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VISTULIAN PERIGLACIAL PHENOMENA IN SOUTH-WEST WALES**

Abstract

Four models are presented concerning the development and preservation of periglacial phenomena in Western Britain. Occurrences of solifluction deposits, fossil ice wedges and other periglacial features are described from South-West Wales, and are related to the Pleistocene stratigraphy of the area. Solifluction deposits are frequently thick beneath the glacial drifts, but are much thinner above. It is suggested that South-West Wales experienced a prolonged Early and Middle Vistulian periglacial phase and a short but severe periglacial phase following Late Vistulian dissolution of the Irish Sea Glacier. Field evidence is found to accord fairly closely with the expected distribution and nature of the various phenomena. The Vistulian glaciation limit should not be unsed as a line marking the northern limit of extensive periglacial features in Great Britain; such features may in fact be more common within the limit than in the south of England.

INTRODUCTION

This paper is concerned largely with peninsular South-West Wales: that is, the county of Pembroke and the immediately adjacent parts of Cardiganshire and Carmarthenshire. Because it is remote from the major upland areas of Wales, the peninsula is thought not to have been subjected to glaciation by ice from the Welsh ice-cap, but to have lain largely within the sphere of influence of the Irish Sea glacier (Fig. 1). Most authors consider that the area was glaciated on at least two occasions by this glacier, although there is considerable disagreement concerning the outermost limits of these glaciations (Charlesworth, 1929; Mitchell, 1960; John, 1970a).

Periglacial phenomena in South-West Wales have received very little attention from former workers. Prestwich (1892) recognized the *head* deposits around the South-West Wales coasts, and described the stratigraphy of several sites. Jehu (1904), during the course of a skilful and comprehensive analysis of the glacial drifts of North Pembrokeshire, provided accurate descriptions of both head and *rubbly drift* (a mixed deposit of head and soli-

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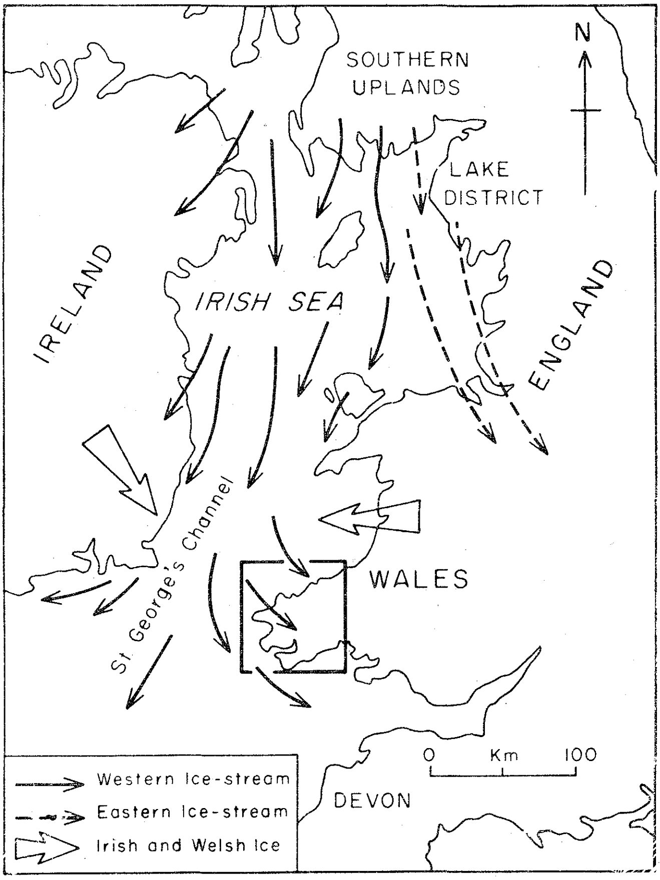


Fig. 1. The sphere of influence of the Irish Sea glacier and its relation to local Irish and Welsh ice (No particular glaciation intended)

The box indicates the area under detailed consideration

flucted glacial materials), although he did not assign a periglacial origin to either. Since 1904 almost all of the attention of geologists and geomorphologists in South-West Wales has been directed towards the clarification of glacial events, and periglacial phenomena have received only passing reference (see, for example, Williams, 1927; Cox, *et al*, 1903; Charlesworth, 1929; Mitchell, 1962; Synge, 1963). On the other hand the adjacent area of Cardiganshire has been the scene of several recent investigations of apparently periglacial phenomena by Dr. & Mrs. E. Watson (1965a, b, 1966, 1967, 1970), and the South-West Peninsula of England has also received greater attention (Te Punga, 1957; Waters, 1961; Stephens, 1966, 1970). The present author has attempted to restore the balance somewhat by describing the stratigraphic relationships of periglacial deposits in a general review of the Pleistocene period in Pembrokeshire (John, 1970a).

Before undertaking the work on which this paper is based, the author considered it possible to construct four models concerning the development of periglacial phenomena:

(1) Because of the location of South-West Wales in the relatively warm oceanic approaches of Great Britain, climatic conditions during glacial and periglacial stages should have been less severe (and certainly less continental) than, for example, the Midlands or Eastern England. As at present, mean summer temperatures would have been lower than in Eastern England, mean winter temperatures higher, and annual precipitation considerably greater (Manley, 1951; Williams, 1969). Consequently permafrost would not have been so widely developed as in Eastern England; features associated with severe permafrost conditions (such as ice wedges) should be encountered infrequently, whereas features associated with relatively mild and humid periglacial conditions (such as solifluction deposits) should be common (Péwé, 1964 ; Watson and Watson, 1967).

