay, Broadhaven, Poppit and Porth Clais) and used lithostratigraphy to interpret and equate the coastal sequences. Several sites were considered to show clear evidence for a major invasion of the coastlands by Irish Sea ice (for example, Traeth-y-Mwnt, Abermawr and Druidston). The occurrence of Irish Sea glacial deposits *in situ* above raised beach sediments of proposed Ipswichian age (for instance, at Poppit) thus appeared to confirm a (Late) Devensian age for this glaciation (John 1970a; Bowen 1973a, 1973b, 1974, 1977a, 1977b). These workers also recorded lithological evidence for periglacial conditions (head deposits) both before and after the glacial event. The greater thickness of head deposits lying between the raised beach and till was used as additional evidence for a Late Devensian age for the till.

The interpretation of individual beds within the coastal sequences at GCR sites is, therefore, important in establishing the sequence of Quaternary events in the region, and particularly for reconstructing the maximum extent of Late Devensian ice. Some evidence has been interpreted differently. For example, at Porth Clais John (1970b) interpreted mixed lithology drift overlying a raised beach as a 'land-facies' of the Irish Sea ice-sheet. Alternatively, Bowen (1977b) argued that these sediments were not *in situ*, and suggested that the distance of glacial transport across St David's Head was too small to have allowed development of a 'land-facies' of the Irish Sea ice. At West Angle Bay, different interpretations of sedimentary units also have had a bearing on the reconstruction of the Late Devensian glaciation. A marine sequence of uncertain age (Stevenson and Moore 1982) is overlain by a diamict containing gravel. Both John (1968a, 1969, 1970a) and Bowen (1974, 1977b) proposed an Ipswichian age for the marine sequence at West Angle, but the overlying diamict was interpreted as head (periglacial) (Bowen 1971b, 1974), or as a Late Devensian glacial deposit; either outwash or a gravelly 'land-facies' of the Irish Sea ice-sheet (John 1968a, 1971a). Bowen, therefore concluded that Milford Haven and West Angle Bay lay in the 'extra-glacial' zone during the Late Devensian, but John envisaged that Late Devensian Irish Sea ice had reached at least this far south.

Amino acid geochronology

Amino acid geochronology has been applied in south-west Wales, allowing correlations to be made with Gower and farther afield (Bowen *et al.* 1985; Bowen and Sykes 1988). Amino acid ratios derived from shells taken from raised beach deposits at Broadhaven (Castlemartin), were correlated with others in Gower (Pennard D/L Stage), and ascribed to the Ipswichian Stage and to Oxygen Isotope Sub-stage 5e of the deep-sea record (Bowen and Sykes 1988). Amino acid ratios on shells from glacial sediments at Abermawr and Banc-y-Warren show that the shells range widely in age from the Early Pleistocene to the Devensian Stage (Bowen 1984). The youngest faunal elements within the Abermawr Till and Banc-y-Warren sands and gravels were ascribed by Bowen to Stages 5 and 3 of the deep-sea oxygen isotope record (Shackleton and Opdyke 1973), thus dating the glacial deposits as Late Devensian.

Palynology

Palynological investigations were undertaken at West Angle Bay by Stevenson and Moore (1982), in an attempt to resolve the controversy surrounding the age of the succession. Although a number of pollen zones dominated by temperate forest taxa was recognised, it was not possible to correlate the sequence on this basis. A radiocarbon date of >35,000 BP (Birm 327) from wood in the interglacial succession also fails to establish the age of the beds, although it precludes a Holocene age (Shotton and Williams 1973).

Sedimentology

Sedimentological and stratigraphic studies of the sand and gravel sequence at Banc-y-Warren were carried out by Helm and Roberts (1975) and Allen (1982). These studies arrived at different conclusions regarding the origin of the deposits (Worsley 1984): Helm and Roberts suggested a deltaic origin, but Allen proposed that the sands and gravels had accumulated in a subaerial fluvioglacial environment. Worsley (1984) concluded that a compromise between the depositional models of Helm and Roberts and Allen was possible: most of the deposits consisted of subaerial outwash, and also showed deposition in water in a deltaic facies.

Caves

South-west Wales has long been noted for its richly fossiliferous cave deposits, which attracted much early scientific attention (for example, Smith 1860, 1862, 1864, 1866; Winwood 1865; Dawkins 1874; Laws 1878; Rolleston *et al.* 1878; Prestwich 1892; Leach 1913, 1918b, 1931, 1945; Dixon 1921; Garrod 1926; Lacaille and Grimes 1955). Interest was further stimulated in studies by McBurney (1959), Clegg (1969) (at the now destroyed Coygan Cave), Bateman (1973), Savoury (1973) and Nedervelde *et al.* (1973), and most recently by the multi-disciplinary investigations of the Little Hoyle and Hoyle's Mouth Caves near Tenby (Green *et al.* 1986; Rae *et al.* 1987). These have improved the understanding of Late Devensian and Late Devensian late-glacial palaeoenvironments in southern Dyfed, and provide further evidence for ice-free conditions in the area during the Late Devensian glacial maximum (Green *et al.* 1986). These sites also provide some of the most detailed evidence currently available for the Upper Palaeolithic period in Wales.

Sea-level studies

This region has also been investigated with a view to understanding Late Devensian late-glacial and Holocene coastal changes. Submerged forest and associated marine and terrestrial beds at Clarach (Taylor 1973; Heyworth *et al.* 1985), at Ynyslas and at Borth Bog (for example, Wilks 1977, 1979; Campbell and Baxter 1979; Heyworth and Kidson 1982) have provided evidence for sea-level and environmental changes. These sites are part of a network that provides data for establishing a picture of late-glacial and Holocene sea-level changes throughout Britain.

Offshore investigations

The reconstruction of Quaternary events has been amplified by studies of submarine deposits off the Welsh coast (Garrard and Dobson 1974; Garrard 1977). Discontinuous patches of till which occur on the floor of the Bristol Channel may support the evidence for an extensive pre-Ipswichian glaciation in the area; but, continuous glacigenic deposits on the floor of the Irish Sea have been ascribed to the

Late Devensian, and used as evidence for the maximum offshore limit of this Irish Sea ice-sheet (Garrard and Dobson 1974; Garrard 1977). Problems still remain in correlating offshore data with the stratigraphical record of the coastal exposures. The offshore reconstruction of Late Devensian maximum ice limits may also not take into account marine erosion at the distal end of the till sheet during the Holocene transgression (Bowen 1977c). The prominent sarns along the west Wales coast (for instance, Sarn Badrig) also have important implications for Late Pleistocene glacial conditions (Foster 1970b; Bowen 1974). These are discussed more fully in Chapter 6.

Ynyslas and Borth Bog

Highlights

A site providing one of the most significant records of sea-level, environmental and vegetational change in the Holocene of Wales. Rock, pollen and radiocarbon evidence has provided a complex dated story of sea-level rise, forest and bog development.

Introduction

Ynyslas and Borth Bog provide a detailed record of coastal and environmental changes during the Holocene. Borth Bog is one of the largest and finest examples of a raised bog occurring near sea-level anywhere in Britain. The pollen biostratigraphy of the site was first studied by Campbell James (Godwin and Newton 1938). The site was also referred to in studies by Godwin (1940a, 1943), and Godwin and Willis (1961, 1964) provided radiocarbon age control. Foraminiferal studies have been carried out at the site by Adams and Haynes (1965) and Haynes and Dobson (1969). Moore (1963, 1966, 1968) studied the pollen biostratigraphy with particular reference to human influences, and the locality has been used in studies of sea-level changes by Churchill (1965), Wilks (1977, 1979) and Heyworth and Kidson (1982). Other accounts are given by Taylor (1973, 1980) and Turner (1977).

Description

Ynyslas and Borth Bog lie on Cardigan Bay just south of the Dyfi Estuary. The site comprises two main parts – the submerged forest and associated beds on the foreshore at Ynyslas (SN604927), and Borth Bog (SN630910) to the east. The submerged forest lies approximately halfway between high and low tide marks at about -1m OD. It was originally exposed by the building of sea defences at Borth, but these exposures are now largely obscured and the forest is best seen between *c.* SN604924 and SN604933. The best exposures occur in winter, especially after storms which reveal the stumps and trunks of the forest embedded in a peat which overlies clay. The upper surface of the forest bed is frequently riddled with borings of the common piddock, while the underlying clays contain shells of the burrowing bivalve *Scrobicularia*. The submerged forest beds continue inland, beneath a shingle and sand spit, to underlie the whole of Borth Bog at a level just below OD.

Borth Bog (Cors Fochno) occupies some 800 ha (2000 acres). It is bordered to the west by the River Leri which separates the main bog from the shingle and sand ridge and the submerged forest – see Figure 10. To the south and east of the bog lies high ground; to the north, the bog borders the flats and salt marshes of the Dyfi Estuary (Yapp *et al.* 1916, 1917). Several islands of higher ground also occur on the edges and in the centre of the bog.

The sequence over much of the bog consists of –

5 Fresh *Sphagnum* peat
4 Greasy peat interpreted as a *Grenzhorizont*
3 Highly humified *Sphagnum* – *Calluna* peat
2 Wood peat and submerged forest bed
1 Basal *Scrobicularia* clay

At the northern margin of the bog, the sequence is interrupted by a wedge of sand, clay and salt marsh clay that cuts across beds 1-4 and the lower part of bed 5, and is overlain by the upper part of the fresh *Sphagnum* peat (Godwin 1943) – see Figure 10.

At Ynyslas, Godwin and Newton (1938) described a sequence of –

5 *Sphagnum* peat
4 Fenwood peat containing a succession of *Alnus* – *Betula* – *Pinus* pollen
3 Alder-carr peat
2 *Phragmites* peat
1 Intertidal *(Scrobicularia)* clay

Interpretation

The submerged forest and basal blue-grey clay containing *Scrobicularia* at Ynyslas were first noted by Keeping (1878), and were discussed by Yapp *et al.* (1916, 1917). The first detailed study at the site was by Campbell James (Godwin and Newton 1938). Godwin and Newton suggested that the close correspondence between the sequences at Ynyslas and Borth Bog, indicated a parallel development of the areas from mid Pollen Zone VIIa of the Holocene. Godwin (1943) ran a line of borings from north to south across the bog as well as a line extending from east to west, linking the first sections to the beach exposures at Ynyslas foreshore – see Figure 10. These data confirmed that, over much of the area, the fossil forest and raised bog overlie the *Scrobicularia* clay. He suggested that the *Scrobicularia* clay was evidence for a marine transgression ending in mid Pollen Zone VIIa, followed by a long period of woodland and bog development that was unaffected by rising

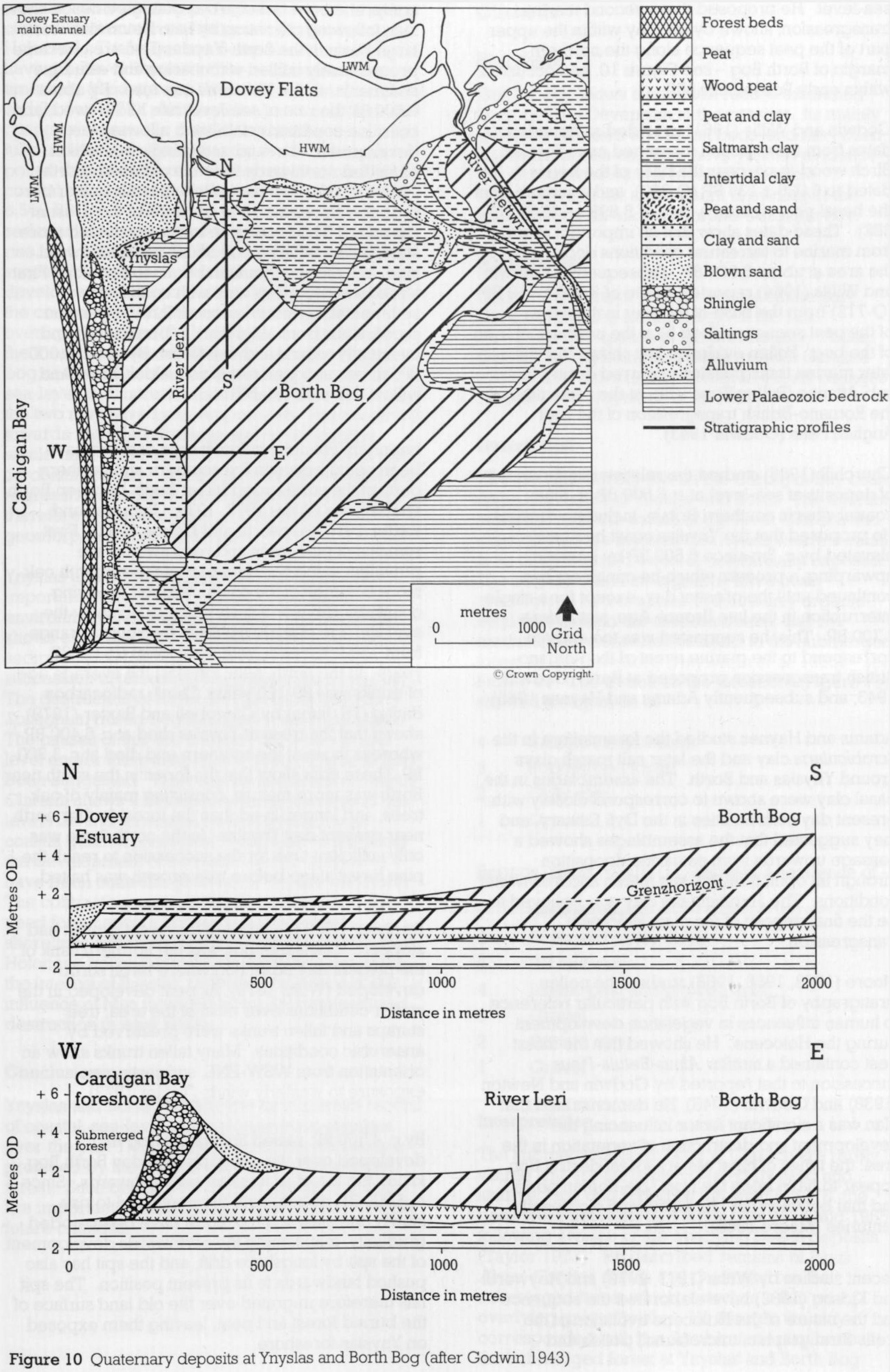

Figure 10 Quaternary deposits at Ynyslas and Borth Bog (after Godwin 1943)

sea-level. He proposed that a second marine transgression, shown by the clay within the upper part of the peat sequence along the northern margin of Borth Bog – see Figure 10, had occurred within early Pollen Zone VIII.

Godwin and Willis (1961) provided radiocarbon dates from the exposed forest bed near Ynyslas. Birch wood *in situ* near the base of the bed was dated to 6,026 ± 135 BP (Q-380), and a sample from the basal peat yielded a date of 5,898 ± 135 BP (Q-382). These dates show that an important change from marine to terrestrial conditions occurred in the area at about 6,000 BP. Subsequently, Godwin and Willis (1964) reported a date of 2,900 ± 110 BP (Q-712) from the base of the clay in the upper part of the peat sequence (bed 5) at the northern margin of the bog. Pollen evidence has shown that this later marine transgression occurred during the sub-Atlantic (Pollen Zone VIII), at the same time as the Romano-British transgression of the East Anglian Fens (Godwin 1943).

Churchill (1965) studied the relative displacement of deposits at sea-level at *c.* 6,500 BP at nine coastal sites in southern Britain, including Ynyslas. He proposed that the Ynyslas coast had been elevated by *c.* 3m since 6,500 BP by isostatic upwarping, a process which he considers has continued until the present day, except for a single interruption in the late Bronze Age, just before 2,700 BP. This, he suggested was too early to correspond to the marine event of the Romano-British transgression proposed at Borth (Godwin 1943; and subsequently Adams and Haynes 1965).

Adams and Haynes studied the foraminifera in the *Scrobicularia* clay and the later salt marsh clays around Ynyslas and Borth. The assemblages in the basal clay were shown to correspond closely with present day communities in the Dyfi Estuary, and they suggested that the assemblages showed a passage upwards from estuarine deposition through an open tidal flat, salt marsh and freshwater conditions. The *Scrobicularia* clay was believed to be the final deposit of the main Holocene transgression.

