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Quaternary of Wales

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Quaternary stratigraphy: Gower

3

Introduction

Over many years, Gower has assumed considerable importance in Quaternary investigations, and stratigraphic sequences around the south and west coasts have yielded important evidence for the marine and terrestrial Pleistocene records.

Early interest in the cave sequences and their mammalian remains was followed by attempts to sub-divide the local rock sequences to provide a chronology of Pleistocene events for the area. The precepts established from lithostratigraphic sequences around Gower have been applied elsewhere for regional stratigraphic correlations. Studies of the coastal and cave sequences and their calibration and correlation by dating methods, have further shown the importance of Gower as a reference area.

The caves

The large number of caves on Gower and their fossil remains first attracted attention. Discoveries of fossil mammals during the 1830s led to major excavations by Colonel E R Wood in many of the caves. These excavations were documented by Benson (1852), Falconer (1860, 1868), Vivian (1887) and Roberts (1887-8), and they were important in establishing Gower for Pleistocene investigations. Indeed, evidence from the caves shaped scientific thought when fierce debates obtained between the 'glacialist' and 'diluvialist' schools. In particular, Gower caves such as Paviland and Long Hole provided evidence to demonstrate the association between extinct Pleistocene mammals and the development of Man (Lyell 1873). The Gower caves figure prominently in modern studies, and their continuing importance is reflected in the GCR site coverage.

Early sub-division of Pleistocene sequences

Gower was used in one of the earliest Pleistocene classifications in Britain. This attempted to establish the relationship between the well developed raised beach deposits and local glacial and cave sediments. Prestwich (1892) suggested that the raised beach deposits were younger than the local glacial drift, and that the caves had been filled with mammalian remains since deposition of the local till. These conclusions were reversed by the Geological Survey: Tiddeman (1900) and Strahan (1907a, 1907b) suggested that the raised beach deposits were pre-glacial or interglacial in age, and were probably penecontemporaneous with bone beds found in some of the caves, such as Minchin Hole. The raised beach and associated bone beds were thus considered to pre-date the glaciation of the area.

The South Wales end-moraine

Charlesworth (1929) ushered in an important phase of investigations and reconstructed a limit for the 'Newer Drift' glaciation in South Wales. He believed that this most recent ice-sheet had impinged only on the easternmost fringe of Gower and was of Magdalenian age (Creswellian-Cheddarian). He considered that the raised beaches pre-dated both the 'Older' and 'Newer Drift' glaciations in the area.

T N George (1932, 1933a, 1933b) set new standards in the investigation of Pleistocene stratigraphy in South Wales in his work on the raised beaches, head and glacial deposits of Gower (Bowen 1984). George (1932, 1933a) synthesised the evidence of earlier workers (for example, Tiddeman 1900; Strahan 1907a, 1907b; Charlesworth 1929) and showed that Gower had been covered by two ice masses of different origin. One had a northerly source and deposited largely local, Welsh rock types; the other had a source to the west and brought erratics from the Irish Sea Basin. George upheld Charlesworth's 'Newer Drift' ice limit in the area and concluded that south of that limit, and covering much of Gower, there were 'Older Drift' glacial deposits of mixed Irish Sea and Welsh provenance; the former deposits being more widespread on the south and, particularly, the western margins of the peninsula. The mixing of the lithologies was used as evidence by George for the contemporaneity of the Irish Sea and Welsh ice masses during the 'Older Drift' glaciation.

George integrated evidence from the coastal sections into a sequence of events; in this sequence, the raised beaches form key marker beds – Table 2. This chronology represents the first sub-division of Pleistocene deposits in Wales, subsequent to the tripartite schemes of earlier workers.

Table 2 Gower chronology (T N George 1932)

9	Modern beach platform – coincident with Heatherslade Beach
8	Submerged forest (Late Neolithic)
7	Heatherslade Beach and platform (Early Neolithic)
6	Newer Drift glaciation – deposits present only along the eastern fringe of Gower, to the north of Mumbles Head (Magdalenian)
5	Cave deposits of Paviland and blown sand

(Aurignacian – possibly latest Mousterian to Early Solutrean)

4 Older Drift glaciation and associated head deposits (Mousterian)

3 Blown sands and the *Neritoides* Beach, containing *Neritoides obtusata* (L.) and ossiferous breccia of Minchin Hole (Late Acheulian to Early Mousterian)

2 *Patella* Beach, containing *Patella vulgata* (L.) formed during a cold period – an interpretation based on erratics in the *Patella* Beach which George considered had been ice-rafted

1 Intense cliff erosion

Griffiths (1937, 1939, 1940) used heavy mineral analysis to ascertain the origins of the ice-sheets and the provenances of the drifts. He defined the limits and directions of movement of the Irish Sea and Welsh ice masses over the region; and suggested that the deposits in Gower showed two significant variations. The deposits in west Gower contained a high chlorite constituent, suggesting that southward moving ice from the Tywi Valley, with a dominant Lower Palaeozoic mineral assemblage, had invaded the area. The deposits on the west side of Langland Bay in east Gower contained a basal heavy mineral suite of Irish Sea provenance ('Older Drift') and an upper suite of heavy minerals from the South Wales Coalfield ('Newer Drift'), both younger than the raised beach.

Correlations

Gower has been incorporated into stratigraphic correlations over wider areas. Zeuner (1945, 1959), for example, argued that the last glaciation consisted of two discrete advances ('Older Drift' and 'Newer Drift') because he assumed the *Patella* Beach was of Monastirian (last interglacial) [Ipswichian Stage] age (Bowen 1984). Wirtz (1953) and Mitchell (1960), however, argued that the *Patella* Beach was older and of Hoxnian age, and was overlain by 'Older Drift' glacial deposits and 'Newer Drift' (Devensian Stage) periglacial sediments, except in east Gower. Subsequently, Mitchell (1972) modified this scheme and suggested that two interglacial beaches occurred in Gower: an erratic-free deposit of Hoxnian age, and an erratic-rich deposit of Ipswichian age. Furthermore he suggested that two head deposits occurred, one erratic-free (Wolstonian) and one erratic-rich (Devensian). This interpretation implied that the Ipswichian Stage was lost in a notional unconformity within some head sequences (Bowen 1973a, 1973b).

Lithostratigraphy

Although George (1932, 1933a) described a lithostratigraphy, Gower has become increasingly important as the result of work by Bowen (1965, 1966, 1970a, 1970b, 1973a, 1973b, 1973c, 1974, 1977a, 1977b, 1977c) who reinterpreted the origins and relationships of stratigraphic units. This work led to a revision of the chronology proposed by earlier workers. The lithostratigraphy of Gower was subsequently correlated with that of the Irish Sea Basin (Bowen 1973a, 1973b).

Central to Bowen's chronostratigraphical model was the assumption that the raised beaches of Gower were Ipswichian in age. This view was based largely on the association of raised marine (interglacial) sediments and faunal remains of apparently Ipswichian age in Minchin Hole Cave (for example, Bowen 1973c; Sutcliffe and Bowen 1973). This led to the use of the raised beach as a stratigraphic marker in the coastal sequences. It followed from this precept that deposits overlying the raised beach in Gower were Devensian in age. Bowen (1970a, 1971a, 1974) demonstrated that only in south-east Gower do unequivocal glacial beds overlie the Ipswichian (*Patella*) raised beach. Elsewhere along the south Gower coast, sediments overlying the raised beach consist of a series of aeolian, colluvial, head of different lithofacies and redeposited glacial sediments. The redeposited glacial sediments were originally deposited during a pre-Devensian ('Older Drift') glaciation and were subsequently redeposited by solifluction and alluviation during the Devensian. The 'Older Drift' glaciation thus antedated the deposition of the interglacial raised beach, for which its deposits provided erratics for incorporation into the beaches, but its precise age was indeterminate (Bowen 1970a, 1984).

Using the proposed Ipswichian raised beach as a marker, Bowen (for example, 1970a, 1971a) distinguished between glaciated and unglaciated areas in Gower. This approach has also been important in ascertaining the age of glacial sediments elsewhere around the coast of South and west Wales, and thereby in delimiting the extent of Late Devensian ice, particularly in respect of the lack of clear terminal features associated with the ice-sheet in many places (Bowen 1973a, 1973b, 1974). This approach is independent of both morphological indicators for estimating the age of the glacial deposits, such as 'freshness of form' and 'degree of dissection', and the now redundant radiocarbon timescale proposed for south-west Wales (for example, John 1970a).

Geochronology

Research during the last decade can be considered under three categories. First, the raised beaches have been dated. Much of this work has been based on the internationally important cave sites at Minchin Hole and Bacon Hole, and is centred on amino acid geochronology and Uranium-series dating (for example, Andrews *et al.* 1979; Bowen 1981a; Campbell *et al.* 1982; Davies 1983; Bowen 1984; Bowen *et al.* 1984; Bowen *et al.* 1985; Stringer *et al.* 1986; Bowen and Sykes 1988).

Second, advances have been made in detailed studies of the Gower cave sequences with new stratigraphic, mammalian, and archaeological evidence (for example, Stringer 1975, 1977a, 1977b; Campbell 1977; Sutcliffe 1981; Currant *et al.*

1984; Henry 1984a; Sutcliffe and Currant 1984; Stringer *et al.* 1986).

Third, detailed sedimentological and quantitative methods have amplified lithostratigraphic description of the coastal sequences (for example, Case 1983; Campbell 1984; Henry 1984a).

These investigations collectively have led to new discoveries on the nature and timing of Late Pleistocene events in Gower. Andrews *et al.* (1979) concluded, from (isoleucine-alloisoleucine) amino acid ratios measured from fossil protein in molluscs from the raised beaches, that two or possibly three separate sea-level events are represented by raised beaches in south-west Britain. The separate identity of two high sea-level events shown by the Outer (*Patella*) and Inner Beaches at Minchin Hole Cave was discussed by Sutcliffe and Bowen (1973) and was confirmed by amino acid ratios (Bowen *et al.* 1985), and ascribed to deep-sea Oxygen Isotope Stage 7 (Inner Beach) and Sub-stage 5e (Outer Beach) (Bowen and Sykes 1988).

Campbell *et al.* (1982) presented amino acid ratios from the raised beach at Broughton Bay, west Gower, showing a correlation with beach remnants regarded as Ipswichian (Sub-stage 5e) age in south-west Britain (Andrews *et al.* 1979). Davies (1983) identified two principal groups of amino acid ratios from raised beaches in southern Britain which she ascribed to Stage 7 and Sub-stage 5e of the deep-sea oxygen isotope scale. These data showed that although most of the raised beach remnants around the south and west coasts of Gower were ascribed to Sub-stage 5e, other older elements were present, for example, the Inner Beach at Minchin Hole and uncemented beach deposits at Horton. These older beach remnants were ascribed to Oxygen Isotope Stage 7 of the marine record (Davies 1983), one of the possible correlations discussed by Bowen (1973c).

Amino acid measurements published before 1985 (and including Davies 1983) were based on samples prepared by a method no longer used because it gave isoleucine-alloisoleucine ratios that were too low, and also because it involved an uncertain, but potentially unacceptable high level of variability (Miller 1985). Since 1983, a modified sample preparation has been used. Although it may appear reasonable to regard the earlier data as internally consistent, and potentially convertible, subsequent analyses which are sufficiently numerous for statistical evaluation, show that the earlier preparation methods (there were several variations on the basic procedure) show large variability, and, moreover, were not sufficiently sensitive to detect additional sea-level events.

Four separate marine/raised beach events have now been detected in Gower (Bowen *et al.* 1985; Bowen and Sykes 1988). The two main ones have been tied to a lithostratigraphy, and used as a basis for the erection of chronostratigraphic stages – the Minchin Hole D/L * Stage, and the Pennard D/L Stage. These have been defined in rock sequences which have characteristic D/L ratios. Two other sea-level events were recognised – one from D/L values from discrete outcrops of raised beach, although, unlike Minchin Hole, not in a stratigraphic sequence. These beach fragments are now believed to be a sub-stage of the Minchin Hole Stage (Bowen and Sykes 1988). The presence of the earliest event is founded on the identification of a mixed molluscan population in raised beach deposits at Hunts Bay, but correlated with deposits elsewhere (Bowen *et al.* 1985). Using a separate geochronologically calibrated amino acid framework for North-West Europe, these stages have been correlated with the oxygen isotope record as follows (Bowen and Sykes 1988; Bowen 1989b) –

Oxygen Isotope Stage	Chronostratigraphic Stage	**
Sub-stage 5e	Pennard Stage	0.1
Stage 7	Minchin Hole Stage	(0.14 (0.17
Stage 9	Unnamed	0.22

*Ratios of D-alloisoleucine to L-isoleucine

**Mean amino acid ratios for *Littorina* sp. and other chemically comparable species.

Conclusions

Some problems remain. The long held belief that the raised beaches around Gower are of Ipswichian age and overlain by Devensian Stage glacial and periglacial sediments, offered an economical model for interpreting the coastal sequences. Amino acid data show that raised beaches of different ages exist, some antedating the Ipswichian Stage. Potentially, this complicates interpreting the age of the overlying sediments (Bowen *et al.* 1985). The age of the pre-Devensian glaciations of the region is only fixed within broad limits – see Chapter 2. Glacial deposits belonging to three distinct glaciations are probably present on the peninsula (Bowen *et al.* 1985). In the absence of terminal features associated with the Late Devensian ice-sheet, the maximum extent of ice was delimited by Bowen (1970a) mostly using lithostratigraphical evidence from the coastal exposures – see Figure 2. A revised and extended ice limit was proposed by Bowen (1984) (Figure 2) for south-west Gower. However, the results of recent drilling and geophysical work show that glacial sediments in this area are older. An earlier glaciation of Irish Sea origin is inferred from erratics and heavy minerals, but a later one of Welsh provenance is represented by deposits dominated by Namurian 'quartzite', and which appear to terminate at the Paviland Moraine (Bowen *et al.* 1985; Bowen, Jenkins and Catt, unpublished – see Figure 2). Remains of glacial sediments from both Welsh and Irish Sea sources are found in the coastal exposures but have been

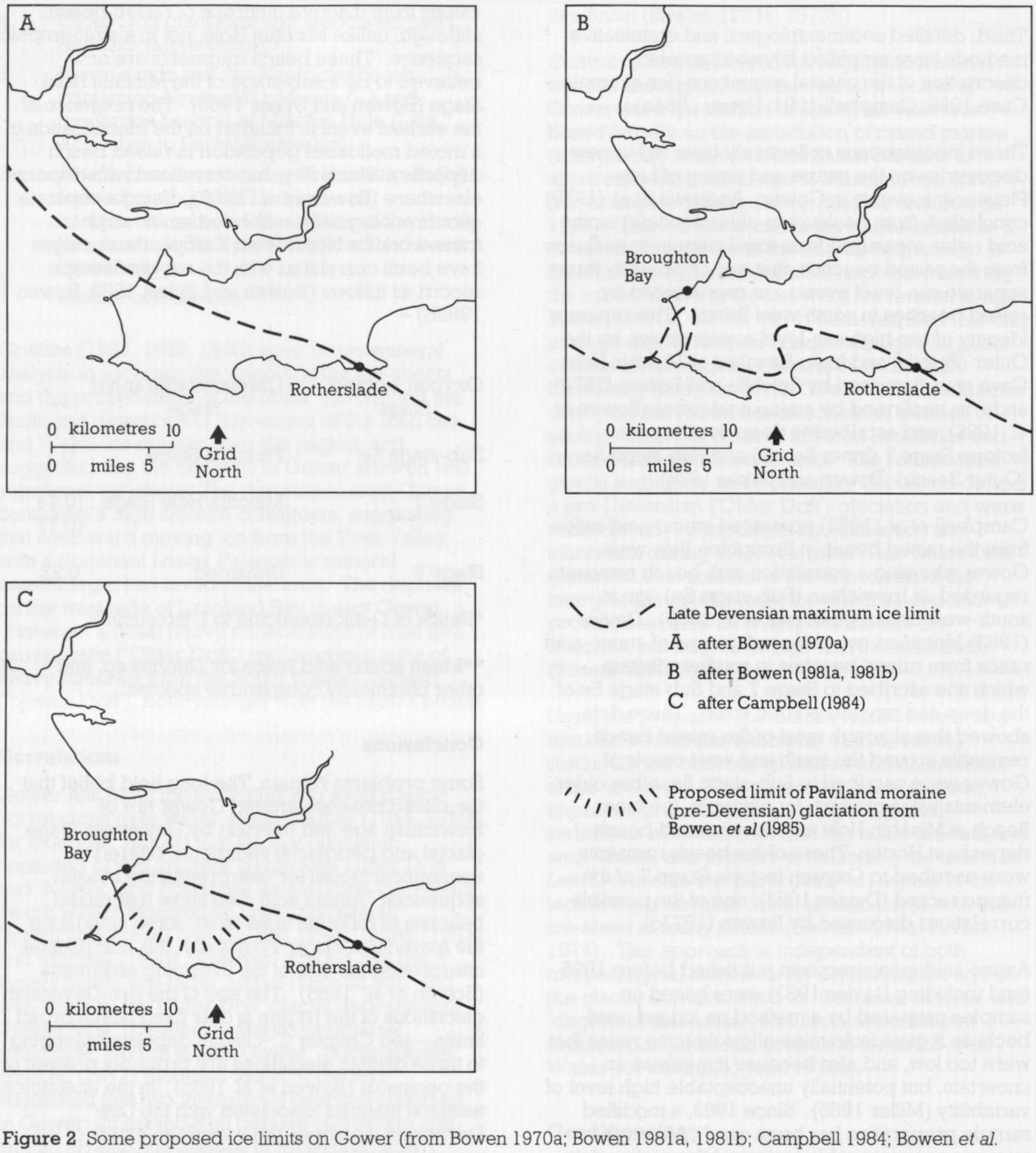

Figure 2 Some proposed ice limits on Gower (from Bowen 1970a; Bowen 1981a, 1981b; Campbell 1984; Bowen *et al.* 1985)

redeposited. Bowen *et al.* (1985) ascribed the earlier Irish Sea glaciation to Oxygen Isotope Stage 10 or earlier, and the Welsh, Paviland Moraine glaciation to Oxygen Isotope Stage 8 or earlier – see Chapter 2.

Finally, although a Late Devensian age for the last glaciation of Gower is evident, its precise timing is as indeterminate as elsewhere in Britain. The recently exposed Pleistocene sediments at Broughton Bay in north-west Gower may be of considerable importance in this context: the site shows Late Devensian shelly glacial deposits overlying an Ipswichian fossiliferous raised beach (Campbell *et al.* 1982; Campbell 1984). A combination of amino acid and radiocarbon dated evidence from the site was recently presented, and was thought to show a Late Devensian age of *c.* 17,000 BP for the emplacement of the glacial sediments (Bowen *et al.* 1985; Bowen *et al.* 1986; Bowen and Sykes 1988).

The selected GCR sites in Gower reflect many of the themes discussed, and in particular, illustrate many of the latest developments in research on the Pleistocene, its sub-division and dating.

Rotherslade (Langland Bay)

Highlights

This locality is a rare site proving the position of the maximum extent of the ice front during the last, Devensian, glaciation. Although the rest of south Gower was unaffected by Welsh ice, lying in the periglacial zone, this area was overrun.

Introduction

The exposures at Rotherslade demonstrate Devensian glaciation in Gower post-dating the raised beach ascribed to Oxygen Isotope Sub-stage 5e. The site provides contrasting evidence to nearby sites at Hunts Bay, Slade and Horton, which demonstrate ice-free conditions throughout the Devensian. The site has a long-standing history of research commencing with the work of Strahan (1907a). It was later studied by George (1932, 1933a, 1933b), Griffiths (1939), Bowen (1966, 1969a, 1970a, 1971a, 1973a, 1973b, 1974, 1977a, 1977b, 1984), Campbell (1984) and Bowen *et al.* (1985). The site has also been mentioned in studies by Stephens and Shakesby (1982), Davies (1983), Shakesby and Campbell (1985) and Bridges (1985).