(2) Because South-West Wales lies close to the southern limits of glaciation by the Irish Sea glacier, the area would not have been over-ridden by ice until near the peak of each glaciation. Consequently one would expect to find evidence of relatively prolonged phases of periglacial activity during both the waxing and waning phases of each glaciation.

(3) From what is known of the growth rates and dissolution rates of Northern Hemisphere ice sheets (Flint, 1971), their waxing phases should have been more prolonged than the waning phases. Hence „early-glacial" periglacial deposits should be thicker, if not more widely distributed, than „late-glacial" periglacial deposits. This should apply in South-West Wales as elsewhere. One would expect that areas further north would have experienced more prolonged glaciation during each glacial stage, and correspondingly less prolonged periglacial activity. On the other hand areas further south would have experienced less prolonged occupation by ice (or no glaciation at all) but more prolonged periglacial conditions (Fig. 2). All other things being equal (e.g. slope, aspect, bedrock lithology) one could predict the greatest development of periglacial phenomena in the south, and the least development in the north of the Irish Sea — St. George's Channel region.

(4) Because the erosive capacity of a glacier diminishes rapidly close to its snout, one would expect some relationship to emerge between the intensity and duration of glaciation at a site and the degree of preservation of pre-existing deposits. It goes without saying that there will be no severe modification of periglacial deposits beyond the limit of glaciation. However, within the limit of glaciation there may be very little destruction of pre-existing

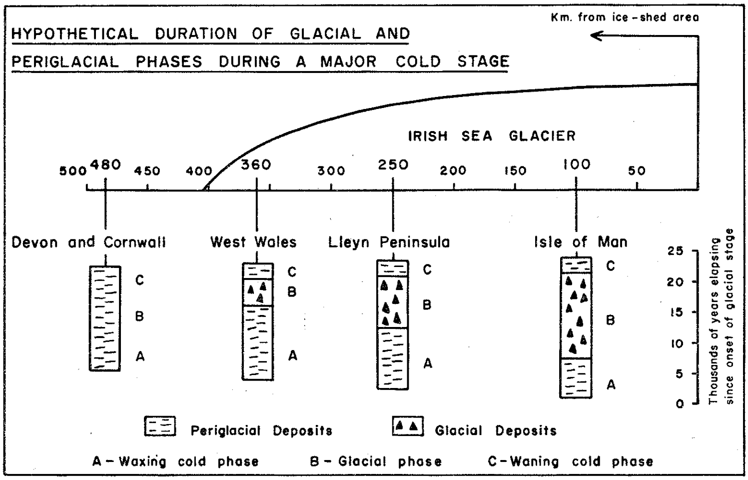


Fig. 2. Model showing the hypothetical duration of glacial and periglacial phases during a major cold stage, within the sphere of influence of the Irish Sea glacier

The columns are intended to be proportional in length to the duration of "cold" climatic conditions at each site

periglacial deposits by over-riding ice close to the glacier snout, while in contrast areas subjected to glaciation beneath the thicker and more dynamic parts of the glacier may experience widespread, and possibly complete, removal of pre-existing superficial deposits of all types. There could be localised preservation of pre-existing deposits in areas not subjected to rapid ice streaming, or in the lee of obstacles, or even in areas of strongly differentiated relief protected by shearing within the ice mass.

It was realised at the outset that these four hypotheses could never be fully substantiated in the field, since they were based in part upon an oversimplified scheme of climatic behaviour and in part upon the theory of an ideal glacier flowing in a perfectly adjusted glacial drainage basin. However, it was felt with some confidence that they were realiable enough to justify some expenditure of time on an exercise in model-testing.

DESCRIPTION OF PHENOMENA

SOLIFLUCTION (HEAD) DEPOSITS

Deposits of head occur widely in South-West Wales. There are thick accumulations beneath steep slopes inland, as for example at Carnllidi (738280), in the Prescelly Mountains of North Pembrokeshire, and near Pentre-Cwrt in the Teifi valley (Evans, 1945; Jones, 1965). However, good exposures are rare except in coastal sections, and it was for this reason that most of the author's work was concentrated on the coast.

As indicated by the work of Dr. Watson (for example, Watson, 1969), there is a widespread occurrence of stratified and pseudo-stratified head deposits in Central Wales which approximate to the *grézes litées* or *éboulis ordonnés* of French workers (Guillien, 1964; Tricart, 1969). In the author's experience, however, in South-West Wales there is very little true inter-stratification of fine silty beds and coarse beds within horizons. On the other hand it is possible to make a rough differentiation of the coastal head deposits on the basis of particle size of frost-shattered fragments, as noted by Galloway (1961) in Scotland. The following categories are widely recognized:

(1) Fine or flaky head (generally composed of shattered shale or mudstone fragments). This type of head is particularly well exposed at Whitesand Bay (733273) and at Aber-mawr (883347) in North Pembrokeshire. At the latter site there is c. 4 m of flaky head, with well-defined pseudo-stratification inclined at 8°. It is composed largely of shattered fragments of Upper Cambrian shale less than 2 cm long, with numbers of small rounded foreign pebbles and occasional larger fragments of upslope quartzite (Pl. 1). The matrix is sandy and gravelly, with no marked concentration of fines.