Moore (1963, 1966, 1968) studied the pollen stratigraphy of Borth Bog with particular reference to human influences in vegetation development during the Holocene. He showed that the forest peat contained a similar *Alnus-Betula-Pinus* succession to that reported by Godwin and Newton (1938) and Godwin (1943). He demonstrated that Man was a significant factor influencing the development and destruction of vegetation in the area: the times of most severe forest destruction appear to have been the Iron Age-Roman period and that between the fourteenth and eighteenth centuries (Moore 1968).

Recent studies by Wilks (1977, 1979) and Heyworth and Kidson (1982) have elaborated the sequence and the nature of the Holocene evolution of the area. Stratigraphic, microfaunal, pollen and comprehensive radiocarbon dating evidence show that, following glaciation by Late Devensian ice, a large basin in the Borth-Ynyslas-Dyfi area became progressively infilled with marine and estuarine sediments, as the Holocene sea rose. By about 6,500 BP the rate of sea-level rise had slowed, and coastline conditions stabilised, allowing the development of a sand and shingle spit which extended northwards from the cliffs near Borth (Wilks 1979). Estimates show that this spit or bar probably lay about 1 km seaward of the present shoreline. This protective barrier provided more stable and sheltered conditions on its landward side, and there vegetation began to develop. First a reed swamp grew, and, with continued sedimentation and drier conditions, vegetation successions from alder-carr to birch scrub and eventually to pine and oak forest. By about 6,000 BP, an oak and pine forest with alder, hazel and willow was well established.

Important changes in forest type and age have been noted between the southern and northern parts of the submerged forest beds, between Borth and Ynyslas (Wilks 1977, 1979; Campbell and Baxter 1979; Heyworth and Kidson 1982). First, remains of pine trees and reed swamp are prevalent in the northern part of the site, with oak more common in the south. Second, tree ring counts by Heyworth (see Wilks 1979) show the average age of large trunks in the south to range from 150-250 years, with some oaks up to 330 years. In the north, near Ynyslas, the average age of trunks was 80-120 years. Third, radiocarbon dating (76 dates) by Campbell and Baxter (1979) shows that the trees at Ynyslas died at *c.* 5,400 BP whereas those at the southern end died at *c.* 3,900 BP. These data show that the forest in the south near Borth was more mature, consisting mainly of oak trees, and longer-lived than the forest farther north near present day Ynyslas. In the north there was only sufficient time for the succession to reach the pine forest stage before tree growth was halted.

By about 4,700 BP, much of the forest growth had stopped. One exception was the northern flank of the present day Borth Bog where birch scrub developed (Wilks 1979). As peat developed in the wetter conditions over most of the area, tree stumps and fallen trunks were preserved by anaerobic conditions. Many fallen trunks show an orientation from WSW-ENE, suggesting an exposure to westerly winds (Taylor 1973).

By *c.* 4,500 BP, raised *Sphagnum* bog had developed over the site of present day Borth Bog, killing the forest as it extended southwards. Since *c.* 4,000 BP, as sea-level has continued to rise slowly, the cliffs south of Borth have been eroded gradually, maintaining the northwards development of the spit by longshore drift, and the spit has also pushed landwards to its present position. The spit has therefore migrated over the old land surface of the buried forest and peat, leaving them exposed on Ynyslas foreshore.

Ynyslas and Borth Bog provide a detailed record of coastal environmental changes in Wales during the Holocene. The sequence is especially significant in having been calibrated with a radiocarbon timescale (Godwin and Willis 1961, 1964; Campbell and Baxter 1979). Although the pattern of recorded changes is clear, the underlying causes are not yet fully understood. Stratigraphic, radiocarbon and pollen data provide convincing evidence that a coastal barrier had developed at the site by about 6,500 BP. By *c.* 6,000 BP, it is also clear that sedimentation was exceeding the rate of sea-level rise, and between *c.* 6,000-4,700 BP, a vegetation succession culminating in oak and pine forest developed on the prograding land surface behind the coastal barrier. Following this 'regressive overlap' (Shennan 1982, 1983) at about 4,700 BP, the forest was overwhelmed by *Sphagnum* peat bog as the result of a rising water table: a rising sea-level and increased rainfall, or a combination of the two may have been responsible. Any tendency towards impeded drainage and waterlogging would have been amplified by the flat surface of the *Scrobicularia* clay. Wilks (1977) suggested that the regressive overlap at Borth Bog and Ynyslas was, therefore, a consequence of local coastal geomorphological conditions.

Ynyslas and Borth Bog provide one of the most important records of Holocene coastal and environmental changes in Wales. The sequence shows evidence for a period of marine sedimentation followed by a phase in which a succession of terrestrial vegetation can be traced. The destruction of forest and the establishment of *Sphagnum* raised bog indicates wetter conditions. The causes of this are unclear, but a rise in sea-level and/or increased rainfall in the Holocene have been suggested. Whereas the sequence at nearby Clarach shows a balance between the rates of sea-level rise and terrestrial sedimentation, local coastal geomorphological conditions, in particular the development of a coastal barrier, appear to have been controlling factors at Ynyslas and Borth. The contrasting records serve to emphasise the need for a network of sites to trace former shorelines and to reconstruct past sea-levels. The Holocene pollen record from Borth Bog enhances the interest of the site, providing evidence of the influence of Man in vegetational development and destruction in west Wales.

Conclusions

Ynyslas and Borth Bog provide an important record of coastal, sea-level and environmental changes over the past 7,000 years. Part of this evidence is provided by the famous exposure of submerged forest. Such detailed records of sea-level change are important because they can be used to predict future changes.

Clarach

Highlights

This locality shows a complex record extending from the Late Devensian to the present. Its mainly organic sediments and forest beds, and the pollen and radiocarbon analyses have yielded evidence that prove reduced sea-levels in the latest Devensian and the subsequent drowning of the forests which developed around Cardigan Bay.

Introduction

Clarach is an important site with a sedimentary record extending from the start of the Late Devensian late-glacial to the present day. Pollen, diatoms and radiocarbon dates provide detailed evidence for environmental and sea-level changes (Taylor 1973; Heyworth *et al.* 1985).

Description

Clarach (SN588830) lies on the Cardigan Bay coast some 8km south of Ynyslas and Borth. The interest occurs around the mouth of the River Clarach and extends onto the modern day beach where a small area of submerged forest is occasionally exposed. The sequence and stratigraphy have been investigated by boreholes in the mainly organic sequence behind the modern beach, and by mechanically excavated sections in the submerged forest on the foreshore (Heyworth *et al.* 1985) – see Figure 11. The trench on the foreshore (Figure 11) showed a sequence of –

4 Shingle storm beach
3 Submerged forest
2 Grey clay
1 Gravel

Borings inland (Figure 11) showed a sequence of –

7 Silt and clay
6 Peats and peaty clays
5 Silt and clay
4 Limnic peat and organic mud
3 Gravel
2 Silt and clay
1 Gravel

Interpretation

The submerged forest beds at Clarach are rarely visible and are normally covered by sand and shingle. First described by Keeping in 1878, the beds were not recorded again until 1964 and 1965, following erosion of the overlying beach deposits (Taylor 1973). He described remains of *Pinus*, *Alnus*, *Corylus*, *Betula* and *Quercus* from the submerged forest which rested on a thin peat, overlying grey silty clay. He thought the clay corresponded with the *Scrobicularia* clay beneath the submerged forest at Ynyslas and Borth Bog

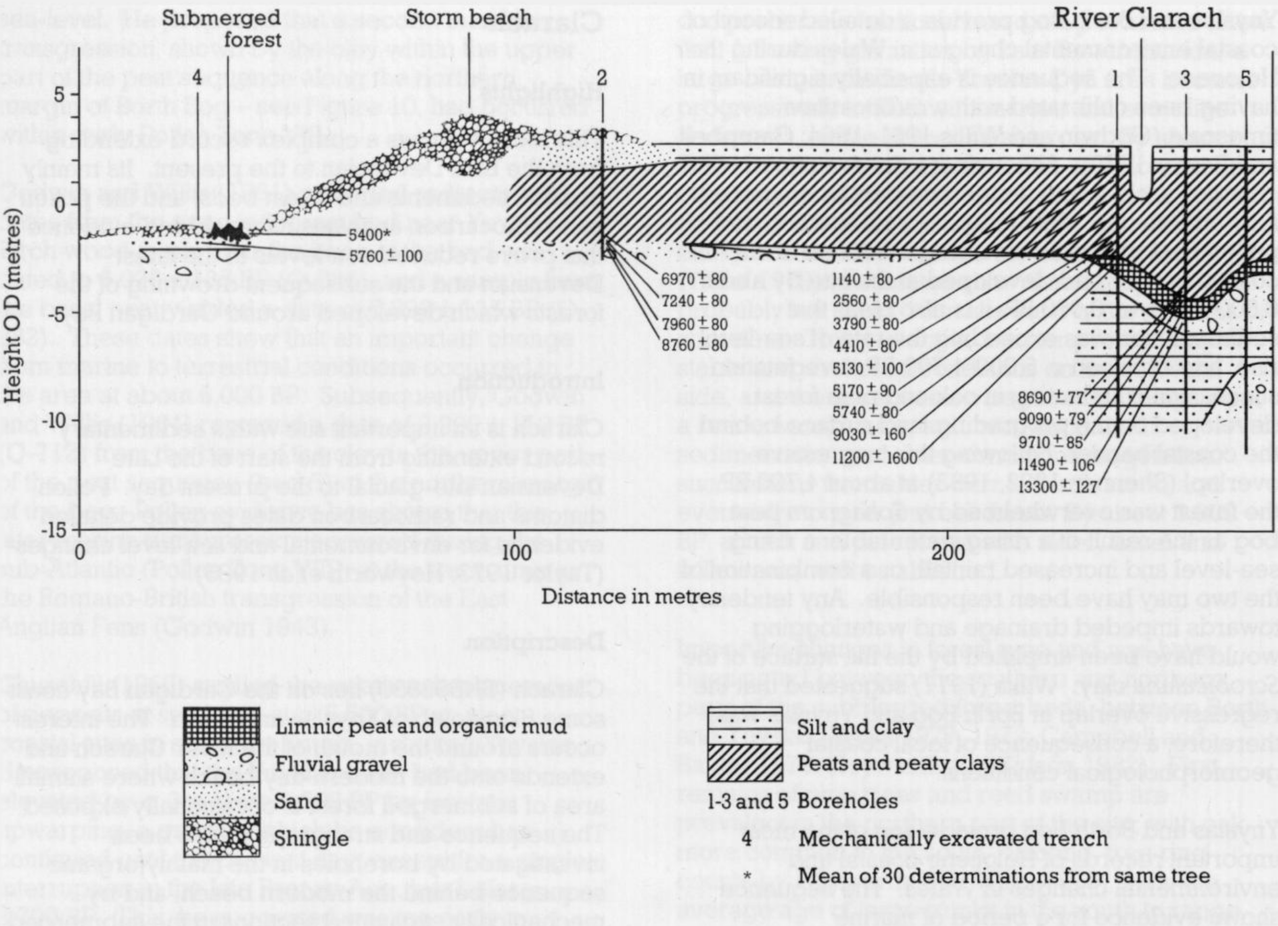

Figure 11 Quaternary sequence at Clarach (from Heyworth *et al.* 1985)

(Godwin and Newton 1938). A radiocarbon date of 5,970 ± 90 BP (NPL-113) was obtained from an *in situ* stump of *Pinus sylvestris* L., showing a close correspondence with the ages derived by Godwin and Willis (1961) from the submerged forest at Ynyslas and Borth.

Taylor investigated the pollen biostratigraphy of the deposits at Clarach in six boreholes. His preliminary study showed that a Devensian late-glacial sequence was present. The earliest evidence from these deposits suggested an environment characterised by local pine and birch woods, in an otherwise open landscape with marsh habitats. These communities were replaced by juniper at the end of late-glacial times, which was in turn replaced by extensive alder-carr with some birch at the beginning of Pollen Zone IV. The evidence indicates a rapid rise in temperature at this time along the coastal plain, leading to the early arrival of hazel *Corylus* and lime *Tilia* (Taylor 1973).

By Pollen Zone VIIa, pine had become established at Clarach and it was tolerant of the windy and salty conditions imposed by the proximity of the sea. The destruction of the forest at *c.* 6,000 BP was ultimately in response to inundation by the rising Holocene sea, influenced by strong tidal action under storm conditions and the wind funnelling effects of the lower Clarach Valley (Taylor 1973). Recently, the site has been re-investigated by Heyworth *et al.* (1985), who drilled additional boreholes in the marshy area behind the storm ridge, and undertook pollen, diatom and radiocarbon analyses – see Figure 11. The earliest organic sediments (bed 4) were radiocarbon dated to about 13,600 BP. Pollen analysis of these deposits indicates a rapid amelioration of climate at this time, with an increase in tree and shrub pollen. However, the late-glacial and early Holocene sediments at Clarach have a pollen assemblage dominated by aquatic species, sedges and grasses, and little tree and shrub pollen is present even as late as 9,000 BP. Local pollen assemblages were reconstructed for this period, but zonation and correlation with other sites is difficult (Heyworth *et al.* 1985). The pollen diagram, however, reveals the start of a cold event (within bed 4) at about 10,900 BP, with the most severe conditions at *c.* 10,550 BP. This can probably be correlated with the climatic deterioration of the Younger Dryas, widely documented from Devensian late-glacial sites elsewhere. The end of this cold period, estimated at *c.* 10,100 BP, is not clearly marked in the pollen diagram (Heyworth *et al.* 1985). The late-glacial sequence, therefore, comprises freshwater fluviatile gravels (beds 1 and 3), silts and clays (bed 2) and organic (largely lacustrine) deposits (bed 4) which indicate that sea-level did not influence sedimentation during this period. Even by *c.* 7,000 BP, sea-level was still probably *c.* 10m below that of the present day. At the beginning of the late-glacial, sea-level was estimated to have been at least as low as 50m below present (Heyworth *et al.* 1985).

The lacustrine and peat deposits (bed 4) were deposited over a period of almost 5,000 years in the late-glacial and early Holocene. During this period, the Clarach Valley was probably occupied by lagoons or channels with current velocities too low to cause appreciable coarse sedimentation. Evidence from the submerged forest exposure on the beach suggests that freshwater silt and clay (bed 5) began to accumulate at *c.* 6,000 BP, its surface becoming rapidly colonised by *Alnus* and *Corylus*. By about 5,400 BP quite large oaks had become established. Shortly after 5,400 BP flooding occurred as sea-level rose, and stumps and trunks of trees were subsequently buried beneath alluvial deposits or by the landward-moving storm beach (Heyworth *et al.* 1985). From about 5,100 BP a succession of peats and clays (bed 6) provides evidence for a dynamic equilibrium between the rates of water table rise and sedimentation. Sea-level rise was clearly the underlying cause of water table rises and increased sedimentation (Heyworth *et al.* 1985). By 2,650 BP sedimentation was keeping pace with, or outstripping, sea-level rise, with sediment supplied by frequent flooding at times of high tide and high river discharge. This situation has persisted to the present day (Heyworth *et al.* 1985).

Pollen, diatom and radiocarbon studies have shown that the sedimentary record can be divided into two main parts: a lower late-glacial/early Holocene sequence of freshwater deposits; and a sequence of subsequent Holocene sediments in which the influences of changing sea-levels may be clearly detected. The site provides unique land-based evidence in west Wales for sea-level conditions during the late-glacial and early Holocene: sea-level, initially as low as -50m OD at *c.* 10,000 BP rose steadily to cause the demise of successive phases of vegetation as woodland developed on the coastal margins of Cardigan Bay. The most notable phase of this vegetation development appears to have occurred at *c.* 5,500 BP when substantial woodland, including pine and oak, became established approximately at ordnance datum, both at Clarach and farther north at Borth and Ynyslas. The destruction of this forest at both sites is believed to have been in response to the rising Holocene sea, although the site records show important differences. At Clarach, the succeeding marsh and alluvial sediments show a state of dynamic equilibrium between the rates of sea-level (and therefore water table) rise, and terrestrial sedimentation. In contrast, at Borth the submerged forest is succeeded by raised *Sphagnum* bog associated with wetter conditions, perhaps increased precipitation and rising sea-levels. The development of an extensive coastal barrier at Ynyslas and Borth appears to have minimised the direct effects of marine sedimentation during the period of Holocene bog formation, but at Clarach the influence of marine conditions during the same period of sedimentation is more clearly demonstrated.

