Chapter 1 An introduction to the Quaternary

The geologically recent ice ages opened some 2.4 million years ago and they include the 'geological present' (Zagwijn 1974; Ruddiman and Raymo 1988). To some the Quaternary is synonymous with the Ice Age. The reality is, however, that there have been many ice ages (glacials), each separated by interglaciaLs, when the climate of the Earth was similar to the present. Quaternary Science seeks to understand the way in which the various interactive systems of the planet Earth have functioned in the past, to explain the present, and thereby to predict the future.

During the Quaternary (the Pleistocene Series and Holocene combined), erosional agencies, particularly those of rivers and glaciers, fashioned the British landscape. The rock debris that this produced was deposited in a variety of environments and became the parent material for soils.

Repeated climatic change subjected the flora and fauna of northern lands to stress. Populations of plants and animals were forced to migrate southward or northward in response to, respectively, worsening or improving climate. Little evolution of the flora occurred and the majority of Quaternary plant species are still with us today. Many former vegetational environments, however, lack modern counterparts; therefore, the geological dictum that 'the present is the key to the past' is not always applicable. Interglacial environments in the British Isles were characterised by a mixed deciduous oak forest (the climax vegetation). This was replaced by tundra and polar desert during the ice ages, when extensive ice-sheets sometimes developed. The last time the British Isles experienced conditions similar to the present was about 125,000 years ago, when the interglacial (part of the Ipswichian Stage) lasted some 10,000 years. Because the present (Holocene) interglacial has already lasted 10,000 years, a geological perspective would indicate that the present flora and fauna consists of rare and endangered species.

Unlike the flora, some elements of the fauna did evolve. The evolution of Man and his increasing capacity for modifying his environment, both deliberately and inadvertently, has been an outstanding characteristic of the Quaternary. Indeed a Russian view is that the period should be called the Anthropogene. Some large mammal types evolved, but they are of limited value in trying to sub-divide the Pleistocene and Holocene. The major extinctions of certain large species (for instance, the mammoth) at the end of the Pleistocene may be in part, if not mostly, attributable to Man.

The succession of ice ages (glacial) and interglacials has occurred at known frequencies, and one of the goals of Quaternary Science is to predict future changes in climate, for example global warming, and to reveal whether Man's activities are sufficient to override natural tendencies in the Earth's climatic patterns.

The Geological Conservation Review sites described in this volume are the building blocks from which the Pleistocene and Holocene evolution of Wales may be determined. They include some unique evidence for the timing of glacier advances and retreats, major changes in sea-level, and movements of the Earth's crust. These sites are important in a wider context, because Wales lies on the margin of the North Atlantic, where climatic change is translated, through the dynamic coupling of atmosphere, oceans and biosphere, into rapid environmental changes. These changes have been exceptionally rapid by comparison with the geological timescale, and their implications are potentially relevant to society. Thus, the Quaternary history of Wales assumes a disproportionate importance in the wider context of research in our hemisphere into why and how environments change through time.

The history of the ice ages

Evidence from planktonic fossils in North Atlantic ocean sediments shows that sea temperatures fell at the beginning of the Quaternary, as polar ice-sheets grew and launched ice-floes into the surrounding seas (Ruddiman and Wright 1987; Ruddiman and Raymo 1988).

Changes in the global climate were driven by two principal controlling (forcing) agencies. First, by movements in the Earth's crust; changes which created and modified continents and oceans, especially mountain ranges and seaways, and which in turn have influenced ocean currents. Second, by changes in the Earth's orbit around the Sun, which have led to variability in the amount of solar radiation received at the outer edge of the atmosphere at different latitudes. Together, these two effects have altered interactions between the atmosphere, the oceans and the continents, notably in bringing about changes in continental and oceanic biomass and chemistry. Such effects have in turn led to climatic change.

Northern hemisphere glaciation began with the closure of the Straits of Panama and the creation of the Isthmus of Panama by crustal upheaval, at about 3.1 million years ago. This ended the latitudinal movement of surface waters between the Atlantic and Pacific Oceans, and replaced it with a meridional flow in the North Atlantic. Thus, warmer waters reached higher latitudes, and created a potential for the increased precipitation necessary for ice growth. Shortly afterwards, glaciers developed in Iceland (Einarsson and Albertson 1988). It was not until about 2.4 million years ago, however, that large ice-sheets spread in middle latitudes (Shackleton *et al.* 1984).