(2) Moderately blocky (or intermediate) head (composed of a variety of more resistant sandstones, shales and limestones, and also igneous rock--types). This is the most widely distributed type of solifluction deposit in South-West Wales, being represented in a great number of coastal exposures. Generally it displays pseudo-stratification, with shattered bedrock fragments set in a sandy and silty matrix (Pl. 2). Representative sites are Gwbert in Cardiganshire (163495), Marros in Carmarthenshire (205075), and Newgale (846224) and Caerbwdy (766245) in Pembrokeshire (John, 1965a; Bowen, 1970a). At Ogof Golchfa (742237) there is a typical exposure of moderately blocky head. It is generally less than 1 m thick, but it is a distinct and colourful layer as a result of its high concentration of Cambrian purple sandstone and shale fragments derived from an abandoned cliff-line. These fragments are for the most part less than 20 cm long, although there are some larger incorporated glacial erratics. Up to 90% of the fragments in this head are angular or sub-angular (John, 1970b).

(3) Blocky head (composed particularly of quartzites, conglomerates and dolerites). This type of head is encountered at several of the important Pleistocene coastal localities in South-West Wales. On occasion it is devoid of pseudo-stratification, and at one or two sites (for example, Pen Dal-aderyn, 717233) it has an open-work texture. Pl. 3 shows a typical blocky head at Pen Dal-aderyn composed of Pre-Cambrian tuff fragments up to 1 m in

diameter. The deposit is chaotic and unsorted, with blocks occasionally embedded in a brown sandy matrix. Other blocky heads with better sorting occur at Druidston (862173), Aber-mawr, and Poppit (145490) on the Teifi estuary. At the latter site the head is up to 6 m thick, and is composed of quartzite fragments up to 50 cm long set in a silty matrix.

(4) Rubble-drift or „rubbly-drift" as described by Jehu (1904). As indicated earlier, this is a variable deposit of frost-shattered upslope bedrock and derived glacial materials, mixed together during the solifluction process (Pl. 4). It has a strong visual affinity to certain types of till, and has indeed been called till by such workers as Synge (1963; 1970). However, fabric analyses indicate that it has invariably been subjected to solifluction at such sites as Aber-mawr, Whitesand Bay, and Porthmelgan (728279). Lithologically similar deposits occur at New Quay, Cardiganshire (395595), while at least part of the drift sequence at Morfa Bychan seems to consist of soliflucted till (Watson and Watson, 1967).

There is clearly a considerable amount of gradation between these categories, and there is by no means always a simple relationship between bedrock lithology and head type. Very few of the solifluction deposits of South-West Wales are composed entirely of upslope bedrock fragments, for generally there is some contamination through the incorporation of pre-existing superficial deposits (Watson, 1969). In some cases there is difficulty in deciding whether to term a particular deposit a true head or a rubble-drift.

At several sites periglacial deposits are sufficiently blocky and chaotically deposited to justify being termed *block-flows* (*coulées de blocaille*), as decribed by Tricart (1969). Predictably, blockfields and blocky scree slopes are commonly encountered in the Prescelly Mountains above an altitude of 300 m. An extreme coastal example is afforded by a horizon of purple blocky head at Pen Dal-aderyn where there are angular boulders up to 1.5 m in diameter amid a tumbled mass of smaller fragments. The deposit is unsorted, and its constituent fragments show no preferred orientation. Also, at the eastern end of Marros Sands, close to Ragwen Point (218072), there are blocks of quartzite weighing several tons incorporated in a blocky periglacial deposit. The evidence from these sites, among others, shows that on certain coastal cliffs instability was so marked during periglacial climatic phases that large-scale collapse of frost-shattered masses occasionally disturbed the process of slow solifluction.

FOSSIL ICE WEDGES, FROST FISSURES AND FROST CRACKS

So far as the author is aware, there are no previous published records of fossil ice wedges and related features in the Pleistocene deposits of South-West Wales, although they are known to be present in adjacent areas. They occur on the Cardiganshire coast in association with patterned ground (Watson, 1965a), and have been described from Gower by Bowen (1966). On Figure 3 the occurrences known to the author from South-West Wales have been plotted.

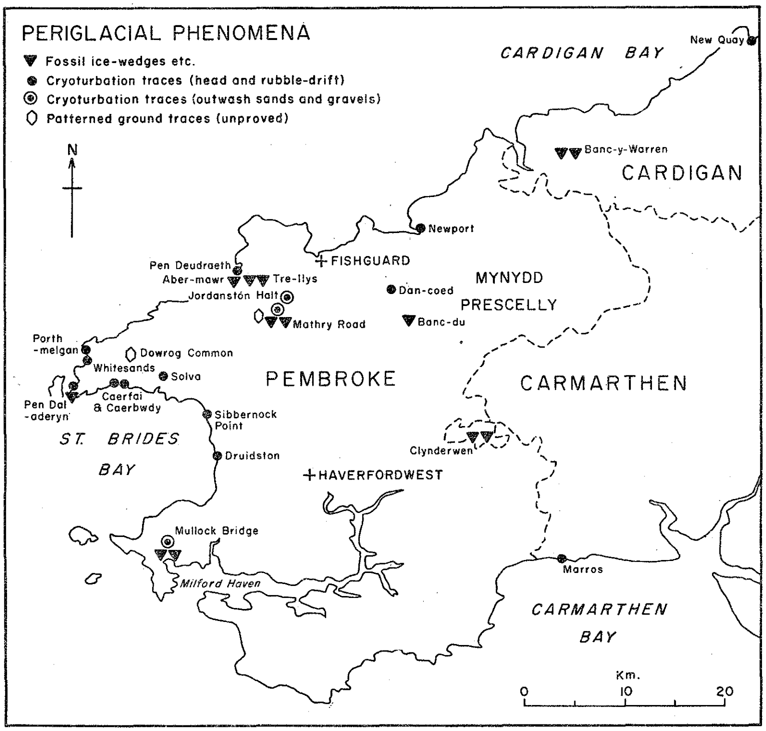


Fig. 3. Occurrences of periglacial phenomena known to the author in South-West Wales