Description

The following generalised sequence occurs at Rotherslade (SS613872) –

5	Modern soil}	(1.0m)
4	Colluvium }	
3	Glacial deposits (14.0m)	
2	Limestone head with red silty sand matrix (3.5m)	
1	Raised beach deposits (0.6m)	

Maximum bed thicknesses after Bowen (1971a)

The raised beach deposits lie on a Carboniferous Limestone shore platform at 10m OD, which is dissected by relict potholes and gullies (Bowen 1971a, 1984). In places, the beach sediments adhere to the walls of these gullies and form a tough cemented conglomerate of limestone pebbles, although erratics from the South Wales Coalfield and Irish Sea Basin are also present (George 1932). The raised beach contains numerous marine shells and shell fragments. The thickest sediments are glacial deposits which are often crudely stratified, well imbricated, and contain an erratic suite typical of Breconshire drift (Bowen 1970a).

Interpretation

The sections at Rotherslade were first described and interpreted by Strahan (1907a). The relationship between the raised beach deposits and the overlying glacial beds was used as critical evidence by Strahan to suggest a 'pre-glacial' or possibly 'interglacial' age for the raised beach sediments at the site and elsewhere around the Gower coast.

George (1932, 1933a, 1933b), who also suggested a 'pre-glacial' age for the *Patella* raised beach, considered that a sand, interpreted by Strahan (1907a) as aeolian, was a fluvioglacial deposit, overlain by a sequence of interdigitating limestone head and glacial sediments representing glacial deposition at an oscillating ice margin. It was unclear if the glacial sediments belonged to the 'Older' or 'Newer Drift' glaciations (George 1933a, 1933b), but he subsequently favoured that this part of east Gower had been overrun by the 'Newer Drift' ice-sheet (George 1970).

Griffiths (1939) identified the heavy minerals from the deposits on the west side of Langland Bay as part of his analysis of South Wales drifts. He considered that the drift at Langland consisted of basal layers rich in Irish Sea minerals as well as containing a few Irish Sea erratics. Higher, only a few 'foreign minerals' occurred while the uppermost layers and overlying gravels contained only 'local' (South Wales Coalfield) erratics and minerals. He concluded that the lower part was ground moraine deposited by combined Irish Sea and local Welsh ice of 'Older Drift' age. The overlying drift showed that some of the underlying material had been incorporated by the succeeding advance of 'Newer Drift' Welsh ice (the Tawe glacier). The coarse upper gravel represented the 'outwash fan' of the retreating 'Newer Drift' Tawe glacier (Griffiths 1939). He therefore believed that "..... at this exposure a complete sequence of deposits representative of both glaciations can be traced in the correct chronological and spatial order"; namely that both post-dated the raised beach.

The exposures at Rotherslade were also studied in a series of papers by Bowen (1966, 1969a, 1970a, 1971a, 1973a, 1973b, 1974, 1977a, 1977b, 1984). He originally suggested that the raised beach at Rotherslade could be Hoxnian, with the overlying deposits consisting of periglacial and redeposited glacial sediments (Bowen 1966). Subsequently, he revised this interpretation, and ascribed the raised beach sediments to the Ipswichian Stage and the overlying deposits, which consisted of head and glacial deposits *in situ*, to the Devensian Stage.

From the evidence at Rotherslade, Bowen (1969a, 1970a, 1984) reconstructed the following sequence of events. During temperate, high sea-level conditions, raised beach sediments accumulated on a limestone shore platform. Erratics from the South Wales Coalfield and the Irish Sea Basin present in the raised beach deposits were considered to have been reworked from glacial sediments of pre-Ipswichian age. As environmental conditions worsened with the onset of the Devensian Stage, locally derived limestone head began to accumulate on the raised beach, and was mixed with colluvial sediments washed from a sparsely vegetated landscape. At the same time, sea-level began to fall and sand from the exposed shore was incorporated into the head deposits (Bowen 1969a, 1971a, 1977a, 1977b, 1984). These head deposits were thought by Bowen (1971a) to have accumulated during the Early and Middle Devensian, under cold but not necessarily continuous periglacial conditions. During the Late Devensian glacial maximum (*c.* 20,000-18,000 BP), Welsh ice crossed the eastern tip of Gower, depositing a sequence of glacial sediments up to 14m thick; lodgement till at the base overlain by crudely stratified and imbricated ablation till (Bowen 1970a) and fluvioglacial sands and gravels (Bowen 1971a). Lenses of till occur in the gravels, the entire deposit having probably formed in the rapidly changing depositional conditions at an ice margin. Imbrication in the gravel layers indicated that part of the sequence had been subjected to redeposition, partly by solifluction and partly by water. A minimum age of *c.* 14,000 BP (Bowen 1969a, 1970a, 1971a) for the glacial deposits was indicated by Devensian late-glacial sediments occupying a kettle hole (now destroyed) in the same lithostratigraphic formation at nearby Derwen Fawr, Swansea (Trotman 1963). Bowen (1969a) suggested that the imbrication and fabric of the glacial sediments at Rotherslade also showed that they had been derived from the north-east. Finally, towards the close of the Late Devensian and into the Devensian late-glacial, loess (Case 1984) and colluvial (slope wash) sediments were deposited as a capping to the sequence. Bowen (1977b) considered the site allowed the extent of the post-*Patella* Beach glaciation (Late Devensian) to be established in east Gower. Bowen's interpretation of the sequence at Rotherslade was supported by Peake *et al.* (1973), Stephens and Shakesby (1982), Shakesby and Campbell (1985) and Bridges (1985).

Amino acid dating and correlation by both older and current preparation methods led to the raised beach being ascribed to Oxygen Isotope Sub-stage 5e (Davies 1983; Bowen *et al.* 1985), and the Ipswichian (Bowen and Sykes 1988).

Campbell (1984) applied a range of techniques including Scanning Electron Microscopy of quartz sand grains, clast lithology, fabric and roundness analyses to the interpretation of the Rotherslade sequence. An absence of Carboniferous Limestone clasts in the glacial sediments (also noted by Strahan (1907a)) suggested deposition by ice moving south-west from the Nedd (Neath) and Tawe Valleys rather than south across the extensive limestone terrain of south Gower. The glacial deposits at Rotherslade were thus considered to represent the south-westward extension of a piedmont ice-lobe in Swansea Bay. This interpretation was also supported by clast fabric analysis which showed a strongly preferred north-east to south-west orientation. Campbell (1984), however, noted that this fabric 'trend' could also have resulted from subsequent redeposition of the glacial sediments by solifluction.

Rotherslade has an important stratigraphic record showing changing environmental conditions in central South Wales during the Late Pleistocene, with evidence for a transition from the high sea-level conditions of the Ipswichian Stage, to cold and eventually full glacial conditions during the Devensian Stage, when east Gower was overrun by south-west moving Welsh ice.

The ascription of the raised beach deposits at Rotherslade (Langland Bay) to Oxygen Isotope Sub-stage 5e (Bowen *et al.* 1985; Bowen and Sykes 1988) (*c.* 125,000 BP) and the pollen analysis of deposits lying in a kettle hole in glacial sediments nearby (Trotman 1963), provide evidence for the ages of these respective deposits. The evidence from Rotherslade is similar to that at Broughton Bay in north-west Gower (Campbell *et al.* 1982; Campbell 1984), and both provide constraints for the extent of Late Devensian ice. Both are dissimilar to the evidence from Hunts Bay, Western Slade, Eastern Slade and Horton, which show ice-free conditions throughout the Devensian (Bowen 1970a).

Rotherslade is important for interpreting Late Pleistocene events in central South Wales; showing a sequence of raised beach sediments overlain by head and glacial deposits. The raised beach has been correlated by amino acid geochronology with Oxygen Isotope Sub-stage 5e of the deep-sea record. This shows that the overlying sediments must be Devensian. Local pollen evidence provides a minimum late-glacial age for the glacial deposits at Rotherslade and shows that the last glaciation of eastern Gower was Late Devensian in age. As such it is important evidence for establishing the maximum extent of Late Devensian ice from the uplands of South Wales.

Conclusions

Rotherslade (Langland Bay) displays a sequence of deposits which represents the entire last glacial cycle. The site is also exceptional because it shows evidence for the last time Britain enjoyed conditions similar to the present, about 125,000 years ago. Then global sea-level was some metres higher than it is today (shown by the raised beach). Glacial deposits were laid down by the last great Welsh ice-sheet.

Hunts Bay

Highlights

A locality which shows outstanding sections of head, colluvium and reworked till deposited during the Devensian when this part of Gower was not glaciated. Devensian rocks overlie raised beach deposits and platform which may indicate at least three episodes of earlier Pleistocene temperate climate.

Introduction

Hunts Bay (SS565867) shows a Pleistocene sequence of marine deposits and terrestrial periglacial sediments, proving that south Gower was not glaciated during the Late Devensian. The site has a long history of research, commencing with the work of Strahan (1907a). It has been studied by George (1932, 1933a, 1933b), Bowen (1970a, 1971a, 1973a, 1973b, 1974, 1977a, 1977b) and Harris (1973). The site was also mentioned by Mitchell (1972), Peake *et al.* (1973), Stephens and Shakesby (1982), Davies (1983), Shakesby and Campbell (1985) and Bridges (1985). Henry (1984a, 1984b) provided descriptions of the exposures, and the raised beaches were dated by amino acid geochronology (Bowen *et al.* 1985; Bowen and Sykes 1988).

Description

The sequence of colluvial and periglacial sediments overlying raised beach deposits can be traced along much of the south Gower coast, but it is extensive and well exposed at Hunts Bay (Deep Slade), where the following generalised sequence (not necessarily in stratigraphic order at any one exposure) occurs overlying a Carboniferous Limestone shore platform. (Stratigraphic terminology of Henry (1984a, 1984b) in parenthesis) –

7 Colluvium and blown sand (Port-Eynon Silt)
6 Limestone head with erratics (Hunts West Breccia and Erratics)
5 Redeposited glacial sediments (Western Slade Diamicton)
4 Fine angular limestone head (Hunts Breccia)
3 Coarse blocky limestone head with red silt matrix (Hunts East Breccia)
2 Colluvial silts (Pwll Du Red Beds)
1 Raised beach deposits (Hunts Bay Beach)

The sequence is laterally variable (Figure 3) and a number of important exposures has been described (named by Bowen (1971a)). These are, a) Hunts Bay East Cove (SS566866); b) Hunts Bay East (SS565867); c) Hunts Bay Centre (SS564868); and d) Hunts Bay West (SS562868).

Interpretation

The Pleistocene sections at Hunts Bay were first described by Strahan (1907a), who noted a sequence of glacial deposits containing Old Red Sandstone, grey sandstones and quartz conglomerates, resting on raised beach deposits which were largely devoid of 'travelled' rock types. The absence of such rocks indicated a 'pre-glacial' or possibly 'interglacial' age for the raised beach (Strahan 1907a).

George (1932, 1933a, 1933b) recorded a sequence of –

4 Head with pockets of glacial sediment
3 Fox red sand and loam
2 *Patella* raised beach
1 *Patella* beach platform

He considered that the raised beach had been deposited before the 'Older Drift' glaciation of the area because it contained very few erratics, and he regarded the overlying head as a typical solifluction deposit. The fox red sand and loam was believed to be fluvioglacial in origin, and pockets of glacial sediments, originally deposited by ice of 'Older Drift' age, had later been incorporated into the head deposits (George 1933a). George showed that the majority of rocks in the glacial gravel had been derived from the South Wales Coalfield to the north, but others of a more distant origin were also present. These included Triassic conglomerate, soda-felsite from Llŷn and other rocks from North Wales and northern Pembrokeshire. The mixture of foreign and local rock types indicated to him the possible confluence between the Irish Sea and Welsh ice masses during the 'Older Drift' glaciation.

The nature and origin of the sequence at Hunts Bay, which makes up a large solifluction terrace, was discussed by Bowen (1970a, 1971a, 1973a, 1973b, 1974, 1977a, 1977b). From the evidence at Hunts Bay and elsewhere in Gower, he reconstructed the following sequence of events. The raised beach (bed 1) was of probable Ipswichian age, and represented a period of high sea-level conditions. With the onset of colder conditions during the Devensian Stage, colluvial silts (bed 2) and blocky limestone head (bed 3) were deposited. The colluvial silts were the product of sheet washing and soil erosion, and much of the material in beds 2 and 3 had been subjected to chemical weathering during the previous temperate (Ipswichian) event (Bowen 1970a, 1971a). This view was supported by Clayden (1977a), who described a possible pre-Devensian weathered profile *in situ* on the plateau above Hunts Bay (SS563873). Unlike the blocky head (bed 3) which was attributed to frost-action on chemically prepared regolith, the finer calibre head (bed 4) was attributed to frost-action on fresh unweathered bedrock, during the later Devensian (Bowen 1971a). Contemporaneously, 'Older Drift' glacial deposits mantling the plateau above Hunts Bay were reworked and redeposited (bed 5) by alluvial and solifluction processes along the valley of Deep Slade (cf. Eastern Slade, Western Slade), and head (bed 6), also continued to form at Hunts Bay. Finally, during the Devensian late-glacial, the colluvium and blown sand (bed 7) were deposited.

Mitchell (1972), however, argued that the Hunts Bay raised beach was erratic-free and was probably Hoxnian (not Ipswichian) in age, and that the overlying lower blocky head and upper fine calibre head (Bowen 1971a) represented the Saalian and Devensian Stages, respectively.

In marked contrast to Mitchell (1972), Bowen therefore regarded sediments overlying the raised

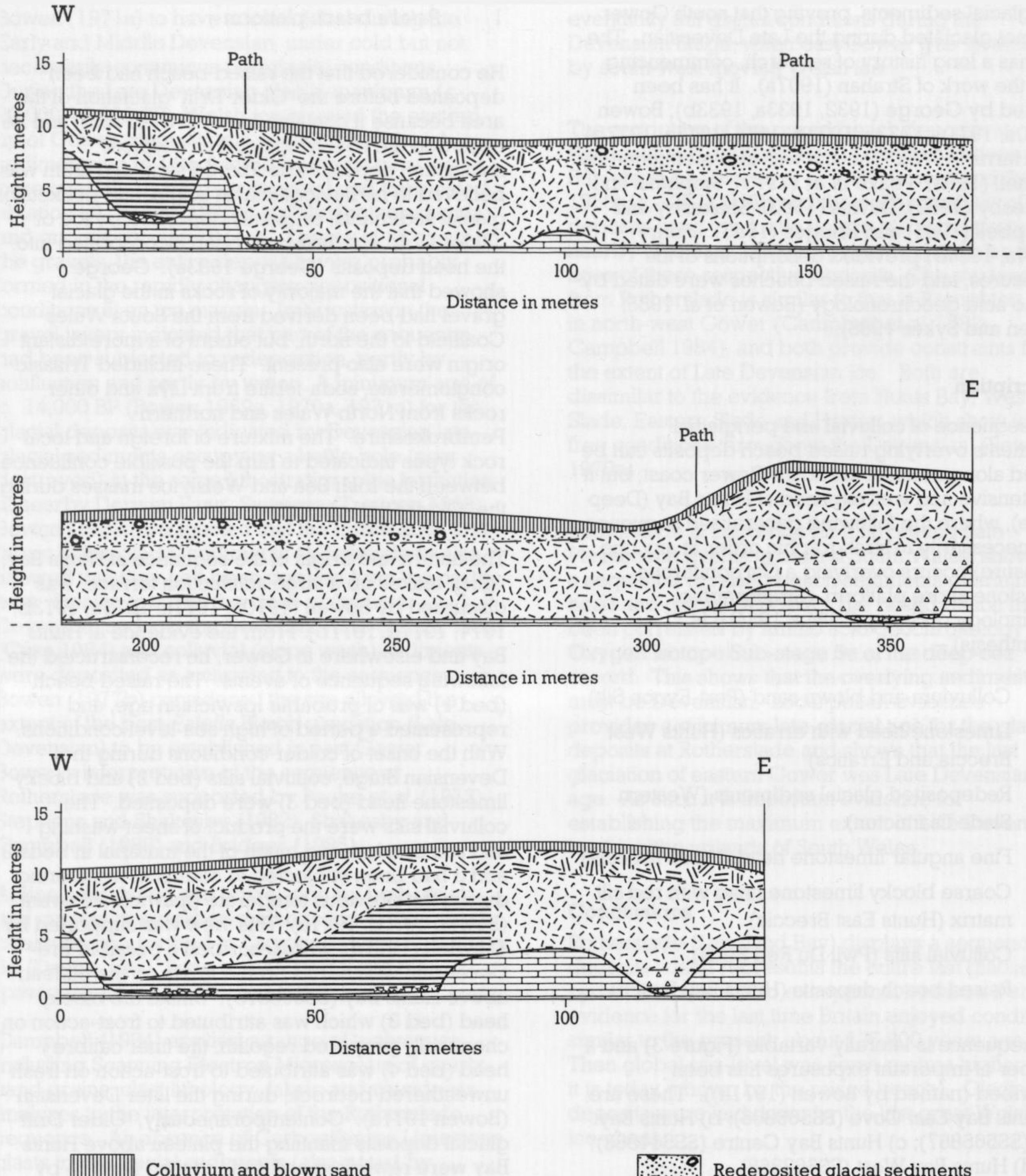

Figure 3 Quaternary sequence at Hunts Bay (after Bowen and Henry 1984)

beach at Hunts Bay as the result of a single depositional cycle during the Devensian. He also noted that the erratic content of the raised beach was highly variable, thus making the basis of Mitchell's interpretation of its age even more untenable. Moreover, interpretation of the sequence as the result of a single depositional cycle did not necessitate loss of the Ipswichian Stage in a notional unconformity within the sequence (Bowen 1970a).

A detailed study of clast fabrics in the head deposits by Harris (1973) tended to confirm the origin of the sediments as solifluction deposits, with head having moved down the valley and from the sides.

From amino acid analysis of fossil marine molluscs Davies (1983) ascribed the raised beach deposits at Hunts Bay West (Site d) to Oxygen Isotope Sub-stage 5e of the deep-sea record, the Ipswichian Stage (*c.* 125,000 BP), as proposed earlier by Bowen (1977b). Raised beach deposits at Hunts Bay East (Site b) also date from this time, although they contain some older shells, probably reworked from deposits of Oxygen Isotope Stage 7 age (*c.* 210,000 BP) (Davies 1983). Amino acid data with greater precision and less variability, show that a fauna of Oxygen Isotope Stage 9 also occurs in this beach (Bowen *et al.* 1985; Bowen and Sykes 1988).

Henry (1984a, 1984b) provided a detailed description of the deposits at Hunts Bay, and gave them formal stratigraphic names (see site description). She showed that the raised beach at Hunts Bay contained a fossil assemblage of marine molluscs characteristic of the middle shore zone of rocky coasts. Foraminiferal and ostracod assemblages indicate temperate, shallow water marine conditions, and Henry concluded that the beach had been deposited during a temperate interglacial episode with sea-level similar to or a few metres higher than at present; amino acid ratios confirmed this as an Ipswichian event (Oxygen Isotope Sub-stage 5e) (Davies 1983; Bowen *et al.* 1985; Bowen and Sykes 1988).

Amino acid geochronology has established that raised beach sediments at the site are Ipswichian in age (Bowen *et al.* 1985; Bowen and Sykes 1988). Deposits overlying these Sub-stage 5e marine beds demonstrate a deterioration of conditions during the Devensian Stage, when sheet-washing and soil erosion was followed by the accumulation of frost-shattered bedrock; at the same time, glacial deposits from an earlier pre-Devensian glaciation were recycled and redeposited by alluvial and solifluction processes. This exceptionally detailed sequence of head deposits is significant in illustrating in a single section some of the range of periglacial sediments and processes associated with the Devensian Stage (Bowen 1971a). Hunts Bay has been proposed as a reference site for limestone head deposits in Gower (Henry 1984a), and together with several other sites, is notable in demonstrating that parts of south Gower were not glaciated during the Late Devensian ice maximum.