Clarach is important in recording detailed information for changing sea-level and terrestrial conditions from the beginning of the Devensian late-glacial to the present day. It provides the most extended record of such conditions presently known from Wales. The sequence shows particularly detailed evidence for relative sea-levels during the Devensian late-glacial. It demonstrates successive phases of vegetation development on the margins of Cardigan Bay and the demise of pine and oak woodland at about 5,400 BP as Holocene sea-level rose. Marine influences are apparent in the remainder of the succession, which is therefore important in demonstrating that the extensive regressive overlap interpreted at Ynyslas and Borth is most probably the reflection of local coastal geomorphological changes, namely the development of a substantial coastal barrier.

Conclusions

Clarach provides detailed information on the nature and timing of changes in the relative level of land and sea over the past 13,000 years. It has the best record for this period in Wales.

Morfa-bychan

Highlights

Controversial periglacial and possible glacial sediments occur here in the finest sections of their kind in Wales. These sediments are important in interpreting the position of glacial and periglacial zones during the Late Devensian.

Introduction

The origin and age of the sediments at Morfa-bychan (SN562764) have been the subject of much debate. The site has a long history of research commencing with Keeping (1882) and Reade (1896). The sediments were interpreted by Watson and Watson (1967) and Watson (1977a, 1982) as slope deposits, accumulated under periglacial conditions during the Devensian Stage. Others, however, have suggested that at least part of the succession is glacial in origin (Wood 1959; Bowen 1974; Vincent 1976). Most workers agree that any glacial sediments do not rest *in situ*. The site is widely regarded as one of the best exposures of its kind in Wales.

Description

Pleistocene deposits exposed on the coast extend southwards from Morfa-bychan (SN565772) for over 1.5 km to beyond Ffos-Las (SN558757). The best exposures are found between Cwm-ceirw (SN563766) and Ffos-Las where, in places, the sediments reach up to 45 m in vertical section (Watson 1977a).

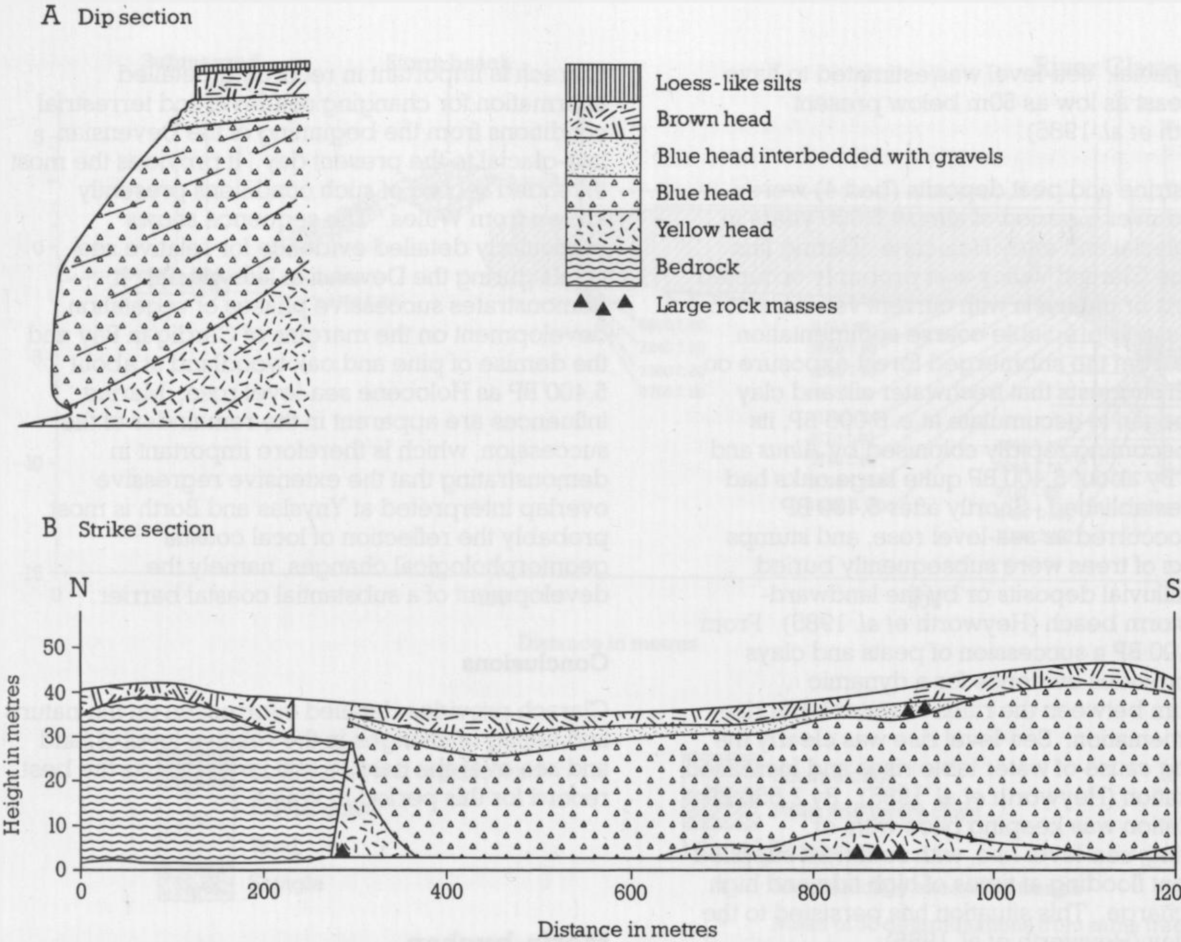

Figure 12 Pleistocene sequence at Morfa-bychan (after Watson and Watson 1967)

Watson (1977a) recognised a succession of –

5 Loess-like silts
4 Brown Head
3 Gravels
2 Blue Head
1 Yellow Head

The sequence is shown in Figure 12.

Interpretation

Early workers regarded the sequence as glacial in origin (Keeping 1882; Reade 1896; Williams 1927). Keeping noted that the sediments were composed entirely of local rock debris, and suggested that they had accumulated during a single glaciation of the area by ice coming from the Welsh uplands.

Wood (1959) reported that the drift at Morfa-bychan mantled a fossil coastline comprising a compound platform made up of a number of wave-cut benches. He described the relationship between the drift and the buried coastline, and believed that the former comprised Welsh till of Saalian age, rearranged by solifluction towards the end of the Devensian Stage.

Watson and Watson (1967) provided a detailed account of the deposits and stratigraphy. They showed that the beds dipped consistently towards the sea, and in strike section they appeared horizontal or very gently dipping – see Figure 12. Individual beds were concave, while the dip of individual beds decreased downslope, and the dips of a series of beds decreased upwards vertically, at any single point – see Figure 12. Detailed stone orientation analyses suggested that the beds, apart from the gravels and loess, had a fabric typical of solifluction deposits; in particular the azimuths of the stones' long axes were grouped tightly around the dip values of the beds (Watson and Watson 1967). Rock fragments in the drift deposits consisted entirely of the Aberystwyth Grits, greywackes and shales of Silurian age, derived from the local hinterland. Thus, in contrast to previous interpretations, they proposed that the sequence was typical of a coastal head, consisting of scree and solifluction deposits with subordinate rainwash gravels and a thin loess, all laid down under periglacial conditions during the Devensian Stage.

The periglacial origin of the entire drift sequence at Morfa-bychan has been restated in a number of papers by Watson (1968, 1970, 1976, 1977a, 1982). The periglacial origin of the Yellow Head, for example, has never been questioned, but the origin of the Blue Head has been debated. Bowen (1977a) noted that many clasts in the Blue Head were striated. He concluded that the basal layers of the Blue Head, at least, might well include till, originally deposited upslope from its present position.

In an attempt to unravel the controversy concerning the origin of the deposits at Morfa-bychan, Vincent (1976) undertook an SEM study of quartz sand grain surface textures from the deposits. These surface textures indicated that the deposits could not be regarded solely as the products of periglacial slope activity (Watson and Watson 1967), and he showed that grains in the Blue Head had surface textures attributable to glacial abrasion.

The interpretation of these beds assumes considerable importance in establishing a sequence of Late Pleistocene events in west Wales. Much controversy has persisted concerning the nature, particularly, of the Blue Head. In arguing that it was periglacial in origin, although perhaps containing some material reworked from an earlier (Saalian?) glaciation, Watson and Watson envisaged that the local area would have been ice-free during the Late Devensian. They used the evidence from this site, and elsewhere in Wales, to propose an extremely restricted glaciation during the Late Devensian. Wood (1959) and Bowen (1973a, 1973b, 1974, 1977a, 1977b) argued that the Blue Head included glacial deposits of Welsh provenance redeposited downslope by solifluction. Wood, like the Watsons, considered that the periglacial conditions responsible for redeposition of the Morfa-bychan sequence had occurred during the Devensian Stage. Indeed, the Watsons suggested that the sequence at Morfa-bychan could be sub-divided to represent the whole of the Devensian Stage. In contrast, Bowen (1973a, 1973b, 1974, 1977a, 1977b) argued that the Morfa-bychan area had been glaciated by westward-moving Welsh ice during the Late Devensian. He cited Garrard and Dobson's (1974) evidence that Welsh till of a similar lithofacies, and up to 12m thick, extended offshore for some 8 km. Bowen (1977a) pointed out that the Morfa-bychan sequence was, therefore, somewhat anomalous in terms of regional stratigraphy, in that the clay-rich sediments had lent themselves to rearrangement by solifluction down the steep coastal slope, both during and after deglaciation of the Late Devensian ice-sheet. The latter view of an extensive Late Devensian glaciation in west Wales was also upheld by Peake *et al.* (1973). Bowen's view that at least part of the sequence at Morfa-bychan was formed of Late Devensian glacial deposits rearranged by periglacial processes is also supported by the work of Potts (1968, 1971) in central Wales, who showed that the majority of periglacial landforms and landscape features had probably formed during the Late Devensian and particularly during the Late Devensian late-glacial.

Morfa-bychan has an important stratigraphical record of environmental and geomorphological changes in west Wales. The interpretation of the sequence is important for understanding Late Pleistocene events and the extent of ice in west Wales. The stratigraphical detail and the extent of the exposures makes this an exceptional site for periglacial scree and solifluction deposits in Wales. The sections show clearly the importance and relationship of localised topographic and lithological controls on the accumulation of solifluction deposits.

Conclusions

Morfa-bychan has an internationally important sequence of ice age deposits. Their interpretation has proved controversial. One view is that they are glacial deposits, whereas another is that they are slope deposits which have sludged downwards from the high coastal slope at their rear. The details and internal structure of the deposits are exceptionally well exposed.

Llan-non

Highlights

This site demonstrates the complexities of glacial and periglacial events in western Mid Wales, showing Irish Sea and Welsh tills and some of the best multi-generation periglacial features in Britain. The site provides outstanding evidence for migrating ice fronts and polar desert during the Devensian Stage.

Introduction

The coastal sections at Llan-non display evidence for glacial and periglacial events and processes. The site is regarded as one of the finest exposures exhibiting periglacial involutions (festoons) and vertical stone structures in Great Britain (Watson and Watson 1971). Additional interest is provided by what some regard as a zone of interglacial weathering, the Llansantffraid Soil. The site was first noted by Williams (1927) and Mitchell (1960, 1962, 1972). The most detailed studies of the stratigraphy and periglacial structures were by Watson (1965b, 1970, 1976, 1977a, 1977b) and Watson and Watson (1971).

Description

The principal sections at Llan-non occur between the rivers Peris and Clydan, which flow west and dissect a low coastal terrace. The sections comprise a low cliff 3.5-4.5m high, almost entirely composed of alluvial gravels. Till deposits crop out to the north of the Peris and south of the Clydan, and the alluvial gravels occupy what is believed to be a fluvially excavated depression in the surface of the till. The following succession was recognised by Watson (1965b, 1976, 1977a) –

4 Fine gravels, sands and silts
3 Torrential alluvial boulder gravels
2 Irish Sea till
1 Welsh till

The sequence shows multi-generation periglacial involutions.

Interpretation

Williams (1927) noted that the drift deposits in the Llan-non area were banked up against what he interpreted as a fossil cliff of 'pre-glacial' age. Wood (1959) likewise described the relationship between the superficial deposits and the fossil cliff, and noted that the drift platform at Llan-non had resulted from the infilling of hollows on a till surface by water-washed, probably solifluction, debris.

Mitchell (1960, 1962, 1972) noted that the base of the exposures north of the Peris river (termed by him the "Llansantffraid sections") comprised a much cryoturbated stony till, which passed laterally southwards into a coarse gravel. The surface of the till and gravels was deeply weathered, frost-heaved and penetrated by vertical weathering cracks. This weathered surface was truncated and overlain by a younger series of gravels, also subsequently slightly disturbed by frost-heaving. The zone of weathering between the two gravels was termed by Mitchell the Llansantffraid Interglacial Soil, and was believed by him to have formed during the Ipswichian Stage. The underlying till was thus ascribed to the Gippingian glaciation (Saalian Stage), and the overlying gravels and subsequent phase of frost disturbance were ascribed to the Devensian. This evidence was used by Mitchell (1960, 1962, 1972) to support his concept of restricted glaciation in Wales in Late Devensian times, with much of the west Wales coast remaining ice-free.

Taylor (1973) noted that a deposit similar to the Llansantffraid Soil occurred to the south, along the coast at Aberaeron. There it contained a pollen assemblage with *Abies*, which he noted was otherwise rarely recorded in British Devensian late-glacial and Holocene pollen diagrams; he further considered that it supported Mitchell's view that the Llansanffraid bed was indeed an interglacial soil of pre-Holocene age. Other workers (Stewart 1961; Rudeforth 1970; Clayden 1977b) disputed that the bed was a soil at all, and doubted its inferred chronological significance. Stewart and Rudeforth suggested that the whole sequence could have resulted from fluctuating environmental conditions during the Devensian Stage, with the 'soil' simply representing a relict permafrost feature. Bowen (1973a, 1974) agreed, and classified it as part of the sequence of Devensian age.

From evidence in the coastal sections between Llan-non and Llansanffraid, Watson (1976, 1977a) proposed the following sequence of events. First, till was deposited by local Welsh glaciers, and subsequently by Irish Sea ice moving southwards. Precursors of the Peris and Clydan rivers then dissected the resulting till surface, first truncating it and secondly, depositing coarse alluvial gravels in a large fan. Where undisturbed, the imbrication of the gravels shows that they were deposited by water moving from east to west. A period of intense cryoturbation under periglacial conditions led to the striking development of vertical stones and involutions in the gravels and in the upper horizons of the till. The lower limit of cryoturbation was interpreted by Watson as a fossil permafrost table, with intense freeze-thaw processes having occurred only in the active layer. A second period of erosion by the two rivers then removed part of the cryoturbated gravels and deposited beds of finer gravels, sands and silts. A renewed phase of cryoturbation, less intense than the first, produced smaller involutions in the later beds; Watson considered that this later episode could in fact be divided into two separate phases of fluvial deposition and cryoturbation. In view of the depth of weathering in the till and lower gravels, Watson (1976, 1977a), like Mitchell (1960, 1962, 1972), argued that they were probably Saalian in age, and attributed the upper alluvial gravels and frost structures to periglacial conditions in the Devensian Stage, when much of the west Wales coast was thought to have been free from glacier ice.

Although Watson provided the most detailed description and interpretation of the beds and structures at Llan-non, his classification has not been accepted by others. Bowen (1974, 1976), for example, argued that the till at Llan-non and Llansanffraid was the product of coeval Welsh and Irish Sea ice in the Late Devensian. Such a view is also supported by the work of Garrard and Dobson (1974) who showed that extensive Late Devensian glacial deposits occur offshore in Cardigan Bay. As such, Llan-non shows contrasting evidence to Morfa-bychan farther north where the deposits suggest the presence of Welsh ice only, and Traeth-y-Mwnt to the south, which clearly demonstrates the incursion of the Irish Sea ice-sheet into south-west Dyfed. Collectively, therefore, these sites demonstrate the complex interaction of the Welsh and Irish Sea ice masses along the west coast of Wales during the Late Pleistocene.