The southern part of the map area has not been adequately investigated in recent years, thus explaining the apparent scarcity of features south of Haverfordwest

Several different types of frost-wedge features are encountered in the field. In this paper a simple three-fold classification is used, somewhat along the lines suggested by Poser (1947):

(a) fossil ice-wedges, with a breadth: depth ratio of 1 : 10 or less. At one time possibly filled with foliated wedge ice;

(b) fossil frost fissures, with a breadth: depth ratio of more than 1 : 10

but less than 1 : 30. At one time possibly occupied by vein ice up to 10 cm thick;

(c) fossil frost-cracks, with a breadth : depth ratio of more than 1 : 30. Possibly related to seasonal frost cracking, but not necessarily filled with vein ice.

Perhaps some of the features were never occupied by ice (although this is difficult to determine) and should be termed *ground fissures* (Dylik and Maarleveld, 1967). The term *sand wedge* is not used here because of its association with extremely arid conditions (see also Worsley, 1967; Johnsson, 1959).

At Mullock Bridge (811080), Pembrokeshire, an excellent ice-wedge cast was exposed for a time (up to 1966) on the worked face of a large gravel-

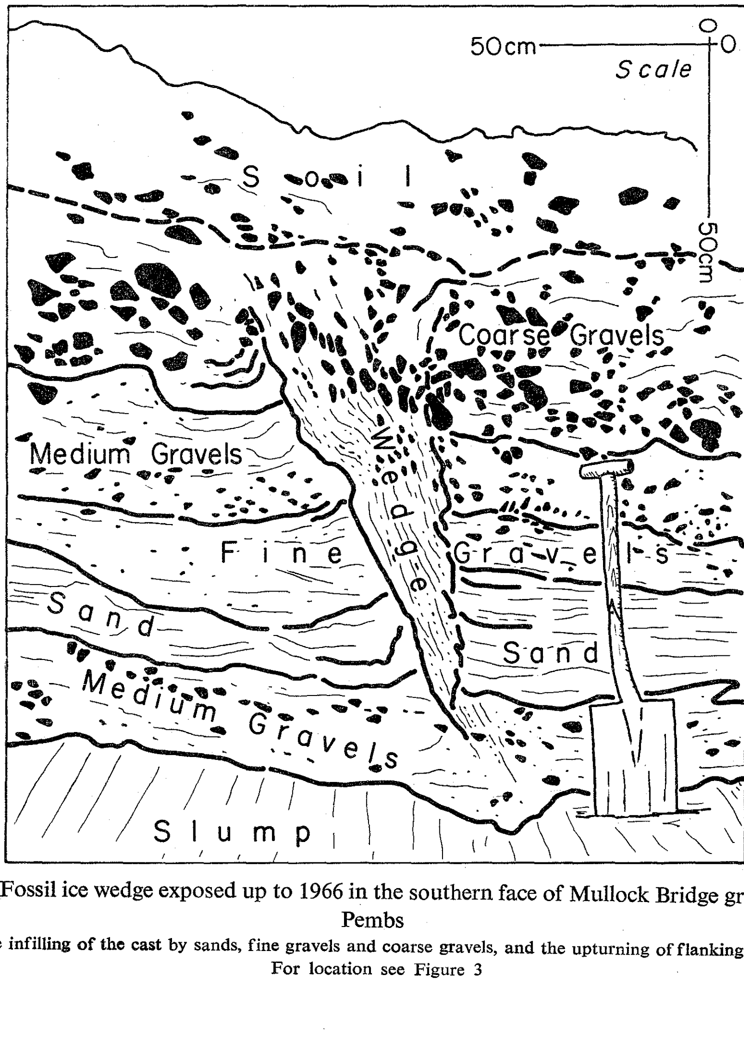


Fig. 4. Fossil ice wedge exposed up to 1966 in the southern face of Mullock Bridge gravel-pit, Pembs

Note the infilling of the cast by sands, fine gravels and coarse gravels, and the upturning of flanking horizons
For location see Figure 3

-pit (Fig. 4). The top of the wedge was located c. 50 cm beneath the flat ground surface of a kame terrace, where it was 50 cm wide. From here it passed downwards obliquely through the base of a horizon of torrential fluvio-glacial outwash gravels into a series of bedded sands and finer gravels. The sharp apex of the wedge occurred at a depth of 1.8 m. The edges of disrupted layers of sand and gravel were upturned sharply. The wedge was filled with a mixed deposit of sand, silt and gravel; most of the larger pebbles were concentrated near the top, where their long axes were for the most part found to be near-vertical. In the same pit several other ice-wedge casts up to 2 m deep have been discovered in the same stratigraphic position, that is, immediately beneath the base of the recent soil profile.