Evidence for long-term climatic change throughout the Quaternary is not readily available on the continents. This is because the continental (land) environment is largely one of net erosion, and evidence for earlier events has been, and is being, continually destroyed. On the other hand, long sequences of sediments build up, more or less continuously, on the floor of the deep open ocean. Investigation of these undisturbed sediments has provided an historical (stratigraphic) framework unequalled in its detail (Shackleton and Opdyke 1973).

Such ocean sediments have provided three principal lines of evidence, all of which indicate simultaneous changes in environmental conditions. These are —

1. Oxygen isotope analysis of the $^{18}O/^{16}O$ ratio in planktonic and benthonic organisms (foraminifera) provides a signal for the variability of the isotopic composition of the global ocean. Because this composition is controlled principally by the volume of ice, it is also a signal of warm and cold events, and of ice growth and decay. It therefore, provides a framework of global significance and applicability (Shackleton and Opdyke 1973).
2. Past sea-surface temperatures (SSTs) may be calculated from assemblages of fossil planktonic organisms in the sea bed sediments.
3. Ice-rafting episodes during colder periods caused the input of coarse sediment to the ocean floor sequence. These periods of clastic sedimentation alternated with episodes of high calcium carbonate ($CaCO_3$) productivity which occurred during warmer times.

The location in cores of the deep-sea sediments of a major reversal in the Earth's magnetic field, the Matuyama-Brunhes reversal at 730,000 years BP (before the present), provides a yardstick with which to estimate the duration and timing of the ice ages. This reversal can be detected in Pleistocene rocks around the world.

Cycles of changing ice volumes, and hence climatic variability as shown by deep-sea cores, have been matched with the changes in the pattern of the Earth's orbital rhythms; its cycles of eccentricity (with a periodicity of 100,000 years), tilt (41,000 years) and precession (23,000 and 19,000 years) (Hayes *et al.* 1976; Imbrie and Imbrie 1979). These strong similarities show that orbital forcing (changing orbital patterns) has almost certainly been responsible for the succession of Quaternary ice ages. However, it does not show how climatic change actually occurs. Orbital fluctuations probably act to trigger interactions between atmosphere, oceans, biosphere and cryosphere (the realm of snow and ice). In these, the role of atmospheric carbon dioxide appears to be of major importance, because it has been shown that orbital changes precede changes in atmospheric carbon dioxide and, in turn, ice volume (climatic) changes (Shackleton *et al.* 1983).

The deep-sea sediment pile has been sub-divided on the basis of its changing oxygen isotope chemistry into a number of successive oxygen isotope stages. These can be recognised on a global basis. Because the mixing time of the global ocean is only about 1,000 years, correlation within the ocean is accurate to within that length of time. These stages (running counter to normal geological practice) are numbered backwards in time and down through the column. Low ice volume stages (interglacials) are given odd numbers, and so the latest, the Holocene, is Stage 1. Times of high ice volume (ice ages) are given even numbers, and thus the last glacial phase is Stage 2. Stages may be sub-divided into sub-stages, for example, Stage 5 into Sub-stages 5a, 5c and 5e.

The age of oxygen isotope stage boundaries is based on their positions relative to the Matuyama-Brunhes magnetic reversal in each sea bed core, and on calculations of thickness founded on an assumption of constant sedimentation rates. The original age calculations (Shackleton and Opdyke 1973) have been refined by means of 'orbital tuning', that is, they have been adjusted using known orbital frequencies (Imbrie *et al.* 1984; Martinson *et al.* 1987).

With these data it is possible to trace the history of the ice ages. The earliest ice-sheets, between 2.4 million and 900,000 years ago, fluctuated on a scale of 41,000 years, which is the rhythm of orbital obliquity (the tilt of the Earth's axis). After about 900,000 years ago, ice-sheets grew to maximum volumes twice their previous size, and fluctuated with a 100,000 year rhythm, namely that of the orbital eccentricity. Other fluctuations in ice volume, superimposed on the longer term patterns, occurred at frequencies of 41,000 and 23,000 years.