Hunts Bay is a classic site for Quaternary research. It shows a sequence of raised marine deposits overlain by colluvial, head and redeposited glacial sediments. The raised beach sediments have been ascribed by amino acid geochronology to Oxygen Isotope Sub-stage 5e of the deep-sea record, although elements of an older reworked fauna are also present in the deposits. Together with the raised marine shore platform, the site therefore provides evidence for three high sea-level stands, at least, during the Pleistocene. Detailed sedimentary evidence has shown that the overlying terrestrial sequence is the product of a single Devensian depositional cycle during both cold and periglacial conditions. This evidence suggests the south Gower coast was not overrun by Late Devensian ice, unlike Rotherslade (Langland Bay) in the east and Broughton in the north-west.

Conclusions

Hunts Bay contains a sequence of deposits representing the last glacial cycle. When the global sea-level was high, about 125,000 years ago, the Hunts Bay raised beach was formed, and represents the last time Britain enjoyed conditions similar to the present. The last ice age is represented at Hunts Bay by cold climate (periglacial) deposits. These show that this site was not covered by an ice-sheet during the last ice age. As such, the evidence is important in establishing the maximum dimensions of the last ice-sheet in Wales.

Bosco's Den

Highlights

A key site yielding a rich Late Pleistocene mammal fauna. This consists of typical cold stage (glacial) species with, in particular, a remarkable accumulation of deer antlers.

Introduction

Bosco's Den (SS559868) is a large fissure cave containing fossiliferous deposits. The site was originally excavated in the mid-nineteenth century and it yielded prolific mammalian remains, which would appear to date from the Devensian Stage. Falconer (1868) concluded that "...On the whole, Bosco's Den of all the Gower Caves, furnishes the more complete succession of marine, brecciated and alluvial deposits disposed in a section of no less than 47 feet". The site was originally excavated by Wood in 1858 (see Falconer 1860, 1868), and was subsequently described by Prestwich (1892), Strahan (1907a), George (1933b, 1970), Allen and Rutter (1944, 1948), and Stringer and Currant (1981).

Description and interpretation

Bosco's Den, once known as Bacon's Eye, and situated only 150m west of Bacon Hole, is on two levels. The lower, which is unfossiliferous, reaches 25 ft (7.6m) above the modern beach, and extends inwards for some 30 ft (9.1m); the upper reaches about 70 ft (21m) above the modern beach and penetrates the limestone cliff for about 75 ft (23m) (Allen and Rutter 1944, 1948). The dividing floor comprises a thick sequence of raised beach deposits overlain by a sequence of fossiliferous cave earth and head deposits.
The first excavations at Bosco's Den were carried

out by Wood in 1858, and these were subsequently documented by Falconer (1860, 1868). Falconer recorded the following generalised sequence –

8	Sandy peat*
7	Stalagmitic floor (<0.3m)
6	Sandy loam (0.4m)
5	Sand (0.7m)
4	Loose breccia (1.2m)
3	Cave earth (2.0m)
2	Cemented breccia*
1	Raised marine sands and gravels*

(* bed thicknesses not recorded)

Bones of ox, wolf and shed antlers of deer (species allied to the reindeer) were recovered from the sandy peat (bed 8), and the remains of cave bear *Ursus spelaeus* (Rosenmüller & Heinroth), wolf *Canis lupus* L., fox *Vulpes vulpes* (L.), *Bos* sp., *Cervus* sp. and *Arvicola* sp. were recovered from the cave earth (bed 3). Falconer (1860) remarked that – "The most remarkable circumstance about these remains was the great excess of deers antlers above the others. Upwards of one thousand antlers, mostly shed and of young animals belonging chiefly to *Cervus guetardi* were collected."

Traces of marine sand and patches of cemented raised beach at Bosco's Den were also noted by Prestwich (1892), Strahan (1907a) and George (1933b). George (1933b) considered the raised marine deposits at Bosco's Den to be related to the *Patella* raised beach found elsewhere around the Gower coast. As such, it was considered to pre-date the 'Older Drift' glaciation of Gower, and its position beneath the cave deposits was used as evidence by George that the cave fauna was of considerable antiquity. He noted that the bones had accumulated *in situ*. Precise interpretations of the age and significance of the finds were not, however, forthcoming, although Strahan had noted that thermophilous taxa such as elephant, rhino, hyaena and cave lion were absent. Strahan emphasised that the precise stratigraphic context of many of Wood's and Falconer's finds was not clear.

Bosco's Den was later described in some detail by Allen and Rutter (1944, 1948) in their survey of the Gower caves, although no new finds were recorded. They noted that the cave was particularly significant for the considerable collection of antlers. Such an accumulation of a single species may be compared with caves at Kuhloch in Germany and San Ciro in Sicily where the remains of 2,500 cave bears and at least 2,000 hippopotamuses, respectively, had been found. (Allen and Rutter 1944, 1948).

Bosco's Den was cited by Stringer and Currant (1981) as an example of a cave where abundant mammalian remains had been recovered, but where there was little evidence for hyaena, or human, activity to account for the accumulations. This, they considered discounted Turner's (1981a) suggestion that the presence and activity of hyaena were prerequisites for such large accumulations, although Turner (1981b) later stressed that it was possible for the bones to have accumulated by other means. The dating and palaeoenvironmental significance of the remains from Bosco's Den have not yet been established, but the fauna can probably be ascribed to the Devensian Stage. Hitherto, no species with distinct warm climate preferences have been recorded. The site is particularly significant in containing deposits that may provide a comprehensive fauna for comparison with the records from adjacent sites at Minchin Hole and Bacon Hole. Well developed interglacial marine sediments also occur.

Bosco's Den's sequence of raised marine deposits and terrestrial sediments are important for interpreting Late Pleistocene events in South Wales. Mammalian remains recovered during early excavations appear to form a 'cold' fauna probably dating from the Devensian Stage, although their precise stratigraphic context is debatable. The site is unusual in having yielded prolific remains of a single species, but their mode of accumulation has not been established.

Conclusions

Bosco's Den contains marine and cave deposits which have yielded important mammalian fossil remains. Over a thousand deer antlers have been recovered from this site.

Bacon Hole Cave

Highlights

This site shows an outstanding sequence of cold and temperate interglacial rocks and faunas. It has yielded the most complete faunal record for the Ipswichian and Early Devensian in Wales from a complex section.

Introduction

Bacon Hole (SS559868) is an important cave in Gower, preserving a sequence of deposits and faunal assemblages important for understanding Late Pleistocene events in Britain. The site contains one of the most detailed records of faunal change recorded at any Ipswichian Stage site in Britain. Bacon Hole has an unusually long history of research which commenced with the work of Wood (see Benson 1852; Falconer 1860, 1868). It was also mentioned by Prestwich (1892), Tiddeman (1900), Strahan (1907a) and George (1932, 1933b). The site became the focus of a controversy concerning possible Palaeolithic cave paintings (Sollas and Breuil 1912; R E Morgan 1913; W L Morgan 1913; Sollas 1924; Wheeler 1925; Garrod 1926). Archaeological finds were described by

Williams (1939, 1941) and the site was partially re-excavated in 1943 by Allen and Rutter (1948). More recently, evidence has been discussed by Bowen (1970a, 1977a, 1977b, 1980a, 1981a), George (1970), Griffiths (1972), Sutcliffe (1976, 1981), Houlder (1977), Stringer and Currant (1981) and Turner (1981a, 1981b). Detailed studies have been carried out by Stringer (1975, 1977a, 1977b), Harrison (1977), Bowen *et al.* (1984), Currant *et al.* (1984) and Henry (1984a). Most recently Stringer *et al.* (1986) have provided a detailed interpretation of the age and significance of the sequence at Bacon Hole. Bacon Hole is an important site for the correlation and classification of the marine sequences of western and southern Britain using amino acid geochronology (Bowen *et al.* 1985; Bowen and Sykes 1988).

Description

Bacon Hole is a large terrestrial cave formed along a near vertical fault in Carboniferous Limestone. The cave opens onto a sloping rock platform at *c.* 11.5m OD (Stringer *et al.* 1986) upon which a sequence of marine and terrestrial sediments occurs. There is little evidence for channelling or reworking of the deposits, and the boundaries between units are unusually clear for cave deposits (Currant *et al.* 1984). In addition there is a remarkable consistency of deposition across the platform into the cave, which assists correlation and interpretation. The following units are recognised (Currant *et al.* 1984; Stringer *et al.* 1986) –

10 Cemented Breccias
9 Upper Cave Earth
8 Upper Sands
7 Grey Clays, Silts and Sands
6 Shelly Sand
5 Sandy Cave Earth
4 Sandy Breccio-Conglomerate
3 Coarse Orange Sands
2 Coarse Grey Sands
1 Basal Pebbles

Schematic sections through the platform and cave sequences are shown in Figure 4.

The first excavation at Bacon Hole by Wood was subsequently documented by Benson (1852) and Falconer (1860, 1868). These workers noted a sequence of –

9 Dark superficial earth (with *Bos* sp., *Cervus* sp., *Vulpes vulpes*, reindeer antlers, roebuck, a variety of littoral molluscs and pieces of pottery)
8 Stalagmite (with *Ursus* sp.)
7 Limestone breccia and stalagmite (with bones of *Ursus* and *Bos*)
6 Stalagmite (enveloping an elephant tusk)
5 Ochreous cave earth and limestone breccia (with *Palaeoloxodon antiquus* Falconer & Cautley, *Dicerorhinus hemitoechus* (Falconer), *Crocuta* sp., *Canis lupus*, *Ursus spelaeus*, *Bos* sp. and *Cervus* sp.)
4 Blackish sand (with bones of *Palaeoloxodon antiquus*, *Meles meles* (L.) and *Mustela putorius* (L.)
3 Stalagmite
2 Marine sand (with *Littorina* sp. shells, bones of *Arvicola* sp. and birds)
1 Limestone floor

Interpretation

Prestwich (1892) noted cemented fragments of raised beach near the entrance to the cave but was unclear about the relative ages of the Pleistocene deposits concluding "..... that the Gower caves have probably been filled up with their mammalian remains since the deposition of the boulder clay". Such a conclusion was reversed by Tiddeman (1900) and Strahan (1907a) who suggested that the raised beach was probably pre-glacial or interglacial and that the overlying bone beds were of similar age; both formations pre-dating deposition of glacial drift in the local area. Strahan (1907a) observed that such an interglacial age corresponded well with the 'warm' fauna recovered from the beds, and alluded to the possibility that the 'colder' fauna excavated by Wood, might have occurred in significantly younger beds not associated with the interglacial phase. Similarly, George (1932, 1933b) maintained that the raised beach at Bacon Hole was of pre-glacial age, and correlated it with the *Patella* Beach.

During the early part of the twentieth century, Bacon Hole featured in a controversy concerning the possible existence of Palaeolithic paintings within the cave. Sollas and Breuil (1912) had claimed that ten red bands on the wall of the cave were painted by Aurignacian Man, and that they were the oldest of their kind in Britain. Some workers, however, claimed that the markings had been formed naturally from oxides within the rock (R E Morgan 1913; W L Morgan 1913; Wheeler 1925; Allen and Rutter 1948), and Garrod (1926) discussed the possibility that they had been produced fraudulently during more recent years. Sollas (1924) maintained, however, that the painted bands were genuine. The status of the cave markings remains obscure, although some authors (for example, Bowen 1970a) allude to the possibility that they are genuine. The archaeological interest of the site was further enhanced by Williams' (1939, 1941) descriptions of finds of Iron Age pottery from the cave floor.

In 1943, Allen and Rutter excavated a small mound outside the cave as part of a comprehensive survey of the Gower caves (Allen and Rutter 1948). They discovered teeth, bones and coprolites; the coprolites they attributed to hyaenas, and their restricted occurrence was seen as evidence that the species may have been relatively rare in Bacon Hole. Their study confirmed the stratigraphical observations of Wood and Benson, and produced

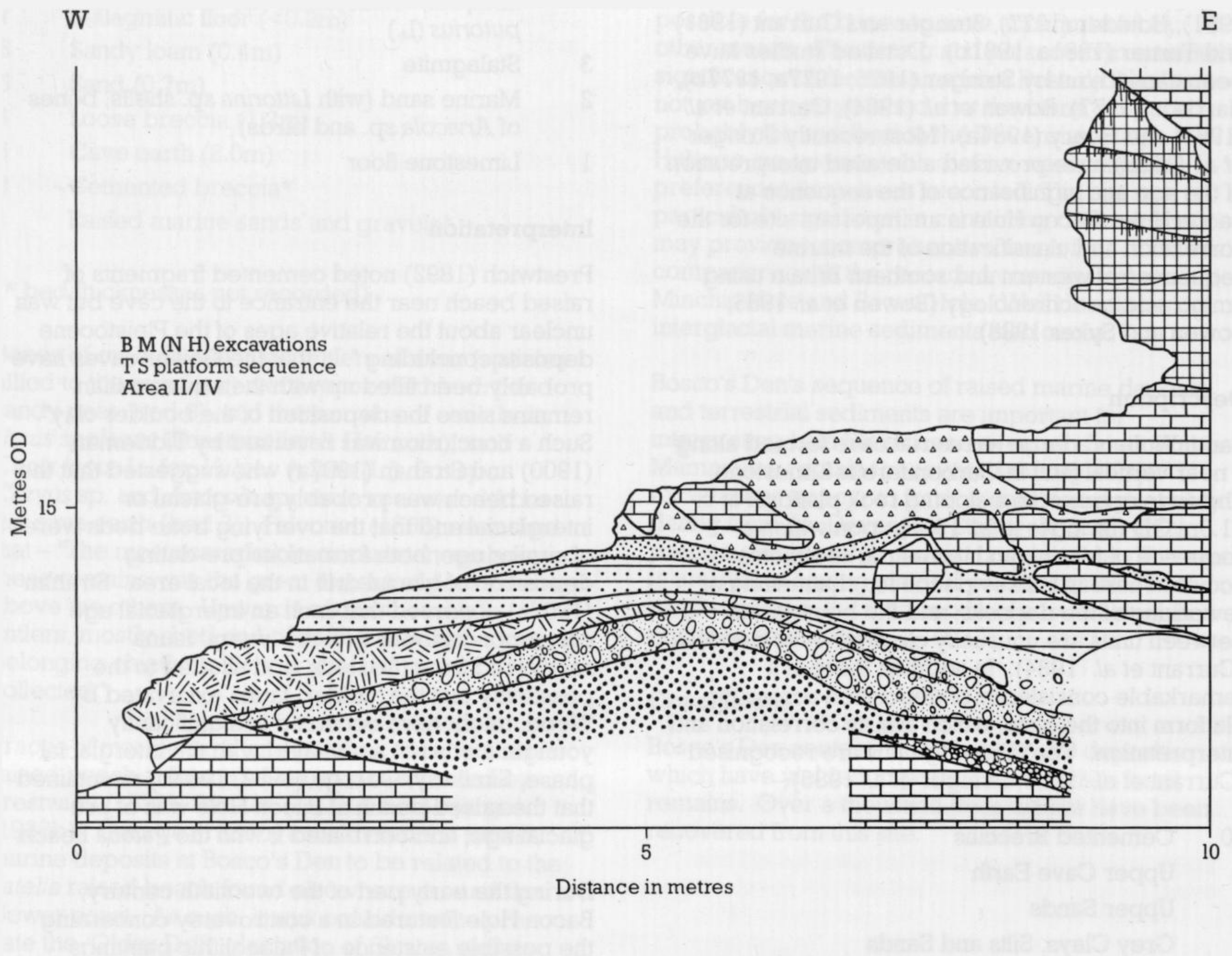

Figure 4 Pleistocene sequence at Bacon Hole Cave (from Currant *et al.* 1984)

additional fossil specimens further suggesting an interglacial age for the older deposits in the cave.

Work in Gower by Bowen, since 1965, has further established the importance of the area for sub-dividing and classifying the Pleistocene stratigraphy of Wales and the Irish Sea Basin. From a re-examination of the Pleistocene stratigraphy in coastal sections and caves around the Gower coast, Bowen (1970a) suggested that the simplest interpretation of the sequences at Bacon Hole (and Minchin Hole), was to regard the 'warm' beds as Ipswichian in age, and the overlying 'cold' beds as Devensian. Such an interpretation has largely been substantiated by more recent detailed examinations of the site (for example, Stringer 1977b; Bowen *et al.* 1984; Henry 1984a; Stringer *et al.* 1986).

In addition to recovering numerous fossils including bison or giant ox, cave hyaena, bank or field vole and various marine and terrestrial molluscs from deposits on the shore platform just outside the cave, Griffiths (1972) made a notable discovery of pieces of fossil ivory (mammoth?) which, he considered, had been shaped by Palaeolithic Man. As a result of this excavation, he attributed the recovered remains to an interstadial phase within a glaciation, presumably during the Devensian Stage.

Excavations in 1974 and 1975 in superficial deposits on the rock platform outside the cave, yielded abundant remains of interglacial fossil mammals, possibly representing the early, middle and late parts of an interglacial (Ipswichian) climatic cycle (Stringer 1975).

Further excavation and additional information led Stringer (1977a, 1977b) to revise the established stratigraphy of the site. He recorded a sequence of –

8 Cemented Breccias (not then excavated)
7 Upper Cave Earth
6 Upper Sands
5 Coarse Brown Sands
4 Grey Clays, Silts and Sands
3 Sandy Cave earth
2 Sandy Breccio-Conglomerate
1 Basal Sands

Stringer demonstrated that the Basal Sands were probably marine in origin, especially towards the base where they contained rounded pebbles and marine molluscs. Scanning Electron Microscopy (SEM) showed that the beach also contained reworked sand from glacial sources. Faunal elements such as horse and northern vole were indicative of open-country, boreal conditions; and a restricted fauna of land snails suggested an environment of bare cliff faces and scree slopes. The presence of fox (Stringer 1977b) and razorbill (Harrison 1977), however, paint a slightly less bleak picture. Stringer concluded that the Basal Sands (his bed 1) represented a period of high sea-level, perhaps during the early part of an interglacial cycle. The overlying Sandy Breccio-Conglomerate (bed 2) generally indicated more typical 'fully' interglacial conditions with mammals of mixed temperate oak forest (for instance, red deer, wood mouse, field vole and bank vole). The succeeding Sandy Cave Earth (bed 3) was considered to represent a more typical cave entrance deposit, but still with a high proportion of marine characteristics. The mammal, fish and bird faunas, the latter with curlew, dunlin, starling and Cory's shearwater (Harrison 1977), were indicative of generally warm conditions during deposition of the bed. Cory's shearwater was displaced at least 10° north of its present range, possibly indicating warmer conditions than at present.

The Grey Clay, Silts and Sands (bed 4) provided rich fossil material including over 100 coprolites, probably of hyaena. Stringer confirmed the presence of giant ox and bison from this bed and also noted the occurrence of northern vole and bean goose (Harrison 1977) which he argued showed a return to more boreal conditions, although several temperate species such as badger, shrew and woodmouse were also recorded. Stringer noted that this bed had contained the 'polished' bones which he suggested had been used to dress animal skins. Houlder (1977) believed these 'tools' represented the oldest evidence (then available) of Man's presence in Wales.

The succeeding Coarse Brown Sands (bed 5) contained (Stringer 1977b) a 'distinct small mammal assemblage', although the significance and nature of the bed was not established. The ivory artefact described by Griffiths (1972) was thought to have originated from this bed (Stringer 1977b). The overlying Upper Sands (bed 6) contained a mixture of marine-derived and wind-blown sand grains, with a foraminiferal assemblage typical of modern British coastal waters.

Stringer also described new finds from the Upper Cave Earth (bed 7), including wolf and hyaena. The faunal assemblage showed a mixture of temperate (for instance, red deer and straight-tusked elephant) and more boreal (for instance, northern vole) species, although the land snail fauna was typically interglacial and indicated an environment of local woodland and scrub. Beds 1-7 were traced under a series of cemented breccias (bed 8) which Stringer considered to be thermoclastic screes, accumulated at the cave mouth during the coldest phases of the Devensian Stage. Subsequent work (Currant *et al.* 1984; Stringer *et al.* 1986) recorded a fauna from the screes including reindeer, brown bear and a new record of glutton (*Gulo gulo* (L.)). Stringer (1977b) concluded that the deposits at the cave entrance were of Ipswichian age and that their fossil fauna was evidence for environmental changes during that stage.

