# Chapter 2 The Quaternary rocks and landforms of Wales

## The sequence of events

No known evidence has survived from that part of the Quaternary when glacial phases were dominated by the 41,000 year rhythm, and the earliest evidence only dates to sometime before half a million years ago, about two thirds of the way through the Pleistocene; but even this is not securely dated.

It seems likely, however, that the earlier ice ages in Wales witnessed repetitive glaciation of the uplands, but it is unlikely that large ice-sheets comparable to those of the last 900,000 years developed. The principal legacy of these early glaciations would have been the modification of the topography of upland Wales. During interglacials it is probable that the coastline was successively reoccupied by the sea, when the great coastal slope, which dominates many stretches of the Welsh coastline and immediate hinterland, was repeatedly fashioned.

## Glaciation of the Celtic Sea and Bristol Channel

The evidence for this, the earliest known Quaternary event in Wales, consists of highly fragmented outcrops of till and sands and gravels in south-west Dyfed, together with scattered erratics in Gower and the Vale of Glamorgan. This glaciation has been called the Irish Sea glaciation, or the 'Older Drift' glaciation, at which time the Irish Sea and Welsh ice-sheets coalesced in South Wales. The direction of Irish Sea ice movement, from north-west to south-east across south-west Dyfed, has been inferred from the distribution of erratic rocks. No other clear indications of this glaciation occur elsewhere in Wales.

The field relationships of these glacial deposits show that they antedate the raised beaches of south-west Dyfed and Gower, because the latter are not overlain by glacial deposits *in situ.* The glaciation is, therefore, older than Oxygen Isotope Stage 9, to which the oldest raised beach faunas have been ascribed (Bowen *et al.* 1985). The basal till at West Angle Bay (Dixon 1921; Bowen 1977b), which underlies marine deposits, may date from this event.

If, as seems likely, the glacial deposits of the Bristol district are the same age (Hawkins and Kellaway 1971), it may be possible to date this glaciation with more precision. At Yew Tree Farm and at Kenn, near Bristol, till is overlain by freshwater beds containing *Corbicula fluminalis* (Müller). These have amino acid ratios (Andrews et *al.* 1984) which have been correlated with those of the Cromerian Stage of East Anglia (Bowen 1989b) and ascribed to Oxygen Isotope Stage 13 (Bowen and Sykes 1988; Bowen 1989b; Bowen *et al.* 1989); so that the early Irish Sea glaciation may be time-equivalent to Stage 14, or older. As such it could correlate with the Elster 1 glaciation of Europe (Bowen et *al.* 1985; Bowen and Sykes 1988). A Stage 16 age is thought to be probable because the oxygen isotope record indicates a major glaciation at this time (Shackleton 1987).

The geomorphological position of the glacial deposits in the Bristol district, together with those of West Angle Bay, at the entrance to Milford Haven, and to a lesser extent the highly dissected deposits on the coastal plateaux of south-west Dyfed, show that the geomorphology of the coastal fringe was similar to that of the present.

Although this is the oldest glaciation for which there is still evidence in Wales, it is probable that an earlier one may have occurred. This is based on the evidence of igneous erratics from eastern Snowdonia and Mynydd Berwyn, which have been discovered in the high level gravels of the Middle Thames, and the Kesgrave Formation of East Anglia (Bowen et *al.* 1985). The fact that erratics from Wales were introduced into the Thames drainage system, suggests that the geomorphology of the Vale of Gloucester and the Lower Severn readily allowed ice from Wales to pass and to surmount the Cotswolds. On the other hand, the evidence adduced here for glaciation of the Celtic Sea and Bristol Channel lowlands, indicates a topography not greatly dissimilar to that of the present. It seems likely that the onset of the 100,000 year ice age rhythm and the incidence of the earliest major glaciations of middle latitude Britain, coincided with major changes in topography.

## The Paviland glaciation

Recognition of the Paviland glaciation is based on the Paviland end-moraine in Gower, and the glacial deposits lying between it and the margin of the Late Devensian glaciation — see (Figure 2). The Paviland moraine was recognised in 1985 and, although greatly degraded, it forms a major lanclform. The end-moraine represents the maximum extent of an ice-sheet which moved from north to south. The principal erratic constituent of the Paviland glaciation is Namurian 'quartzite' derived from the North Crop of the South Wales Coalfield, notably from Mynydd-y-garreg, in south-east Dyfed. It is possible that it transported the great block of 'quartzite' known as Arthur's Stone, which forms the capstone to a Megalithic tomb on Cefn Bryn, in Gower. Some large boulders of this Namurian sandstone lie beyond the Paviland moraine on the foreshore at Western Slade. These could indicate a more extensive advance than that marked by the end-moraine, but equally, they may have been derived from the periglacial deposits, including recycled glacial material, which infill the valleys of Eastern Slade and Western Slade.

Local field relationships in south-west Gower show that this glaciation antedated the oldest local raised beaches (at Horton and Butterslade), which have been ascribed to the Minchin Hole Stage (Oxygen Isotope Stage 7). On these considerations, therefore, the Paviland glaciation is provisionally ascribed to some time before this stage. One possibility is that it is time-equivalent to part of the Anglian Stage, when extensive glaciation occurred in the Midlands and eastern England, which has been correlated with Oxygen Isotope Stage 12 (Bowen and Sykes 1988; Bowen 1989b).

