Chapter 3 Quaternary stratigraphy: Gower

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 penecontemporaenous 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
Stage 9	Unnamed	(0.17 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 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.

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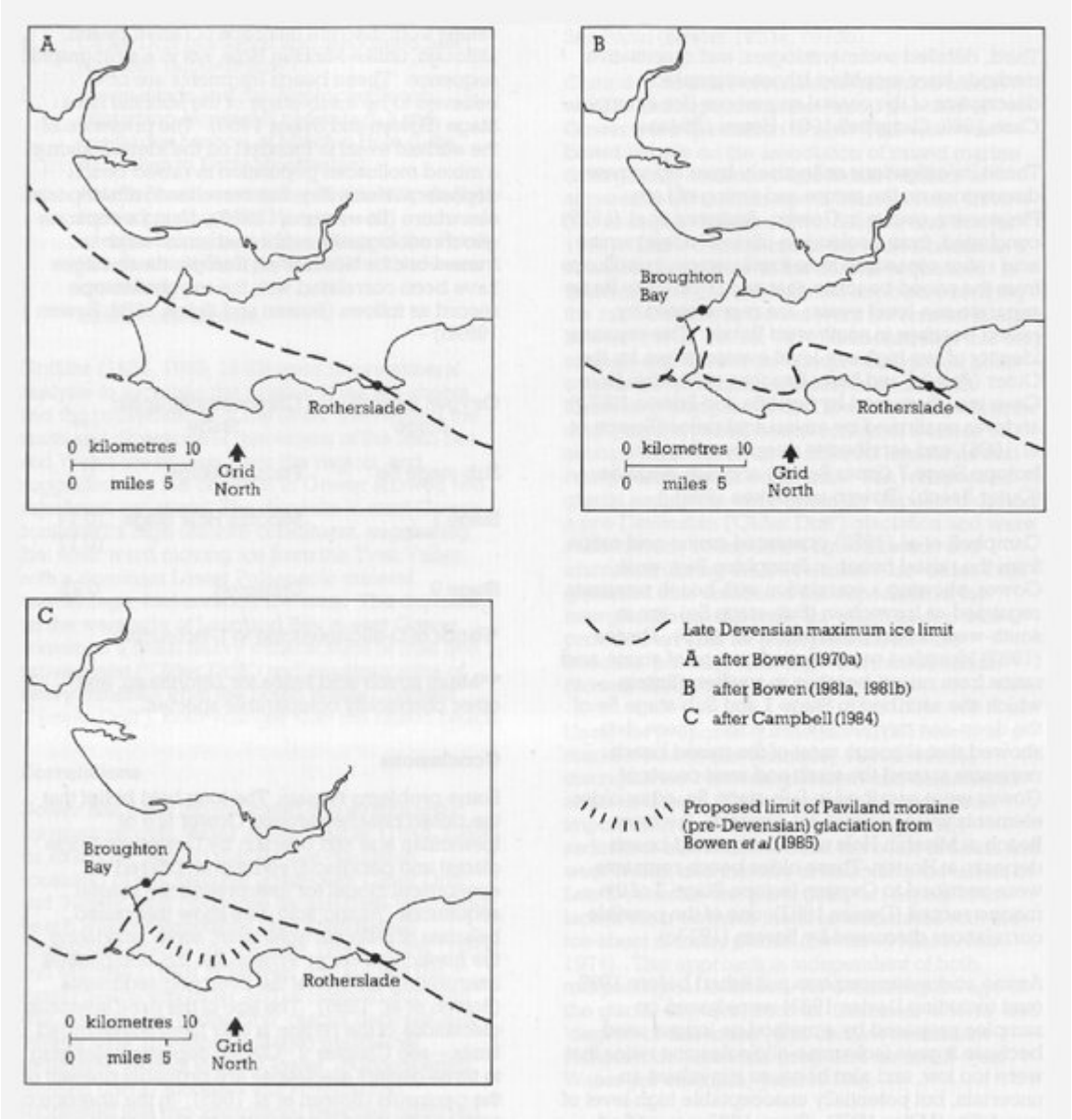

(Figure 2) Some proposed ice limits on Gower (from Bowen 1970a; Bowen 1981a, 1981b; Campbell 1984; Bowen et al. 1985)