Following a paper (Turner 1981a) on the importance of hyaena (*Crocuta crocuta* Erxleben),

Table 3 Uranium-series age determinations on stalagmite samples from Bacon Hole

Sample No.		Age	Corrected Age	Stratigraphic significance
1978–801	:01 :02	14,000 ± 2,000 18,600 ± 1,999	13,000 ± 3,000 12,800 ± 1,700	Broken block of surface stalagmite giving minimum age for Devensian fauna
1981–250		81,000 ± 18,000	–	Minimum age for the interglacial elements in Upper Cave Earth (bed 9)
1981–212	:01 (top) :02 (middle) :03 (bottom)	129,000 ± 16,000 136,000 ± 23,000 142,000 ± 27,000	– 125,000 ± 26,000 129,000 ± 30,000	All are broken blocks of stalagmite floor incorporated into Shelly Sand (bed 6)
1981–252	:02 :01	116,000 ± 18,000 122,000 ± 11,000	107,000 ± 21,000 –	This stalagmite probably formed on the underlying Sandy Cave earth (bed 5)
Mean of last 5 determinations		127,000 +9,000 -8,000	122,000 ± 9,000	These dates relate to the main interglacial fauna and the last major Pleistocene marine transgression at the site

as a bone accumulating agent during the Ipswichian in Britain, Stringer and Currant (1981) used the faunal evidence from Bacon Hole to refute Turner's claims. They noted that hyaena was absent or poorly represented in a fauna of otherwise Ipswichian character at the site, but that it is associated later in the sequence with deposits considered to post-date the warmest part of that stage. This, they believed, refuted Turner's hypothesis on the 'unique' role of hyaenas in producing bone accumulations in caves, and the restricted occurrence of *Crocuta crocuta* in Britain during the Ipswichian Stage. In reply, Turner (1981b) noted that other animals could have been responsible for the bone accumulations at some sites (for instance, wolf or bear), but emphasised the overwhelming evidence pointing to hyaena as the most probable and important single agent.

Following Stringer's (1975, 1977a, 1977b) interpretation of the sequence at Bacon Hole, considerable efforts were made to establish a more precise chronological framework for the deposits. Bowen *et al.* (1984) obtained amino acid ratios from shells of *Patella vulgata* and *Littorina* found in – a) the Basal Sands, b) the Sandy Breccio-Conglomerate, c) the Sandy Cave Earth and d) the Grey Clays, Silts and Sands. Their results confirmed that all the stratigraphic units up to and including the Grey Clays, Silts and Sands were of Ipswichian age.

Currant *et al.* (1984) and Stringer *et al.* (1986) presented a comprehensive series of Uranium-series age determinations (Table 3) from Bacon Hole, which place the interglacial fauna at the site between *c.* 130,000 and 80,000 BP. They adopted a slightly revised site stratigraphy and recognised a coarse lag deposit at the base of the succession (the Basal Pebbles) and an additional bed (the Shelly Sand) between the Sandy Cave Earth and the Grey Clays, Silts and Sands – see site description.

By combining all the available data, especially from Henry (1984a) and Stringer *et al.* (1986), the following sequence of Pleistocene events at Bacon Hole can be reconstructed. Deposits accumulated before Oxygen Isotope Sub-stage 5e, as shown by a Uranium-series age determination of 175,000 ± 19,000 BP on a stalagmite layer capping altered sediments in a cleft in the cave floor. These sediments only occur at one location in the cave and appear to have been largely removed elsewhere by marine scouring during a period of pre-Oxygen Isotope Sub-stage 5e high sea-level (perhaps represented by the Basal Pebbles (bed 1); Bowen *et al.* 1985). The succeeding Coarse Grey and Orange Sands (beds 2 and 3) were deposited during a period of cool dry climate with relatively open vegetation. A rise in relative sea-level accompanied by a rise in temperature and humidity saw deposition of the Sandy Breccio-Conglomerate (bed 4), the Sandy Cave Earth (bed 5) and the Shelly Sand (bed 6). The Sandy Breccio-Conglomerate may represent a storm beach, marginally higher than its modern day equivalent, and closely related on altitudinal, lithological, aminostratigraphic and faunal grounds with the +2m *Patella* Beach in the nearby Minchin Hole. Stringer *et al.* (1986) provided a date of *c.* 122,000 BP (from broken stalagmite fragments, not *in situ*, from the top of bed 5) for this marine transgression, which they claimed was the first direct correlation of a British Ipswichian fauna with the high sea-level of Oxygen Isotope Sub-stage 5e. Amino acid ratios from the terrestrial snail *Cepaea nemoralis* (L.), allowed correlation of the Sandy Cave Earth (bed 5) at Bacon Hole with the interglacial deposit at Tattershall, Lincolnshire (Hughes 1984). Stringer *et al.* (1986) considered that the Grey

Clays, Silts and Sands (bed 7) marked a change in the environment, with falling sea-level and temperature. Mammoth *Mammuthus primigenius* (Blumenbach) is recorded for the first time in this bed, and temperate birds of the preceding beds are replaced by species now only known as winter visitors to Britain. The Upper Sands (bed 8) indicate a drier phase, with deposition of marine-derived wind-blown sediments. Stringer *et al.* (1986) concluded that the Upper Cave Earth (bed 9) was deposited during a period of lower sea-level than the superficially similar Sandy Cave Earth (bed 5). The former (bed 9) contains a restricted mammal fauna of interglacial character, a minimum age for which is indicated by a Uranium-series date of *c.* 81,000 BP obtained from stalagmite enclosing a tusk of *Palaeoloxodon*. This phase probably represents an Early Devensian interstadial, time-equivalent to Oxygen Isotope Sub-stage 5a. Stringer *et al.* (1986) noted that *Palaeoloxodon* and *Dicerorhinus* continued to be unusually abundant in this Early Devensian fauna. A date of *c.* 13,000 BP for broken stalagmite from the uppermost part of the Cemented Breccia (bed 10), provides a minimum age for the more typically cold Devensian fauna within these sediments.

The faunal sequence at Bacon Hole, therefore, would appear to record a number of cycles similar to those in the deep-sea oxygen isotope record (Sub-stages 5a, 5c and 5e). A boreal environment with relatively low sea-level was followed by warmer conditions in Oxygen Isotope Sub-stage 5e; this phase, with sea-level close to that of the present day, has been dated at *c.* 122,000 BP. The following deposits, containing less typically interglacial faunas, are associated with lower sea-levels until around 80,000 BP (Oxygen Isotope Stage 5a?). Subsequently, breccias with a 'cold' fauna were deposited (Stringer *et al.* 1986).

The sequence at Bacon Hole Cave (and nearby Minchin Hole Cave) presents a unique opportunity in Britain to correlate sea-level and palaeotemperature data with the deep-sea oxygen isotope record. The amino acid data and lithostratigraphy are more complete at Minchin Hole Cave, but the faunal evidence from Bacon Hole is more detailed, and it has provided unique information concerning the nature and complexity of the Ipswichian-Devensian transition. The dating of specific beds in the sequence by amino acid and Uranium-series techniques, has contributed towards a geochronological framework for British evidence during the Ipswichian and Devensian Stages (Bowen and Sykes 1988; Bowen 1989b).

Conclusions

Bacon Hole Cave is one of the most important sites in Europe. It is the only site in Britain which contains evidence for sub-dividing the important period of time between 130,000 and 70,000 years ago. That time period is important because it led directly to the last major ice age. It provides important evidence showing how the world moves from an interglacial into an ice age. As such it may be used as an analogue for future changes in climate. A full range of modern techniques has been applied at Bacon Hole Cave. The evidence is of high quality, it is plentiful and well preserved, and is exceptional by international standards.

Minchin Hole Cave

Highlights

The complex story of changing Pleistocene sea-levels is nowhere better seen than in the rocks and mammal faunas of this site. Its detailed evidence for Ipswichian and earlier interglacial events is unrivalled, and forms one of the most important Pleistocene sites in Wales.

Introduction

Minchin Hole Cave (SS555869) has been studied for over a century and is noted for the diverse faunal remains contained in its sequence of marginal marine and terrestrial sediments. The sequence provides an opportunity to study the simultaneous effect of climatic change on sea-levels and local terrestrial environments. The site was chosen by George (1932) as the type locality for the *Patella* raised beach. The first major excavations at the site were carried out by Wood in 1850 (see Falconer 1860, 1868). It was also noted by Prestwich (1892), Strahan (1907a) and Baden-Powell (1933) and was partially re-excavated by George (1932, 1933b). From the early 1940s to 1957, further extensive investigations were conducted by Allen and Rutter (1948) and Rutter and Mason (Rutter 1948, 1949, 1950, 1952, 1953, 1955, 1956, 1957), and its stratigraphical significance in the context of the Pleistocene history of the Irish Sea Basin discussed (Bowen 1966, 1969a, 1970a, 1971a, 1973a, 1973b). Minchin Hole was further excavated in the 1970s and the initial results and implications presented by Sutcliffe and Bowen (1973) and Bowen (1973c). The site has also been mentioned by Williams (1941), Bowen (1973d, 1974, 1977a, 1977b, 1980a, 1984), Peake *et al.* (1973), Sutcliffe (1976), Harrison (1977), Campbell *et al.* (1982) and Campbell (1984). A geochronology has been based on the epimerization of isoleucine in fossil shell protein from the raised beaches (Andrews *et al.* 1979; Bowen 1981a; Davies 1983; Bowen *et al.* 1984; Bowen *et al.* 1985; Bowen and Sykes 1988). Detailed biostratigraphical descriptions have been given by Sutcliffe (1981), Sutcliffe and Currant (1984) and Henry (1984a).

Description

Minchin Hole is the largest of the Gower caves. It is a single chambered fissure cave cut in Carboniferous Limestone; it opens onto a narrow gully entered by the sea at high tides.
William Buckland visited Minchin Hole in July 1831,

but there is no record of any excavation (Sutcliffe 1981). Falconer (1860, 1868) documented Wood's excavations in 1850 and recorded a sequence of sands with extant marine shell species, overlain by bone-bearing beds containing remains of narrow-nosed rhinoceros *Dicerorhinus hemitoechus* and straight-tusked elephant *Palaeoloxodon antiquus.* He noted that the Gower caves contained two apparently distinct faunal assemblages: one with the above temperate species, and another with woolly mammoth *Mammuthus primigenius* and woolly rhinoceros *Coelodonta antiquitatis* Blumenbach, indicating colder conditions (Sutcliffe 1981). *Hippopotamus* was not recorded from the deposits at either Minchin Hole or Bacon Hole, but Falconer did record it as a member of a comparable 'warm' fauna at nearby Ravenscliff Cave.

George (1932) provided the first detailed description of the stratigraphic succession near the cave entrance –

4 Wind-blown sand
3 Coarse gritty sand with common remains of *Neritoides obtusata* (L.) – the *Neritoides* Beach
2 Ossiferous breccia with remains of a temperate mammal fauna
1 Pebbly beach with common remains of *Patella vulgata* (L.) – the *Patella* Beach

Allen and Rutter (1948) and Rutter (1948, 1949, 1950, 1952, 1953, 1955, 1956, 1957) recorded additional Pleistocene mammalian specimens, the stratigraphic context of which is uncertain, and evidence of human occupation (Iron Age, Roman and Saxon) from the upper levels. Details of the Iron Age B and Roman remains were given by Williams (1941). This series of excavations exposed, for the first time, an earlier raised beach deposit, subsequently rediscovered and called the Inner Beach (Sutcliffe and Bowen 1973) which was not encountered by George at the cave entrance.

Recent excavations have described a more detailed sequence (Sutcliffe 1981; Henry 1984a; Sutcliffe and Currant 1984) –

12 Flowstone floor**
11 Breccia**
10 Flowstone floor**
9 Upper Red Cave Earth**
8 Earthy Breccias
7 *Neritoides* Beach*
6 Fallen flowstone block
5 *Patella* Beach*
4 Flowstone floor
3 Lower Red Cave Earth
2 White layer (incipient stalagmite?)
1 Inner Beach

* These beds make up the Outer Beach

** Inner and Outer Talus Cones

This sequence is shown schematically in Figure 5.

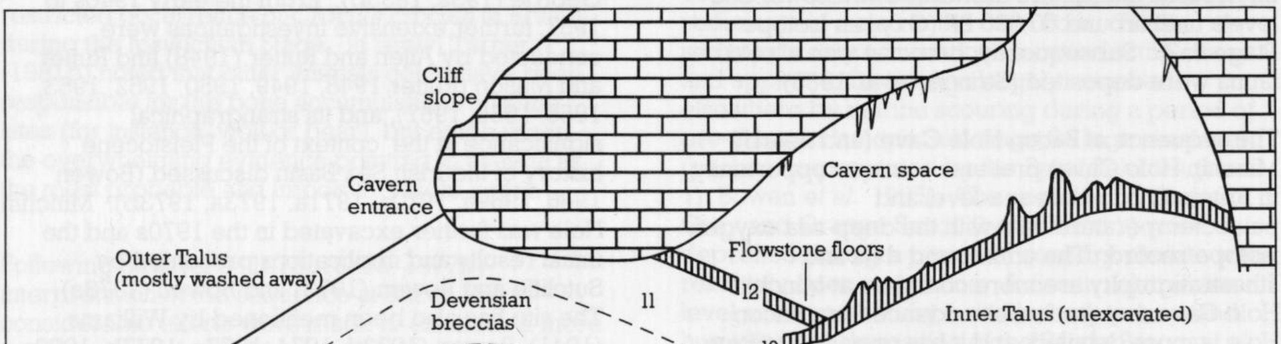

Figure 5 Pleistocene sequence at Minchin Hole (from Sutcliffe and Currant 1984)

Interpretation

In discussing the evidence from the Gower caves, in particular, the relationship between the glacial deposits and breccias of the area, Prestwich (1892) concluded that the caves had probably been filled with their mammalian remains after deposition of the local boulder clay. Strahan (1907a), however, considered that the bone-bearing beds were related to and were similar in age to, the raised beach deposits of Gower, which he believed to be of pre-glacial or interglacial age. He believed that the bone-beds pre-dated the earliest glaciation of Gower.

This relationship was confirmed by George (1932, 1933b). By recognising two distinct marine units (his beds 1 and 3) separated by terrestrial deposits (bed 2), George (1932) concluded that "..... the stratigraphical distinction that can be made between the *Patella* Beach and the *Neritoides* Beach thus represents a time interval of not inconsiderable dimensions". He regarded both beaches as being older than the first ('Older Drift') glaciation of the area, and considered the *Patella* Beach to have been deposited under conditions of incipient glaciation. The latter claim was refuted by Baden-Powell (1933) who observed that the fauna of the *Patella* Beach could easily be found in the area today. George (1970) maintained, however, that distantly-derived igneous erratics in the *Patella* Beach of South Wales may have been carried by drifting ice at the onset of arctic conditions.

The Pleistocene chronology of Minchin Hole was discussed in the context of a wider region by Bowen (1966, 1969a, 1970a, 1971a, 1973a, 1973b). Originally, he accepted Mitchell's (1960) proposal that the *Patella* Beach (bed 5) at Minchin Hole was Hoxnian, and from this, argued that the Ossiferous Breccia (bed 2 of George 1932) was Saalian, the *Neritoides* Beach was Ipswichian Stage and the overlying breccias (beds 9-12) were Devensian Stage (Bowen 1966). Subsequently, however, Bowen (1969a, 1970a, 1971a, 1973b) after establishing a lithostratigraphy for the coastal Pleistocene deposits around Gower, argued that the marine and bone-bearing beds were Ipswichian, and the overlying deposits were Devensian. Bowen (1971a) noted that the evidence from Minchin Hole could be used to support Zeuner's (1959) claim that the 'last interglacial' was characterised by two discrete high sea-level events (Main and Late Monastirian).

New excavations (Bowen 1973c; Sutcliffe and Bowen 1973) revealed an 'Inner Beach' (bed 1) as well as a *Patella* (Outer) Beach recorded by George. George considered the *Neritoides* deposit to be a transitional marine and terrestrial lithofacies. Sutcliffe and Bowen reconstructed the following sequence of events – the Inner Beach (bed 1) was deposited during a sea-level stand higher than at present. With a fall of sea-level, the surface of the Inner Beach became cemented (unit 2) and the Lower Red Cave Earth (bed 3) accumulated with its contained bones. A subsequent rise of sea-level to just above the present level cut a cliff in the Inner Beach and Red Cave Earth. The Outer Beach (consisting of the *Patella* (bed 5) and *Neritoides* (bed 7) Beaches combined) was deposited unconformably on the earlier sediments. As sea-level fell again, sand from the exposed sea floor was blown into the cave. Environmental conditions deteriorated during the Devensian, and the Outer and Inner Talus Cones (beds 9-12), made up of frost-shattered scree, accumulated, with the Outer Talus Cone blocking the cave entrance. This was all but completely removed during the Holocene.

Sutcliffe and Bowen (1973) proposed that both the Inner and Outer Beaches, together with the intervening ossiferous deposits, were Ipswichian, although Bowen (1973c) noted the possibility that the two beaches could represent separate interglacials (the Hoxnian and the Ipswichian), with the intervening cave earth perhaps representing a cold interval (the Wolstonian?), or with the Inner Beach representing an interglacial between the Hoxnian and Ipswichian (Oxygen Isotope Stage 7). Bowen noted that if the beaches were Hoxnian and Ipswichian respectively, then the Red Cave Earth must have formed over a period of 200,000 years which is unlikely. He therefore regarded the two high sea-level phases as two events in the Ipswichian Stage. The *Neritoides* Beach was grouped as part of a *Patella* Beach sequence (see also Bowen 1973d, 1974, 1977a, 1977b; Peake *et al.* 1973).

In a study of the bird fauna, Harrison (1977) recorded dunlin *Calidris alpina* (L.) and razorbill *Alca torda* (L.) from the lower beds of the sequence at Minchin Hole, tending to confirm their interglacial character. He noted that the dunlin bones had probably been introduced in owl pellets, but that the razorbill may have nested within the cave.

Recent work at Minchin Hole has provided a more precise chronological framework for the sequence, with the application of amino acid geochronology and Uranium-series techniques (for example, Andrews *et al.* 1979; Davies 1983; Bowen *et al.* 1985; Bowen and Sykes 1988). Further amplification of the lithostratigraphy and biostratigraphy have also been provided (Sutcliffe 1981; Sutcliffe and Currant 1984; Henry 1984a).

Andrews *et al.* (1979) used amino acid ratios from *Patella vulgata* to correlate the Outer (*Patella*) Beach at Minchin Hole with raised beach remnants elsewhere in south-west Britain and suggested that it was Ipswichian in age. Following this, Bowen (1980a) suggested that the *Neritoides*, the *Patella* and the Inner Beaches at Minchin Hole might correspond with the high sea-level stands of Oxygen Isotope Sub-stages 5e, 5c and 5a. The amino acid ratio derived from the Inner Beach (Bowen 1981a), indicated a greater age than that obtained from the *Patella* Beach; but both were still considered to belong to the Ipswichian.

Following the earlier amino acid work (Andrews *et* *al.* 1979; Davies 1983), and using Uranium-series age determinations from broken stalagmite at Bacon Hole, the current amino acid dating (Bowen *et al.* 1985) shows that the Outer Beach *(Patella)* is probably time-equivalent to Oxygen Isotope Sub-stage 5e, and the Inner Beach contains faunal elements of Oxygen Isotope Sub-stages 7a and 7c (Bowen and Sykes 1988).

Work at Minchin Hole by Sutcliffe (1981), Henry (1984a) and Sutcliffe and Currant (1984) allows the following generalised sequence of events to be reconstructed. 1) The Inner Beach (bed 1) probably formed during temperate conditions with relative sea-level from 3 to 5m higher than at present (Sutcliffe 1981; Sutcliffe and Currant 1984). Its mixed molluscan fauna has been ascribed to sub-stages of Oxygen Isotope Stage 7 (Bowen and Sykes 1988). An erratic of volcanic tuff (perhaps from south Pembrokeshire or Anglesey) may derive from an Irish Sea glaciation which pre-dates Stage 7 (Bowen 1984; Henry 1984a). Following partial cementation and cracking of the Inner Beach, the Lower Red Cave Earth (bed 3) was deposited. This indicates a fall in relative sea-level when frost-shattered and colluviated material accumulated during colder conditions. The fauna from the Lower Red Cave Earth contains a large form of northern vole, *Microtus oeconomus* (Pallas), which led Sutcliffe (1981) to correlate the bed with the Basal Sands horizon at Bacon Hole, where similar remains were recovered (Stringer 1977b).