The cause of change in the pattern of ice age rhythms at about 900,000 years ago is not known. One theory suggests that it was caused by a change in the behaviour of the ice-sheets; after that time marine-based ice-sheets developed on continental shelf areas such as Hudson's Bay, the Baltic and the Irish Sea. They were able to grow rapidly and to reach considerable thicknesses; their collapse and disappearance was also probably catastrophic. Another theory attributes the change in scale and intensity of glaciation to changes in atmospheric circulation caused by renewed uplift of high mountain and plateau areas; for example, the Sierra Nevada in North America, and the Himalayas and Tibetan Plateau in Asia were uplifted to such elevations that caused waves in the circulation of the upper atmosphere. This brought cold air to lower middle latitudes and produced the cooling necessary for glaciation. Evidence exists to support both of these theories, which may not be mutually exclusive.

Wales in the Quaternary

Because of its maritime position adjacent to the warm North Atlantic, it is probable that ice in Wales accumulated rapidly in response to orbital changes which cooled the land. A conventional text-book view would be that, initially, ice thickened in upland hollows enlarging them into cirques. The ice then flowed out from these into valleys, over-deepening and over-steepening their slopes as it moved. Converging valley glaciers coalesced on lowlands where they formed piedmont lobes which eventually grew in size to form an ice-sheet (for example, Flint 1943). An alternative theory proposed that ice developed more or less everywhere across the landscape (instantaneous glacierisation) (Ives *et al.* 1975), especially on upland plateaux that were partially surrounded by higher ground. For example, it is clear that the thickest ice mass in Wales lay on plateau areas such as that between the Rhinog and the Arenig Mountains, and that there it far exceeded ice thicknesses farther north in Snowdonia (Greenly 1919; Foster 1968). Another theory proposed that marine-based ice-sheets grew on shallow water continental shelf areas (Denton and Hughes 1981), such as the Irish Sea (Bowen 1981c).

Different ancient rock types carried by the ice can be used to trace the sources and directions of ice movement. These erratics, together with landforms streamlined in the direction of flow, provide a good indication of the pattern of such movement, even over very large areas. Wales was glaciated on a number of occasions by ice from several sources. An Irish Sea ice-sheet invaded the margins of Wales; its Cheshire-Shropshire-Staffordshire lobe moved into the Welsh Borderlands, and another glaciated Ll■n and parts of west Wales. At one time this Irish Sea ice crossed south-west Dyfed and penetrated into Carmarthen Bay. Its maximum extent is unknown, but it probably filled the Bristol Channel and reached the Isles of Scilly. The sources of the Irish Sea ice lay in Ireland and as far afield as the Lake District and southern Scotland. Alternatively, Welsh ice was dispersed from a central Welsh ice cap, the axis of which lay east of the Rhinog Mountains and west of Rhobell Fawr and Arenig Fawr. Northern Snowdonia, Cadair Idris, and the Brecon Beacons (especially the dip-slope of Fforest Fawr) all nourished their own ice caps; and a smaller ice centre lay on Pumlumon — see (Figure 1).

Glacial erosion

Glacial erosion was not uniform. Three characteristic landforms show that this was the case. These are — (i) cirques (conies), (ii) troughs (U-shaped valleys) and rock basins, and (iii) streamlined forms such as ridge tops and roches moutonees. The distribution of such features shows that glacial erosion was most intense in north-west Wales — see (Figure 1). There is a clear relationship between areas of high precipitation today and areas of intense glacial erosion which, if 'the present is the key to the past', shows how precipitation was important in initiating and nourishing

Pleistocene ice caps. Important glacial erosional features do, however, occur well outside the main areas — see (Figure 1). For example, the deep rock basins of the lower Neath and Teifi Valleys. These may have been formed during early glaciations for which little other evidence remains.

Glacial deposition

The products of glacial erosion were transported, then deposited by a variety of means. Till (boulder clay) was deposited beneath ice as lodgement till, from within the ice as englacial till (melt-out till), and from the surface of melting ice as supra-glacial and flow till. These deposits often have colours characteristic of the rocks from which they were derived, and they contain erratics showing over what terrains and rock formations the ice had travelled. In general, till forms a blanket-cover over the landscape. Landforms composed of till, such as moraines, either mark the maximum extent of an ice advance, such as the Llanfihangel–Crucorney (Crocornau) moraine, or they prove still-stands and minor readvances of the ice margin during deglaciation (ice wastage), as, for example, at Glais in the Swansea Valley. Drumlins, streamlined mounds of till, were formed by rapid glacier flow; they occur on the Denbighshire Moors and at Hirwaun, south of Fforest Fawr and also at lower altitudes, for example, in Anglesey — see (Figure 1).