## The Minchin Hole Stage

Minchin Hole Cave, Gower, contains the proposed stratotype for this stage (Bowen *et al.* 1985) in the sand bed which has been named the Inner Beach. On the basis of its amino acid geochronology it has been ascribed to Oxygen Isotope Stage 7. The Inner Beach deposits contain two populations of marine molluscs, recognised on the basis of their different amino acid ratios, 0.18 and 0.14, which probably represent the respective faunas of Oxygen Isotope Sub-stages 7c and 7a. Hitherto, there has been no formally defined stage to which these could be chronostratigraphically related in Britain. It does, however, correspond with the Stanton Harcourt interglacial event previously recognised from non-marine evidence, and, later, dated by amino acid methods (Bowen 1989b; Bowen *et al.* 1989).

Because the critical rock unit lies in a cave, it is difficult to relate it to deposits over a wider area. Amino acid geochronology, however, has enabled wider correlation with other marine deposits. The raised beach at nearby Horton contains shells with amino acid ratios ascribed to the Minchin Hole Stage.

Uranium-series, thermoluminescence and electron spin resonance dating methods show that cave sediments of Oxygen Isotope Stage 7 age also occur at Pontnewydd Cave in Clwyd (Green 1984). It is not possible, however, to relate these to Pleistocene deposits outside the cave.

## A cold climate event between the Minchin Hole and Pennard Stages

Between the marine beds of the Minchin Hole Stage (Oxygen Isotope Stage 7) and the Pennard Stage (Oxygen Isotope Stage 5, Sub-stage 5e; see below), there occurs at Minchin Hole the Lower Red Cave Earth (head). This bed is proof of a cold climate event. It has, therefore, been ascribed to Oxygen Isotope Stage 6. A large form of the northern vole *Microtus oeconomus* (Pallas), now found living in northernmost Scandinavia, was discovered in it, showing an extremely cold Arctic environment for the deposit. Bowen et *al.* (1985) drew attention to the likelihood that similar aged deposits could overlie Minchin Hole Stage raised beach sediments elsewhere.

Raised beaches of the Minchin Hole Stage crop out at Butterslade, Overton Cliff and Horton in Gower. At Horton, this beach is overlain by two lithofacies of limestone head. A short distance below, and away from it, a younger beach of Pennard Stage age occurs in a gully. It would seem on this evidence that the head deposits overlying the higher beach may, at least in part, antedate the younger beach. Similar stratigraphical relationships are clearly displayed in sections in northern France (Lautridou 1982). The majority of sites, however, shows that the Pennard Stage marine transgression removed pre-existing deposits.

## The Pennard (Ipswichian) Stage

The proposed stratotype for the Pennard Stage is the Outer Beach bed at Minchin Hole Cave (Bowen *et al.* 1985). This bed has been ascribed to Oxygen Isotope Sub-stage 5e on the basis of its amino acid geochronology, calibrated by Uranium-Thorium age determinations on speleothem (stalagmitic tufa) collected at Minchin Hole and at nearby Bacon Hole (Bowen *et al.* 1985; Stringer *et al.* 1986; Bowen and Sykes 1988). The Pennard Stage is, in age terms, synonymous with the Ipswichian Stage of England, and the Eemian Stage of the Netherlands.

Terrestrial beds overlying the Ipswichian Stage raised beaches at both Minchin Hole and Bacon Hole are also probably of Ipswichian age. Bacon Hole contains one of the best known mammal faunas of this age.

The Ipswichian Stage (Pennard) raised beach is extensive in Gower, at Marros and Ragwen Point in Carmarthen Bay, and at points throughout southwest Dyfed. It may also be represented by the Porth Oer and Red Wharf Bay raised beaches in Gwynedd and Anglesey, respectively. The former raised beaches show that the platforms and abandoned cliffs of the Welsh coastline were reoccupied by the sea about 122,000 years ago. Since that time they have been degraded by subaerial slope processes, and some of them have been glaciated by Devensian ice. Only in geologically recent times have some been stripped of their sediment cover for the sea to attack the cliff base again — for example, at Morfa-bychan and in Cardigan Bay between Llan-non and Aberarth.

On the assumption that a widely recorded British interglacial fauna with hippopotamus is everywhere of Ipswichian age (Sutcliffe 1981), the fossiliferous cave sediments at the Cefn Caves in the Elwy Valley of Clwyd should also probably date, at least in part, from the Ipswichian Stage.

Other sediments which have been ascribed to the Ipswichian are — (i) the Llansantffraid Soil described by Mitchell (1962), (ii) an ancient brown earth soil at Hunts Bay, Gower (Clayden 1977a) and, (iii) numerous pockets of red clays south of the limit of the Late Devensian ice-sheet in the Vale of Glamorgan (for example, Crampton 1966c, Bowen 1970a).

## The Devensian (Weichselian) Stage

In the British Isles the Devensian (Weichselian) Stage is sub-divided into three sub-stages as follows (Mitchell et *al.* 1973):

Upper (Late) Devensian 26,000 to 10,000 BP

Middle (Mid) Devensian 50,000 to 26,000 BP

Lower (Early) Devensian before 50,000 BP

Broadly, these divisions correspond with Oxygen Isotope Stage 2 (Late Devensian), Stage 3 (Middle Devensian), Stages 4, 5a to 5d (Early Devensian). The inclusion of Sub-stages 5a to 5d in the Devensian corresponds with international usage (Sibrava et *al.* 1986).