The Inner Beach and Lower Red Cave Earth were cliffed by the sea when the Outer Beach was deposited. The Outer Beach is a storm beach facies, and is best developed at the cave mouth where it comprises a mixture of boulders, shingle and shell fragments (Sutcliffe 1981). It has an altitudinal range of about 6m within the cave and is ascribed to Oxygen Isotope Sub-stage 5e by aminostratigraphic correlations with Bacon Hole Cave (Bowen *et al.* 1985; Bowen and Sykes 1988). Uranium-series determinations of 127,000 ± 21,000 to 107,000 ± 10,000 BP on a fragment of flowstone (unit 6) resting on the surface of the Outer (*Patella*) Beach (bed 5) precludes a later age for the Outer Beach (Sutcliffe and Currant 1984). The *Patella* Beach is overlain by the *Neritoides* deposit, (bed 7) and although George (1932) described a breccia between the two units, more recent excavations have not yet confirmed this relationship, although in places the *Neritoides* Beach does merge with brecciated limestone. For the most part, the *Neritoides* Beach is a sandy deposit containing the remains of rodents, other small mammals and many small littoral gastropods. The deposit formed during a fall in relative sea-level after the *Patella* Beach event (Sutcliffe 1981; Henry, 1984a). It is thought to be a transitional deposit between the fully marine *Patella* Beach and the overlying terrestrial sediments (the Earthy Breccias).

The Earthy Breccias (bed 8) contain the remains of birds (Harrison 1977; Sutcliffe and Currant 1984) and relatively abundant mammalian remains including – spotted hyaena *Crocuta crocuta,* lion *Panthera leo* (L.), bear *Ursus* sp., narrow-nosed rhinoceros *Dicerorhinus hemitoechus,* red deer *Cervus elaphus* L., fallow deer *Dama dama* (L.), field vole *Microtus gregalis* Pallas and wood mouse *Apodemus sylvaticus* (L.). A previous record of horse (Sutcliffe 1981) was erroneous (Sutcliffe and Currant 1984). This fauna is typical of the Ipswichian Stage, though it lacks *Hippopotamus* (Sutcliffe and Currant 1984). The Earthy Breccias were deposited at a time of relatively lower sea-level than that of today.

As environmental conditions deteriorated after the Ipswichian Stage, sea-level continued to fall and the Outer and Inner Talus Cones formed at Minchin Hole. Cemented sand in the Outer Talus deposits was probably deflated from the exposed shore as sea-level fell. The uppermost layers of the talus are thermoclastic in origin and are of presumed (Late) Devensian age.

The Inner Talus is capped with a thick flowstone, and this is overlain by some Holocene deposits, including Romano-British occupation debris (Sutcliffe and Currant 1984). Finally, the continuing rise of the Holocene sea to its present level removed most of the Outer Talus deposits from the cave entrance.

Minchin Hole provides one of the longest Pleistocene records in Wales. Of particular importance is the existence of two distinct marine deposits (Inner and Outer Beaches), both representing former relative high sea-level stands. A composite single interglacial age for these beaches was once proposed, but recent evidence suggests that the Outer (*Patella*) Beach is Ipswichian (Oxygen Isotope Sub-stage 5e), while the Inner Beach has been ascribed to Oxygen Isotope Stage 7. The intervening Lower Red Cave Earth, therefore, represents a period of lowered sea-level later in age than the Inner Beach, but earlier than the Outer (*Patella*) Beach. The *Neritoides* Beach represents a transition between the fully marine Outer (*Patella*) Beach and the overlying terrestrial sediments. Faunal, amino acid ratio and Uranium-series evidence points strongly to an Ipswichian age for the Outer Beach, *Neritoides* Beach, and the overlying Earthy Breccias. All succeeding deposits are interpreted as having accumulated when sea-level was lower than at present during the Devensian Stage.

Although Bacon Hole provides the more complete faunal record for the Ipswichian and Early Devensian (Stringer *et al.* 1986), Minchin Hole provides a longer record of sea-level changes.

Conclusions

Minchin Hole Cave contains the longest record of ice age time in Wales. Of European significance, is evidence at the site for two high global sea-level events, one at 200,000 years ago, the other 125,000 years ago. It proves a period of severe climate between about 200,000 and 130,000 years ago, and evidence for the last ice age. Because Minchin Hole was beyond the extent of the last ice-sheets, such evidence from that time relates to cold climate processes and events. The changeover from the last interglacial (125,000 years ago) to the last ice age is of some significance. This may contain important pointers for future climate. The full range of modern techniques has been applied at Minchin Hole Cave, and its scientific status is international in importance.

Cat Hole Cave

Highlights

This site has yielded a 'cold' Pleistocene mammal fauna and Upper Palaeolithic artefacts from periglacial climate screes. These have been assigned to the Devensian late-glacial, indicating the possibility that many such screes in Wales date from this final glacial phase.

Introduction

Cat Hole Cave (SS538900) contains artefacts and fossils that can be dated towards the close of the Devensian Stage (Late Devensian late-glacial). Numerous flint artefacts of Creswellian type have been recovered in association with a 'cold' fauna including mammoth, woolly rhinoceros, horse, reindeer, arctic fox and arctic lemming taken to be typical of the Devensian Stage. The site was first excavated by Wood in 1864 and was mentioned by Vivian (1887), Roberts (1887-8), Morgan (1919), Garrod (1926) and Allen and Rutter (1948), but it was not re-excavated until the late fifties (McBurney 1959). Campbell (1977) provided a detailed description and interpretation of the site, supported by accounts of the pollen (Campbell 1977), the land snails (Evans 1977b) and the bird faunas (Bramwell 1977). The site has also been referred to by McBurney (1965), Houlder (1977) and Bowen (1974, 1980a).

Description

Archaeologically Cat Hole is the most important of the inland caves of Gower. It is formed in a crag of Carboniferous Limestone at a level *c.* 10m above the floor of the dry valley of Parkmill at about 30m OD (Campbell 1977). It has two main entrances and chambers, the largest chamber reaching some 40 ft (12m) maximum width. The cave lies only about 250m from the megalithic tomb of Parc le Breos. The limestone platform outside the cave supports a sequence of terrestrial sediments that was excavated by McBurney (1959) and Campbell (1977) and that can be generalised as follows –

4 Modern soil
3 Weathered scree
2 Scree
1 Silt and sand

A more detailed sub-division of the sequence was provided by Campbell (1977). Substantial deposits remain *in situ*, both in the cave and on the platform outside.

Interpretation

The first known excavations at Cat Hole were carried out mainly inside the cave and at the mouth to the larger entrance by Wood in 1864, but the results were not recorded in Falconer's (1860, 1868) work on the Gower caves. A brief mention of the remains was, however, made by Vivian (1887), and Wood's finds which were housed in the British Museum (Natural History), were itemised by Roberts (1887-8). These included – two human skulls, numerous flint cores and flakes, a stone hammer, a bronze celt, pottery, shells of limpet, oyster and whelk and remains of bear, fox, hyaena, wild cat, Irish deer, reindeer, red deer, horse, woolly rhinoceros, vole, mammoth, sheep or goat and pig (Roberts 1887-8). Two of Wood's other finds, a gnawed bone and a worked bone, were housed in the Museum of the Royal Institution of South Wales, Swansea (Morgan 1919). Although Wood did not record the stratigraphy, his collection of flint artefacts was assigned by Garrod (1926) to the Upper Palaeolithic, either to the Upper Aurignacian or Magdalenian, and a close resemblance was noted between these artefacts and those recovered from Paviland Cave in south Gower (Sollas 1913). Wood's finds from Cat Hole were also discussed by Allen and Rutter (1948), who noted that although the faunal list contained some recent species, it was essentially a 'cold' Pleistocene assemblage. They observed that the human remains had been unearthed near the surface in the cave and were, therefore, not likely to be of an early date.

Further excavations at Cat Hole were conducted by McBurney in 1958 and 1959 (McBurney 1959). The results of the 1959 season have not been published, although Campbell (1977) refers to some of McBurney's unpublished data. McBurney excavated outside the larger cave entrance, recording details of stratigraphy and find locations. Most of the 280 flint artefacts, and many of the faunal remains were recovered by McBurney from the scree and weathered scree (beds 2 and 3). McBurney considered that most of the implements were of Creswellian-type culture and described several artefacts not previously recorded from Creswellian assemblages. A small, finely worked needle and bone awl were also recovered. Most of the flints were scattered vertically throughout the scree (bed 2) but were the result of a single occupation. McBurney accounted for the vertical scattering by solifluction or other natural re-sorting. In addition to many of the species recovered by Wood, he discovered the remains of aurochs *Bos*, arctic fox *Alopex lagopus* (L.), mountain hare *Lepus timidus* L., badger *Meles meles*, Norway lemming

Lemmus lemmus (L.), and a number of unidentified rodents and birds. He considered the fauna to be typically Devensian late-glacial, although Campbell (1977) noted that the list was mixed, with species such as goat, sheep and aurochs more likely to be Holocene in age.

The third excavation was conducted by Campbell in 1968 (Campbell 1977). He excavated adjacent to McBurney's trenches and at the entrance to the smaller cave. The latter site proved unrewarding and was abandoned. Campbell recognised the same basic stratigraphy as McBurney, but he sub-divided the sequence in greater detail, and discovered additional mammal, artefact, granulometric and pollen evidence. Land snails were analysed from the sequence (Evans *in* Campbell 1977), and a bird fauna was described (Bramwell *in* Campbell 1977).

Campbell observed that the artefacts from Cat Hole showed surprising typological variation and that they occurred at three of four separate levels, rather than scattered more or less randomly as McBurney (1959) had suggested. Although McBurney had interpreted the scattered artefacts as a result of natural re-sorting by, for example solifluction, Campbell suggested that their vertical distribution reflected a number of distinct occupations; two perhaps of later Upper Palaeolithic age and two of Mesolithic age.

From pollen analysis Campbell interpreted systematic changes in the flora which spanned the Devensian Stage and Holocene. He observed that Devensian late-glacial Pollen Zones I, II and III were well represented in the pollen spectra, but that the record of the remainder of the Devensian and the Holocene was compressed. This reflected that the greatest thickness of deposits at Cat Hole is of Devensian late-glacial age. In relating the archaeological evidence to the pollen record, he concluded that the later Palaeolithic artefacts belonged entirely to Devensian late-glacial Pollen Zone I, and that the Mesolithic artefacts were associated with the early part of the Holocene. The Creswellian artefacts described by McBurney were believed by Campbell to have originated from a horizon time-equivalent to Pollen Zone III (the Younger Dryas). Bowen (1980a) noted that some of the pollen in Campbell's reconstruction might be derived.

Campbell also presented detailed faunal analyses and plotted the vertical distribution of all undisturbed teeth, bones and bone fragments found during his excavations. He concluded that the fauna associated with the later Upper Palaeolithic artefacts of Devensian late-glacial/Pollen Zone I age, would probably have included red fox *Vulpes vulpes*, arctic fox *Alopex lagopus*, brown bear *Ursus arctos* L., woolly rhinoceros *Coelodonta antiquitatis*, horse *Equus przewalski*, red deer *Cervus elaphus*, giant deer *Megaceros giganteus* Blumenbach, reindeer *Rangifer tarandus* L. and mountain hare *Lepus timidus*. Smaller mammals, such as arctic lemming *Dicrostonyx torquatus* (Pallas), Norway lemming *Lemmus lemmus* and tundra vole *Microtus gregalis* were also associated with the Devensian late-glacial sediments at Cat Hole. Campbell demonstrated that faunal elements such as goat, sheep and aurochs were clearly associated with the Holocene sediments at the site, and were not part of a 'mixed' single fauna described by earlier workers. Small mammals such as the woodmouse, water vole and mole were also associated with more temperate conditions during the Holocene. Similarly, Campbell noted that Wood's record of mammoth *Mammuthus primigenius* may have been associated with Devensian sediments of pre-Devensian late-glacial age at the site. This general interpretation of deposits according to the included fauna was also supported by analysis of the bird faunas from Cat Hole (Bramwell 1977).

Detailed analysis of the land snail faunas by Evans (1977b) *(in* Campbell 1977) did not reveal a Late Pleistocene 'cold' fauna but rather one of Holocene age that occurred within the older Devensian late-glacial sediments as an intrusive element; the snails had exploited the cavities of the loose rock rubble which comprised the bulk of the deposits (Evans 1977b). This was particularly well shown by the fauna found in the scree (bed 2). The lithology, pollen, small and large mammal fauna of this complex layer all indicated a cold climate, an open-country landscape and a Devensian late-glacial age; only the molluscan fauna was unequivocally of a warm temperate Holocene character (Evans 1977b).

The deposits at Cat Hole therefore reveal a sequence of changes during cold climate open-country (tundra) conditions when frost-shattered scree accumulated together with a generally 'cold' fauna including, for example, reindeer, arctic fox, arctic and Norway lemming. The site is also notable for a record of mammoth. The deposits also contain pollen indicating a pattern of floral changes characteristic of the Devensian late-glacial. The presence of Upper Palaeolithic Man at this time is indicated by numerous artefacts believed to be of Creswellian-type, and the site shows that variants of this culture extended into Wales. Faunal and pollen analyses clearly reveal the change from the generally cold conditions of the Devensian late-glacial to the Holocene, the latter being characterised by more temperate conditions and the presence of Mesolithic Man. The relative dating of the screes at Cat Hole by faunal, archaeological and pollen analytical means, provides evidence to suggest that scree found at many coastal sections around south Gower, may also have accumulated, at least in part, during the Devensian late-glacial.

Mammal, tools, pollen and sedimentary evidence from Cat Hole Cave have allowed the reconstruction of a detailed sequence of Devensian late-glacial and Holocene conditions. A 'cold' mammal fauna, found in association with Creswellian 'type' culture artefacts, provides the principal basis for dating most of the sediment sequence to the Devensian late-glacial. Pollen evidence also strongly suggests that most of the deposits at Cat Hole date from this time.

Conclusions

Cat Hole has yielded an exceptional combination of evidence for the fauna, flora and archaeology of the last 13,000 years, and is thus an important site for the period following the last major ice age.

Eastern Slade and Western Slade

Highlights

This site provides evidence, in the form of reworked glacial sediments, that this part of South Wales was glaciated by Irish Sea ice during a pre-Ipswichian glaciation. Its colluvial sediments and redeposited drift are proof that Devensian ice did not reach this part of Gower.

Introduction

Coastal exposures between Eastern Slade (SS489854) and Western Slade (SS484855) show evidence for the late Middle and Late Pleistocene history of south Gower. The locality is a reference site for redeposited pre-Devensian glacial sediments. It demonstrates that south Gower was free of glacier ice during the Late Devensian. The site was first described by Strahan (1907b) and later featured in studies by George (1932, 1933a, 1933b). The sequence was described and interpreted by Bowen (1966, 1969a, 1970a, 1971a, 1973b, 1974, 1977a, 1977b, 1984), and mentioned by Peake *et al.* (1973), Stephens and Shakesby (1982) and Bridges (1985).

Description

Between Oxwich Point and Horton, a fossil sea-cliff is buried by superficial deposits which were trimmed by the sea during the Holocene. At Western Slade, Eastern Slade and Horton, fault-guided dry valleys run inland to a plateau which is

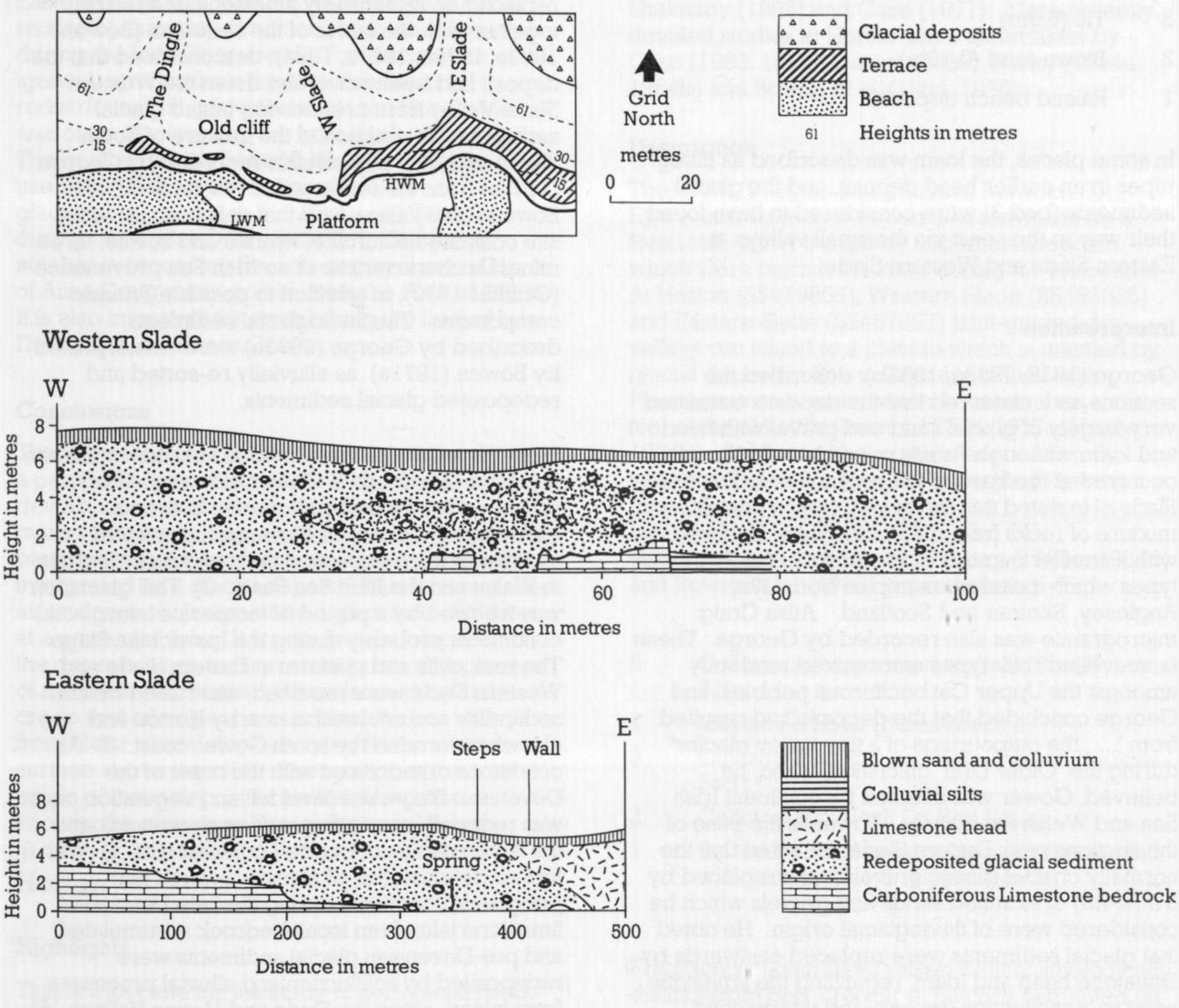

Figure 6 Quaternary sequence at Eastern Slade and Western Slade (after Bowen and Henry 1984)

mantled with glacial deposits. These valleys are infilled with Late Pleistocene sediments that extend onto the coastal margin as an apron or terrace. The following sequence overlies a Carboniferous Limestone shore platform.
(Stratigraphic terminology of Henry (1984a, 1984b) in parenthesis) –

3 Blown sand and colluvium (Port-Eynon Silt)
2 Redeposited glacial drift (Western Slade Diamicton) and limestone head (Hunts Breccia)
1 Colluvial silts (Pwll Du Red Beds)

This sequence is shown in Figure 6. Raised beach sediments may occur towards the base of the sections (Strahan 1907b; George 1932; Bowen 1970a) but are not usually exposed.