In another large gravel pit at Mathry Road (923310) in North Pembrokeshire there are further occurrences of fossil ice wedges, frost fissures and frost cracks. Again, they are preserved in fluvio-glacial outwash sands and gravels close to the ground surface, with their upper parts developed in coarse torrential gravels and passing downwards into alternating narrow horizons of sand and gravel. One particularly fine wedge is over 3 m deep and over 1 m broad at the top, and is filled with contorted gravels similar to those at the present ground surface. In 1963 many fossil frost fissures were observed at regular intervals of 1 m on a worked face of the pit, suggesting that they may have been part of a polygonal network. The most perfectly developed of the fissures in this series was 4 m deep, although most were less than 75 cm deep. Another fissure, show in Figure 5, has a somewhat complex form. It is just traceable as narrow crack through a cryoturbated surface horizon of coarse gravels, but beneath a depth of c. 60 cm the crack broadens somewhat until it is c. 15 cm wide, with a distinct wedge form in a lower horizon of coarse gravels at c. 1 m depth. The wedge narrows down to a depth of c. 2 m at which level there is a complex cryoturbated area with a small subsidiary fissure extending obliquely downwards for a further 20 cm. Beneath this there are still traces of the main fissure down to a depth of c. 3 m. There is another quite separate fissure with a depth of 1.2 m and a maximum width of c. 10 cm extending downwards obliquely from a disrupted sand layer. This feature, like several others in the pit, is quite devoid of any connection with the ground surface. A notable characteristic of the fissures observed is that they are all filled with erected pebbles and gravel particles; further, they are all bounded by down-turned gravelly horizons.

There are several other localities in South-West Wales where fossil ice wedges have been discovered in outwash sands and gravels. In 1965 there were several such features (one of them 1.8 m deep) exposed close to the surface in the lower gravel-pit at Tre-llys (898349), and in the same year ice-wedge casts up to 1 m deep were seen in the Cardigan Sand and Gravel

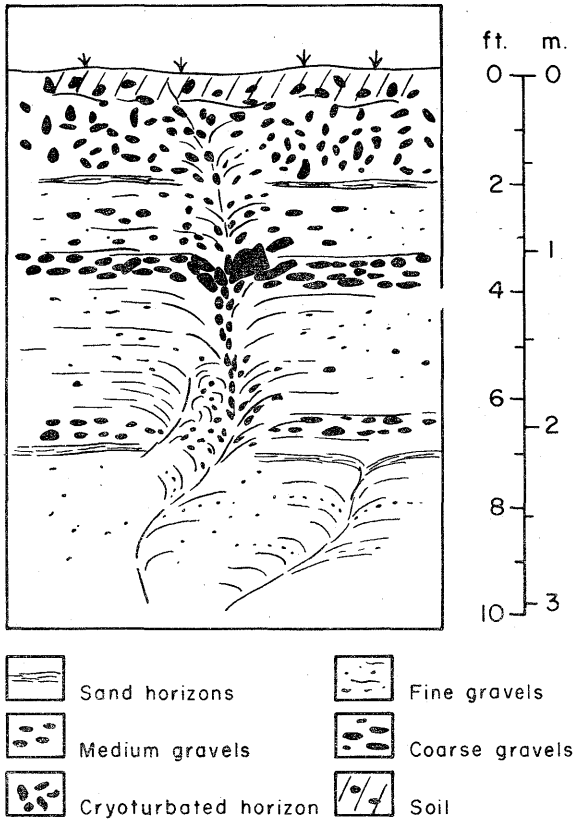


Fig. 5. Fossil frost fissures, Mathry Road gravel-pit, Pembs.

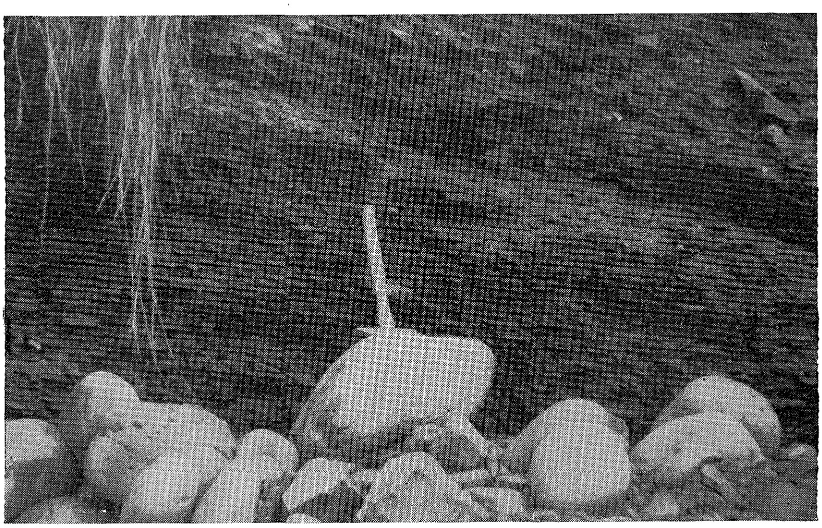
Note the traces of fissures which are devoid of contact with the ground surface, and the down-turning of horizons at the fissure edges. For location see Figure 3

Co. pit at Banc-y-Warren (202482). In all cases the wedges were filled with sand and gravel from the host horizon, and were associated with up-turned strata on their flanks. One further interesting site was a sand-pit near Llandre, Carms (093203), where ice-wedge casts up to 5.5 m deep are described by Bowen (1970a). Unfortunately this pit was filled in some years ago before the author could record the stratigraphic relationships of the fossil features,