Although involutions and vertical stone structures can be seen at many sites along the Cardigan Bay coast, they are best developed between Llan-non and Llansanffraid; and they were probably formed in the active layer of former permafrost. The cryoturbated gravels and till at Llan-non provide exceptionally detailed evidence for a number of distinct periglacial phases, which have yet to be dated.

Llan-non is a rare exposure through a periglacial alluvial fan. The succession of till, alluvial gravels and associated periglacial structures has been used to reconstruct a sequence of Late Pleistocene events. The interpretation of one bed, the Llansantffraid Soil, however, has proved controversial. The multi-generation periglacial structures at the site are unparalleled in Wales, and they are amongst the finest of their kind in Britain. Glacial sediments at Llan-non are important for interpreting the complex interaction of the Irish Sea and Welsh ice masses along the west Wales coast during the Late Pleistocene.

Conclusions

The alluvial fan gravels at Llan-non are unique in Wales. They were deposited by the Peris and Clydan streams towards the end of the ice age. What makes the gravels exceptional, even by international standards, is the way in which they have been disturbed and arranged into distinctive structures by the former development of large ice lenses in the sub-soil. These have been used as examples in text-books.

Traeth-y-Mwnt

Highlights

This locality shows Irish Sea till and sand and gravels assigned to the Devensian, last, glaciation. The section is affected by enigmatic glaciotectonic folds.

Introduction

Traeth-y-Mwnt (SN194519) is an important exposure through glacial sediments which show large-scale glaciotectonic deformation structures. The sections provide important evidence for the incursion of Irish Sea ice into Ceredigion. The site featured in an early study by Williams (1927) and was described and discussed recently by Davies (1988).

Description

The sections at Traeth-y-Mwnt occupy the eastern part of the bay and extend laterally for about 100m. They reach about 15m in maximum height and comprise a sequence of –

3 Hillwash and blown sand

2 Shelly fluvioglacial sands and gravels

1 Shelly grey Irish Sea till

The principal glaciotectonic structure at Traeth-y-Mwnt is a large over-fold, about 15m across and 12m high. The feature is strongly accentuated by alternating bands of different textures and colours within the till sequence. Other parts of the till sequence also exhibit evidence of severe disturbance, in the form of near-vertical bedding. Further sedimentological interest is provided by fluvioglacial sands overlying the till, which show well developed fault structures. The sands are in turn overlain by cryoturbated gravels.

Interpretation

Williams (1927) correlated the till at Traeth-y-Mwnt with the Lower Boulder Clay of his widely found tripartite sequence, for example, at Gwbert (SN163495). He noted the occurrence in the till of frequent Carboniferous Limestone clasts, many of which contained large radiating masses of *Lithostrotion*. Shell fragments, including *Cyprina* (*Arctica*) *islandica* L. and *Astarte* sp., were also noted, suggesting that the till had been deposited by ice moving onshore from the Irish Sea Basin. He regarded the overlying sands and gravels as fluvioglacial in origin and correlated them with the Middle Sands and Gravels of his tripartite classification. They had been deposited at the margin of a retreating ice-sheet, but no explanation was offered to account for the deformation structures in the underlying till (Williams 1927). The Irish Sea till at Traeth-y-Mwnt was also noted by Bowen (1977b).

Recently, Davies (1988) described and reinterpreted the sequence, arguing that it comprised a basal lodgement till overlain by varved glacio-lacustrine sediments, flow tills and fluvioglacial sands and gravels. The succession was believed to have accumulated during stagnation and deglaciation of the Irish Sea ice-sheet. Davies accounted for the glaciotectonic structures by a combination of subglacial deformation processes and post-depositional mass movements.

The position of Traeth-y-Mwnt in a regional Pleistocene chronology is not well established. In view of lithostratigraphical evidence elsewhere along the coast, it is likely that the glacial sediments at Traeth-y-Mwnt were deposited by southward moving Irish Sea ice (John 1968b; Bowen 1977b). In view of amino acid geochronological studies at nearby Banc-y-Warren and Abermawr (Bowen 1984), the deposits at Traeth-y-Mwnt are probably Late Devensian in age. It is interesting to note the similarity of the faulting structures in the sands at Traeth-y-Mwnt to those described at Banc-y-Warren (for example, Helm and Roberts 1975; Allen 1982; Worsley 1984), although they need not have formed in the same way(s).

The principal interest of the site lies in large deformation structures in the till. Although the scale of deformation is probably unparalleled elsewhere in Wales, no comprehensive and satisfactory explanation has yet been offered. The absence of an overlying till might imply that deformation was not caused by a readvance of ice, as has been proposed at, for example, Dinas Dinlle (Whittow and Ball 1970) – see Chapter 7. The till at Traeth-y-Mwnt occupies a deep and narrow coastal inlet which lies perpendicular to the inferred direction of ice movement. Although speculative, it is possible that deformation occurred as basal till was forced downwards into the tightly confined embayment.

Traeth-y-Mwnt provides an important section through Irish Sea glacial sediments which are probably the product of Late Devensian Irish Sea ice that moved generally south across the area. Traeth-y-Mwnt is, therefore, important for demonstrating the incursion of Irish Sea ice into Ceredigion and, with other reference sites, helps to show the complex interactions of Welsh and Irish Sea ice along the coast of west Wales. The site is also important for a series of spectacular large-scale glaciotectonic deformation structures. The precise environmental conditions for the sequence and structures, however, remain to be established.

Conclusions

The exposures at Traeth-y-Mwnt display large-scale deformation structures in glacial deposits. Although these structures have been interpreted as having formed on land, another view is that they developed through the process of submarine slumping in a cold climate sea, adjacent to marine-based glaciers.

Banc-y-Warren

Highlights

Complex fluvioglacial sediments here have afforded evidence of sedimentation during ice wastage at the end of the Devensian. A complex pattern of stream, lake and delta deposition, and collapse above melting entrapped ice has emerged.

Introduction

Banc-y-Warren (SN204475) is an important site in south-west Wales that has attracted interest for over sixty years. The site is geomorphologically striking, consisting of a group of steep-sided conical hills made up of sands and gravels that rise some 50m above the northern flank of the lower Teifi Valley. Banc-y-Warren is the most prominent of these hills. Both the origin and dating of the deposits have proved controversial. The Pleistocene deposits were first studied by Jehu (1904), and the sediments and their included fauna were described in some detail by Williams (1927). The site was mentioned by Charlesworth (1929), Wirtz (1953), Mitchell (1960, 1962, 1972), Synge (1963) and Jones (1965), and, in the late 1960s, much interest was stimulated by radiocarbon dates from the sediments (John 1967, 1968c, 1970a; Brown *et al.* 1967; Shotton 1967; Boulton 1968; John and Ellis-Gruffydd 1970). More recently, the site has been referred to by John (1969, 1973), Unwin (1969), Bowen (1971b, 1973a, 1974, 1977b) and Bowen and Lear (1982). Detailed accounts of the stratigraphy and sedimentology of the site were provided by Helm and Roberts (1975) and Allen (1982), and the available dating and sedimentological evidence from the site was reviewed by Worsley (1984). Amino acid ratios have been given by Bowen (1984).

Description

Glacigenic sands and gravels can be examined in pits at Cnwc-y-Seison and Cil-maenllwyd, and these constitute the Banc-y-Warren exposures referred to by early workers. The sediments form a continuous sheet that extends from Alma Grange (SN210460) through Banc-y-Warren to Aberporth (Helm and Roberts 1975). In detail, the succession varies laterally but may be generalised as one of fine current-bedded sands overlain by coarser sands and gravels exhibiting cross-bedding and slump structures. These in turn are overlain by very coarse, poorly stratified gravels. The gravels contain erratics from both Welsh and Irish Sea sources including Cambrian sandstones, Old Red Sandstone, flint, Chalk and a variety of igneous rock types. The finer grained, yellow sands yield whole marine shells and shell fragments, scattered nodules and layers of organic debris (Unwin 1969), and pollen and wood fragments (John 1969). The sediments exhibit complex patterns of small-scale faulting and the whole sand and gravel sequence is thought to overlie till (Williams 1927; Jones 1965). Fossil ice-wedge casts up to 1m deep were noted in the sands at Banc-y-Warren by John (1973). Williams (1927) mapped the extent of the sands and gravels. He also provided a general account of the sedimentology, noting the presence of cross-stratification, the water-worn appearance of the gravel clasts which included a mixture of Irish Sea and Welsh rock types, faunal details of the comminuted shallow marine molluscs and the presence of numerous small faults.

Interpretation

Although the deposits at Banc-y-Warren were mentioned by Jehu (1904), Williams (1927) made the first thorough description and interpretation of the succession as part of his synthesis of Pleistocene stratigraphy in western Cardiganshire. He classified the beds as part of the Intermediate Sands and Gravels division of his tripartite sequence. He concluded that the beds were deposited as fluvioglacial outwash from the margin of the Irish Sea ice-sheet, and interpreted the mounds as kames. The faults were believed to have been caused by the melting of buried ice masses (Williams 1927).

Shortly after, Charlesworth (1929) in his classic paper *The South Wales end-moraine*, briefly referred to the deposits at Banc-y-Warren. These he interpreted, largely on the basis of their external form, as end-moraines of the 'Newer Drift' ice-sheet, and constructed his 'Newer Drift' limit around them accordingly. Wirtz (1953) noted the fresh appearance of the beds at Banc-y-Warren, and also interpreted them as marking part of the 'Newer Drift' ice limit, although he envisaged that only a small tongue of the Irish Sea ice had impinged upon north Preseli and south Ceredigion in the area of the lower Teifi Valley.

The deposits at Banc-y-Warren were also noted by Mitchell (1960, 1962, 1972) who, unlike Charlesworth (1929), regarded the deposits as

fluvioglacial outwash from a retreating Irish Sea ice-sheet of Gipping age.
Jones (1965) considered that the deposits had been laid down in a lake. He noted that the deposits were flat-topped, that they ended in steep south-west facing slopes and that the sequence coarsened upwards from fine sands to gravels. He interpreted the deposits as having been formed in a delta built into a deep proglacial Lake Teifi which, at that time, stood at the level of the postulated Llantood (Llantwyd) overflow. In the discussion following Jones' paper, however, Bowen argued that the supposed overflow channels were in fact subglacial in origin.

Banc-y-Warren attracted much attention in the late 1960s when radiocarbon determinations were attempted. Three radiocarbon assays were undertaken on organic material from the sands: and these gave dates of 31,800 +1,400 -1,200 BP (I-2559) (Brown *et al.* 1967); 33,750 +2,500, -1,900 BP (I-2564) (John 1967); and > 39,900 BP (I-2802) (John and Ellis-Gruffydd 1970). The radiocarbon determinations were used to support John's (1965b) and Bowen's (1966) earlier concept of an extensive Devensian glaciation in the Irish Sea Basin and Preseli. John (1967) suggested that pollen and radiocarbon evidence from Banc-y-Warren indicated a period of forest growth probably during a Middle Devensian interstadial, and that these organic remains had been incorporated into the kamiform deposits by fluvioglacial processes during the Late Devensian. However, he noted the occurrence of reworked Carboniferous and Mesozoic spores in the pollen assemblage, together with pieces of Tertiary lignite, acknowledging that the remains had most likely been reworked from a variety of older deposits. Indeed, strong reactions to the validity of the radiocarbon dates were forthcoming (Shotton 1967; Boulton 1968), but whereas certain difficulties in interpreting the organic remains and dates were acknowledged, the original interpretation was maintained by John (1968c, 1969, 1970a) and John and Ellis-Gruffydd (1970).

Subsequent reviews (for example, Unwin 1969; Bowen 1971b, 1973a, 1974, 1977b; Bowen and Lear 1982) have noted the equivocal nature of the faunal and radiocarbon dated evidence from the site. A Late Devensian age for the deposits, however, was still favoured by Bowen and Bowen and Lear on stratigraphical grounds. Recent amino acid ratios from fossil marine molluscs at Banc-y-Warren are consistent with the succession being of Late Devensian age (Bowen 1984), and show that the derived shell content of the deposits ranges in age from Early Pleistocene to Devensian; a discovery which invalidates all previous radiocarbon dates on bulk shell samples.

Helm and Roberts' (1975) detailed sedimentological account of the exposures interpreted the deposits as a complex of three large lake deltas formed in variable but substantial water depths, with thick cross-bedded gravels representing the foresets, and the sands the bottomset beds. Gravel channel fillings amongst the sand bottomsets were considered to have been cut and filled by turbidity currents which originated as slumps from the foresets. They discounted Williams' (1927) suggestion that faulting in the sequence had occurred from the melting of included ice masses, and, instead, they interpreted the faults as having been formed as a result of slope instability. Concurring with Jones (1965), Helm and Roberts associated one of their deltas with the Llantood (Llantwyd) overflow channel.
In a sedimentological study, Allen (1982) concluded from the lenticular gravels and the fault system at Banc-y-Warren that the deposits had accumulated as a fluvioglacial outwash spread on top of a downwasting ice-lobe in the Teifi Valley. He accepted the possible deltaic nature of the large gravel foresets but considered that they had probably been deposited in a restricted waterbody unrelated to a 'proglacial Lake Teifi'. He believed that extensive faulting of the sediments had occurred due to the downwasting of a single extensive prismatic wedge of ice beneath the entire sedimentary suite. Perhaps the most conclusive evidence in favour of a subaerial outwash origin for the sediments was the unlithified sand clasts described in some detail by Allen.
Worsley (1984) considered that despite the enigmatic nature of much of the sedimentological data, it was difficult to resist the conclusion that these 'clasts' must have been frozen immediately prior to deposition, and that this evidence, in conjunction with the highly irregular form of the channel margins, suggested at least seasonal freezing of the aggrading sedimentary surface. He concluded that such a mechanism could not be reconciled with a deep water environment (Jones 1965; Helm and Roberts 1975).

A deltaic origin for part of the sequence at Banc-y-Warren seems possible, but the surviving evidence tends to support an origin as subaerial outwash for the bulk of the sequence. The site is also important for the developing Late Pleistocene chronology of south-west Wales, and is one of only very few sites where both radiocarbon and amino acid time-scales are available. Although the radiocarbon dates are misleading, amino acid ratios from the site provide strong evidence to suggest a Late Devensian age for the sequence. Banc-y-Warren forms part of an integral network of stratigraphic sites in south-west Wales that reveal major environmental variations during the Late Pleistocene. Although sequences associated with Late Pleistocene interglacial conditions (for instance, Poppit Sands, West Angle Bay, Porth Clais, Marros Sands), glacial conditions (for instance, Abermawr, Traeth-y-Mwnt, Druidston Haven) and periglacial conditions (for instance, Porth Clais, Marros Sands) are better developed elsewhere in south-west Wales, Banc-y-Warren is arguably the most important reference site for fluvioglacial processes and events in the region. The combination of excellent stratigraphic detail and the morphology of landforms, makes Banc-y-Warren of outstanding geomorphological interest. It is one of very few sites in Wales where detailed sedimentological techniques have been applied to interpret Pleistocene sequences. During the protracted history of investigations at the site, a number of radically different models of sedimentation has been proposed. The most recent evidence indicates that the majority of the succession was deposited as subaerial outwash with a subordinate proportion of the sequence originating as delta front sediments deposited in small, ephemeral water bodies. The site also provides important evidence for the dating of Late Pleistocene events in south-west Wales, particularly for establishing that the last glaciation of northern Preseli and southern Ceredigion occurred in the Late Devensian.

Conclusions

Banc-y-Warren is an outstanding site that has been subjected to the most detailed sedimentological investigations. It is generally agreed that there are elements in the internal composition of its landforms which suggest that some of the deposits were laid down in a lake during the last ice age, about 18,000 years ago.

Poppit Sands

Highlights

Poppit affords evidence of high sea-levels probably during the last, Ipswichian Stage, interglacial, followed by periglacial then glacial conditions. During the latter, Irish Sea ice deposited till in northern Preseli.