The sections at Eastern Slade and Western Slade were first described by Strahan (1907b) who recorded a sequence of –

4 Loam (3.0m)
3 Till (6.0m)
2 Blown sand (0.10m)
1 Raised beach deposits

In some places, the loam was described as filling pipes in an earlier head deposit, and the glacial sediments (bed 3) were considered to have found their way to the coast via the small valleys at Eastern Slade and Western Slade.

Interpretation

George (1932, 1933a, 1933b), described the sections and observed that the deposits consisted very largely of glacial sand and gravel with head and loam, although *Patella* raised beach deposits occurred at the base of the sections near Eastern Slade. He noted that the glacial gravel contained a mixture of rocks from the South Wales Coalfield with a smaller number of Precambrian and igneous types which included examples from Llŷn, Anglesey, Skomer and Scotland. Ailsa Craig microgranite was also recorded by George. These far-travelled rock types were mixed randomly amongst the Upper Carboniferous pebbles, and George concluded that the deposits had resulted from "..... the outpourings of a tiny valley glacier" during the 'Older Drift' glaciation, when, he believed, Gower was affected by confluent Irish Sea and Welsh ice masses. Towards the base of the sections near Eastern Slade, he noted that the normally chaotic glacial gravels were replaced by 8 ft (2.4m) of stratified sands and gravels which he considered were of fluvioglacial origin. He noted that glacial sediments were replaced eastwards by limestone head and loam, regarding the limestone head as a solifluction deposit, and interpreting small lenses of finer-grained material within the head as seasonal meltwater deposits. The capping loam was derived from older superficial deposits by wind action. The entire sequence of deposits had been trimmed flat by the sea sometime after deposition of the 'Older Drift'. George (1932) termed the upper surface of the terrace the 'Post Older Drift Platform', and considered it to be equivalent in age and origin to similar features in Rhosili and Hunts Bays.

Bowen (1966, 1969a, 1970a, 1971a, 1973b, 1974, 1977a, 1977b, 1984) recorded the sequence given in the site description of this report. He noted that colluvial silts (bed 1) were exposed in the lee of a large limestone buttress at Western Slade, and that they showed bedding indicating derivation from the north-west – see Figure 6. The unit was considered to post-date glaciation in the area because it contained derived erratics and was nowhere overlain by glacial deposits *in situ* (Bowen 1970a). The colluvial silts were overlain by slope deposits consisting of limestone head and redeposited glacial sediments (bed 2) or a mixture of both, with the proportion of head being greatest near limestone outcrops. Bowen (1970a, 1971a, 1984) noted that the redeposited till was confined to the middle of the bay at Western Slade and was replaced on its flanks by limestone head. This, together with the fabric of the sediment (Bowen 1969a, 1970a, 1971a, 1984), demonstrated that the deposit had been reworked down the Western Slade Valley from pre-existing inland glacial sediments. In addition to the mixture of South Wales and Irish Sea erratics recorded by George (1933a) from the redeposited glacial sediments, Bowen (1984) also noted that colluvial silts at the site contained staurolite, kyanite and zoisite, three minerals characteristic of an Irish Sea provenance (Griffiths 1939), in addition to possible Triassic components. The fluvioglacial sediments described by George (1933a) were reinterpreted by Bowen (1971a) as alluvially re-sorted and redeposited glacial sediments.

From the evidence in the coastal sections at this site and from elsewhere in Gower, Bowen (1971a) proposed the following sequence of events. 1)During an earlier pre-Devensian glaciation, sediments were deposited in Gower from sources in Wales and the Irish Sea Basin. 2) This glaciation was followed by a period of temperate interglacial conditions, probably during the Ipswichian Stage. The rock cliffs and platform at Eastern Slade and Western Slade were modified, and raised beach sediments accumulated at nearby Horton and elsewhere around the south Gower coast. 3) As conditions deteriorated with the onset of the Devensian Stage, sea-level fell and vegetation cover was reduced, promoting surface sheet-wash and the accumulation of bedded colluvial silts. 4) With a further deterioration of climate towards full periglacial conditions during the Late Devensian, limestone talus from local bedrock accumulated, and pre-Devensian glacial sediments were redeposited by solifluction and alluvial processes from inland, along the Slade and Horton Valleys. 5) Finally, towards the end of the Late Devensian, loess and colluvial sediments (bed 3) were deposited as a capping to the sequence (Bowen 1971a).

The sequence of sediments at Eastern Slade and Western Slade therefore provides an important record of environmental and geomorphological changes in Gower. The site shows particularly important evidence for the pre-Devensian glacial history of Gower, and is a reference site for redeposited glacial and other sediments of pre-Devensian age. During an 'early' glaciation, Gower was affected by ice, not only from the South Wales Coalfield, but also from the Irish Sea Basin. The sections also provide stratigraphic evidence to show that this part of south Gower lay outside the maximum limit of the Late Devensian ice-sheet.

Eastern Slade and Western Slade demonstrate the combined effects of topographic control and sedimentary processes on the accumulation and distribution of different sediment types. The site provides evidence with which to interpret coastal drift exposures elsewhere along the south Gower coast, and forms an integral part of a network of sites in Gower that constrain the position of the maximum limit of Late Devensian ice across the peninsula.

Eastern Slade and Western Slade provide a rock record of changing conditions in south Gower during the Late Pleistocene. The occurrence of igneous erratics from the Irish Sea Basin in redistributed till, provides evidence that Gower was once glaciated by ice from the Irish Sea Basin. The mixing of Irish Sea and Welsh rock types was used by T N George to show that Gower was glaciated by confluent Irish Sea and Welsh ice during the 'Older Drift' glaciation. The site is notable in recording the sole occurrence in Gower of Ailsa Craig microgranite from the Firth of Clyde. It is also important for establishing the limit of Late Devensian ice across Gower.

Conclusions

These localities are important as reference sites for a particular deposit which is nowhere else developed in such detail. This consists of a massive unsorted deposit (that is ranging from clay particles to large boulders) which was originally interpreted as a glacial deposit. That is, it was used as evidence to demonstrate a glaciation of Gower at a particular time. It is now known, however, that the deposit is not, in its present position, a product of an ice-sheet. Instead, it was formed by soil creep and other processes down the two valleys from older glacial deposits lying on the plateau surface above the cliffs. Recognition of the true origin of these deposits revolutionised the knowledge of ice age history in South Wales.

Horton

Highlights

This is a key site for the study of periglacial head, colluvial and loessic sediments dating from the Devensian Stage. Below these occur remnants of marine raised beaches probably formed in two separate interglacial periods, allowing the elucidation of a long and complex climatic and sea-level record.

Introduction

Exposures of superficial deposits near Horton (SS482856) show evidence of changing environmental conditions in south Gower. Until recently, it was held that head and colluvial deposits of Devensian age overlay raised beach deposits of Ipswichian age at Horton. Recent work, however, indicates that the raised beach deposits date from two separate sea-level events, which poses a question about the age of the sediment overlying the earlier beach (Bowen *et al.* 1985). Loessic deposits which are common around the South Wales coast are particularly well exposed at Horton. The site was first described by George (1933a), and subsequently by Wirtz (1953). The interpretation is attributed to Bowen (1966, 1969a, 1970a, 1971a, 1973a, 1973b, 1974, 1977a, 1977b), and references to the site have also been made by Mitchell (1972), Peake *et al.* (1973), Stephens and Shakesby (1982) and Case (1977). More recently, detailed studies at Horton were undertaken by Case (1983, 1984), Davies (1983), Henry (1984a, 1984b) and Bowen *et al.* (1984, 1985).

Description

The 200 ft (61m) coastal platform between Port-Eynon and Oxwich is terminated seawards by a fossil cliff, partly buried by superficial deposits which were marine trimmed during the Holocene. At Horton (SS479856), Western Slade (SS483856) and Eastern Slade (SS487857) fault-guided dry valleys run inland to a plateau which is mantled by glacial deposits. The valleys are infilled with Pleistocene sediments which form terraces at the foot of the old cliffs (Bowen 1971a, 1977a; Henry 1984b). At Horton, the exposures are laterally variable (Figure 7), but they show the following generalised sequence above a Carboniferous Limestone shore platform at *c.* 10m OD. (Stratigraphic terminology of Henry (1984a, 1984b) and Bowen *et al.* (1985) in parenthesis) –

5 Colluvium, blown sand and silt (Port-Eynon Silt)
4 Limestone head (Hunts Breccia)
3 Colluvial silts and boulders (Horton Boulder Bed)
2 Colluvial silts (Pwll Du Red Beds)
1 Raised beach deposits, largely uncemented with red silt (Horton Upper Beach)

Fragments of cemented raised beach, lithologically distinct from bed 1, occur in patches cemented on the walls of gullies in the exposed limestone shore platform (Horton Lower Beach; Davies (1983), Bowen *et al.* (1985)).

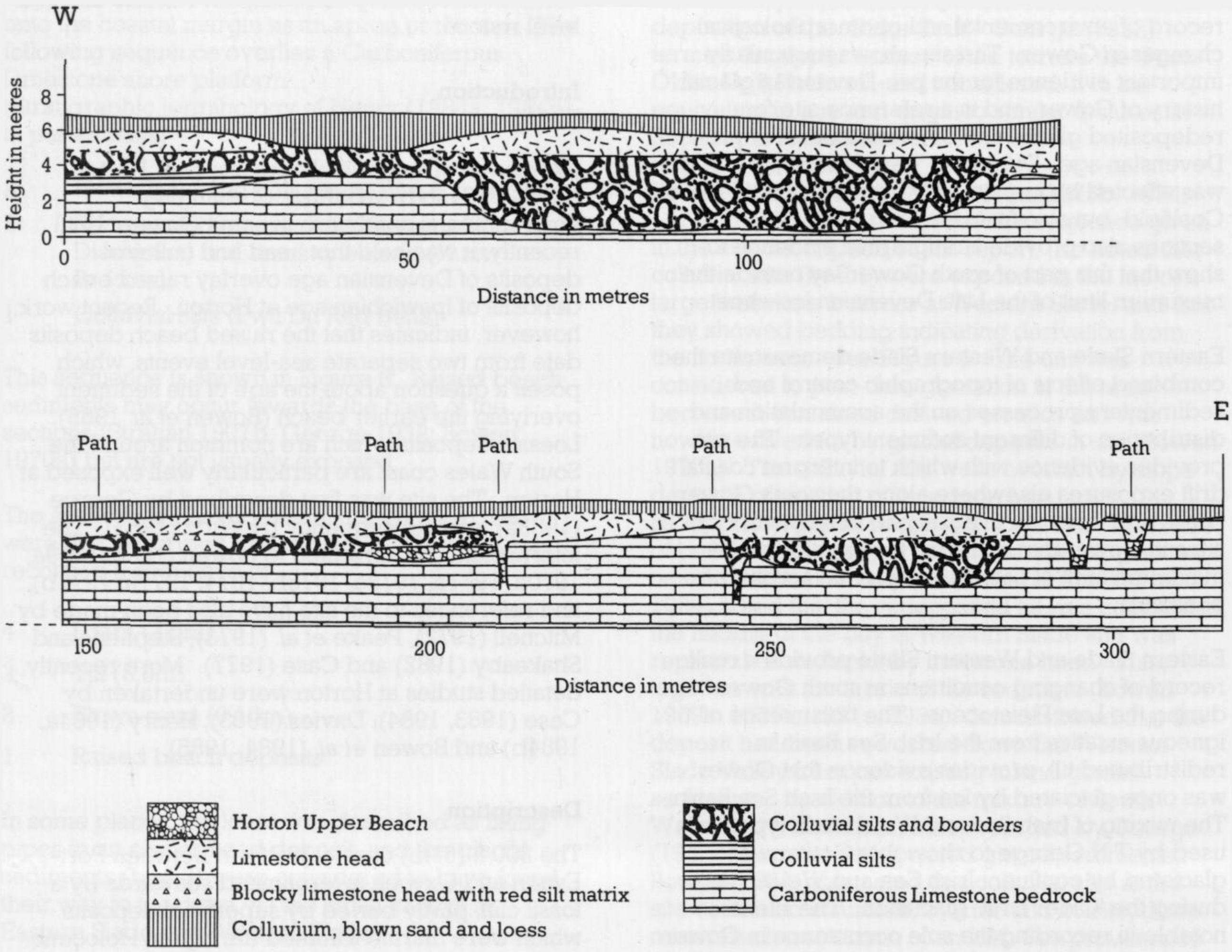

Figure 7 Quaternary sequence at Horton (after Bowen and Henry 1984)

Interpretation

The Pleistocene deposits at Horton were first described and interpreted by George (1933a) who noted a coarse breccia containing massive limestone blocks overlying bedrock. Pockets of glacial material and solitary erratics, including several igneous rock types from outside the local area, were scattered through the breccia. He therefore concluded that the deposit was 'not merely a local talus' and 'had undergone some measure of transportation by ice' (George 1933a).

Wirtz (1953) referred to raised beach deposits at Horton, which he considered to be of Holstein age (Hoxnian Stage). These were overlain by cold-climate 'frost-shattered rubble' attributable to one or more phases of glacial climate. In a series of papers, Bowen (1966, 1969a, 1970a, 1971a, 1973a, 1973b, 1974, 1977a, 1977b) described and interpreted the stratigraphy at Horton. The raised beach (bed 1) differed from the typical *Patella* Beach (George 1932) around Gower in its uncemented character, its matrix of colluvial material and its high erratic content, both from South Wales and the Irish Sea Basin sources. He suggested that the anomalous matrix may have been translocated downwards or accumulated contemporaneously with the beach. He referred to the boulder bed described by Wirtz (1953) as 'frost-shattered rubble', and noted that the boulders did not have the angular edges characteristic of periglacial material. Rather, they were subrounded and compared with 'joint-bounded weathered limestone' from 'the fossil cliff at the rear of the exposure'.

From the evidence at Horton, Bowen (1969a, 1970a, 1971a, 1977a, 1977b) proposed the following sequence of events –

1. During the 'Older Drift' glaciation, glacial sediments were deposited in Gower. Erratic and stratigraphic evidence from South and west Wales suggested that this 'early' glaciation was probably multiple in nature and from both Irish Sea Basin and local Welsh sources.
2. During high relative sea-levels in the succeeding Ipswichian Stage, raised beach deposits (bed 1) accumulated at Horton, and erratics became incorporated into the beach

from the earlier 'Older Drift' glacial deposits. During this interglacial phase, temperate soils formed locally and weathering occurred on the limestone cliffs. The red, probably colluvial matrix of the raised beach shows that it may have accumulated late in the Ipswichian. Bowen (1970a) tentatively correlated this phase of formation with the Neritoides Beach at nearby Minchin Hole Cave.

3 As sea-level began to fall and climate deteriorated in the succeeding cold Devensian Stage, reduced vegetation cover promoted sheet-wash and colluviation. Soils from the plateau and weathered limestone from the local cliffs moved downslope to form the colluvial silts (bed 2) and boulder beds (bed 3) at Horton. The dominance of weathered limestone blocks in the latter bed and the lack of appreciably angular material strongly suggests that these deposits did not form under periglacial conditions (Bowen 1971a, 1974).

4 However, probably during the Late Devensian, periglacial conditions were experienced at the site, limestone head (bed 4) accumulated and elsewhere, for example, Western Slade, 'Older Drift' glacial deposits were reworked from the plateau, along fault-guided valleys to the coast.

5 Case (1977, 1983) suggested that head formation at Horton was succeeded, without hiatus, by deposition of sand and silt (bed 5). This largely wind-blown deposit formed at the end of the Devensian, with proglacial outwash from the Late Devensian ice-sheets as a source for the aeolian silt (Case 1977, 1983). Cryoturbation of the upper head deposits (bed 4) at Horton may also have occurred at this time (Bowen 1966) and loess and colluvial deposits (bed 5) may well have continued to form into the Holocene (Bowen 1971a). The entire sequence of cold-climate and periglacial deposits (Beds 2-5) at Horton was thus considered by Bowen (1973b) to represent the whole of the Devensian Stage (but see Bowen et al. 1985). During the Holocene, the drift sequence was marine trimmed.

In addition to the sequence described by Bowen (1970a), Stephens and Shakesby (1982) noted a sub-horizontal bed of well rounded limestone cobbles in the head sequence at Horton, the origin of which was uncertain. One possible interpretation, however, is that the limestone pebbles are from reworked (that is soliflucted) raised beach sediments.

Case (1983, 1984) examined the Port-Eynon Silt (bed 5) as part of a detailed study of Quaternary airfall and coversand deposits in South Wales. He confirmed the origin of the sediment as a loess and concluded that it had accumulated during dry, cold and windy conditions at the end of the Devensian Stage. The mineralogy of the deposit, however, showed that the loessic silt had probably been derived from Irish Sea glacial deposits to the west, and not from proglacial Welsh outwash as he had previously suggested (Case 1977). A thin layer of sand capping the loess at Horton was also described (Case 1983, 1984) and was considered to be the product of Holocene dune formation.

Henry (1984a, 1984b) described the lithological characteristics of the deposits at Horton and proposed formal lithostratigraphic units (see site description). She showed that two raised beaches at Horton (Horton Upper Beach (bed 1) and Horton Lower Beach (isolated on the limestone platform); Bowen *et al.* 1985) could be distinguished on lithology, texture, clast roundness and foraminiferal assemblage. She concluded, however, that in both beaches, the forams indicated temperate shallow marine conditions, and that the beaches represented sea-level stands at least as high as at present.

Davies (1983) had already, in an amino acid geochronological study of the raised beaches of Gower, presented data which suggested that the two raised beach deposits at Horton were of different ages. She suggested that the largely uncemented raised beach deposits (bed 1; Horton Upper Beach) could be correlated with Oxygen Isotope Stage 7 of the deep-sea record *(c.* 210,000 BP). The Horton Lower Beach, only found cemented to the limestone bedrock and not in a stratigraphic context, was correlated with Oxygen Isotope Sub-stage 5e *(c.* 125,000 BP): in common with many other raised beach deposits in Gower. Bowen *et al.* (1985) and Bowen and Sykes (1988) presented further amino acid geochronological data for the raised beach deposits at Horton, using an improved measurement technique. The ascription of the beaches, however, remains unchanged, but fauna from two separate events is contained in the Upper Beach.

The occurrence at Horton of raised beach sediments of different ages, causes problems in interpreting the overlying beds (Henry 1984a, 1984b; Bowen *et al.* 1985). The Horton Lower Beach was deposited during Oxygen Isotope Sub-stage 5e. The terrestrial deposits overlying the Horton Upper Beach (bed 1), however, are all thought to have been deposited in the Devensian Stage. Henry (1984a, 1984b) proposed that the colluvial silts (bed 2) and colluvial silts with boulders (bed 3) accumulated during the Early and Middle Devensian: as sea-level fell and climate deteriorated, vegetation cover was reduced and sheet washing of previously weathered deposits occurred. During ensuing periglacial conditions in the Late Devensian frost-shattered limestone head (bed 4) accumulated (cf. Bowen 1970a, 1971a). Case (1977, 1983, 1984) has shown that head formation was followed without a break by deposition of wind-blown sand and loess (bed 5).

Horton is, therefore, an integral member of a network of sites in Gower that shows evidence for changing conditions during the Late Pleistocene.

The occurrence of raised beach deposits of different ages makes the site especially important, but causes problems in interpreting the ages of the deposits which overlie the oldest beach. Horton is a reference site for the colluvial deposits and associated boulder beds. It may be regarded as a standard section for the loess in South Wales.

Conclusions

Horton displays two adjacent raised beaches of different ages. One is about 200,000 years, and the other 125,000 years old. It is also important because it is the type-site for loess in South Wales. Loess is a wind-blown silt which was deposited from large dust storms towards the end of the ice age. Loess is extensive in South Wales, but rarely is it seen to such advantage as at Horton. Loess is an important element in South Wales soils, and provides the loamy character of many of the most productive soils in the region.

Long Hole Cave

Highlights

A site with rich Pleistocene mammal remains and human artefacts dating from the Ipswichian and Devensian Stages. 'Cold' and 'warm' mammal faunas and pollen indicate several phases of marked climatic and vegetational change, varying from temperate interglacial and interstadial conditions to arctic desert.