The Devensian stratotype is at Four Ashes, near Wolverhampton; and it shows Late Devensian Irish Sea till overlying gravels of the Early and Middle Devensian.

## Early and Middle Devensian Sub-stages

Bacon Hole Cave, Gower, contains the only potentially complete and demonstrable lithostratigraphic, biostratigraphic and geochronological record of Early Devensian time in Britain (Stringer *et al.* 1986). Bracketing Uranium-Thorium age determinations on the rock sequence show that a major part of Oxygen Isotope Stage 5 is represented here. The post Sub-stage 5e sediments are fossiliferous, and their mammalian fauna demonstrates a warmer interval between the deposition of marine sediment (representing Substage 5e) and the speleothem ('Stalagmite Floor') dated to 81,000 ±

18,000 BP (Stringer et *al.* 1986). It is probable that this warmer interval corresponds to Oxygen Isotope Sub-stage 5c (*c.* 105,000 BP), and that the speleothem and overlying head deposits accumulated throughout the remainder of Devensian time. Other Uranium-series dates potentially allow further division of the cold period and the scree units.

The Devensian fossiliferous sequence of cave deposits overlying the Pennard raised beach at Minchin Hole (Sutcliffe 1981) has been correlated with beds at Bacon Hole (Bowen et *al.* 1985). It is probable that the lower beds of the Outer Talus at Minchin Hole (Sutcliffe and Bowen 1973) are also of Early Devensian age.

Because they lie between the Pennard (Ipswichian Stage/Oxygen Isotope Sub-stage 5e) raised beach and glacial and glacio-marine beds of proposed Late Devensian age, head deposits in Gower, south-west Dyfed, Ll■n and Anglesey, are ascribed to Early and Middle Devensian time. In Gower, the succession of Devensian head deposits consists of basal colluvial (red) beds, limestone scree and redistributed older (pre-Devensian) glacial deposits. Western Slade has been proposed as the standard section for this redistributed older glacial material in South Wales and south-west England. Their recognition as recycled glacial deposits, not glacial beds *in situ* (Bowen 1966, 1970a, 1971a, 1973b), has helped in settling the controversy on the glacial sequence in Wales that has continued since the discussion of the issue by Prestwich (1892) and Tiddeman (1900).

With the exception of Long Hole Cave, it has not proved possible, hitherto, to identify discrete deposits of Middle Devensian age in Wales. Deposits of that age, however, are probably represented in the head units referred to above.

## Possible Early Devensian glaciation in Wales

Evidence for Early Devensian glaciation in Europe and North America has long been the subject of debate and speculation. The ability to discriminate, using amino acid geochronology, between shelly deposits of Early and Late Devensian age has made it possible, however, for the first time, to demonstrate Early Devensian glaciation in Britain (Bowen et *al.* 1985; Bowen and Sykes 1988; Bowen 1989b). Hitherto, presumed Early Devensian glacial and glacio-marine deposits have only been identified in Orkney, Caithness and in Ulster. In comparison with the Late Devensian, this earlier British ice-sheet was displaced farther north, which is probably related to the position of the zone of effective precipitation for ice-sheet growth (Bowen 1989b). No unequivocal evidence for this Early Devensian glaciation is yet available from Wales, although it seems unlikely that the Welsh mountains were ice-free at that time.

In north-west Wales, Whittow and Ball (1970) recognised two 'stadial' events or ice cap advances. In the Criccieth district these are represented respectively by the Criccieth Till and the Llanystumdwy Till (Simpkins 1968).

The significance of the multi-till sequence in southeast Ll■n has caused much debate — see Chapter 7. The sequence of deposits there might further be interpreted as consisting of — (1) Criccieth Till deposited by Snowdonian ice (Early Devensian), (2) zone of weathering and ice-wedges (Middle Devensian), (3) Llanystumdwy Till deposited by Snowdonian ice (Late Devensian) — see (Table 1). This hypothesis is additional to the existing ones.

## The Late Devensian

The Late Devensian glaciation of Wales was effected by ice coming from Welsh centres of dispersal and from the Irish Sea Basin — see (Figure 1). The extent of both ice-sheets has been the subject of debate (Bowen 1973a, 1973b). The dimensions and nature of the ice-sheets and the timing of their growth and shrinkage are still poorly understood.

The distribution of distinctive erratics, however, enables the relative strength and dimensions of some Welsh ice-streams to be estimated. For example, in the South Wales Coalfield, the Vale of Neath ice was sufficiently powerful to cross its south-east interfluve and deposit typical Brecknockshire drift at heights above 300 metres near Pen Moelgrochlef (Bowen 1970a). Therefore, in a downstream direction the Vale of Neath ice was at least 300m thick. Upstream, however, the Fforest Fawr ice failed to cross the Pennant Measures escarpment at Craig-y-llyn. In Gwynedd, ice from the main ice cap crossed the Rhinog Mountains of the Harlech Dome. The Wye glacier was at least 300m thick where it impinged on the Black Mountains in Gwent (Dwerryhouse and Miller 1930). Given the known extent of ice (Figure 14), it is difficult to escape the conclusion that most of the Welsh upland was submerged at the maximum of the Late Devensian glaciation.