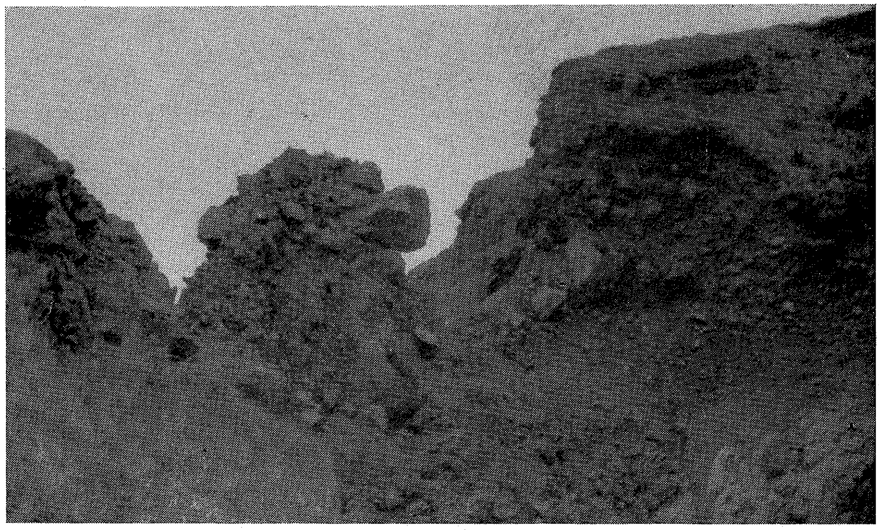
Two other small ice-wedge casts deserve mention, since they occur not in outwash sands and gravels but in head (Fig. 6). The first of these, in the drift exposure at the southern end of Aber-mawr beach, is about 60 cm deep, and is seen to pass from the base of a thick head horizon down into a series of ice-contact sands and gravels. The second, exposed in the sequence of head deposits at Pen Dal-aderyn, originated at the base of a cryoturbated

Pl. 1. Fine flaky head at Aber-mawr, Pembrokeshire

The head is composed of angular shale flakes with some rounded erratic pebbles and larger quart zite fragments

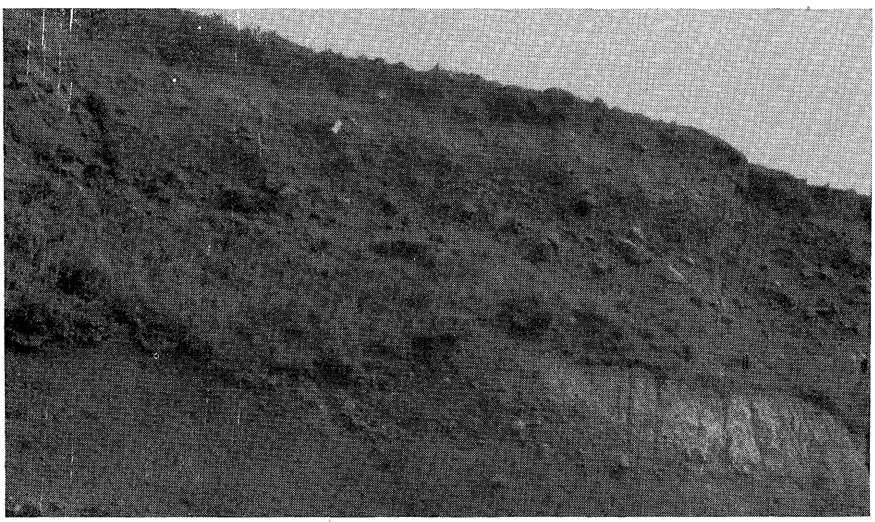


Pl. 2. Moderately blocky (intermediate) head exposed just above the level of the storm-beach at Aber-mawr, Pembrokeshire



Pl. 3. A blocky head at Pen Dal-aderyn, Pembrokeshire

The blocks are of Pre-Cambrian tuffs from the immediate vicinity



Pl. 4. Rubble-drift exposed at the top of the drift section at Aber-mawr, Pembrokeshire

Beneath the rubble-drift are two facies of true head and a thin layer of calcareous Irish Sea till (exposed at lower right and wedging out in the centre of the photograph); above the rubble-drift is a thin layer of blown sand and recent soil