Introduction

Long Hole Cave (SS452851) is important for deposits which have yielded faunal remains, artefacts and pollen. Excavations at the site during the last century produced what could be identified as 'warm' and 'cold' mammal faunas. More recent excavations have revealed a series of well stratified sediments together with fossils and artefacts from mainly pre-late-glacial times in the Devensian Stage. The site was first excavated by Wood in 1861 (see Falconer 1868). Evidence from the site was subsequently discussed by Lyell (1873), Roberts (1887-8), Garrod (1926), Allen and Rutter (1948) and Bowen (1980a). Campbell (1977) provided a detailed account of the sequence and its interpretation, and Evans (1977b) (*in* Campbell 1977) analysed the land snail fauna.

Description

Long Hole Cave is situated in cliffs of Carboniferous Limestone in south-west Gower. The cave lies at *c.* 55m OD and from a SSE-facing entrance, opens directly into a single passage some 15m long. A sequence of terrestrial sédiments comprising cave earths, scree, weathered scree and fine-grained wind-blown sediment up to 3m thick rests on a limestone floor. Substantial deposits are thought to remain *in situ.* Full details of the stratigraphy are provided by Campbell (1977).

The first known excavations at Long Hole by Wood were largely within the cave, and they were later documented by Falconer (1868). Initially, the cave was blocked by a talus cone, but after this had been removed, Falconer recorded a single layer of ferruginous cave earth mixed with angular limestone fragments overlying the limestone floor. The 'cave earth' was noted as being about 7 ft (2.1m) thick, but there was no trace of marine sand or shingle, like that found at nearby Minchin Hole and Bacon Hole. Falconer recorded a mixture of 'warm' and 'cold' Pleistocene faunas, with – cave bear *Ursus spelaeus*, badger *Meles meles*, polecat *Mustela putorius*, marten *Martes* sp., otter *Lutra lutra* L., red fox *Vulpes vulpes*, wolf *Canis lupus*, spotted hyaena *Crocuta crocuta*, wild cat *Felis sylvestris* Schreber, lion *Panthera leo*, Irish elk *Megaceros giganteus*, reindeer *Rangifer tarandus*, red deer *Cervus elaphus*, bison *Bison priscus*, wild boar *Sus scrofa* L., horse *Equus ferus* Bodaert, and European wild ass *Equus asinus*, narrow-nosed rhinoceros *Dicerorhinus hemitoechus*, woolly rhinoceros *Coelodonta antiquitatis*, straight-tusked elephant *Palaeoloxodon antiquus*, mammoth *Mammuthus primigenius*, mountain hare *Lepus timidus*, rabbit *Oryctolagus cuniculus* (L.) and water vole *Arvicola terrestris* (Hinton). Flint and chert artefacts associated with the fauna were also unearthed (Falconer 1868). These finds were regarded with considerable interest because, according to Sir Charles Lyell (1873), they provided "the first well authenticated example of the occurrence of *D. hemitoechus* in connection with human implements". The finds were therefore used as evidence for the 'antiquity of Man', clearly showing the relationship between the handiwork of Man and the remains of animals, many of which were extinct (Roberts 1887-8).

Interpretation

The stone implements found by Wood were fully described by Garrod (1926), who suggested that the artefact assemblage was probably of Middle or Upper Aurignacian age. She noted, however, that the fauna associated with it was mixed, some of the mammals being of known interglacial ('warm') and others of glacial ('cold') character. This indicated that there had been either some disturbance of the cave earth or that two levels were present but that they had not been detected. For the same reasons, Allen and Rutter (1948) thought that the contemporaneity of Palaeolithic Man with *Dicerorhinus hemitoechus* was questionable.

Campbell in 1969 (Campbell 1977) cut a trench adjacent to Wood's at the cave entrance. He presented detailed stratigraphic, granulometric, faunal, artefact and pollen evidence in his analysis of the sequence. Land snails found in the older deposits were present, but as at Cat Hole, only as an intrusive Holocene element (Evans 1977b).

Campbell reconstructed the following sequence of events. The earliest stage recorded is the

Ipswichian when a temperate woodland environment prevailed, with a thermophilous flora and a fauna including *Bison* or *Bos*. Several of Falconer's species such as *Palaeoloxodon antiquus* and *Dicerorhinus hemitoechus* may also have originated from this temperate phase or even earlier (Campbell 1977). A prolonged period of arctic tundra development is then indicated by the pollen record. This phase is interrupted early in the sedimentary sequence by deposits with pollen that indicate the development of boreal coniferous forest with *Picea, Pinus* and *Betula*, and which allow a correlation tentatively with the Early Devensian Chelford Interstadial at *c*. 65,000 BP. The lithology of the bed containing the Chelford pollen is dominantly weathered scree, and Campbell observed that Palaeolithic artefacts (of presumably Mousterian culture (Bowen 1980a)) were associated with it. A Chelford Interstadial age was supported by a fauna including elk and marten. This phase was followed by a protracted period of steppe and tundra conditions during which screes accumulated. These were believed to have been deposited during the Middle Devensian; they were characterised by a comparative abundance of *Juniperus* and *Salix* pollen, and by a fauna including hyaena, mammoth, woolly rhinoceros, horse, giant deer, reindeer and mountain hare (Campbell 1977). Artefacts indicating the presence of Upper Palaeolithic Man are associated with these deposits. Bowen (1980a) agreed that the pollen record from these sediments was consistent with the Middle Devensian, perhaps reflecting conditions during the Upton Warren Interstadial.

According to Campbell, the Late Devensian ice maximum was indicated in the Long Hole sequence by the apparent minimum of tree and shrub pollen, accompanied by deposition of fine-grained wind-blown sediment. This severely cold phase was associated with a fauna of arctic fox, horse and reindeer. Devensian late-glacial Pollen Zones I, II and III and Holocene Pollen Zones IV-VIII were also distinguished in the sequence at Long Hole (Campbell 1977).

Thus, Campbell's work showed that at least four separate faunal assemblages ranging from the late Ipswichian Stage through the Devensian Stage, and clearly associated with climatically related changes in lithology and pollen, occurred within Long Hole Cave. Falconer's original species list is considered to be a mixture of Ipswichian ('warm') and Devensian ('cold') mammal faunas.

The evidence from Long Hole, particularly the pollen record, was discussed by Bowen (1980a). He noted that except for the event referred to the Chelford Interstadial, and the rise in *Juniperus* and *Salix* pollen, no other indications of Early and Middle Devensian interstadial conditions were then known from Wales. Bowen stressed, however, that Campbell's pollen analysis had been carried out on sediments that were technically head and colluvium and there was therefore a distinct possibility that some of the pollen was derived. This was probably true, especially for the basal layers. The Chelford pollen might easily be reworked pollen of Ipswichian age. Equally, both events recorded could be equivalent to Oxygen Isotope Sub-stages 5e and 5c (Bowen 1980a).

The record of elk *Alces alces* (L.) from Long Hole was of particular interest, as this species was extremely rare in Britain prior to the Late Devensian Allerød. The antler base, found in 1969, is now preserved at the Baden-Powell Museum, Oxford. Re-examination of the specimen, however, indicates that it should almost certainly not be referred to *Alces alces* but to reindeer *Rangifer tarandus* (Lister 1984).

With the reservations noted earlier, the pollen record is perhaps the best so far available in Wales for the whole of the Devensian Stage, showing possible evidence for a brief temperate interlude correlated tentatively with the Chelford Interstadial. The site thus covers an important part of the Pleistocene record that is not well represented at other sites; for instance, it contrasts with Minchin Hole where the sequence shows strong evidence for changing marine and terrestrial conditions during the Ipswichian Stage and earlier. The Long Hole sequence also contrasts with those at Bacon Hole and Cat Hole Caves where particularly detailed palaeoenvironmental evidence for the Ipswichian and Early Devensian stages and the Devensian late-glacial are represented, respectively.

Long Hole Cave contains an important record of changing conditions from the Ipswichian Stage through the Devensian Stage into the Devensian late-glacial. The site is particularly important for its pollen record which covers the Devensian Stage. This record shows that a period of arctic conditions was interrupted by the development of boreal coniferous forest. This warmer phase has been correlated with the Early Devensian Chelford Interstadial; as such, the site provides the only evidence in Wales for this event. Long Hole Cave is therefore the only known Welsh site with fossil, implement, rock, pollen and spore evidence for changing climatic conditions in Wales during the Early and Middle Devensian.

Conclusions

Long Hole Cave contains deposits representing all of the last ice age: from about 80,000 years ago to 10,000 years ago. It contains archaeological evidence for the earlier part of the last ice age. In addition, some of the deposits contain pollen which show the former existence of boreal (northern) forest. It is an important site because of the range of evidence it contains.

Worm's Head

Highlights

This site provides an important record of climatic change from the last, Ipswichian, interglacial through the cold and periglacial phases of the Devensian. Evidence presented for the presence of an interglacial soil has provoked much research interest.

Introduction

Worm's Head (SS396874) records important information for changing conditions in central South Wales during the Late Pleistocene. Its raised marine sediments, periglacial head and glacigenic sediments have long been recognised (George 1932), but the site has gained further importance through the description of a possible interglacial soil (Ball 1960). The site was first mentioned by Strahan (1907b) and was subsequently described by George (1932, 1933a, 1933b). It has featured in studies by Ball (1960), Bowen (1965, 1966, 1969a, 1970a, 1974, 1977b), and more recently was mentioned by Stephens and Shakesby (1982). Aspects of the Pleistocene deposits were also studied by Tindall (1983) and Campbell (1984).

Description

Raised beach, glacigenic and periglacial head and colluvial sediments are widely distributed on the 'outer', 'middle' and 'inner' heads that make up Worm's Head, and they were mapped by George (1932). These deposits, however, are best developed on the south and west flanks of the inner head overlying a Carboniferous Limestone shore platform, where the following sequence occurs (Ball 1960) –

5	Dull grey-brown sandy loam, almost stoneless (0.75m)
4	Dull grey-brown, stony sandy loam, with common Devonian and Carboniferous sandstones (glacial sediment) (1.0-2.0m)
3	Brown loam with abundant angular limestone clasts (head) (3.0m)
2	Red sandy-clay loam, with rare limestone pebbles (0.25-0.45m)
1	Cemented *Patella* raised beach deposits

Most beds from this sequence are well displayed on a small knoll or terrace separated from the inner head (SS396874), although sections through the raised beach, head and glacial deposits also occur on the west side of the inner head (SS392877).

Interpretation

The Pleistocene sequence was first described by Strahan (1907b) who recorded a succession of raised beach, head and sand bordering the inner head of Worm's Head. George (1932) mapped these deposits, and considered that the distribution of the glacial gravels was particularly significant (George 1933a). He noted that a drift terrace bordered much of the Worm, but that, on the south side of the main upstanding hills, locally derived limestone head was preserved above the *Patella* raised beach but no glacial sediments. This contrasted to the east and west margins of the hills where mixed lithology gravel occurred; which could only satisfactorily be explained, George (1933a) suggested, on the assumption that the inner, middle and outer heads had formed three buttresses protecting ground to the south from the onslaught of the ice. George (1932, 1933a, 1933b) envisaged that the *Patella* Beach had formed before the 'Older Drift' glaciation of South Wales. He noted the similarity between the glacial gravels on Worm's Head and those at Rhosili, and suggested that they had been derived from the north and north-east during the 'Older Drift' glaciation, when confluent Welsh and Irish Sea ice masses may have affected the south and west coasts of Gower.

George (1933a) also described the upper loam (bed 5) as a loess-like deposit which had probably been derived from the underlying glacial sediments, and which had accumulated under aeolian conditions. He noted, however, that this loess-like sediment provided a flat capping to many of the sections along the Gower coast, and suggested that, like the drift terrace at Rhosili, these sediments had finally been fashioned by marine agencies. The platform was tentatively referred to as the 'Post Older Drift Platform', although its specific age was uncertain (George 1932).

Ball (1960) described what he believed to be an *in situ* interglacial soil (bed 2). The micro-fabric and mineralogy of this deposit suggested that it was transitional between *terra fusca* and *terra rossa* soils commonly found on limestone around the Mediterranean today (Ball 1960). He concluded that the soil had formed under slightly warmer summer conditions than at present, and postulated that it was *in situ* relict material, formed during interglacial (Ipswichian) conditions; moreover that together with other similar deposits, it had only survived locally in areas not glaciated by Late Devensian ice.

Accepting that the sediment described by Ball (1960) might contain elements of an interglacial soil, Bowen (1965, 1966) considered that the bed had been reworked by solifluction. Subsequently, Bowen (1969a, 1970a, 1971a, 1974, 1977b) suggested that such sediments had formed by soil erosion and sheet-washing. He classified them as colluvial silts and compared them to the 'limon rouges' of the Mediterranean. Bowen (1970a) noted that such sediments were widespread in south Gower, and that they formed an important stratigraphic unit, suggesting that they had been deposited by colluviation at the foot of the coastal cliffs, as sea-level fell towards the end of the Ipswichian Stage. At that time, an ever increasing area of sea-bed was exposed, and deflated sand from this source may also have been mixed with the colluviated remnants of interglacial soil, perhaps even with residual Keuper Marl and the fines washed from glacial deposits of pre-Ipswichian ('Older Drift') age (Bowen 1969a, 1970a). The mixed lithology drift (bed 4) on Worm's Head, and at Rhosili, had been deposited as outwash from the Late Devensian ice-sheet which may have reached its southern limit where Whitford Point now lies (Bowen 1970a). Stephens and Shakesby (1982) suggested that drift overlying Ball's (1960) interglacial soil, might be redistributed pre-Devensian glacial sediment, or, alternatively (for example, Bowen 1970a), Late Devensian outwash.

Tindall (1983), in an examination of diagnostic sedimentary properties of the deposits on Worm's Head, noted that the fabric of bed 4 (the outwash sediments of Bowen (1970a)) showed a marked downslope orientation, and she concluded that the glacial sediments were not *in situ*, but had been soliflucted into position. She also recorded that elsewhere (for example, at SS396874) these beds were disrupted by periglacial convolutions.

Campbell (1984) concluded from Scanning Electron Microscopy studies of sediments that there was no evidence for a protracted period of *in situ* interglacial weathering as proposed by Ball (1960), and the presence of many well rounded marine-type quartz sand grains supported Bowen's view that the deposit (bed 2) contained deflated (wind-blown) marine sand. Ball (1985 - personal communication), now accepts that interglacial soil material on Worm's Head is probably not *in situ*. Campbell's (1984) SEM data, however, did not allow a palaeoenvironmental interpretation of the mixed lithology drift on Worm's Head, although he suggested that they were compatible with redeposited glacial material.

The raised beach deposits of both inner and outer Worm's Head (for example, bed 1) were formed during the Ipswichian Stage, as shown by amino acid geochronology (Bowen *et al.* 1985; Bowen and Sykes 1988). The colluvial sediments (bed 2) and head deposits of local lithology (bed 3) accumulated during the subsequent Devensian Stage. The origin of the gravels (bed 4), however, remains uncertain. They may represent soliflucted deposits from a glaciation that pre-dated the Ipswichian Stage, or they may have been deposited as outwash from the Late Devensian ice-sheet. The overlying silty sand (bed 5) is probably a mixture of wind-blown and colluvial sediments deposited towards the close of the Devensian Stage.

Worm's Head is important for sediments which show a sequence of changing conditions from the high sea-levels and temperate conditions of the Ipswichian Stage (Oxygen Isotope Sub-stage 5e) through cold, to fully periglacial conditions in the Devensian Stage. The site became particularly important following Ball's (1960) description of a possible interglacial soil. This has since been shown to be a colluvial deposit. Worm's Head remains important in understanding Late Pleistocene events in south-west Gower, particularly for establishing the precise limit of the Late Devensian ice-sheet.

Conclusions

Worm's Head displays a sequence of deposits representing the last glacial cycle. In particular, it contains a colluvial (slope wash) deposit previously interpreted as a soil profile, which is important evidence for showing how the last interglacial changed into the last ice age.

Rhosili Bay

Highlights

A key site where fluvioglacial sands and gravels, thick periglacial heads and possible till deposits provide vital evidence for reconstructing Devensian environments in west Gower, including possible evidence for a Late Devensian ice lobe in Carmarthen Bay.

Introduction

Rhosili Bay (SS414900) shows evidence for the glacial and periglacial history of west Gower. Thick head (periglacial) deposits are exposed in coastal cliffs for about 2km at the foot of Rhosili Down, and these form one of the finest examples of a solifluction terrace in Wales. Deposits at Rhosili also help to establish the maximum limit of the Late Devensian ice-sheet in west Gower. Site investigation commenced with Prestwich (1892). It was reinterpreted by Strahan (1907b) and was studied in detail by George (1932, 1933a). Aspects of the Pleistocene history of the site were also dealt with by George (1933b, 1938), Griffiths (1939), Bowen (1966, 1970a, 1973a, 1973d, 1974, 1977a, 1977b, 1980a), Peake *et al.* (1973), Green (1981b), Campbell and Shakesby (1982), Stephens and Shakesby (1982) and Bridges (1985). Campbell (1984) provided a detailed description.

Description

Rhosili Down is formed of Devonian Old Red Sandstone. It trends north-south, and rises steeply above the coastal plateau of Gower to a height of 193m OD. At several localities Old Red Sandstone sandstones and conglomerates crop out as tors. At the west side of Rhosili Down, a large solifluction terrace has been cliffed by the sea. Exposures in the terrace show that, for much of its length, it consists of head (periglacial) of local Old Red Sandstone sandstones and conglomerates. Towards the north end of the bay (SS414900), however, a more complex sequence is seen – see Figure 8; (Campbell 1984) –

5 Blown sand

4 Colluvium (0.5m)

3 Upper head (2.0-3.0m)

2 Gravel containing clasts of mixed lithology (6.0m)

1 Lower head (2.0-3.0m)

The gravel (bed 2) extends laterally for only 150m, and then lenses out to be replaced by head. It overlies the lower head (bed 1) with a sharp undulating boundary, and evidently corresponds with the 'glacial gravel' described by George (1933a) and the 'outwash' of Bowen (1970a). The boundary between beds 2 and 3, however, is gradational, and large pockets of sand and gravel from bed 2 are incorporated within the upper head. Till has also been described from the site, within the gravels of bed 2 (Campbell and Shakesby 1982; Campbell 1984).

Interpretation

Pleistocene deposits were first recorded at Rhosili Bay by Prestwich (1892), who described a bed of shelly sand and gravel (bed 2) between layers of Old Red Sandstone rubble in the coastal terrace. The presence of marine shell fragments in the gravelly drift led him provisionally to refer to the deposit as a 'raised beach'. Strahan (1907b), however, considered the gravel to be glacial in origin, noting the presence of many far-travelled Old Red Sandstone and South Wales Coalfield erratics. He concluded that the gravel had been derived from a northern source, and interpreted the upper and lower 'rubble' beds as strictly local talus deposits derived from the Old Red Sandstone hills above the bay. Strahan (1907b) could not locate shells similar to those described by Prestwich (1892), but he speculated that the *Mya, Turitella* and *Nassa* shells had been derived from a sea-bed, probably in Carmarthen Bay. This implied a south-east flow of ice, which he suggested might also account for the presence of several igneous (Irish Sea) erratics in the gravel.