Estimating the extent of the Irish Sea ice is more difficult, because the nature and the dimensions of this ice-sheet are controversial. Irish Sea ice deposits, of presumed Late Devensian age, lie at elevations of over 300m in the north and middle Welsh Borderland, at over 400m in north-west Wales (Moel Tryfan), and at over 180m in Preseli: from which the relative thicknesses of the ice can be estimated.

The traditional view is that the Irish Sea ice-sheet was land-based (for example, Thomas 1976) and that it advanced across a dry sea-floor, exposed as a consequence of the global lowering of sea-level. A reinterpretation of the glacial deposits of the Isle of Man as glacio-marine in origin (Eyles and Eyles 1984), suggests that the Irish Sea ice-sheet in that region was marine-based (Bowen 1981c; Denton and Hughes 1981).

A marine-based Irish Sea ice-sheet would, in places, have been grounded on an isostatically depressed crust. Its distal margin would have been controlled by sea-level (not climate) and, given the evidence for its maximum extent in Preseli and Wexford, it is clear that these areas would have functioned as pinning points which prevented surging and collapse of the ice domes (Eyles and McCabe 1989).

The timing of Late Devensian glaciation in Wales and the Irish Sea is difficult to establish. Radiocarbon analyses from the Cheshire-Shropshire-Staffordshire lowland give dates which are too early to be useful in fixing the onset of glaciation. The date of 18,000 years obtained on a woolly rhinoceros bone from one of the Tremeirchion Caves, may provide critical evidence. However, some doubt must attach to its reliability, the sample being of unknown stratigraphic provenance. Furthermore, the enhanced radiocarbon content of the atmosphere before 17,000 years ago (Shackleton *et al,* 1988) may point to a somewhat older true age for this sample.

Radiocarbon dates from basal organic samples in kettle holes show that Late Devensian deglaciation was locally complete in the lowlands of north-west Wales by 14,468 BP, and in the Isle of Man by 19,000 BP. The Isle of Man dates, however, are almost certainly too old. Indications of somewhat earlier deglaciation of the Irish Sea ice-sheet are available from a combination of radiocarbon and amino acid dates. The radiocarbon dated age of shells (*Macoma calcarea* Gruelin) collected from glacio-marine deltas in Ireland is about 17,000 BP; and these have amino acid ratios of 0.07. Similar ratios occur in shells from proposed glacio-marine deposits in County Cork, Waterford, south-west Dyfed and the Isle of Man. These show that deglaciation had occurred in these areas by 17,000 BP, and that glacio-marine conditions obtained at that time in the southern Irish Sea Basin. From these considerations it is reasonable to assume that Late Devensian glaciation reached its greatest extent not long before, and the conventional date of 20,000 to 18,000 BP is, therefore, retained here.

## The sequence of deglaciation

If, as has been suggested, the Irish Sea ice-sheet were marine-based and the Welsh ice-sheet land-based, their modes of deglaciation were probably different. It is likely that both reached their maximum extent at about the same time. The proposal that the Irish Sea ice-sheet was marine-based has helped towards the construction of an integrated model of glaciation and deglaciation. The Irish Sea ice terminus in the St George's Channel has been located along a zone crossing from south-west Dyfed to Wexford; this is marked by a thickening of the drift on the sea floor. To some extent the ice was probably 'pinned' between the Pembrokeshire peninsula and Wexford. Beyond the ice margin, the crust would have been depressed for a considerable distance. It is proposed that glacio-marine muds of this age occur at Fremington, North Devon, and possibly at Broughton Bay, in Gower.

Initial deglaciation of Late Devensian Irish Sea ice was probably rapid, as is shown by widespread deposition of glacio-marine muds. De-stabilisation of the ice margin would have led to rapid calving of the ice and marine downdraw. The fluvioglacial deposits and landforms of Preseli, for example, probably developed rapidly. These include the Fishguard glacial drainage channels which may have been cut by catastrophic discharges.

Glacio-marine muds in south-west Dyfed and in the Urn Peninsula contain a shell fauna with amino acid ratios which indicate an age of approximately 17,000 BP. Their deposition was diachronous, from south to north. During deglaciation, the Irish sea ice margin may have stabilised through 'pinning' against the Ll■n peninsula. In such an interpretation, the lake terraces described by Matley (1936) might be reinterpreted as glacio-marine deltas? In north-east Wales, the origin of the Wrexham 'delta terrace' may well be re-evaluated in the context of the marine-based ice-sheet paradigm. Eventual disintegration of the Irish Sea ice in Liverpool Bay may have allowed outflow of Welsh ice from North Wales, with fast glacier flow streamlining the drumlins of the Denbighshire Moors, a similar origin to that proposed for the drumlins of the 'Drumlin Readvance' in Ireland (McCabe 1987).

Glacio-marine deposition may have transgressed onshore along major valleys. Thick deposits occur in the Lower Teifi Valley (Nunn and Bortas 1977), where the Llechryd Formation is widespread (Bowen and Lear 1982). Deltas which occur between Cardigan and Lampeter have previously been interpreted as deposits formed in part of proglacial Lake Teifi (Charlesworth 1929), but it is significant that satisfactory evidence for an ice-margin for the alleged ice dam which impounded that lake has never been identified. The same is true in the Ewenny Valley, where laminated sediments recovered from boreholes drilled by the British Geological Survey could also be glacio-marine. This might also explain the anomalous discovery of Irish Sea erratics and shell fragments at Pencoed (Strahan and Cantrill 1904).