Introduction

Poppit Sands (Poppit) (SN146489) shows a sequence of deposits which provides evidence for marine, periglacial and glacial episodes in south-west Wales during the Late Pleistocene. The site is particularly important for a well developed shore platform overlain by raised beach sediments. The site was first noted by Jones (1965) and has been described by John (1968a, 1970a, 1971a), Bowen (1971b, 1973a, 1973b, 1974, 1977a, 1977b) and by Peake *et al.* (1973). The most detailed description and interpretation is provided by John (1970a, 1971a), Bowen (1977a, 1977b) and Bowen and Lear (1982).

Description

A raised shore platform overlain by raised beach sediments was first recorded at Poppit by Jones (1965). The succession was more fully described by John (1970a) as –

4 Irish Sea till (2.0m)
3 Blocky head (6.0m)
2 Raised beach sediments (1.7m)
1 Rock platform

The shore platform lies between 1.7 and 3m above high water mark; and can be traced along the coast between Cei-bach and Trwyn Careg-ddu for 1 km (John 1970a). The raised platform consists of a planed surface on tightly folded Lower Palaeozoic shale and sandstone beds, quite unlike the present shore platform which is being differentially eroded (Bowen 1977a, 1977b; Bowen and Lear 1982). The overlying raised beach deposits are characterised by a great deal of lateral variation in the size of pebbles and the nature of the matrix. In places, the beach deposits consist largely of shingle and small pebbles cemented with iron oxide and manganese oxide. Elsewhere it is made up entirely of boulders over 0.7m in diameter. It contains no shells (Bowen and Lear 1982). At the eastern end of the sections, the raised beach sediments are associated with up to 2m of stratified sand and silt (John 1970a; 1971a). Elsewhere, they are overlain directly by a blocky head, up to 6m thick, derived from the high local backslope which reaches 183m OD. The head is succeeded by up to 2.0m of Irish Sea till, although this is largely concealed by vegetation on the degraded surface of the drift terrace (Bowen 1977a). John (1970a) described the blocky head at Poppit as the lower head, the upper head being absent, although it occurred on the other side of the Teifi at Gwbert (Jones 1965; John 1970a). (The latter section no longer survives.)

Interpretation

From evidence at Poppit and elsewhere in the local area, John (1968a, 1970a, 1971a) proposed the following sequence of events. The rock platform was fashioned during an interglacial period when sea-level approached 15m (50 ft) OD. The raised beach sediments were believed to have been deposited during the Ipswichian Stage, when sea-level may have reached as high as 9m (30 ft) OD. John (1970a, 1971a) considered that the site fully deserved the status of type locality for the raised beaches of west Wales, and he accordingly named the period of their formation the Poppit Interglacial. The overlying head indicated a period of periglacial conditions in the succeeding Devensian Stage. He concluded that the head could be sub-divided into various facies; these reflecting a prolonged period of periglacial climate that was characterised by a number of distinct climatic fluctuations. The periglacial phase at Poppit was followed by deposition of till by ice moving southward from the Irish Sea Basin in the Late Devensian (locally named Dewisland) glaciation. The Irish Sea till at Poppit has not been studied in detail. John (1970a), however, believed that an equivalent till bed occurred at Gwbert on the opposite side of the Teifi Estuary. From the Gwbert till, MacDonald (1961) and Jones (1965) had recorded a wide range of erratics including granite from Ireland, Eskdale granite from the Lake District and a series of rock types from Llŷn and Meirionedd, confirming that it was ice from the Irish Sea Basin which had invaded the area around Gwbert and Poppit.

Such an interpretation was broadly followed by Bowen (1971b, 1973a, 1973b, 1974, 1977a, 1977b), who also regarded the Poppit raised beach sediments as being Ipswichian in age, with the overlying periglacial and glacial sediments attributable to the Devensian Stage.

Although the sequence at Poppit has not been dated, Bowen and Lear (1982) described a laminated clay, some 0.5m thick, interbedded with angular boulders and rounded cobbles from the raised beach near Trwyn Careg-ddu (SN148489). This clay contained a foraminiferal assemblage including *Elphidium crispum*, a species not present in the modern fauna of the bay. Since *E. crispum* had been shown to occur in sand and gravel sandwiched between till beds in the central part of Cardigan Bay, Bowen and Lear suggested that it was therefore of some use in correlating the upper till of Cardigan Bay, of believed Late Devensian age, with the till at Poppit.

Although Poppit is of interest primarily for its well developed shore platform and overlying raised beach deposits, the remainder of the succession also provides important information on changing environmental conditions in south-west Wales during the Late Pleistocene. The sequence shows that a period of high relative sea-level, probably during the Ipswichian Stage, was followed by a prolonged phase of periglacial climate when thick head deposits were formed. This was followed by fully glacial conditions when ice moved into northern Preseli from the Irish Sea Basin. Although Irish Sea till deposits are better exposed at Traeth-y-Mwnt and Abermawr, Poppit is a key reference site for raised beach deposits and, unlike the former sites, demonstrates the interaction of marine and terrestrial conditions in south-west Wales.

The shore platform and raised beach sediments at Poppit are amongst the finest features of their kind in Wales. The sections are particularly important in integrating both marine and terrestrial evidence in a single exposure. The sequence shows that high sea-levels, probably during the Ipswichian Stage, were followed by periglacial conditions when head accumulated. The succeeding till clearly demonstrates the onset of fully glacial conditions and provides important evidence for the movement of the Irish Sea ice-sheet into northern Preseli.

Conclusions

The raised shore platform and pre-last ice age (interglacial) raised beach deposits at Poppit are text-book examples of their kind. The raised beach was probably formed about 125,000 years ago. The sequence exposed here also shows the history of the last ice age.

Abermawr

Highlights

This site shows unrivalled evidence of two periglacial episodes and an intervening glacial event; all assigned to the Devensian Stage. These sediments lie within what may be a pre-Devensian meltwater channel.

Introduction

Abermawr (SM883346) shows one of the most detailed sequences of surface deposits in south-west Wales, and provides important information for changing environmental conditions in the region during the Late Pleistocene. The site has a long history of research commencing with the work of Jehu (1904). It has featured in studies by Synge (1963, 1969, 1970), John (1967, 1970a, 1971a, 1973), John and Ellis-Gruffydd (1970), Bowen (1971b, 1973a, 1973b, 1974, 1977a, 1977b, 1982, 1984) and Peake *et al.* (1973). Detailed descriptions were provided by John (1970a) and Bowen (1977a, 1977b, 1982, 1984).

Description

Exposures of Pleistocene sediments extend for about 300m at the northern end of Abermawr Bay. The following sequence can be given from the descriptions by John (1970a) and Bowen (1977a, 1977b, 1984) (maximum bed thickness in parenthesis) –

9 Sandy loam (0.6m)
8 Upper head – Jehu's (1904) 'rubble drift' (2m)
7 Fluvioglacial sands and gravels (4.5m)
6 Irish Sea till – Abermawr Till (2.4m)
5 Upper blocky head with scattered erratics (3.6m)
4 Water-worn gravels (3.6m)
3 Lower blocky head with scattered erratics (1.5m)
2 Green-grey clay – weathering horizon
1 Shale head (1-3m)

Raised beach sediments have not been recorded from Abermawr, but because the base of the succession has not been proved these may lie concealed beneath the modern shingle beach (Bowen 1971b, 1977a, 1977b). A further small section mainly through periglacial head, with intraformational fossil ice-wedge casts, is recorded at the southern end of the bay (John 1973).

Interpretation

The sections were first described by Jehu (1904), who considered that Abermawr was one of the best drift sections in north Pembrokeshire and regarded it as especially important for the fine development of the Upper Boulder Clay (bed 8) of his tripartite classification. Although this unit was taken to be primarily glacial in origin, Jehu noted that the deposit showed traces of bedding and contained many angular and subangular rocks derived from the local area. He concluded that the Upper Boulder Clay or 'rubble drift' might, therefore, represent a glacial deposit modified by subaerial agencies, rearranged and partially sorted by meltwater.

Jehu's Lower Boulder Clay is also present at Abermawr (bed 6), and he recognised a variety of rock types in the modern beach probably derived from it. These included Ailsa Craig microgranite, granite from Kirkcudbrightshire, and a variety of other igneous rocks from southern Scotland and the Lake District. Such an assemblage, together with marine shell fragments found in the till, provided strong evidence for the incursion of ice from the Irish Sea Basin into north Pembrokeshire (Jehu 1904).

Synge (1963, 1969 1970) also recognised the upper till at Abermawr, and further noted that the lower head deposits (bed 3) contained reworked glacial erratics. From this evidence, Synge postulated that the area had been glaciated on three separate occasions: he considered the redistributed glacial material in the lower head facies to be of Elster age, with the shelly Irish Sea till, and the more stony upper till being Saalian and Weichselian, respectively.

In contrast, other workers (for example, John 1970a; Bowen 1971b, 1974, 1977a, 1984) placed the entire sequence in the Devensian Stage, recognising only a single till (bed 6); the upper till of Jehu and Synge, being regarded as a head deposit, a mixture of local slope deposits and reworked glacial material (bed 8). John (1970a, 1971a) considered that the only true glacial deposits at Abermawr were therefore the Irish Sea till and its associated outwash (beds 6 and 7). These were underlain by a thick sequence of periglacial slope deposits (John 1973) and overlain by a thinner head which he suggested demonstrated that the Irish Sea glaciation had been preceded by a prolonged periglacial phase and succeeded by a shorter one. He noted a weathering horizon in the lower head, and suggested that it represented an amelioration of climatic conditions, possibly during an interstadial in the Devensian Stage. Complex bedding structures in the outwash sands and gravels showed they had been deposited in a dead-ice (stagnating) environment. The lower head and Irish Sea till were considered equivalent to corresponding horizons at Poppit (John 1970a).

John (1967, 1970a) and John and Ellis-Gruffydd (1970) noted abundant fragments of marine mollusca and pieces of carbonised wood in the till at Abermawr. Although *Pinus* was found, other fragments examined at Kew Gardens came from coniferous species not currently growing in North-West Europe. Radiocarbon dates from samples of the wood of >40,300 BP (NPL-98) and >54,300 BP (GrN-5281) (John and Ellis-Gruffydd 1970) plus the presence in the samples of reworked pre-Pleistocene pollen and spores suggested that the wood was possibly Tertiary in age. The radiocarbon dates were therefore not taken to be significant for the development of a Late Pleistocene chronology at Abermawr (John and Ellis-Gruffydd 1970), but a Late Devensian age for the till was favoured on the basis of a radiocarbon timescale developed at other sites in Pembrokeshire (John 1965b, 1967, 1968c, 1970a; John and Ellis-Gruffydd 1970). It was, however, admitted that the Abermawr Till (bed 6) and associated fluvioglacial sediments (bed 7) could represent a pre-Devensian glaciation in north Pembrokeshire, as postulated by Wirtz (1953).

Bowen (1974) supported the single glaciation hypothesis for the Abermawr sequence (John 1970a). Both Bowen (1971b, 1974) and John, however, noted that erratic pebbles found in the lower head (bed 3) had been derived from a glaciation that pre-dated the Devensian Stage. Like John, Bowen considered that beds 1-5 were periglacial slope deposits, and suggested that although the significance of the gravels (bed 4) was unclear, they might have been deposited by fluvial action under conditions of climatic amelioration (Bowen 1977a, 1977b, 1982). Bowen also noted a weathering horizon (unit 2) in the lower head deposits. This was considered to be a seepage weathering horizon in which the shale had locally decomposed to a green-grey clay. The environmental and chronological significance of this horizon, however, was not discussed, although beds 1-5 were considered to have been deposited during periglacial conditions in Early and Middle Devensian times (Bowen 1973a).

In addition to the mixed assemblage of cold and warm molluscs recorded by John (1970a) from the Abermawr Till, Bowen (1982) further noted that it also contained a cold fauna of foraminifera, including *Elphidiella arctica* Parker & Jones. Amino acid epimerization studies of marine molluscs from Abermawr (Bowen 1984) showed that the derived shells in the till ranged in age from Early Pleistocene to Devensian. The youngest faunal elements present in the Abermawr Till, therefore, indicated that the shells had been derived from sediments deposited during a marine transgression in the Devensian, and transported to Abermawr by the Late Devensian ice-sheet.
The sands and gravels (bed 7) overlying the shelly till were regarded by Bowen (1971b, 1982) as the products of deglaciation of the Late Devensian ice-sheet, while the upper head was a periglacial scree deposit, representing cold conditions after melting of the ice (Bowen 1982).

The location of the Pleistocene deposits at Abermawr significantly enhances the geomorphological interest of the site: "..... the thick lower head shows every indication of being banked against the steep wall of a meltwater channel, and the rest of the drift fill similarly marks the channel wall for some hundreds of metres inland" (John 1970a). This evidence may therefore indicate that the channel, and perhaps others in the remarkable Gwaun-Jordanston system of channels, were probably first cut in pre-Devensian times. Bowen (1971b), however, regarded the 'channel' as a pre-diversion valley of the Western Cleddau. The sequence of deposits at Abermawr provides a key stratigraphic record of environmental and geomorphological changes in northern Preseli during the Late Pleistocene. It may occupy a meltwater channel possibly cut in pre-Devensian times, and provides evidence for the incursion of an ice-sheet from the Irish Sea Basin into northern Preseli. The sequence further demonstrates that periglacial conditions were prevalent both before and after the Irish Sea glaciation of the area. The sands and gravels are thought to represent outwash from the melting of the Irish Sea ice-sheet. Amino acid dating of the included fauna within the Irish Sea till provides evidence to suggest that the Irish Sea glaciation of northern Preseli occurred during the Late Devensian, and the site therefore helps to place constraints on the extent of the Late Devensian ice-sheet in south-west Wales. Raised beach sediments (such as those at Poppit Sands) are not exposed at Abermawr, but the glacial and periglacial sediments are better exposed than elsewhere in south-west Wales.

Abermawr has one of the most detailed stratigraphical sequences in south-west Wales. The Abermawr Till clearly demonstrates that northern Preseli was glaciated by Irish Sea ice, and amino acid ratios from the till provide convincing evidence that the glacial event was Late Devensian in age. The sequence also records important evidence for melting of the Late Devensian Irish Sea ice, and shows that periglacial conditions affected the area both before and after the glacial episode. The location of the sequence in a possible meltwater channel could have geomorphological and chronological implications for the interpretation and relative dating of similar landform features elsewhere in the region.

Conclusions

Abermawr provides one of the most detailed sequences of ice age deposits in south-west Wales. The sequence spans most of the last glacial cycle and shows evidence for an earlier period when scree accumulated under cold climatic conditions. Shell bearing clay deposits at Abermawr have been traditionally interpreted as the products of a land-based ice-sheet. It has recently been suggested that they are marine sediments, deposited in the ocean as the ice-sheets retreated towards the north.

Porth Clais

Highlights

A key site showing evidence in the St David's Head area of a pre-Devensian glaciation, of high sea-levels with raised beach deposits during the Ipswichian, and glaciation and periglacial environments during the Devensian. Atypical till deposited during the Devensian by Irish Sea ice helps to define ice limits at that time.

Introduction

Porth Clais (SM741237) provides one of the most complete exposures of Late Pleistocene sediments in Preseli and has long been regarded as a classic locality for interpreting Late Pleistocene events in south-west Wales. The sequence provides evidence for a succession of marine, periglacial and glacial depositional episodes. Considerable controversy, however, has arisen concerning the interpretation of the sequence. Some regard part of the sequence as till, a 'land-facies' of the Irish Sea ice-sheet, while others maintain that the sediments have undergone substantial periglacial disturbance and are not in place. The site attracted much interest with early studies by Prestwich (1892), Hicks (1894) and Leach (1911). It has been discussed more recently by Zeuner (1959), Mitchell (1962), Synge (1963), Bowen (1966, 1973a, 1974, 1977b, 1984) and John (1965a, 1965b, 1968a, 1969, 1970a, 1970b, 1971a, 1973). The most detailed accounts were provided by Leach (1911) and John (1970b).