George (1932, 1933a) gave a comprehensive account of the deposits at Rhosili in his classic accounts of the raised beaches and glacial deposits of Gower. He suggested that the glacial gravel (bed 2) occurred as a large wedge which thinned to the south. Southwards, the upper and lower head deposits merged imperceptibly, and he considered that deposition of the glacial gravel had been merely "a brief interlude" in the formation of the head deposits. He recorded a number of far travelled rock types from the glacial gravel which included soda felsite (from Llŷn), perlitic-rhyolite (Pembrokeshire?), Llandovery mudstone (Haverfordwest?), horneblende-porphyrite (south Scotland), quartz-hyperite (south Scotland) and Precambrian slate. However, these rock types, thought to have been transported to Gower by Irish Sea ice, formed only a small proportion of the total assemblage so he was confident that the bulk of the gravel had been derived from the north; citing in particular, the presence of Millstone Grit from the North Crop, and Carboniferous Limestone traceable on its fossil content to north-west Gower. The shells described by Prestwich (1892) were considered to have been dredged from the floor of Carmarthen Bay as the Welsh ice moved southwards. The mixture of Welsh and Irish Sea erratics was used as evidence (George 1933a) to

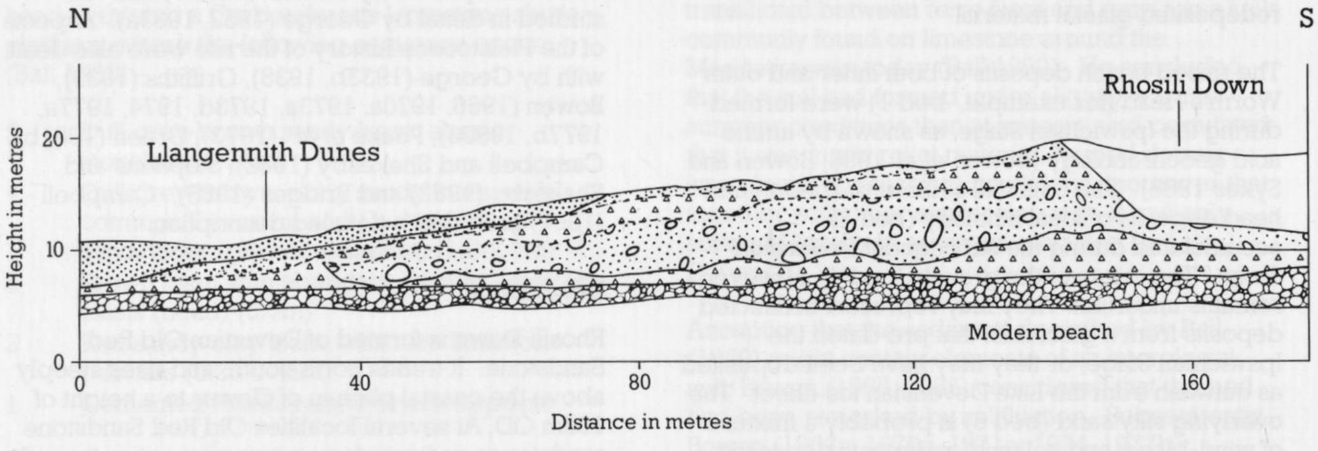

Figure 8 Quaternary sequence at Rhosili Bay (after Campbell 1984)

suggest that during the 'Older Drift' glaciation, Carmarthen Bay and the Loughor Estuary had been congested contemporaneously with ice masses both from the Welsh uplands and from the Irish Sea Basin. The mixed provenance of the drift deposits in west Gower in general, and Rhosili in particular, was later confirmed by heavy mineral analyses (Griffiths 1939).

George (1933a) considered that the Old Red Sandstone rubble horizons (beds 1 and 3) at Rhosili had been emplaced in a 'rigorous climate', and noted that the surface of the drift terrace was almost flat-topped, sloping gently seawards. Because this terrace and those elsewhere in Gower were cut across deposits of markedly different types (glacial gravel, cemented and uncemented heads, silts and sands), George (1932) remarked that they could not have been formed solely by subaerial processes, and he suggested that the final moulding of the features had taken place by planation during a short period of marine erosion, of unspecified age. He termed such features the 'Post Older Drift Platform'.

Bowen (1966) initially considered that the glacial gravels (bed 2) were of Saalian age, although he revised this in later papers. He accepted that shells in the gravels at Rhosili had been picked up by ice from the floor of Carmarthen Bay and the Loughor Estuary (Bowen 1970a). These shells were then incorporated into outwash from the margin of the Late Devensian ice-sheet which stood somewhere in the region of present day Whitford Point (Bowen 1970a). Gravels from this ice-sheet were deposited at Rhosili and on nearby Worm's Head. He considered that the Irish Sea erratics described by George had been reworked by the Devensian ice from earlier 'Older Drift' glacial deposits. Unlike George he did not believe that the sediments had been deposited by confluent Irish Sea and Welsh ice masses of 'Older Drift' age, citing the relatively undissected and fresh nature of the drifts as evidence for a Devensian age.

Following deglaciation of the Late Devensian ice-sheet, head deposits continued to form at Rhosili, covering the earlier outwash (Bowen 1970a, 1973a, 1973d, 1974, 1977a, 1977b, 1980a). Bowen noted that, as at Morfa-bychan (west Wales), local site conditions had been particularly favourable for the accumulation of solifluction deposits; a high slope of well jointed and well bedded Old Red Sandstone, and a westerly aspect which would have encouraged numerous freeze-thaw cycles, led to deposition of an upper head up to 15m thick. Bowen (1974, 1977a, 1980a) remarked that much of the upper head (bed 3) had probably accumulated during the Devensian late-glacial, and that the impressive solifluction terrace had formed over a period of, at most, 5,000 years. Rhosili Bay could be contrasted (Bowen 1973a, 1977a) with sequences at Glanllynnau in north-west Wales and Horton in south Gower where site conditions had not favoured head accumulation. At Horton, for example, the Devensian Stage was represented by only *c.* 2m of deposits (Bowen 1977a).

Winter storms in 1979-1980 revealed sediments at the base of the section that Campbell and Shakesby (1982) interpreted as till. Although the stratigraphic relationship of some of these deposits to those in the cliff behind was uncertain, others were interstratified with sands and gravels in bed 2. The clast lithologies and fabric pattern of the till indicated a north-west source, and this led to speculation (Campbell and Shakesby 1982; Stephens and Shakesby 1982) that Late Devensian ice may have reached farther south than others envisaged. They suggested that Carmarthen Bay may have been occupied by a large piedmont ice lobe, similar to that described in Swansea Bay (Charlesworth 1929; Bowen 1970a).

Following the discovery of the till, the site was re-investigated by Campbell (1984), who applied methods including Scanning Electron Microscopy, fabric analysis and clast lithological and roundness measurements to the interpretation of the sequence. From the evidence at Rhosili, Campbell (1984) proposed the following sequence of events. During the Late Devensian, around 18,000 years ago, Welsh ice moved southwards across Carmarthen Bay and on to west Gower to deposit shelly till at Broughton Bay. At that time, Rhosili Bay was probably in the periglacial zone, and the lower head may date from this time or even earlier in the Devensian Stage. The Late Devensian ice-sheet appears to have been near its maximum limit, and a mixture of fluvioglacial outwash and, perhaps, flow tills was deposited at the northern end of Rhosili Bay along the proglacial fringe of the ice-sheet. The lower head was truncated, possibly by glacial streams, before deposition of the glacial sands and gravels with their included marine shell fauna from Carmarthen Bay. The mixture of well rounded gravel clasts with large angular blocks of head, suggests that slope deposits may have been incorporated contemporaneously with fluvioglacial debris from the ice-sheet. Following melting of the ice-sheet, favourable site conditions promoted the accumulation of a thick upper head deposit (Bowen 1970a) which now forms the bulk of the solifluction terrace. Towards the end of this periglacial phase, sheet-washing formed a capping layer of colluvial sediments (bed 4). During the Holocene, dune sands (bed 5) were deposited at Llangennith and the northern end of Rhosili Down, and the whole terrace was trimmed by the rising sea.

Additional interest at the site was provided by Green's (1981b) discovery of a flint Palaeolithic handaxe from the foot of the terrace at the southern end of Rhosili Down (SS414088). He suggested that the handaxe, which on its form was of approximately Ipswichian age, had probably been incorporated into the solifluction deposits during the cold Devensian Stage; there was no evidence to suggest that the handaxe had been rolled or transported by fluvial agencies. This was only the second such 'stray' find of a Palaeolithic handaxe in Wales (Green 1981b).

The sequence, therefore, records evidence for two periglacial phases separated by an event when outwash and associated sediments from a nearby Late Devensian ice margin were deposited. The upper head, which forms much of the impressive terrace at Rhosili, is thought to have accumulated in about 5,000 years, following wastage of the Late Devensian ice-sheet and during the Devensian late-glacial. Irish Sea erratics in the glacial outwash gravel provide vital evidence for the enigmatic, possibly 'Older Drift' (pre-Devensian) Irish Sea ice-sheet, which is thought to have affected parts of south and west Gower. The site has also been used as important evidence for the location of the Late Devensian maximum ice margin in west Gower. The exposures provide contrasting evidence to nearby sites at Broughton Bay and Worm's Head.

Rhosili Bay provides a sequence of deposits which demonstrates two phases of periglacial climate in which a large terrace of solifluction deposits accumulated, and between which fluvioglacial sediments were deposited. The latter were deposited by Late Devensian ice and are interbedded with possible flow till, suggesting that the Late Devensian ice-sheet reached almost into Rhosili Bay. The solifluction terrace, associated bedrock slopes and tors are one of the finest landform assemblages of their kind in Britain and clearly show the relationship between bedrock lithology, site aspect and slope factors in the formation of solifluction terraces.

Conclusions

The drift terrace in Rhosili Bay is made up of a succession of deposits which may be used to delimit the maximum extent of the last Welsh ice-sheet. The terrace is also important because of the evidence it provides for the rates of operation of cold climate processes on hill slopes. It is unique in Wales because it can be shown that the majority of its deposits accumulated between the time of ice disappearance and the onset of post-glacial conditions 10,000 years ago.

Broughton Bay

Highlights

A remarkable Devensian multiple till sequence yields evidence of former ice limits. Raised beach sediments and derived faunal elements in the till provide evidence for an earlier temperate interglacial event in the Ipswichian.

Introduction

Broughton Bay (SS417930) is a site of considerable interest, for its deposits contain materials that have been used to date major geomorphological events and changing environmental conditions of regional significance since the Ipswichian Stage. Sedimentologically, the deposits are interesting because of their glaciotectonic structures. Holocene dune sands overlying the Pleistocene sediments also contain dateable horizons. Although the Pleistocene sequence has only been revealed by coastal erosion within the last 10 years, the site has attracted considerable interest, and it was first described by Campbell *et al.* (1982) when an amino acid analysis of molluscan shells was published. Further, similar dating was discussed by Davies (1983), Bowen (1984), Campbell (1984), Campbell and Shakesby (1985, 1986a, 1986b), Bowen *et al.* (1986) and Worsley (1986). The site

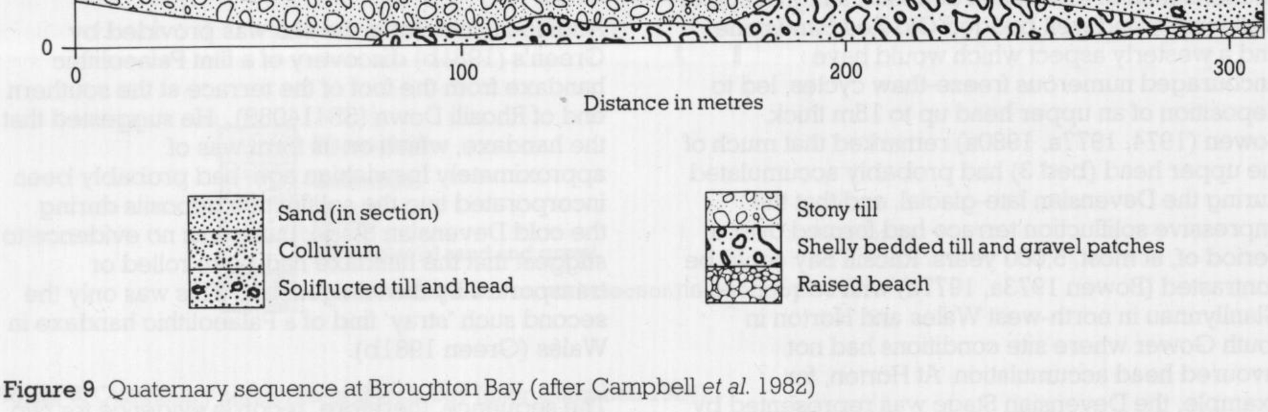

Figure 9 Quaternary sequence at Broughton Bay (after Campbell *et al.* 1982)

was also described by Campbell and Shakesby (1982, 1983), Stephens and Shakesby (1982), Bridges (1985) and Shakesby and Campbell (1985). Details of the Pleistocene and Holocene sequences can be found in Campbell (1984), and Lees (1982, 1983), respectively.

Description

The exposures run east from Twlc Point (SS417931) for about 300m and attain a maximum thickness of about 10m. The stratigraphy (Campbell 1984) is –

7 Holocene dune sand
6 Colluvium (1.5m)
5 Solifluted till and head (5.0m)
4 Stony till (5.0m)
3 Bedded till containing marine shell fragments and pieces of wood (2.0m)
2 Limestone head (0.5m)
1 Raised beach conglomerate

The stratigraphy at the site is shown in Figure 9. The basal raised beach deposits are fragmentary and are only found near Twlc Point. They rest on a Carboniferous Limestone, probably marine-cut, platform and contain abundant marine shell fragments, principally of *Littorina littoralis* (L.). The raised beach grades upwards into limestone head, which is overlain by till units in which the bedding is often well defined, and from which an assemblage of 21 identifiable shell species has been recognised (MacMillan *in* Campbell *et al.* 1982; Campbell 1984). Wood fragments (Salicaceae) have also been recovered. Overlying the shelly tills (bed 3) and a thin discontinuous sand and gravel layer, is an unfossiliferous bed of stony till (bed 4), which is succeeded by redistributed till, head and colluvium. The colluvium fills well developed cracks which penetrate the stony till, and, in plan, form a polygonal pattern. Both the shelly and stony tills at Broughton Bay show glaciotectonically induced folds, most clearly displayed by close bedding in the shelly till. These structures are also seen, under favourable circumstances, in plan form on the foreshore. The structures appear as gentle anticlines and synclines in the sections and in an elliptical pattern elongated north to south on the beach (Campbell 1984).

Interpretation

The results of amino acid analysis of specimens of *Littorina littoralis* from the raised beach deposits indicated an Ipswichian Stage (Campbell *et al.* 1982) age, but shells from the till (bed 3) were of similar age or possibly slightly younger. However, faunal evidence suggested that the assemblage of shells in the till was fully interglacial, with several species found only at more southerly latitudes today. Campbell *et al.* (1982) concluded that it must have been ice of Devensian age and no older, which, moving southwards across the eastern part of Carmarthen Bay, incorporated shell litter that had accumulated during the preceding interglacial; the fabric pattern and erratic content of the shelly till at Broughton Bay was consistent with this view. A study of amino acid ratios from raised beaches around Gower by Davies (1983), showed that most of the deposits were of the same age, and they were provisionally ascribed to the Ipswichian (Oxygen Isotope Sub-stage 5e). This study included further data from Broughton Bay. With an improved method of analysis, and using calibration provided by Uranium-series ages from Bacon Hole Cave, it was confirmed that the raised beach deposits at Broughton Bay could be ascribed to Sub-stage 5e (Bowen *et al.* 1985; Bowen and Sykes 1988).

The data of Campbell *et al.* (1982) did not, however, determine the point at which the Broughton Bay (shelly) Till was deposited during the Devensian, and attempts were made to establish the age more precisely by radiocarbon dating of Salicaceae fragments (Campbell and Shakesby 1985). An initial determination of >42,000 (HAR-5443) was obtained by radiocarbon dating. A second sample was dated using the isotopic enrichment method and yielded a date of 68,000 +13,000 -5,000 BP (GrN -12508). Campbell and Shakesby noted a relatively close correspondence between the Broughton Bay date (GrN -12508) and the date of 60,800 ± 1500 BP (GrN - 1475) (for example, Worsley 1980) for the Chelford Interstadial site in Cheshire. They concluded that the wood may therefore have been from a temperate willow species growing during the Chelford Interstadial but later incorporated into the Broughton Bay Till by ice of probable Late Devensian age. They had doubts about the radiocarbon date, however, and did not rule out an Ipswichian (or even earlier interglacial) or pre-Pleistocene age for the wood. Worsley (1986) noted that the date could be seriously misleading, and suggested that its apparent association with the Chelford Interstadial event was possibly the result of a radiocarbon assay on contaminated material, and this possibility was acknowledged by Campbell and Shakesby (1986b).

Bowen *et al.* (1986) recorded that the till at Broughton Bay contained shells of *Macoma balthica* (L.), the youngest of which (by amino acid and radiocarbon dating) could be shown to be Late Devensian (*c.* 17,000 BP) in age (see also Bowen and Sykes 1988) and therefore indigenous, unlike the derived Ipswichian elements. Although a Late Devensian age for the till was also favoured by Campbell and Shakesby (1986a), certain difficulties were noted in reconciling the new radiocarbon and amino acid dated evidence to existing data from the site. Amino acid ratios from *Macoma* correspond with ages of *c.* 17,000 BP elsewhere in the Irish Sea Basin, and could show that the shelly diamict is glacio-marine in origin – see Chapter 1.

Campbell (1984) applied a variety of detailed techniques, including Scanning Electron Microscopy, to interpret the following sequence of events at Broughton Bay. 1) During high sea-levels in the Ipswichian Stage, the raised beach deposits (bed 1) accumulated. 2) Towards the end of the Ipswichian, as climate deteriorated and sea-level fell, the Loughor Estuary and Carmarthen Bay became dry land. 3) During the Late Devensian, ice advanced southwards across the Loughor Estuary and Carmarthen Bay, incorporating marine shells, pieces of wood and estuarine sediments, and depositing tills (beds 3 and 4) at Broughton Bay. The stony upper till represents farther travelled debris within the ice-sediment profile, although it is believed to have been deposited contemporaneously with the lower till. 4) Following the wastage of Late Devensian ice, a phase of periglacial conditions occurred, and the upper layers of the till were rearranged by solifluction, and deposits of locally-derived head were formed (bed 5). Frost-cracking of the head and till deposits may have occurred during this periglacial phase, and surface washing of the unvegetated sediment surface may have given rise to the colluvial deposits (bed 6) which filled the cracks and capped the sequence.

The Quaternary sequence at Broughton Bay is completed by Holocene dune sands (bed 7) which run the full length of the bay, but which reach their maximum height west of Broughton Farm. The archaeology and depositional history of these dunes was studied by Lees (1982, 1983). The age of the dunes is not yet clear, but it appears that they were already in existence by the Roman period, with a renewed phase of sand mobility in late Mediaeval times when intense storms are known to have affected much of the South Wales coast (Lees 1982, 1983).

Considerable interest is provided by the glaciotectonic structures in the Pleistocene sequence at Broughton Bay. The origin of these structures has not yet been established, but various models of formation have been suggested (Campbell and Shakesby 1983; Campbell 1984). The Late Devensian ice-sheet may have been near its maximum extent locally, and the contortions in the till layers could have been caused by oscillations of this ice front. Alternatively, the structures may have formed as a result of differential ice or overburden loading. Campbell and Shakesby (1983) and Campbell (1984), however, thought that they resulted from horizontal stresses set up in the sediments as the constricted ice moved southwards between Burry Holms and Llanmadoc Hill.

Stratigraphic data from Broughton Bay and other Pleistocene sites in Gower, suggests that the Late Devensian ice-sheet was near its maximum southward limit at Broughton Bay. It is only at Broughton Bay, and east of Langland Bay (east Gower) that till *in situ* is seen to overlie raised beach sediments of Ipswichian age (Bowen 1984). This shows that the Late Devensian ice-sheet impinged upon the east and west margins of the peninsula where major valley glaciers emerged from the South Wales Coalfield. Broughton Bay is notable for being the only permanently exposed multiple till sequence in central South Wales, and for being one of the first sites in Britain where both glacial and interglacial beds have been dated by amino acid geochronology.

Broughton Bay provides a record of Late Pleistocene environmental changes in central South Wales, and in particular, new evidence for the glacial and interglacial history of west Gower. Its raised beach conglomerate, deposited during Oxygen Isotope Sub-stage 5e (Ipswichian Stage) is overlain by a sequence of tills deposited during the Late Devensian. Glaciotectonic deformation structures in the till, and Holocene dune sands with archaeological and organic material, enhance the interest of the site.

Conclusions

Broughton Bay shows a sequence of deposits which span the last 125,000 years or so. It also provides an important constraint on the limit of the last Welsh ice-sheet. The shell fauna from some of the glacial deposits could be evidence that the earth's crust was depressed considerably in this area about 17,000 years ago.