This model of rapid, even catastrophic, deglaciation is not consistent with an hypothesis of Late Devensian ice readvance in North Wales, but it is consistent with the oxygen isotope signal of deglaciation in North Atlantic deep-sea cores (Ruddiman 1987). Its timing, however, with the retreating ice-margin stabilised at the 'Drumlin Readvance' limit in north-east Ireland at 17,000 BP, is earlier than the commencement of significant deglaciation identified by Ruddiman (1987), largely for the Laurentide ice-sheet of North America. Evidence for later deglaciation of the marine-based Barents Shelf ice-sheet at 15,000 BP (Jones and Keigwin 1988) shows that global deglaciation was not synchronous. Earlier deglaciation of the marine-based Irish Sea ice-sheet, at about 17,000 BP, may not be inconsistent with its more southerly position.

## The Devensian late-glacial

Latest Devensian Stage events which occurred between the deglaciation of the main Late Devensian ice and the commencement of the Holocene ('post-glacial') fall within Devensian late-glacial time. These, however, have not been defined in an entirely satisfactory way. To some extent this is because in the late-glacial, geological-climatic (climatostratigraphic), chronostratigraphic and geochronological terminology has been used, incorrectly, in an interchangeable and synonymous fashion.

A threefold sub-division of south Scandinavian Late Weichselian (Devensian) deposits was originally proposed using macroscopic plant remains, evidence which corresponded with lithostratigraphic sub-divisions. These showed a sequence of cold-temperate-cold environments. Pollen analysis became the basis for precise identification of the temperate event, based on the stratotype at Allerød (in Denmark). The Allerød event is recognised by means of identification of Pollen Zone II which shows a flora with maximum percentages of arboreal pollen (mostly *Betula*).

This is the middle of the three late-glacial pollen zones; the earlier Pollen Zone I was equated with the cold Older Dryas, and the later Pollen Zone III with the cold Younger Dryas, both named after the arctic-alpine plant *Dryas octopetala* L. Greater resolution sub-divided the Older Dryas to make possible the recognition of a further temperate event, the Bølling Interstadial.

Late-glacial pollen diagrams have customarily been zoned on this basis (Mitchell *et al.* 1973). It became evident, however, that the Scandinavian sequence of events was not precisely comparable with those proven in the British Isles, and that a considerable regional diversity occurred in Britain's vegetational history.

A simpler interpretation of the late-glacial is to regard it as a period of gradual climatic warming during and after deglacation of the main Late Devensian ice-sheet. This warming was interrupted latterly by a deterioration in climate leading to the establishment of glaciers in upland Britain between 11,000 and 10,000 years ago, that is during the Younger Dryas (Watts 1980).

Notwithstanding the considerable variation in regional vegetational history in Britain, the broad pattern of events is clear. The evidence shows that there was a continuous development of soils and plant communities from before 14,500 BP.

A widespread increase in *Juniperus* pollen, at about 13,000 years ago, is believed to be one of the consequences of climatic improvement. This rapid expansion of *Juniperus* has been used to define the base of the Windermere Interstadial (Pennington 1977; Coope and Pennington 1977), based on a stratotype at Low Wray Bay, Windermere, Cumbria. In the latter part of the Windermere event, the fluctuating amounts of *Betula* and *Juniperus* pollen indicate probably declining, albeit fluctuating, temperatures (Coope and Brophy 1972; Pennington 1977). The fossil colecptera (beetles) indicate a warming earlier here than elsewhere, at about 14,600 BP, and thus indicate an earlier beginning for the Windermere Interstadial (Coope 1977; Coope and Pennington 1977) than the general warming indicated by *Juniperus.* The term 'late-glacial interstadial' has been used synonymously, more or less, with the Windermere Interstadial.

In Wales, the Younger Dryas is characterised by glacier growth in the uplands and the development of large permanent snow patches. It was a time when discontinuous permafrost obtained and when an extensive, frequently spectacular, periglacial inheritance was fashioned.

The timing of glacier growth in Snowdonia and in the Brecon Beacons has, to some extent, been constrained by radiocarbon dating. It is doubtful, however, that this is sufficiently precise to allow comparison with the detail of glacier growth discernible elsewhere, for example in Scotland, and certainly not for purposes of precise geochronological definition of the event.

Periglacial modification of the land surface was extensive and, in places, radical during the Younger Dryas. Glacial deposits were subject to reworking and solifluction downslope, often forming large terraces, and alluvial redeposition as stream gravels and alluvial fans. The occurrence of permafrost is shown by ice-wedge pseudomorphs (casts) and open-system pingo scars. Overall, the degree of landscape modification during less than a thousand years of Younger Dryas time was considerable, confirming notions that geomorphological activity is essentially episodic.

## The Holocene

By international agreement the commencement of the Holocene is deemed to be 10,000 BP. The warming at the close of the Late Devensian, briefly interrupted by the Younger Dryas event, continued. Pollen analysis has shown that the Holocene in Wales was a time of development of temperate deciduous mixed oak forest and its progressive modification by Man (Taylor 1980). Regional variation in the vegetational history occurred, but the main course of development is clear.