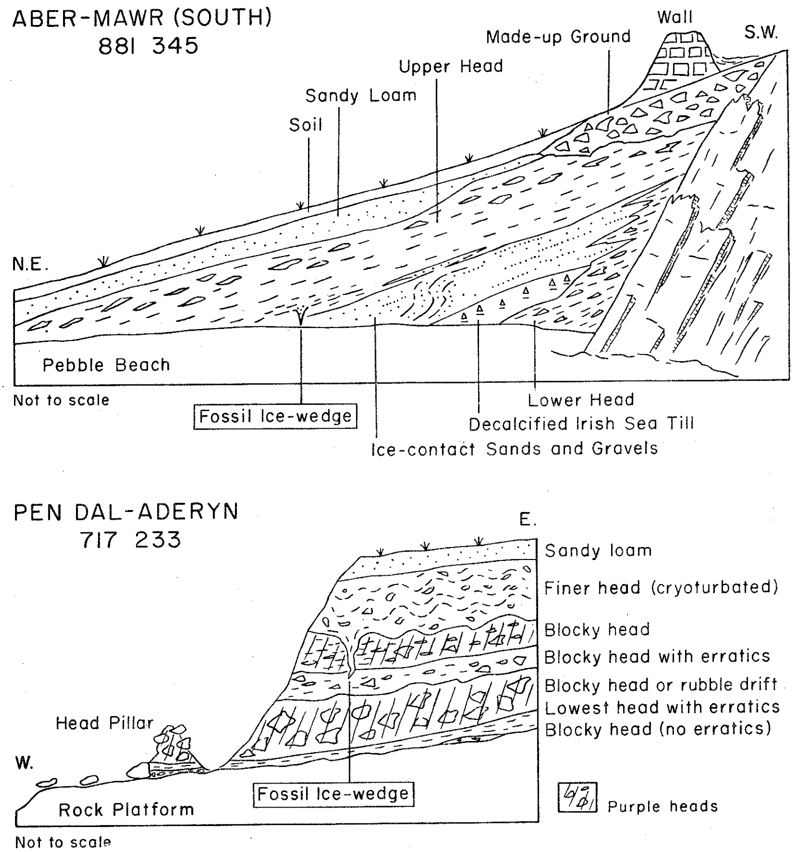


Fig. 6. Fossil ice wedges associated with head horizons in North Pembrokeshire

The scales for the two diagrams are variable

head horizon and passes down through a horizon of moderately blocky head with pseudo-stratification into a lower blocky head. The wedge contains traces of fossil foliations and erected head fragments, and has a depth of 1 m.

The evidence from South-West Wales, therefore, suggests that fossil ice wedges, fissures and cracks may be relatively common. As elsewhere in Britain, they may well occur even more widely than suggested in Figure 3, for the number of undiscovered occurrences must be much higher than the number of sites recorded (Galloway, 1961). While the distribution map (Fig. 3) may suggest a more frequent occurrence in the north of the area, this is simply a reflection of the fact that most of the author's work has been concentrated there. Ice-wedge casts have been found close to the surface in most of the gravel-pits examined in detail, and one may assume, with some confidence, that they probably occur in all those areas where fluvio-glacial outwash materials are widespread.

Generally they occur close to the ground surface, indicating that most were not formed until the process of sand and gravel deposition had ceased. However, at Mathry Road there are signs of frost cracking and even frost fissure growth before the end of terrace aggradation. There are marked similarities with some of the features described by Worsley (1966) from Cheshire, and some of the narrowest frost fissures may well have developed syngenetically (West, 1968). Again, the two wedges described in association with head deposits at Aber-mawr and Pen Dal-aderyn are intraformational, and show that head formation (and, at the latter site, cryoturbation) continued after the formation of the ice wedges.

OTHER PERIGLACIAL PHENOMENA

Other types of periglacial phenomena are widespread in South-West Wales. Cryoturbation traces are encountered particularly frequently, especially in coarse-grained deposits close to the ground surface. For example, on the clifftop at Caerfai, on the south side of St. David's Peninsula, there is c. 2 m of violently „churned" moderately blocky head; and less violent cryoturbation is also to be seen in head at Sibbernock Point (852214), Whitesand Bay (738273), Marros, Parrog (048397), Solva (800243), and in the Gwaun Valley, Pembrokeshire. Many other examples could be cited. At a few localities cryoturbated head occurs close to bedrock at the base of a Late Pleistocene drift sequence. For example, on the cliffs to the north of Porthmelgan cryoturbated head may be seen *in situ* beneath a non-calcareous till. There is a similar exposure on the low cliffs east of Caerbwdy and near the western extremity of the New Quay drift cliff (Mitchell, 1962). Traces of cryoturbation can also be seen in the coarse torrential gravels which cap many of the outwash sand and gravel exposures, for example at Jordanston Halt (918325) and Mullock Bridge, and in rubble-drift exposures close to the surface, as at Pen Deudraeth and Druidston.

Involutions do not occur anything like as frequently as on the Cardiganshire coast (Watson, 1965a). The only example known by the author in South-West Wales is a single involuted silt layer in solifluction deposits at Dan-coed (035338) in the Gwaun Valley.

Patterned ground has not been proved from South-West Wales, and it is certain that it does not occur on the scale described by Shotton (1960) from the Midlands or Williams (1964) from East Anglia. However, it does occur on the foreshore near Aberayron (Mitchell, 1962), just outside the area under consideration, so it may well be found upon more detailed examination of likely sites. Indeed, apart from the suggestion of patterned ground on the gravel surface at Mathry Road, the author has observed a trace of a polygonal pattern on air photographs at Dowrog Common (777278), St. David's Peninsula (Fig. 3). This site needs to be investigated further.

Two-tier cliffs have been examined by Wood (1959, 1962) for the area north of New Quay, where he has concluded that much of the upper bevel is the result of denudation under a periglacial climatic regime. A similar combination of vertical lower cliff and more gently-sloping upper cliff is to be seen on many of the coasts of South-West Wales, where again there is a good case to be made for periglacial modification (Savigear, 1953).

Scree slopes and lobate forms are widespread in the Prescelly Mountains, although most of them are now vegetated and clearly fossilised. For example, there are large accumulations of scree and frost-shattered blocks on the steep south face of Mynydd Carningli (063373) above an altitude of 300 m, and lower down the slopes stone streams and lobes of blocky material are encountered (094312). There are chaotic accumulations of frost-shattered blocks on the flanks of several of the upstanding carns, or tors, of the mountains; Carnmenyn (144325), Carngoedog (128332), and Carnalw (139338) may be cited as examples. There are also litters of blocks around tors at much lower altitudes, for example at Poll Carn (953245) and Maiden Castle (954248), both of which lie below an altitude of 135 m. These and other tors in South-West Wales have been atributed by Linton (1955) to the process of deep rotting and exhumation, but there can be no doubt that their present forms have evolved above all in response to periglacial processes.