Fluvioglacial deposition and erosion

During deglaciation (ice wastage) the ice margins 'retreat', shrinking towards their centres of origin. Evidence for pauses in this retreat are marked by the end-moraines such as those in the South Wales valleys, the Wye Valley, and at Tregaron in the Teifi Valley. In the upper Clwyd, glacier thinning led to the detachment of masses of stagnant ice: for example, in the Alun and Wheeler Valleys where eskers and kettle holes developed. Similar ice wastage phenomena developed south of the Pennant Measures Scarp in Glamorgan east of the Ewenny Valley, and where the Nantlle, Glaslyn and Ffestiniog glaciers combined in eastern Ll■n.

Impressive numbers of glacial meltwater channels occur in Wales. The majority appear to have been fashioned by subglacial erosion (that is erosion by streams below the ice); the pattern of some, such as the Fishguard channels, allows the course of deglaciation to be reconstructed. Initially, glacial drainage in Preseli was directed southwards and south-westwards, but with ice retreat in Cardigan Bay, rivers were able to flow to the north. In the Arfon foothills, glacial drainage channels run from north-east to south-west, and probably formed beneath and just inside the ice margin. Some of the most spectacular subglacial channels in Wales occur in the lower Teifi Valley at, for example, Cilgeran and Cenarth, the gorges through which the Teifi flows today.

Formerly, many glacial drainage channels were interpreted as having been fashioned by proglacial lake water spilling over watersheds or spurs. It is difficult, however, to ascribe any channel unequivocally to such an origin, although independent evidence (such as shoreline features and delta deposits) sometimes shows the existence of a former proglacial lake, such as Lake Teifi — see Chapter 2.

Principles of classification

One of the main challenges of Quaternary research is to correlate events on the land with the oxygen isotope stratigraphy derived from the ocean floor. This is not easy to accomplish because the continents are areas of net erosion. The record is, therefore, often fragmentary, and only rarely do deposits at any one site show evidence for more than a single ice age or interglacial event. The reconstructed rock sequence, therefore, is built up from place to place — see Table 1. A further problem is that successive ice ages produce similar evidence, that is, comparable rock types and fossils. They are homotaxial and appear to be the same, but are of different ages, so it is not always easy to determine the correct position of a given deposit in time. Thus, dating techniques are important although, unfortunately, these are not uniformly applicable in all areas and in all parts of the Pleistocene sequence. Moreover, all dating techniques have their own inherent problems and sources of error.

Quaternary events on the continents are recognised from the actualities of the rocks. Thus, a till is evidence for a glaciation, and stratified sands and gravels may relate to a period of ice wastage (deglaciation). Head deposits (scree or solifluction sediments) indicate a cold climate. A peat or lake deposit containing fossil pollen grains could show a temperate (interglacial) event. Classification of Quaternary events has in recent years been based on the establishment of stages, recognised on the evidence of either ice age or interglacial events. These have been founded on a typical section (type section or stratotype) that demonstrates such an event, a standard to act as a yardstick with which other sites may be compared or correlated.

Before continental (onshore) sections can be correlated in time with the global oxygen isotope framework, it is first necessary to 1) examine and describe them, 2) correlate between such onshore sections, and 3) classify the evidence available in the sections.

Lithostratigraphy

Lithostratigraphy (rock stratigraphy) is concerned with the description and organisation of rocks into lithological units (beds, members and formations) based on their intrinsic characteristics. The lithostratigraphic succession of Pleistocene deposits in Wales has been determined mainly along the coastline, where good exposures have been created by marine erosion. These exposures are important because they show both marine and terrestrial deposits — see Table 1. Marine deposits consist, for example, of raised beach (former shoreline) deposits, marine muds, sands and gravels. Continental deposits include till, fluvioglacial sands and gravels, several varieties of head deposits (for example, scree), loess (cold climate wind-blown silt) and wind-blown sand.

Drawing inferences about the origin of Quaternary sediments is not always straightforward, and deposits are often interpreted in a variety of ways by different workers. Three examples have figured prominently in the history of investigations in Wales.