Description

The site is located close to a small cave, Ogof Golchfa (SM742237), about 90m west of Porth Clais harbour, and is sometimes referred to as Ogof Golchfa (John 1970b). The sections occur on a small headland which supports several raised shore platform remnants which vary in height from *c.* 3m to 9m OD (John 1970b). The exposures crop out around the margins of a small, 45m wide, vegetated terrace that slopes seawards at about 2°. John (1970b) noted the following sequence of deposits lying above the raised platform –

5	Sandy loam (0.75m)
4	Upper head (0.6m)
3	Non-calcareous local till (*c.* 2m)
2	Lower head and beach pebbles (*c.* 2m)
1	Raised beach shingle with erratics (*c.* 1m)

The marine platform is cut across a fine-grained dolerite sill, intruded in near vertical Lower Cambrian shales and sandstones (Cox *et al.* 1930). Parts of the sill form slight ridges across the platform, and, in places, striae-bearing ice-smoothed surfaces have been preserved. Most of the striae trend north-west to south-east (John 1970b).

Both Leach (1911) and John (1970b) noted the presence of large, well-worn boulders on the rock platform, sometimes embedded within the raised beach shingle. Most of the boulders are not far-travelled although one large erratic boulder of 'diabase' (microgabbro) projects from the drift cliff

(Leach 1911). The platform bears few traces of the raised beach shingle, which is best developed above the entrance to Ogof Golchfa. The pebbles there are well rounded and comprise a mixture of local Cambrian rock types as well as Chalk flints, and igneous rocks from the St David's Head area. Leach noted that, in places, the shingle was cemented to the platform. The beach deposits grade up into a stratified head comprising a mixture of raised beach shingle set in a red-brown sandy matrix. Leach described the raised beach deposits as *c.* 3m thick, but John observed that this figure should include 2m of what he considered to be soliflucted beach material.

John (1970b) noted that the lower head was overlain by up to 2m of red-brown non-calcareous till, which, in places, lay directly on the striated shore platform. It contained a mixture of local rocks as well as farther-travelled igneous types.

Leach (1911) did not recognise an upper head overlying the till, unlike subsequent workers (for example, Mitchell 1962; Synge 1963; Bowen 1966; John 1970b). It is distinctly coloured as a result of a high concentration of purple Cambrian sandstone and shale fragments (John 1970b). To the west it is replaced by a 'rubble drift' of mixed local bedrock fragments and soliflucted till. It is succeeded by a thin veneer of sandy loam, often stoneless and silty, but also containing bands of flaky bedrock fragments and pebbles derived from the till.

Interpretation

Prestwich (1892) noted that the raised beach contained both local Cambrian rocks and more far-travelled igneous rocks and Chalk flints, but offered no explanation for the mixture. Hicks (1894) described large boulders of picrite and granite found on the cliff tops near Porth Clais and concluded that the area had been glaciated by ice from a northern source. From local evidence, such as striae and crag and tail features, he suggested that the northern ice had crossed the Porth Clais area from north-west to south-east.

The interpretation of the sequence was further elaborated by Leach (1911) who was the first to describe till at the site. He noted that the till overlay both the head and raised beach, and, in places, lay on the striated rock platform directly. He concluded that "Since this deposit rests in part on a striated surface and contains striated stones and erratic boulders, its glacial origin is clear". The Porth Clais section was thus comparable with sections in Gower, and because the raised beach at these sites always occurred beneath the glacial sediments, a 'pre-glacial' age for the bed was favoured by Leach. The large erratics associated with the rock platform were considered by him to have been deposited by floating ice both before and during accumulation of the raised beach shingle, he concluded that the shingle must have been deposited during a period of cold climate.

From the evidence at Porth Clais, Mitchell (1962) and Synge (1963) developed a Late Pleistocene chronology of events for south-west Wales, based on stratigraphical analogies with sites on both sides of the Irish Sea Basin. Erratics found in the Porth Clais raised beach were considered to have been derived from deposits, now destroyed, of Lowestoft (Anglian) age, while the beach itself was considered to have accumulated during the Hoxnian Stage. The lower head and till were ascribed to the Saalian Stage. Both authors envisaged that the Porth Clais area had not been affected directly by Weichselian (Devensian) ice. Subsequently, however, it has been more simply suggested that the Porth Clais area was glaciated by Devensian ice, and that the raised beach deposits are of Ipswichian age (Bowen 1973a, 1974, 1977b, 1984; John 1965a, 1965b, 1968a, 1970a, 1970b). Despite such broad agreement, major differences have arisen in interpreting the evidence at Porth Clais.

According to John (1970b), the raised shore platform was fashioned during temperate interglacial conditions. Its age was uncertain, although it was probably Hoxnian or older, and possibly of composite age. Erratics found in the raised beach were considered to represent an early glaciation, of probable Saalian age. John disagreed with Leach's suggestion that large erratic boulders could have been ice-rafted during formation of the raised beach, particularly in view of the widely accepted correlation between Late Pleistocene glacial stages and low stands of the sea. He accepted that the boulders were both rounded and foreign but considered, in view of the slumped face of the exposure, that they could have fallen from the till. He placed the raised beach deposits in the Ipswichian Stage, and the overlying lower head (including soliflucted elements of the raised beach) at the beginning of the Devensian Stage, believing it to mark the onset of cold, periglacial conditions. The overlying non-calcareous till was considered to have been deposited as a 'land-facies' of the north-west to south-east moving Irish Sea ice-sheet. Fabric data from the till, although equivocal, suggested that the till had not been deposited beneath a powerful ice stream but in an ice wastage environment as flow or ablation till. The till has not been dated, but radiocarbon dates from fluvioglacial sediments at Mullock Bridge, south of Porth Clais, indicated that the Porth Clais till was of probable Late Devensian age (John 1965b). It was therefore comparable to equivalent horizons at Druidston Haven, Abermawr and Poppit Sands. Further, the upper head was attributed to a short periglacial phase towards the end of the Late Devensian, and the upper sandy loam was considered to represent a mixture of aeolian and colluvial (hillwash) sediments, formed possibly during an ensuing cold-temperate, arid phase.

Bowen (1977b) suggested that glacial sediments at the site were neither *in situ* nor representative of a 'land-facies' of the Irish Sea glacier (John 1970b), and he argued that the distance of glacial transport across the St David's Head area was too small for the Irish Sea till to have lost its usual characteristics.

He suggested that the considerable coastal slopes around Porth Clais had promoted redeposition of the glacial sediments, and he contrasted the site with Druidston Haven to the south, where the glacial sediments had been extensively preserved at the base of a steep-sided coastal valley. Porth Clais had therefore been glaciated by Late Devensian ice, but local site factors had led to substantial re-sorting of the sediments.

Porth Clais demonstrates that a period of high interglacial sea-levels, probably during the Ipswichian Stage, was followed by a phase of periglacial conditions. There is evidence to suggest that this periglacial phase was succeeded by a period of fully glacial conditions. The precise dating of events at Porth Clais has not been established, although most recent workers prefer an Ipswichian age for the raised beach sediments with the periglacial and glacial sediments belonging to the Devensian Stage. A Late Devensian age has been suggested for the till at Porth Clais, but the interpretation of these sediments is debatable. The glacial deposits lack the marine shell fragments commonly found at other sites in the region where Irish Sea ice moved onshore (for instance, Traeth-y-Mwnt, Abermawr, Poppit Sands and Druidston Haven). Its interpretation as a 'land-facies' of the Irish Sea ice-sheet (John 1970b) has been seen as unsatisfactory, and the till may have been redeposited under periglacial conditions (Bowen 1977b).

Porth Clais provides a sequence that can be used to reconstruct changing environmental conditions in south-west Wales during the Late Pleistocene. It provides one of the finest examples of raised beach sediments in the region and shows marine and terrestrial beds in a single section. Although the interpretation of till at the site is controversial, it is important for establishing regional patterns of ice movement: it demonstrates that St David's Head was glaciated by Irish Sea ice during the Late Devensian, and helps to constrain the maximum limit for this ice-sheet in south-west Wales.

Conclusions

Porth Clais shows a succession of ice age deposits which represent the history of the last glacial cycle in south-west Wales. The till (boulder clay) shows that the St David's Head area was glaciated by an Irish Sea ice-sheet which moved from north-west to south-east.

Druidston Haven

Highlights

This site shows the best exposure of Devensian Irish Sea till in southern Preseli, at a position taken to be close to the southern limit of ice during the last glaciation. The till and periglacial sediments lie within a channel interpreted as evidence of an even earlier glaciation.

Introduction

Druidston Haven (Druidston) (SM862172) on the west-facing shore of St Brides Bay, contains one of the most extensive and best exposed sections through Irish Sea glacial sediments in south-west Wales. The sequence of deposits shows a succession of marine, periglacial and glacial episodes during the Late Pleistocene. Although dating of the sequence has proved difficult, some regard the site as the southernmost occurrence of Late Devensian till *in situ* in the area. The site was first investigated by Cantrill *et al.* (1916) and has featured in studies by Bowen (1966, 1973a, 1973b, 1974, 1977b, 1984), John (1965a, 1967, 1968a, 1969, 1970a, 1971a) and John and Ellis-Gruffydd (1970). Detailed accounts of the sequence and its interpretation are provided by John (1965a, 1970a).

Description

The exposures extend laterally for about 150m and comprise a sequence of –

6	Sandy loam (0.3m)
5	Upper head
4	Irish Sea fluvioglacial sands
3	Irish Sea till (*c.* 15m)
2	Lower head (up to 2m)
1	Raised beach deposits

The sediments occupy a deeply-cut rock channel, interpreted by John (1965a, 1970a) as a glacial meltwater channel.

The raised beach sediments recorded at Druidston (for example, Bowen 1973a, 1973b, 1974, 1977b, 1984; John 1968a, 1970a, 1971a) occur at the base of the section. This gravel, stained and cemented, has not been relocated in recent years. John recorded that this bed was overlain by blocky quartz sandstone head, also stained with iron oxide. These head deposits are succeeded by highly calcareous Irish Sea till containing northern erratics, numerous fragments of marine molluscs (sixteen species from both cold and warm environments recorded) and pieces of carbonised wood, including *Pinus* sp. (John 1967). The till is decalcified to a depth of *c.*1.3m at the top and in a thin layer at its base. The upper layers of till contain a high proportion of sand and gravel, and these grade upwards into interbedded outwash sands (bed 4), layers of till and, finally, solifluction deposits (bed 5) (John 1970a).

Interpretation

Dating of the sequence at Druidston has proved difficult. A Late Devensian age for the till was suggested by John (1970a) for two main reasons. First, the glacial and periglacial sediments were considered to overlie raised beach deposits of presumed Ipswichian age. Second, a series of radiocarbon dates from sites in south-west Wales was used as evidence (John 1965b, 1967, 1968c) for a Middle Würm (Devensian) interstadial in the region. He argued that the subsequent ice advance, which incorporated the organic remains, must therefore have been of Main Würm (Late Devensian) age. A date of >36,300 BP (I-1687) from a bulk sample of marine mollusc fragments from the till, however, did not help to establish its age any more precisely (John and Ellis-Gruffydd 1970). The faunal assemblage was, however, similar to that at other sites in the region (where finite dates indicating a Late Devensian age for the sediments had been obtained), but John and Ellis-Gruffydd admitted the possibility that the till at Druidston could be pre-Devensian.

Bowen (1966) originally suggested that the till was of pre-Devensian age and that it had been rearranged by solifluction onto a Hoxnian raised beach during the Devensian. John (1965a, 1970a), however, maintained that fabric analysis of the till showed that it was *in situ*, and this was agreed by Bowen (1973a, 1973b, 1974, 1977b, 1984) who regarded the site as an important stratigraphic locality for the association of Ipswichian (not Hoxnian) raised beach sediments and Late Devensian Irish Sea glacial sediments. Druidston is the southernmost limit of the raised beach overlain by till in this part of south-west Wales (Bowen 1974, 1977b). At localities to the south, for example at Milford Haven, the beach is succeeded by periglacial head deposits only. The evidence was therefore seen to place important restrictions on the maximum limit of the Late Devensian ice-sheet in south-west Wales. In contrast to Porth Clais, to the north, where site conditions had promoted redeposition of glacial sediments during the Devensian, the till at Druidston is substantially *in situ*, preserved within the steep walls of a coastal valley (Bowen 1977b).

Also using evidence from the adjacent area, John (1965a, 1970a) interpreted the following sequence of events. During high relative sea-levels in the Ipswichian Stage, raised beach sediments (bed 1) were deposited. This was followed by the accumulation of autochthonous head deposits (bed 2) during a prolonged period of periglacial climate in the Early and Middle Devensian. During the Late Devensian, Irish Sea ice moved onshore from the north-west (John 1971a) depositing shelly Irish Sea till (bed 3). The wasting phase of the ice-sheet was marked by the deposition of fluvioglacial sediment (bed 4). The upper head (bed 5) formed in a later, shorter periglacial phase, probably during Pollen Zones I-III of the Late Devensian late-glacial (John 1969).

As at Abermawr, John (1970a) argued that the sediments occurred within the walls of a glacial meltwater channel. Following his premise that the sequence at Druidston consisted of an Ipswichian raised beach overlain by a series of cold-climate Devensian sediments, he considered that the channel must therefore be pre-Devensian, and probably Saalian in age.

Although dating of the sequence has proved controversial, Druidston provides an important record of changing environmental conditions during the Late Pleistocene. In several respects, it is comparable with other stratigraphic sites in the region; it demonstrates a period of high interglacial sea-levels, probably during the Ipswichian Stage, followed by periglacial and glacial conditions in the Devensian Stage. However, whereas raised beach deposits are better developed at Poppit Sands and Porth Clais, and the glacial succession at Abermawr more firmly established within the regional Pleistocene chronology, Druidston can be regarded as a reference site for the Irish Sea till in south-west Wales, and it helps to establish former patterns of ice movement in the region. Its position, as the southernmost exposure of unequivocal undisturbed till in southern Preseli, provides a crucial reference point for the maximum limit of Late Devensian ice in this part of Wales.

Druidston provides the best exposure through Irish Sea till in southern Preseli. The sequence is important for demonstrating a succession of marine, periglacial and glacial episodes in a single section. It is particularly valuable as the southernmost occurrence of Irish Sea till *in situ* in the region, and therefore helps to establish the maximum extent of Late Devensian ice in south-west Wales.

Conclusions

Druidston Haven shows a thick sequence of last ice age deposits. The deposits which have traditionally been interpreted as glacial in origin, could also have dropped into a sea from floating or grounded ice. The extensive exposures in these deposits makes Druidston an important site for future work.

West Angle Bay

Highlights

A unique site showing glacial sediments perhaps attributable to more than one glaciation. A pre-Devensian till may underlie Ipswichian raised beach deposits, and both overlie a rock platform which is thus not attributable to the last, Ipswichian, interglacial.

Introduction

West Angle Bay (West Angle) (SM853031) is important because it shows a sequence of marine and terrestrial sediments that record major changes in environmental and geomorphological conditions in south-west Wales during the Late Pleistocene. Although dating of the beds exposed has been controversial, the site is potentially one of the most important in Wales. The interpretation of the sediments at West Angle is also relevant to the establishment of local ice limits. The site attracted early studies by Cantrill *et al.* (1916), Dixon (1921) and Leach (1933) and since by John (1965a, 1968a, 1969, 1970a, 1971a, 1974), John and Ellis-Gruffydd (1970), Mitchell (1972), Bowen (1973a, 1973b, 1973d, 1974, 1977b, 1980a, 1981a, 1984), Peake *et al.* (1973) and Shotton and Williams (1973). The palynology of the site was studied in detail by Stevenson and Moore (1982).

Description

Pleistocene sediments are well exposed for about 100m at the head of West Angle Bay. The following generalised sequence occurs above a bedrock platform –

5 Sandy loam
4 Red gravel
3 Sands, silts, loams and peat
2 Cemented raised beach deposits
1 Irish Sea till

The sequence is laterally variable, and the exposures are subject to change through erosion; this has resulted in difficulties in comparing the sequences described by different workers (Stevenson and Moore 1982). A comparable sequence to that above was also noted in an old, and now infilled, brick pit behind the main cliff line (Dixon 1921).