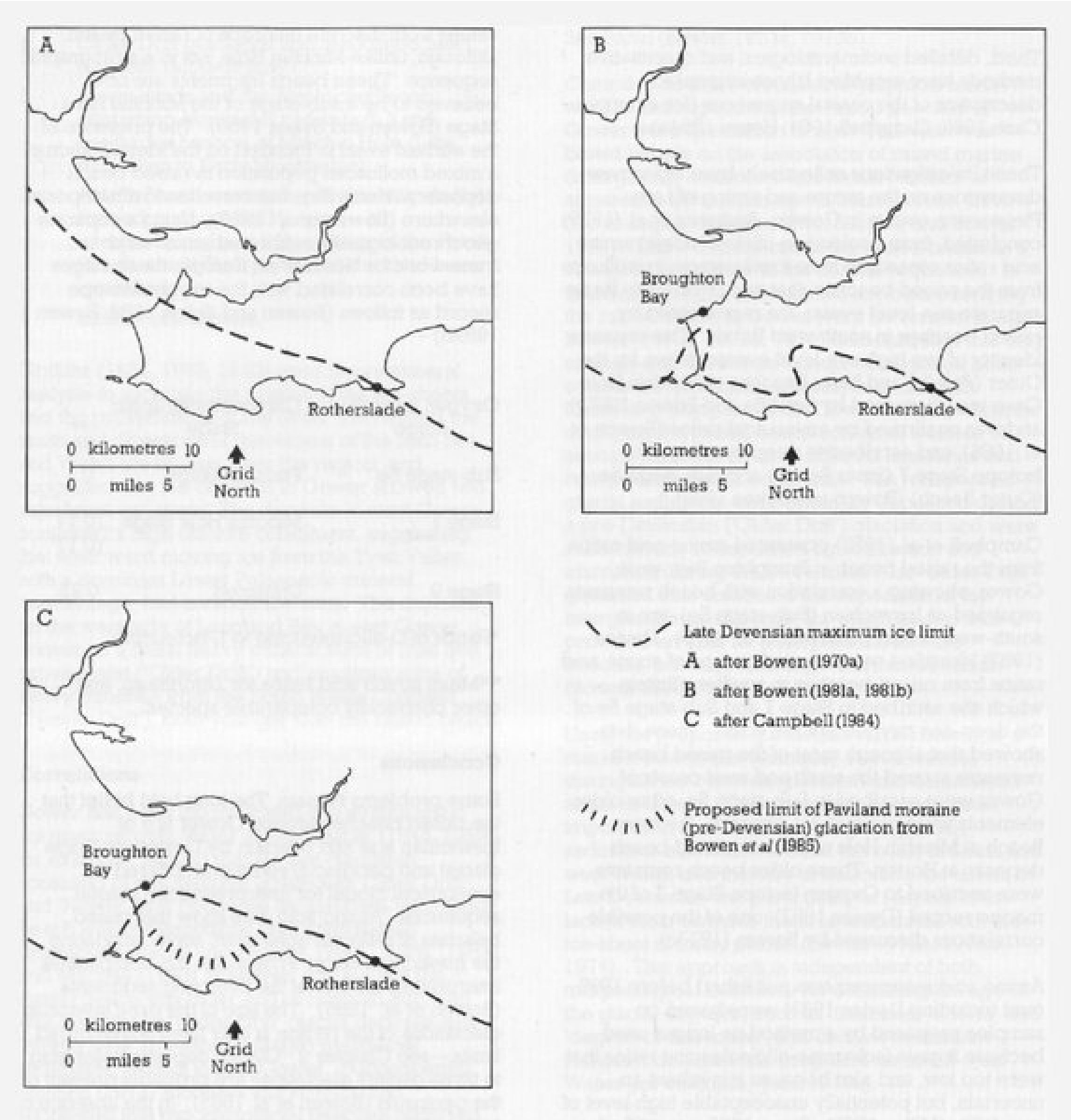
Along the coastline of Wales, the Holocene rise in sea-level culminated about 5,000 years ago, and this is recorded by the alternation of coastal peat beds and marine clay in Swansea Bay (Godwin 1940b), at Clarach (Heyworth *et al.* 1985) and Ynyslas (Taylor 1973) in Cardigan Bay, and along the coast of Clwyd (Tooley 1974).

Inland, colluvial materials were deposited on hillslopes, and, on flood plains, gravel accumulations were subject to terracing as streams changed their courses in response to hydrological variations. Landslips occurred in several Welsh valleys, especially in the South Wales Coalfield where the removal of ice support from over-steepened valley sides caused collapse (Woodland and Evans 1964).

Throughout Devensian late-glacial time, and into the Holocene, the earth's crust recovered from its depression beneath the ice. Rates of relative land/sea-level change due to the interplay between ice retreat (during deglaciation), rising global sea-level and crustal recovery, were subject to wide variation. Because deglaciation of the Welsh coastlands occurred earlier, and crustal rebound was advanced before the rise in global sea-level was able to influence the coastline, spectacular Holocene raised beaches do not occur. The only features attributable to such coastal recovery are the slightly raised Holocene beaches of Anglesey (Mon) just above present sea-level, which compare with the 'Main Postglacial' shorelines farther north, such as those in Scotland.

There is, however, an extensive inheritance of raised, possible glacio-marine deposits and deltas, which have considerable potential for determining the extent and course of isostatic recovery in Wales. These may point to a considerable crustal depression in the Late Devensian and equally to a rapid and elastic recovery, largely completed before *c.* 13,000 BP, when the earliest of the Scottish late-glacial rebound beaches, for instance those in East Fife, was fashioned. It is possible that the thickness of the Late Devensian Irish Sea ice-sheet exceeded that in Scotland, a proposal not inconsistent with the asymmetrical nature of the Late Devensian ice-sheet as compared with the proposed Early Devensian ice-sheet, which may have expanded to the north of Scotland across areas which remained ice-free during the Late Devensian.