1. In Gower, a deposit containing erratic pebbles was once interpreted as a glacial sediment (George 1932, 1933a). Now, however, it is regarded as a cold climate periglacial deposit, formed by the downslope movement of materials including sediments derived from older, truly glacial deposits (for example, Bowen 1971a).
2. In Mid Wales and along the Cardigan Bay coastline, a characteristically blue diamict (a poorly sorted, pebbly clay deposit) consisting almost entirely of local rock types, has been interpreted variously as a till (Wood 1959; Potts 1971), as a recycled till (Potts 1971; Bowen 1973a, 1974) or as a periglacial slope deposit (Watson and Watson 1967; Watson 1970).
3. The dark blue-purple calcareous clay, often containing marine shells or shell fragments, called Irish Sea till has, at some localities, recently been reinterpreted as a glacio-marine mud; that is, it was deposited in the sea when plumes of trapped sediment were released from floating or grounded ice. Such differences of opinion about the depositional origins of sediments have led to radically different environmental reconstructions and of the precise sequence of events.

Additional information about the nature and the sequence of events may be provided by depositional and erosional landforms: for example, subglacial eskers and kettle holes demonstrate the former presence of stagnating ice that had lost all forward motion.

Formal classification of the Pleistocene and Holocene rocks of Wales by recognising formations (the fundamental mappable lithostratigraphic unit) has not occurred widely (for example, Henry 1984a), and description has been largely at the level of beds.

Biostratigraphy

Biostratigraphy is concerned with the organisation of the rock column into units on the basis of their fossil content, and the correlation of these units in often widely separated sections. The fossil record of the Quaternary of Wales is discontinuous, but it does provide important information.

Fossil marine molluscs (snails and bivalves) are found in the interglacial raised beaches which formed when global sea-level was relatively high. Others were incorporated from the sea floor into ice-sheets, and they now occur in glacial and fluvioglacial sediments. Hitherto, marine fossils have only provided a limited amount of palaeoecological and stratigraphic information. Non-marine snails have been more widely used for biostratigraphy, but not so much in Wales. They also provide better palaeoecological information, and have been used for amino acid dating.

Large and small fossil mammals are found in the Welsh cave deposits, notably in Gower, South Pembrokeshire and the Elwy Valley of Clwyd, and these have allowed important palaeoecological inferences to be drawn. They have, however, proved to be of limited use for long range biostratigraphic correlation.

Pollen analytical investigations of sediments are important because they allow a reconstruction of the former vegetation, and this in turn allows inferences to be drawn about the prevailing climate at the time the sediments were formed. Deposits containing pollen usually only occur plentifully in the rocks of the last 13,000 years or so. However, they allow precise biozonation of the younger sedimentary sequences, with characteristic floras being used to define pollen assemblage zones (biozones).

Correlation

Correlation should be pursued by all possible means. Unlike many pre-Quaternary rocks, however, the greater variability in lithology and the discontinuous nature of Quaternary rocks makes correlation difficult. Furthermore, the cyclical nature of climatic events has formed repetitive, homotaxial rock sequences, which make correlation and dating difficult. For example, it is known that interglacial raised beaches of different ages lie at similar elevations around our coasts. Likewise, repetitive glaciation from similar ice centres could have produced more or less identical deposits.

The correlation of most Pleistocene rocks in Wales is based on telecorrelation, which is a method founded on the assumption that repetitive sequences of rocks are of broadly similar age. To some extent, independent geochronometric age determinations have confirmed such correlation, but in some cases, absolute age determinations have revealed a greater complexity in the rock record than had been inferred from the rock sequences alone.

As the climate improved towards the close of the last glacial phase (Devensian Stage), after about 15,000 years ago, Wales was progressively colonised by vegetation. The pollen assemblage zones which represent the vegetation at particular times have been used for correlation. These biozones are the representatives in the fossil record of migrating, and therefore time-transgressive (diachronous), floras. Radiocarbon dating of significant changes in vegetational history, is a better basis for attempting a time correlation.

Classification

The classification of Pleistocene rocks, and thus of events, has by custom been based on climatic change: that is, by defining ice ages (glacials) and the relatively warmer periods between (interglacials). In addition, 'interstadials', episodes of climatic improvement within a glacial, and separate episodes of cold 'stadial' ice advances have been recognised. In Britain and North-West Europe, interglacials have been defined on the basis of their vegetational history. By definition, these must show a climate at least as warm as the Holocene (present interglacial). This is inferred from pollen assemblages showing a mixed oak deciduous forest. Specific interglacials are recognised by their vegetational 'signatures', although these were not based on the appearance of new species, acme development, nor extinctions, but rather on floral assemblages which consist of species still in existence. In other words, the definitive assemblage floras were controlled not by evolution but by the prevailing climate. It has been argued (Bowen 1978) that this is not a satisfactory means for sub-dividing the time represented in the rock record. Glacials have been recognised and defined by the identification of cold climate deposits such as till and periglacial scree.