Interpretation

At West Angle, Dixon (1921) interpreted the sequence as till overlain by raised beach sands and gravels, and head deposits. The till contained scratched clasts, including igneous rock types, in a stiff purplish clay. He suggested that the site was unique in showing raised beach deposits overlying glacial sediments; for at other localities on the Welsh coast the relationship was reversed. This indicated an interglacial rather than pre-glacial age for the raised beach deposits. Dixon noted that the till in this section was underlain by a black clay with debris of silicified Carboniferous shells. This bed, he concluded, could be Lower Limestone Shales rotted *in situ*, but was more likely an ancient estuarine mud because it contained nests of pyrite and selenite.

Although till beneath raised beach deposits was also recorded by Leach (1933), it was not subsequently seen by John (for example, 1965a, 1968a, 1969, 1974) who recognised stained and cemented raised beach deposits (bed 2) conformably overlain by a sequence of sands, silts and clays (bed 3) containing organic debris. A sharp unconformity was noted separating these sediments from an overlying red gravelly deposit (bed 4). According to John, the red gravel was glacial in origin, being either fluvioglacial outwash or a gravelly 'land facies' of the Irish Sea ice-sheet (John 1968a, 1971a). On stratigraphic grounds, and from radiocarbon dates obtained from elsewhere in south-west Wales, he considered the till here to be Late Devensian in age; proving that the Late Devensian ice-sheet reached at least as far south as West Angle and the Milford Haven area (John 1971a).

John (1969) suggested that there had been no hiatus in deposition between the raised beach sediments and the overlying sands, silts and clays. The sediments were therefore closely related in age (John 1968a). The raised beach had been deposited close to present day high water mark, and the overlying sediments had been deposited under estuarine conditions. The site recorded a relatively comprehensive marine transgression during which the sea may have risen to 6m (20 ft) OD. The sands and silts contained abundant organic remains, including small wood fragments, leaves and marine shell fragments. A preliminary study (Field 1968) of pollen from these beds showed that the vegetation of the area probably comprised a mixed oak and alder forest with pine and hazel and salt-tolerant plants – the latter probably living close to the water's edge. John (1968a) considered that the cemented raised beach at West Angle probably dated from an early phase of an interglacial and that the overlying deposits were estuarine, representing a marine transgression towards the peak of the same interglacial. A temperate interglacial phase is clearly indicated, but the pollen data do not allow it to be correlated with the pollen sequence of any standard interglacial stage elsewhere. The raised beach sequence was, however, tentatively assigned to the Ipswichian Stage, although some pollen known to occur in Hoxnian deposits elsewhere was noted (Field 1968; John 1969; John and Ellis-Gruffydd 1970).

Bowen (for example, 1973a, 1973b, 1974, 1977b) also supported an Ipswichian age for the interglacial succession at West Angle Bay, noting, however, that the palynological evidence was equivocal.

A radiocarbon date of >35,000 BP (Birm 327) was obtained from *Alnus* wood collected by Ribbon and Bowen from the base of a peat bed at 3.6 - 3.9m OD in the interglacial succession (bed 3) (Shotton and Williams 1973). Although this age determination did not help to date the deposits any more precisely, it was important in precluding a Holocene age.

Like Dixon (1921), excavation allowed Bowen (1973a, 1973b, 1974, 1977b) to record an Irish Sea till (bed 1) at the base of the sections beneath the interglacial succession. According to Bowen, West Angle Bay provided important, if not unique, evidence for a pre-Devensian glaciation in South Wales; such a discovery was also of considerable importance because the interglacial deposits were separated from the underlying bedrock platform by till. The site demonstrated that at least one glacial period had occurred between planation of the rock platform and deposition of interglacial sediments; and therefore showed that the formation of the raised shore platform and raised beach sequence had not been contemporaneous. Bowen (1974) also suggested that the interglacial sequence (beds 2 and 3) showed clear evidence for two different stands of sea-level, probably during the Ipswichian Stage.

Bowen (1971b, 1974) reinterpreted the gravels (bed 4) at West Angle, previously described as till (John 1970a), as periglacial head deposits. Therefore, the Milford Haven and West Angle area had not been glaciated during the Late Devensian, but lay in the 'extra-glacial' zone (Bowen 1974). The red periglacial gravels were considered to have accumulated during Early and Middle Devensian times (Bowen 1977b).

An Ipswichian age for the raised beach deposits was also favoured by Mitchell (1972). The upper red gravel, however, was regarded by Mitchell as soliflucted till of Saalian age; the equivalent of the till described by Dixon (1921), but moved down into its present position by freeze-thaw processes in the Devensian Stage.

In view of the controversy and considerable interest surrounding the interglacial succession, a detailed re-investigation of the palynology of the site was undertaken by Stevenson and Moore (1982). Four pollen assemblage zones were defined (from bed 3), all dominated by temperate forest taxa, thus confirming a temperate environment during deposition. However, they were unable to correlate the sequence precisely with other British and Irish interglacial sites, although certain features of the West Angle pollen diagram, they suggested, correlated most closely with some Hoxnian pollen diagrams from eastern England. Periods of forest disturbance were noted in the profile and were considered to have been caused by local flood catastrophes. The red gravels overlying the interglacial sequence were considered to be head (periglacial).

The sequence of glacial, interglacial and periglacial sediments at West Angle Bay provides a key stratigraphic Late Pleistocene record. The nature and dating of the sediments have proved controversial and the sequence has been interpreted in a number of ways. The simplest of these interpretations recognises a sequence of Ipswichian Stage sediments overlain by Devensian glacial and periglacial sediments (for example, John 1968a). However, recent work suggests that the interglacial sediments have Hoxnian affinities (Stevenson and Moore 1982) and that they overlie an Irish Sea till (Bowen 1974, 1977b).

West Angle Bay also provides important evidence for a succession of different sea-level stands, and evidence to suggest that the shore platforms and raised beach deposits found commonly around the coast of south-west Britain are not necessarily contemporaneous: at West Angle, the raised beach is separated from a rock platform by glacial sediments.

The controversy regarding the interpretation of the sediments which overlie the interglacial sequence at West Angle has led to different interpretations of the maximum extent of the Late Devensian ice-sheet in the region. Some authors have regarded the red gravel as glacial in origin, envisaging that Late Devensian ice reached at least as far south as Milford Haven. Others, however, argued that the same deposits had a periglacial origin, placing the maximum limit of the Late Devensian ice-sheet somewhat farther to the north.

West Angle Bay displays one of the most complete Pleistocene sequences in Wales. It is important for showing what is believed to be the only known example of pre-Devensian till in Wales. Because this till rests on a presumably interglacial rock shore platform and is overlain by interglacial raised beach deposits, the evidence is important for demonstrating that the platform and raised marine sediments here and probably, therefore, elsewhere in Wales, are not contemporaneous. Although the succession shows a number of clear environmental and geomorphological changes in the region during the Late Pleistocene, dating of the sequence has proved controversial; and an Ipswichian age for the raised beach sequence is not firmly established. The disputed origin of deposits overlying the raised beach sediments, has a major bearing on reconstructing the maximum limit for Late Devensian ice in this part of south-west Wales.

Conclusions

West Angle Bay contains one of the longest sequences of ice age deposits in Wales. The lowest bed (normally only found below beach level) may be evidence for the oldest known glaciation of Wales. It is overlain by marine deposits which are thought to be 125,000 years old. The origin of the red gravel deposit overlying the marine beds is controversial.

Hoyle's Mouth and Little Hoyle Caves

Highlights

These localities show sediments which span the last 50,000 years, including the Late Devensian ice maximum and the Devensian late-glacial. These contain rich fossil mammal faunas typical of a glacial period, together with human artefacts.

Introduction

The Little Hoyle and Hoyle's Mouth Caves are important for sequences of deposits which have yielded rich faunas and artefacts dated towards the end of the Late Devensian. Environmental and geochronological evidence from recent excavations at Little Hoyle Cave show that the deposits probably span 50,000 years, although the principal mammal finds (which include bear, red fox, reindeer and collared lemming), are thought to date from the Late Devensian glacial maximum (*c.* 18,000 BP) and the Late Devensian late-glacial. Faunal evidence from nearby Hoyle's Mouth Cave has also been ascribed to the latter period on the basis of archaeological finds. Both caves have a longstanding history of research.

Hoyle's Mouth Cave

Description

Hoyle's Mouth Cave (SN112003) or 'the Hoyle' is a winding tunnel cave formed in Carboniferous Limestone. The large entrance at 21m (70 ft) OD opens northwards onto marshy land of the Ritec Valley, and must once have overlooked a long inlet of the sea. According to Garrod (1926) its various passages and chambers run for a total length of about 130 ft (39.6m). The deposits in the cave have been much disturbed, although it appears that in places up to 1m of ossiferous cave earth and breccia was originally sealed by a layer of stalagmite 0.09m thick (Leach 1931). More recently, Savory (1973) described a sequence near the cave entrance of –

4	Disturbed layer with Creswellian culture flints, early Iron Age, Roman and post-Mediaeval potsherds, recent animal bones, shells, iron-slag, charcoal and several hearths
3	Powdery yellow earth with bones of hyaena, cave bear and bison? and occasional flints
2	Sandy yellow silt
1	Sticky brown earth with stones

Continuing excavations by the National Museum of Wales (H S Green) have shown that deposits *in situ* remain at the site.

Interpretation

The first exploration of the cave was made in the 1840s by Colonel Jervis and Major Pugett, although no account is left of their discoveries (Leach 1931). However, according to the Reverend G N Smith, they dug up three Celt axes, two of flint and one of bronze. In 1860, Smith himself began to dig, although no plans nor stratigraphic details accompanied his brief reports read before the British Association at Oxford (1860), Cambridge (1862), the Cambrian Archaeological Association at Haverfordwest (1864), and the Naturalists' Association at Bristol (1866). The 1860 paper was also republished as a local pamphlet *On the Tenby Bone Caves*. Smith recorded that the Hoyle had contained a stalagmite floor overlying a stony cave earth. The stalagmite and cave earth had been much intermixed and he was therefore never satisfied that the flints and human bones that he found had originated beneath the stalagmite floor. By 1866, Smith had recovered about 200 flint flakes, and others of 'chert' together with bones of bear, sheep, pig, dog and fish, and shells (limpet, mussel, periwinkle, cockle). According to Smith the artefacts had been fashioned by Neolithic Man, who he also considered had raised the tumuli on the nearby 'Ridgeway'.

The Hoyle was explored again in 1865 by Winwood and Sanford in conjunction with Smith (Winwood 1865). This excavation revealed an undisturbed breccia in the farthest part of the cave which yielded the remains of cave bear, hyaena, fox, deer, ox, the bones of a large bird and flint. Winwood thought that recent shells and rolled pebbles within the cave indicated occupation by the sea on at least two occasions. He also excavated at the cave entrance where he found a large quantity of artefacts in association with Irish elk, ox and horse. He noted that some of the tools were not flint, but a non-local vitrified igneous rock, later designated by J F N Green as 'adinole' (Leach 1931). Human remains, probably associated with the artefacts, were also found below the level of the stalagmite floor.

The Hoyle was visited by W Boyd Dawkins in 1872, gathering materials for his book on cave hunting (Dawkins 1874). The flints he found were considered by him to be of Palaeolithic age.

Laws (1877-8) recorded mammal remains of species already described from the cave. He noted that their significance was limited, as the deposits in which they were found were mixed and disturbed. At approximately the same time, Rolleston *et al.* (1878) explored the cave, noting that there were 'no objects of special interest'. Their investigation at Hoyle's Mouth was therefore concluded at an early stage and attention diverted to nearby Little Hoyle or Longbury Bank Cave.

Around 1878, Jones began to dig at Hoyle's Mouth and an account of the deposits and a plan of the cave was published (Jones 1882). From disturbed deposits in the innermost chamber, he recorded bones of many of the species described earlier, and flint chips. Nearer to the cave entrance, and beneath unbroken stalagmite, he recovered remains of brown bear and a single flint flake, and at the cave entrance bones of reindeer, wild boar, recent animals, humans and a variety of flint and adinole artefacts. Jones was sceptical about the earlier records of hyaena, cave bear and Irish elk and suggested that the cave had been a dwelling and burial place during the Neolithic, and not the Palaeolithic as Dawkins had suggested. Laws (1888), however, suggested that the cave had probably been a hyaena den in Palaeolithic times, but that Neolithic Man had subsequently used it as a dwelling place and cemetery.

Hoyle's Mouth was next visited by Prestwich (1892) who found evidence of Neolithic flints and flakes only. In contrast, Dixon (1921) discerned the presence of Aurignacian and Magdalenian cultures of the Palaeolithic age, with flint implements representing the Aurignacian culture, and those of adinole the Magdalenian. Garrod (1926), however, while supporting a broadly Palaeolithic age for the industries, saw no basis for such a sub-division.

Leach (1913, 1918b, 1931, 1945) provided reviews of the early excavations and finds from Hoyle's Mouth. He thought that the cave had probably been a bear and hyaena den during Palaeolithic times, and inhabited periodically by Man in Neolithic, Bronze Age, Iron Age and early historic times.

With the belief expressed by Leach (1931) that few undisturbed deposits remained at the Hoyle, interest in the site subsequently dwindled. However, a threat to exploit the cave commercially led to a rescue dig by the National Museum of Wales in 1968 (Savory 1973). Savory dug trenches at the cave entrance and immediately inside the cave recording details of the stratigraphy (see site description). He noted that although the deposits were largely unstratified, there could be little doubt that most of the flints discovered by earlier workers had been derived from deposits in the cave, originally sealed by a stalagmite layer. He suggested that these artefacts represented occupation in the Late Devensian late-glacial or early Holocene, and that they were of broadly Creswellian culture. He was particularly influenced by Webley's report on the silty sand at Hoyle's Mouth which was compared to a similar deposit in Nanna's Cave, Caldey which Cornwall (*in* Lacaille and Grimes 1955) considered had been deposited during the Boreal period of the Holocene. Savory, therefore, argued that the silty sand at Hoyle's Mouth also dated from the Boreal, *c.* 8000-6000 BC, although he noted that this did not agree with the late-glacial (or earlier) fauna. He considered it possible that the cave had been occupied by Man before the end of the Devensian Stage, with occupation lasting into the Boreal and Atlantic periods of the Holocene. This suggestion was supported by some of the flint artefacts which had a markedly microlithic tendency, and whose Mesolithic character was also consistent with this later Holocene phase. In contrast, ApSimon (1976) suggested that Savory's (1973) correlations were very loosely based; placing the Creswellian industries at the Hoyle into the late-glacial rather than the early Holocene, a practice also followed by Houlder (1977).

The site has also been mentioned by George (1970) and Bowen (1974) in a regional context, and continuing excavations by the National Museum of Wales (H S Green) are expected to elaborate the sequence.

Little Hoyle Cave

Description

Little Hoyle Cave (SS112999), sometimes known as Longbury Bank Cave, is situated in a narrow Carboniferous Limestone ridge. Three entrances open on the north side of the ridge, one on the south side. The centre of the cave is connected to the surface via a large chimney. The cave lies at *c.* 20m OD, around 7m above the floors of the narrow valleys on either side. It would probably have been within the range of the Ipswichian sea-level (Green *et al.* 1986). The stratigraphic succession is complex, and it varies at different locations within the cave (Green *et al.* 1986). Green *et al.* opened trenches within the cave, adjacent to the chimney and on platforms at the northern and southern entrances. On the north platform they recorded the following sequence –

10	Soil
9	Orange-brown clay with stones
8	Upper scree
7	Buff-grey silt
6	Stony silt
5	Pink clay
4	Middle scree
3	Orange and black clay
2	Lower scree
1	Bedrock

Interpretation

The first known exploration of Little Hoyle Cave was made by Winwood in 1866 who partly excavated a kitchen midden in the north chamber (Laws 1888; Leach 1931). His discoveries included bones of *Bos,* goat, badger and dog, shells of marine molluscs, pottery fragments, flints and human bones. Many of these remains were probably of post-Pleistocene age (Green *et al.* 1986). The cave was also cursorily examined around 1870 by Smith, although no records of his discoveries were made (Laws 1888; Leach 1945). Excavations in 1877 by Power and Laws (Laws 1878), revealed breccia cemented to the cave walls and overlying deposits on the cave floor as 'brackets' or 'shelves'; beneath these cemented breccias, they discovered a variety of mostly historic and one or two pre-historic remains. According to Green *et al.* (1986) no certain Pleistocene fauna was recovered.