**References**

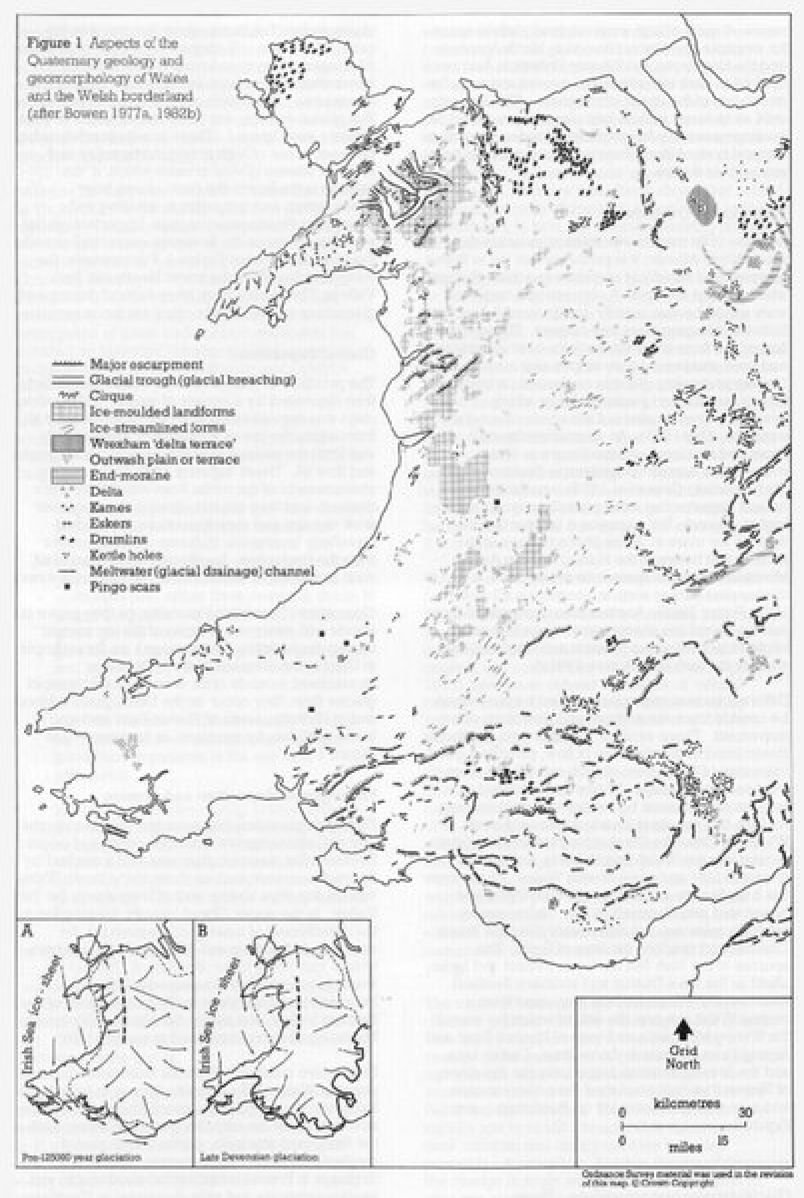



*(Figure 2) Some proposed ice limits on Gower (from Bowen 1970a; Bowen 1981a, 1981b; Campbell 1984; Bowen et al. 1985)*

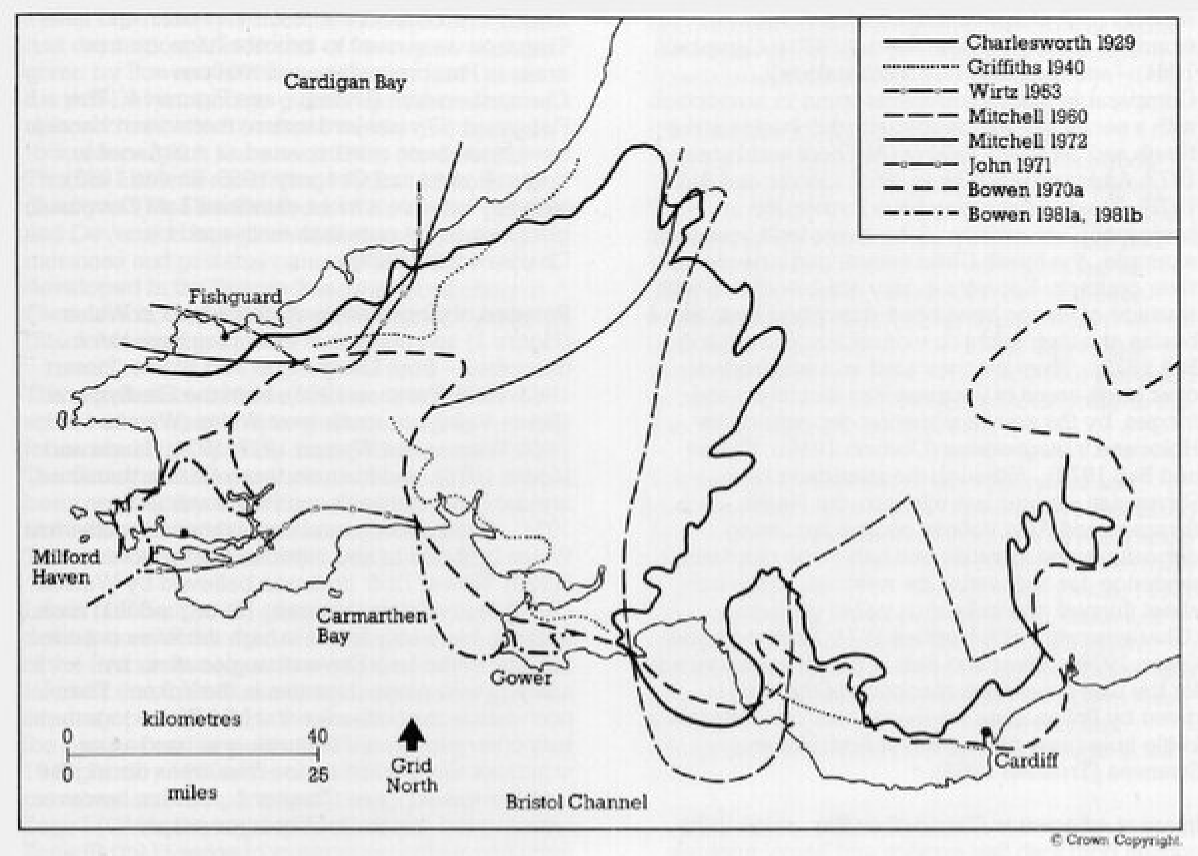
A Pleistocene correlation chart for Wales