Definition and classification on such a basis is at best informal and, at worst, potentially misleading. This is all the more so because the record is fragmentary and must be arranged in proper sequence by adding and overlapping the available surviving fragments — see (Table 1).

Stratigraphical procedure for classifying rocks is based on chronostratigraphy and the recognition and definition of chronostratigraphic units (time-rock units), such as stages, series and periods. These are made up of sequences of rock that accumulated during a particular span of time, and are defined in a chosen, type section (stratotype). The age of such units, in years before the present, may be determined by geochronology. The distinction between chronostratigraphy and geochronology is an important one, but it has frequently been overlooked by expert writers and editors alike. Hedburg (1976) uses the analogy of an hour glass to explain the distinction. The sand in the glass represents the chronostratigraphic unit (that is the tangible or physical unit), and the time taken for the sand to pass from the upper to the lower half of the glass is the time interval or geochronological unit, an abstract concept which measures the passage of time.

One of the goals in reconstructing Quaternary history is to arrange the rocks into their original order and into chronostratigraphic units. If it is possible to determine their actual ages by geochronological means, so much the better. Most rocks, however, cannot be so readily dated, and correlation is attempted by other means.*

An attempt to classify the Quaternary rocks of the British Isles by defining chronostratigraphic units was made by Mitchell *et al.* (1973). They defined a sequence of temperate and cold stages. 'Fixed points in time' were provided by the temperate stages, which were defined from their vegetational history (from pollen analysis). This method has been criticised (see above): its standard sequence of stages was not based on the demonstrable, direct superposition of rock units; for it is generally rare to see representatives of one stage above those of another at one locality. The classification has been criticised, mostly because it oversimplified the sequence of events and because it cannot accommodate additional events. A multiple approach to these problems has led to the recognition of a much more complex pattern, and a chronostratigraphy which reflects this sequence of events.

The emergence of techniques for dating rocks, especially for those older than the range of radiocarbon dating, has not only demonstrated greater complexity and allowed precise correlation, but has also provided the means of relating Pleistocene rocks to the global oxygen isotope framework (Kukla 1977; Bowen 1978). The oxygen isotope stages of the deep-sea record (for example, Shackleton and Opdyke 1973; Sibrava *et al.* 1986) provide the standard stratigraphical scale with which continental sequences are now routinely correlated.