Between 1877 and 1878 the cave was examined by Laws and a committee comprising Rolleston, Lane Fox (better known as General Pitt Rivers), Busk, Dawkins, Evans and Hilton-Price; accounts of their findings were published by Laws (1878) and Rolleston *et al.* (1878). This phase of excavations was centred largely upon emptying the central chimney of deposits, from which were recovered the human remains of some 9-11 individuals associated with Roman and later finds, flints and other implements, bones of domestic animals and shellfish. From the northern cave, Rolleston and his team recorded some 160 fragments of bone and teeth including remains of rhinoceros or elephant, mammoth, bear, red deer, eagle and black grouse, some of which had apparently been gnawed by hyaenas. In all, some 500 fragments of human bone were recovered from Little Hoyle, but Rolleston *et al.* considered there was no evidence for Man having been contemporary with the extinct Pleistocene mammals: although there was some evidence to suggest that the northern cave had been occupied by Man, perhaps in Bronze Age times, most of the remains had entered the cave via the chimney and were of possibly relatively recent age. Rolleston *et al.* also noted that the cave had at some time probably been invaded by the sea, although Dixon (1921) considered this unlikely. From this phase of excavations is an important watercolour, now preserved in Tenby Museum, and entitled *Longbury Bank cave near Penally, explored by Prof. Rolleston and E Laws.* This painting is important in allowing a comparison of the early accounts of the cave with more recent excavations (Green *et al.* 1986).

Laws in 1888, in his book *The history of Little England beyond Wales* ... , concluded that the cave had been exhausted by earlier work, remarking that the accumulated evidence indicated that the cave had been a hyaena den during the Pleistocene, while he also considered the site to be "... the most instructive Neolithic find in Pembrokeshire". Reviews of the early excavations and finds from the Little Hoyle were provided by Leach (1913, 1918b, 1931, 1945).

More recently, three seasons of excavations (1958 - 1963) have been undertaken by McBurney (McBurney 1959). He described a sequence which included two principal scree beds, the lower and upper screes. From the upper scree he recovered a number of bones including those of reindeer, bear and fox, charcoal, and a single, large, typically Creswellian culture, pen-knife blade. The lower scree yielded one identifiable bone, that of *Lepus* cf. *timidus.* He tentatively suggested a Late Devensian late-glacial rather than Holocene age for the Creswellian artefact. More recently, Bowen (1974) used McBurney's evidence in support of a Devensian age for the scree.

Recently, Little Hoyle was selected by the National Museum of Wales as the Upper Palaeolithic representative in a programme of excavations intended to elaborate the Palaeolithic settlement of Wales. One aim of this programme was the definitive publication of McBurney's work; this and the preliminary results of the excavations at Little Hoyle carried out by Green and his colleagues during 1984 and 1986 were published by Green *et al.* (1986).

Detailed geochronological and environmental evidence presented by Green and his team has shown that the surviving deposits at Little Hoyle span some 50,000 years. A Uranium-series age determination of 47,500 +9,500 -8,500 BP on a wall stalagmite capping provides a minimum age for the underlying deposits. Bone remains including *Ursus* and *Rangifer,* in the cemented breccia beneath such capping material, would therefore appear to be Early or Middle Devensian in age, coming from the oldest deposits so far known from the cave.

Most of the cave deposits were formed fluvially or as thermoclastic scree, and appear to date from the Late Devensian. Uranium-series and radiocarbon dates from bones in a red sandy silt in the north cave, are closely grouped at around 18,000 BP. This shows that the included fauna of brown bear *Ursus arctos,* reindeer *Rangifer tarandus,* fox *Vulpes vulpes,* arctic lemming *Dicrostonyx torquatus,* water vole *Arvicola terrestris,* tundra vole *Microtus gregalis,* hare *Lepus* sp. and some large birds dates, at least in part, from the Late Devensian glacial maximum. Currant *(in* Green *et al.* 1986) suggested that elements of a Pleistocene fauna including large mammalian herbivores such as woolly rhinoceros and mammoth, recovered by earlier workers, also probably dates from this phase, as such species did not survive in Britain after the retreat of the Late Devensian ice-sheet.

The succeeding deposit contains a fauna including reindeer, arctic lemming, Norway lemming *Lemmus lemmus,* water vole, northern vole *Microtus oeconomus,* shrew *Sorex* sp., and is dominated by bones identified by C Harrison (BMNH) as those of barnacle goose *Branta leucopsis* (Bechstein). It seems likely that this fauna dates from the Late Devensian late-glacial (Green *et al.* 1986).

The 'platform sequence' recorded by Green *et al.*, although not yet dated, would also appear to be Late Devensian late-glacial (*c.* 13,000-10,000 BP) in age. Preliminary pollen evidence shows a period of fluctuating climate with three successively more severe cold phases, separated by successively less mild phases. Green *et al.* noted that the exact chronological position of the Upper Palaeolithic settlement of the Little Hoyle could not yet be finally resolved, but they suggested that the upper scree of the platform sequence (bed 8), with its included Creswellian artefact (McBurney 1959), might date from Late Devensian late-glacial Pollen Zone III.

Further work at Little Hoyle by Green *et al.* is expected to provide dating of the platform sequences, which would seem to offer the best possibility for correlation with the sequence inside the cave. Bones from the site have also been used in a comparative dating study using amino acid, radiocarbon and Uranium-series techniques (Rae *et al.* 1987).

Hoyle's Mouth and the Little Hoyle Caves provide some of the most detailed evidence currently available from the Upper Palaeolithic period in Wales. Recent excavations show that the deposits at Little Hoyle cover about 50,000 years. Faunal remains dated to *c.* 18,000 BP show that the area attracted both a varied large and small mammal fauna during the Late Devensian. This dated evidence is particularly important for it lends support to the views of Oakley (1968), Bowen (1970b) and Molleson and Burleigh (1978) that parts of South Wales may have been inhabited by Man even at the peak of the Late Devensian glaciation, and also suggests that the area was free from glacier ice at this time. Much of the sequence and its included fauna at Little Hoyle, however, would appear to date from the Late Devensian late-glacial, and it is believed that the upper scree from the platform sequence, together with McBurney's Creswellian artefact, may date from as late as Pollen Zone III of the late-glacial. The vertebrate fauna from that period is dominated by the bones of the barnacle goose, which appears to have been present at the site as a breeding population. This is the first such record from Pleistocene Britain. Faunal evidence from Hoyle's Mouth has also been dated, archaeologically, to approximately the same time.

These caves provide contrasting records to the more extensive sequences at Minchin and Bacon Hole Caves, Gower, and, together with Cat Hole Cave, provide a detailed record of environmental changes towards the end of the Devensian.

The Hoyles Caves provide an important record of environmental conditions in the Devensian Stage. Little Hoyle, in particular, is important for showing detailed faunal, archaeological, pollen and other palaeoenvironmental evidence that can be related to a radiometrically dated timescale. This evidence establishes that the principal faunal remains and artefacts date from both the late-glacial and the earlier glacial maximum of the Late Devensian. The evidence also supports the belief that parts of South Wales were inhabited by Man at the peak of the Late Devensian glaciation.

Conclusions

The caves of Little Hoyle and Hoyle's Mouth, contain an important sequence of deposits representing the last ice age. In particular, they contain fossils of the ice age fauna, together with archaeological remains showing that Man was active in the area at that time. Dating techniques have shown that the deposits represent some 50,000 years, and the principal fossil and archaeological remains date from the maximum of the last ice age, about 18,000 years ago, and from the period between about 14,000 years and 10,000 years.

Marros Sands

Highlights

This site shows deposits spanning the Ipswichian-Holocene interval, and including Ipswichian raised shoreline deposits, Devensian periglacial sediments which indicate that the area lay south of the Devensian ice limit, and Holocene submerged forest.

Introduction

Marros Sands (Marros) (SS210073) is important for its Late Pleistocene sequence of raised beach and head deposits which represents a succession from interglacial marine to periglacial conditions. Palaeobotanical and stratigraphical evidence indicates that the marine sequence was probably formed during the Ipswichian Stage, and the site records possible evidence for a number of high sea-level stands during this time. Head deposits at the site probably accumulated during the subsequent Devensian Stage when it lay in the periglacial zone. The geomorphological interest of the site is enhanced by extensively developed submerged forest and associated beds which occur along Marros Sands (Leach 1918a). The site was first described by Strahan *et al.* (1909) and was also mentioned by Leach (1910). More recently it has been described by John (1968a, 1971a, 1973), Bowen (1970a, 1973a, 1973b, 1974, 1977b) and Peake *et al.* (1973).

Description

The Pleistocene sequence is well exposed in coastal cliffs between Marros (SS201071) and Ragwen Point (SS219072). Cemented and stratified head deposits are also well exposed near Gilman Point (SS227075). Holocene submerged forest and associated beds occur along much of the shore at Marros Sands, and they are particularly well developed between SS200074 and SS214072.

The sequence is laterally variable, but along much of the coastal cliff comprises –

4	Hillwash sediments
3	Head
2	Raised beach shingle and sand (often mixed with head)
1	Rock shore platform

At Ragwen Point the sequence is (Bowen 1970a) –

8	Hillwash sediments
7	Head
6	Colluvial silts
5	Cemented sand
4	Raised beach sediments
3	Cemented sand
2	Raised beach sediments
1	Rock shore platform

Beds 2 to 6 and the lower part of bed 7, at Ragwen Point, are partly cemented by iron and manganese oxides (John 1971a). The head, of angular shale and quartzite blocks, reaches about 12m maximum thickness. It was sub-divided into at least four facies by John, but only two by Bowen (1974) – a lower blue shale head and an overlying brown sandstone head. Cryoturbation structures occur in the head deposits (John 1973), and well developed fossil ice-wedge casts penetrate the brown head (Bowen 1974). Polygonal fossil ice-cracks are also exposed in periglacial deposits near Marros Mill (Bowen 1974).

Interpretation

The raised beach deposit at Ragwen Point was first described by A Strahan (*in* Strahan *et al.* 1909) as a concreted sand with small pebbles, just above HWM, and beneath a small cliff of 'boulder clay'. No shells were observed in the raised beach deposit, which was correlated with the raised beaches in Gower, of believed 'pre-glacial' or 'inter-glacial' age (Tiddeman *in* Strahan 1907a). Leach noted the drift deposits in the coastal cliffs at Marros, and described a sequence of glacial drift and local talus deposits farther west along the coast, near Amroth.

Subsequently, in 1965, Bowen discovered the raised beach at Marros Sands (Bowen 1966) and gave an account of the sediments and stratigraphy in the coastal cliffs between Marros and Gilman Point (Bowen 1970a).

At Marros, the raised beach is succeeded by a sandy, silty mud which lies below the head deposits (Bowen 1970a). This bed yielded various seeds and fruits, moss stems and beetle fragments, together with pollen (Mitchell *et al. in* Bowen 1970a). The palaeobotanical data indicated that trees and bushes were rare at the time of deposition, but that there was a rich herbaceous flora with a strong calcicole element. Bowen (1970a) considered that this environment was probably very similar to the Allerød phase of the Devensian late-glacial, with open countryside, young soils and rich meadows. From the stratigraphic and palaeobotanical evidence, he interpreted the following sequence of Late Pleistocene events at Marros. During high interglacial sea-levels, in the Ipswichian Stage, raised beach sediments were deposited. The fossiliferous, sandy silty mud probably accumulated in a dune slack during temperate conditions towards the end of this interglacial phase, and it marks a transition between fully interglacial and periglacial conditions. The upper beds of raised beach shingle and sand at Ragwen Point (beds 4 and 5) may represent a further high sea-level stand during an Ipswichian Stage interglacial, and this Bowen tentatively correlated with the *Neritoides* sand at the key interglacial site of Minchin Hole, Gower (Bowen 1970a). He otherwise considered all deposits overlying the raised beach and dune slack sediments at Marros to be unquestionable periglacial slope deposits derived from the interglacial cliff line behind the sections; concluding that the absence of even a single erratic proved the non-glacial origin of the sediments. He argued that the head deposits had accumulated during the Devensian Stage when Marros lay in the periglacial zone, an interpretation followed by John (1971a, 1973). John also suggested that huge quartzite blocks weighing several tons, in the head, showed a high degree of instability on the coastal cliffs during these periglacial conditions. Occasional catastrophic collapses of huge blocks had interrupted the otherwise slower, but dominant, process of solifluction. The evidence was used by Bowen (1970a) to demonstrate that the area was south of the Late Devensian (Welsh) ice-sheet which did not reach this part of south Dyfed and the Carmarthen Bay area. The head deposits contained no trace of erratic material, but Bowen (1977b) noted that the plateaux adjacent to the coastline bore unmistakable boulder trains and outliers of till and fluvioglacial sediments: these deposits, he suggested, demonstrated a pre-Devensian glaciation of the area by an Irish Sea ice-sheet moving NNW to SSE. Similar interpretations of the sequence were followed by Bowen (1973a, 1973b, 1974) and Peake *et al.* (1973).

A fine example of a cemented and stratified scree occurs at Gilman Point. Bowen (1977b) noted that a considerable thickness of limestone head mantles the former cliff here. The deposit consists of colluvium with boulders. This is overlain by a blocky, calcite-cemented head that fines upwards into scree beds which dip off the limestone outcrop. Cementation of similar screes elsewhere in Britain is thought to have occurred during discontinuous permafrost conditions in the Late Devensian (Prentice and Morris 1959).

The geomorphological interest at Marros is enhanced by well developed submerged forest and peat beds which crop out along the modern beach. Leach (1918a) noted that the beds extended from near HWM to the lowest levels of the shore uncovered by Spring tides, and stretched almost continuously for a mile along Marros Sands. Leach described a sequence of –

4 Peat and submerged forest
3 Peaty soil with roots and leaves of aquatic plants
2 Blue 'slime'
1 Unstratified rubble (head)

Leach noted that the peat and submerged forest bed contained abundant leaves, twigs, branches and trunks of trees; stems, leaves and roots of marsh plants; mosses; hazel nuts, oak cupules, alder catkins; seeds and seed capsules of small plants and a large quantity of other disintegrated plant tissues. A Holocene age for the beds was suggested by Leach (1918a).

The sequence of deposits at Marros provides an important record of Late Pleistocene and Holocene environmental conditions and changes. The site demonstrates evidence for periods of high sea-level, probably during the Ipswichian, when raised beach sediments accumulated. Several facies of raised beach shingle separated by cemented sand are present at Ragwen Point, and the sequence may therefore provide rare evidence for marked climatic and sea-level fluctuations during this stage. These horizons have been correlated tentatively with raised beach deposits at Minchin Hole Cave, Gower (Bowen 1970a). The period of raised beach sedimentation came to an end with deteriorating climatic conditions, revealed by palaeobotanical evidence. Thick head deposits and colluvial

sediments accumulated at Marros, probably during the Devensian Stage, and the site therefore sets a limit for the maximum extent of Late Devensian ice of Welsh provenance in the west Carmarthen Bay area. Marros is also notable for the fine development of infilled crack and polygonal structures that occur in the head deposits. These have not been dated, although similar cracks were noted in Late Devensian glacial sediments in west Gower: these features were considered to be either frost or desiccation cracks of Late Devensian late-glacial age (Campbell 1984). The submerged forest beds at Marros extend the stratigraphic record into the Holocene. These deposits have not been studied in detail and the site therefore has potential for Holocene sea-level studies.
Marros provides a rock record containing marine and terrestrial evidence. It demonstrates rare evidence for fluctuating sea-levels, probably in the Ipswichian Stage. Pollen evidence records the transition from these temperate interglacial conditions to periglacial conditions in the Devensian Stage, when substantial colluvial and head deposits accumulated. The association of marine deposits overlain by periglacial sediments establishes that Marros lay in the extra-glacial zone during the Late Devensian.

Conclusions

Marros Sands shows extensive exposures of marine and periglacial (cold climate) deposits. This is an important site, because it shows that ice-sheets did not cross this area after 125,000 years ago. It, therefore, provides important evidence for the reconstruction of the last Welsh ice-sheet; and proves that although it covered most of Wales and crossed west Gower, it did not cover this area.