| Irish Sea Province | Welsh Province | South Gower | Gower Caves | Chronostratigraphy | Oxygen Isotope Stage | Age (in thousands of years BP) |
|---|---|---|---|---|---|---|
| loess head solifluction deposits | North Wales, Mid Wales and Brecon Beacons cirque moraines and protalus ramparts | Horton loess | Cat Hole breccia | Younger Dryas (Late Devensian) | 2 | 10 |
| Cwm yr Eglwys peat | Traeth Mawr peat | | | Allerod (Late Devensian) | | 11 |
| | Glanllynnau basal clay | | Bacon Hole stalagmite | | | 12 |
| | | | | Older Dryas (Late Devensian) | | 13 |
| Abermawr Till, Trevor Till, Banc-y-Warren sands and gravels, Moel Tryfan shelly drift | Langland Bay and Broughton Bay Tills, Llanystumdwy Till | head | Minchin Hole Outer Talus Cone, Bacon Hole breccia | | | 14 |
| | | | | | | 17 |
| | | | | | | 24 |
| remanié molluscan fauna in overlying beds | Glanllynnau: weathered surface and frost cracking of Criccieth Till? | | Long Hole breccia | Middle Devensian | 3 | 59 |
| | Criccieth Till, Langland Bay head | Western Slade redeposited glacial sediments | Bacon Hole breccia | Early Devensian | 4 | 71 |
| Red Wharf Bay, Porth Oer, Abermawr lower heads | | | Bacon Hole stalagmite | | 5a | 80 |
| | | | | | 5b | |
| | | Colluvial beds | Bacon Hole temperate fauna | | 5c | 105 |
| | | | | | 5d | 122 |
| Red Wharf Bay, Porth Oer and Poppit raised beaches? | Langland and Broughton raised beaches | Hunts Bay Beach | Minchin Hole Outer Beach | Ipswichian (Pennard D/L Stage) | 5e | 128 |
| | | Horton head? | Minchin Hole Lower Red Cave Earth | | 6 | 186 |
| Pontnewydd Cave Intermediate Complex | | Horton (Upper), Butterslade and Overton raised beaches | Minchin Hole Inner Beach | Minchin Hole D/L Stage | 7 | 245 |
| | | | | Hoxnian Stage ? | 8 | 303 |
| | | Hunts Bay Beach marine fauna | | | 9 | 339 |
| | | | | | 10 11 | 423 |
| | | Paviland Till | | Anglian | 12 | 478 |
| Kenn Freshwater Beds | | | | Cromerian | 13 | 524 |
| | | | | | 14 15 | 620 |
| West Angle and Kenn Tills, South Wales Irish Sea drifts? | | Irish Sea remanié drifts | | Elster I | 16 | 659 |
| | | | | | 17 | |

*(Table 1) Geochronology (age) of Oxygen Isotope Stage boundaries is from Martinson et al. (1987) [back to stage 7], and Imbrie et al. (1984). Specific events are radiocarbon dated at 10, 11, 12, 13, 14 and 17,000 years BP (details in text). The Pennard and Minchin Hole D/L Stages are from Bowen et al. (1985). For chronostratigraphic correlations see Bowen and Sykes (1988), Behre (1989) and Bowen et al. (1989). Sites outside Wales are correlated with Oxygen Isotope Stages as follows — Upton Warren, St Germain II and Odderade (Sub-stage 5a), Chelford, BrOrup and St Germain I (Sub-stage 5c) and Stanton Harcourt and Aveley (Stage 7).*




*(Figure 1) Aspects of the Quaternary geology and geomorphology of Wales and the Welsh borderland (after Bowen 1977a, 1982b)*




(Figure 14) Some suggested Late Devensian ice limits in South Wales (from Bowen and Henry 1984; Campbell 1984)