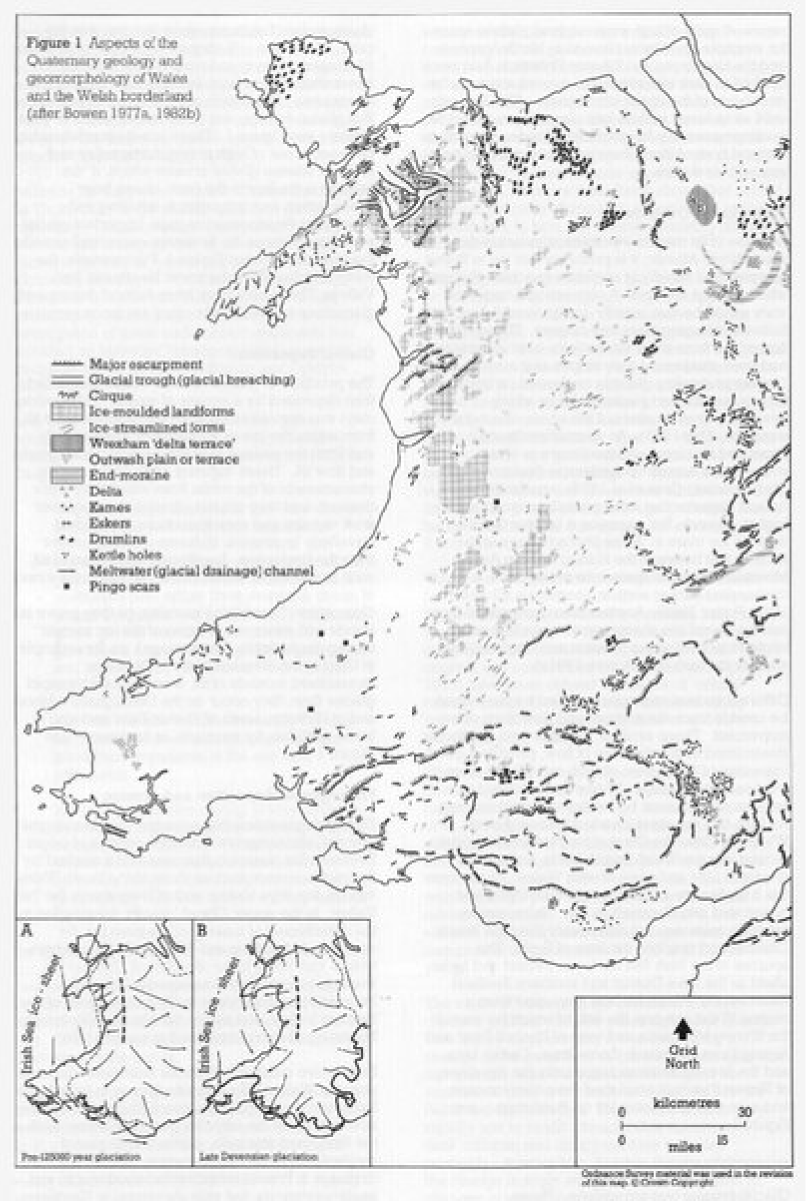
In Wales, a chronology based on the concepts of 'Older' and 'Newer Drifts' (Wright 1914; Charlesworth 1929; George 1932) dominated classification for more than fifty years. It was replaced by a scheme based on sections in East Anglia and Ireland (Mitchell 1960, 1972). A classification based on the superposition of actual rock sequences had started to emerge by 1970 (for example, Bowen 1970a, 1973a, 1973b). Progressive amplification of this lithostratigraphy in subsequent years led to the rejection of the East Anglian and Irish models in Wales. In parallel, a global oxygen isotope stratigraphy was also emerging (Bowen 1973a, 1973b, 1977a, 1981a; Bowen (*in* Jenkins *et al.* 1985); Bowen *et al.* 1985; 1986; Bowen and Sykes 1988). These advances have been underpinned by the coastal exposures of Gower, which thus comprise a type area, and supplement the regional stratotype sections now proposed at Minchin Hole and Bacon Hole Caves (Bowen et *al.* 1985; Stringer et *al.* 1986).

In the Gower rock sequence it has been possible to recognise the global events of the last 250,000 years or so. These include correlatives of Oxygen Isotope Stages 1, 2, 3, 4, 5 (including its substages), 6 and 7, with some evidence for a Stage 9 high sea-level event. Other evidence in Gower permits recognition of the oldest glaciations in Wales, the earliest of which may be more than half a million years old.

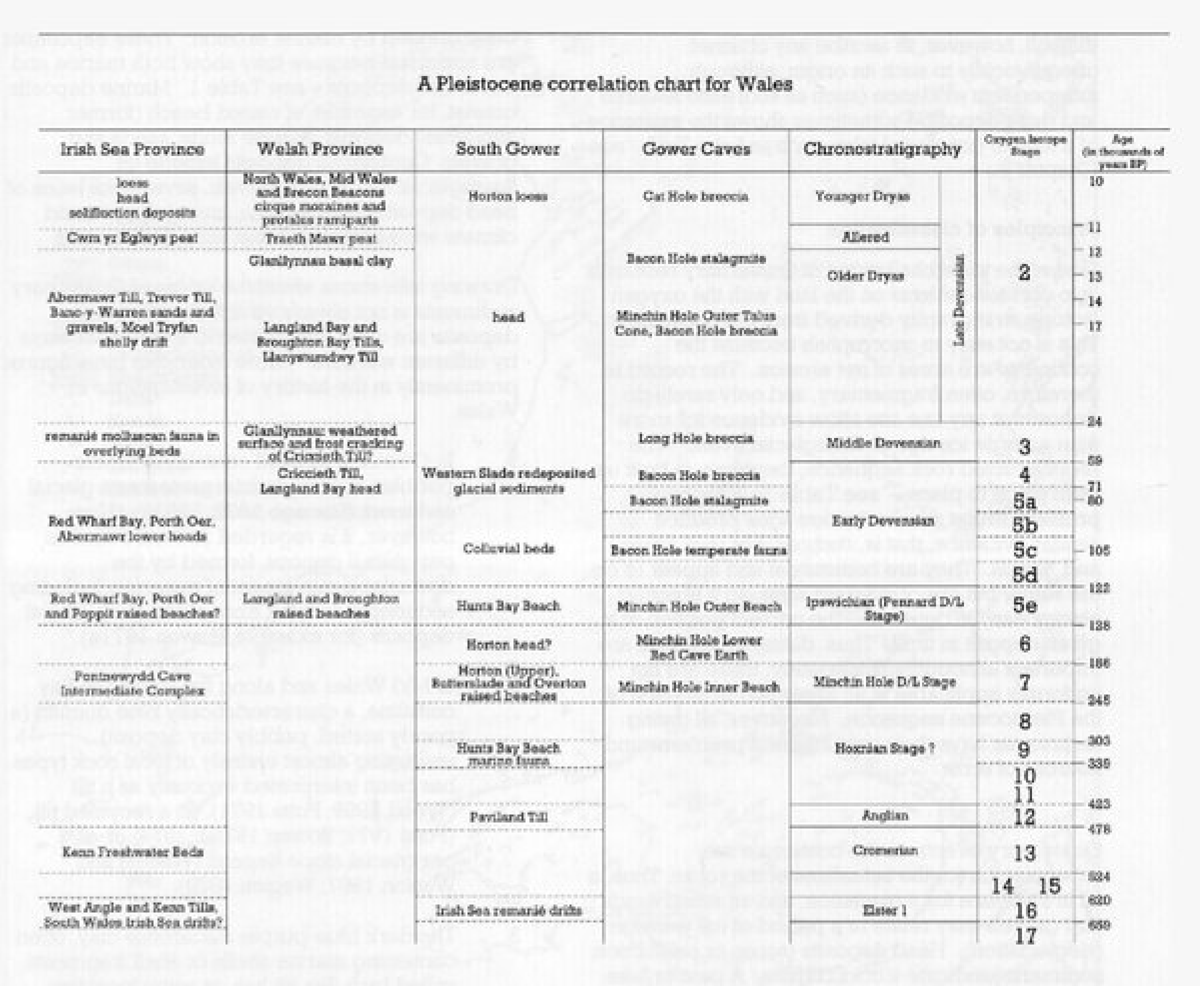
*Editor in Chiefs note

In an attempt at achieving a common international approach to correlation and a common chronostratigraphic language, geologists have chosen a stratotype for the base of the Pleistocene Series at Vrica, in southern Italy. There, the lower boundary of the Pleistocene (boundary stratotype) has been placed in a sequence of marine rocks, defining the base of the series (and of the Quaternary) at a level that has been dated geochronologically at 1.6 million years before the present.

References



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



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 y: Eglwys peat	Traeth Mawr peat			Allerød			11
	Glanllynnau basal clay		Bacon Hole stalagmite	Older Dryas			12 13 14
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				17
remanié molluscan fauna in overlying beds	Glanllynnau: weathered surface and frost cracking of Criccieth Till?		Long Hole breccia	Middle Devensian		3	24
	Criccieth Till, Langland Bay head	Western Slade redeposited glacial sediments	Bacon Hole breccia	Early Devensian		4	59
Red Wharf Bay, Porth Oer, Abermawr lower heads			Bacon Hole stalagmite			5a	71 80
						5b	
		Colluvial beds	Bacon Hole temperate fauna			5c	105
						5d	
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	122
		Horton head?	Minchin Hole Lower Red Cave Earth			6	128
Pontnewydd Cave Intermediate Complex		Horton (Upper), Butterslade and Overton raised beaches	Minchin Hole Inner Beach	Minchin Hole D/L Stage		7	186
				Hoxnian Stage ?		8	245
		Hunts Bay Beach marine fauna				9	303
						10 11	339
		Paviland Till		Anglian		12	423
Kenn Freshwater Beds				Cromerian		13	478
						14 15	524
West Angle and Kenn Tills, South Wales Irish Sea drifts?		Irish Sea remanié drifts		Elster I		16	620
						17	659

(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).