Sandy loams and blown sands occur widely at the surface in association with other periglacial deposits in South-West Wales. The loams are up to 1–2 m thick, and sometimes they display „honeycomb" structures and other loessic affinities (George, 1933). Thus they may be held to be indicators of periglacial conditions (Péwé, 1969), although they are not as thick nor as extensive as the loess deposits of the Midlands and Eastern England (Williams, 1969).

Thus periglacial deposits, structures and landforms are widespread throughout the area under consideration. While Watson (1969) has gone so far as to describe „the periglacial landscape" of the Aberystwyth region in West-Central Wales, the present author would prefer not to go so far. Rather, he would describe the landscape of South-West Wales as one which has been modified during specific stages of the Pleistocene by periglacial agencies. It remains to elucidate these stages, so far as they can be interpreted from the relationships between periglacial phenomena and other Pleistocene deposits exposed in coastal sections.

RELATIONSHIPS BETWEEN PERIGLACIAL PHENOMENA AND THE PLEISTOCENE DRIFT SEQUENCE

In many of the coastal drift exposures of South-West Wales periglacial deposits and structures are revealed within comprehensive Pleistocene drift successions. The two most useful marker horizons are the ubiquitous raised beach (John, 1968a) and the glacial sequence of Irish Sea tills, related local tills and outwash sands and gravels. The Irish Sea tills are especially useful for the purpose of relative dating, since they have recurring lithological characteristics which make them readily recognizable, and since they occur at equivalent stratigraphic positions at a number of important sites (John, 1970a). The sequence of coherent deposits most often encountered is as follows :

6. Sandy loam and blown sand
5. Upper head and rubble-drift
4. Fluvioglacial sands and gravels
3. Irish Sea tills and local tills
2. Main (lower) head
1. Raised beach

This succession appears to be typical of those parts of the South-West Wales coast which were affected by the Irish Sea glacier (Fig. 1). There are, however, variations in the stratigraphy on the Cardiganshire coast north of New Quay, where the influence of ice from the Welsh uplands is manifested (Williams, 1927), and also on the south coast of Pembrokeshire and Carmarthenshire, which may have been unaffected by Irish Sea ice (Bowen, 1970b). But whatever the detailed distribution of glacial deposits in this area, there can be no doubt that two distinct horizons of periglacial deposits are represented: a generally thick horizon of Main (lower) head beneath the glacial drifts, and a generally thin horizon of Upper head above. The simplest interpretation suggests that the Irish Sea glaciation was preceded by a long periglacial phase and succeeded by a shorter periglacial phase. From a consideration of the field evidence the following further points can be made concerning these phases.

EARLY PERIGLACIAL PHASE

The head deposits belonging to this phase are occasionally interdigitated with pebbles and shingle from the underlying raised beach, as at Whitesand Bay and Poppit. At Porthclais there is evidence that an old storm-beach has been largely redeposited by solifluction (John, 1970b), and at other sites rounded erratic pebbles presumably derived from buried raised beaches are incorporated in the Main head. It is likely that periglacial conditions were initiated soon after the raised beach stage, for there are no signs of intervening deposits between the raised beach and the Main head.

There are considerable variations in lithology within the Main head. For example, at Aber-mawr (which may be taken as a type locality for the Pleistocene succession in Pembrokeshire) there are horizons of blocky, moderately blocky and fine head all within the Main head sequence (Fig. 7a). In the long exposure of Main head above the raised beach at Poppit there are further variations in head type, ranging from blocky head close to the Cei-bach boathouse to horizons of widely dispersed flaky fragments in a silty matrix further towards the east (Fig. 7b). While some of these variations are related to variations in the lithology and vulnerability of the bedrock source, the relationship is not always so simple, and in places the changes appear to have palaeoclimatic significance.

There are relatively few associated periglacial phenomena to assist in the interpretation of the Main head. At Aber-mawr there is a suggestion of a weathering break between horizons (1) and (2), but there is no soil profile development on a scale sufficient to confirm this. At Druidston the whole exposed thickness of Main quartzite head beneath Irish Sea till appears to have been subjected to a phase of intense rotting, although this may have occurred prior to head accumulation. No ice-wedge casts or related features have yet been discovered in the Main head, and indeed the thickest accumulations of the head do not even bear traces of cryoturbation. On the other hand where glacial deposits directly overlie very thin head or frost-shattered bedrock (as near Trwynhwrddyn Headland (732273) or at Newport), traces of cryoturbation can be observed.

Many of the accummulations of Main head on the South-West Wales coasts have been over-ridden by Irish Sea ice. In places the Irish Sea till contains considerable amounts of angular bedrock fragments which must have been derived from over-ridden head in the near vicinity. At Aber-mawr the Irish Sea till is separated from the underlying Main head by an unconformity which shows a sharp truncation of the head horizons (Fig. 8), and a detailed examination of the till-head interface reveals drag structures and interdigitation indicative of ice erosion prior to the deposition of the till. At some sites (such as Gwbert (163495), Porthmelgan and Whitesand Bay) there is very little Main head remaining beneath the Irish Sea till, but it would be unwise to speculate concerning the amount of superficial material removed. On the basis of other evidence it seems that the Irish Sea glacier which over-rode the northern part of Pembrokeshire was thin and incapable of much effective erosion (John, 1965 a), but nevertheless the possibility must be entertained that cryoturbated horizons of the Main head may have been removed, or

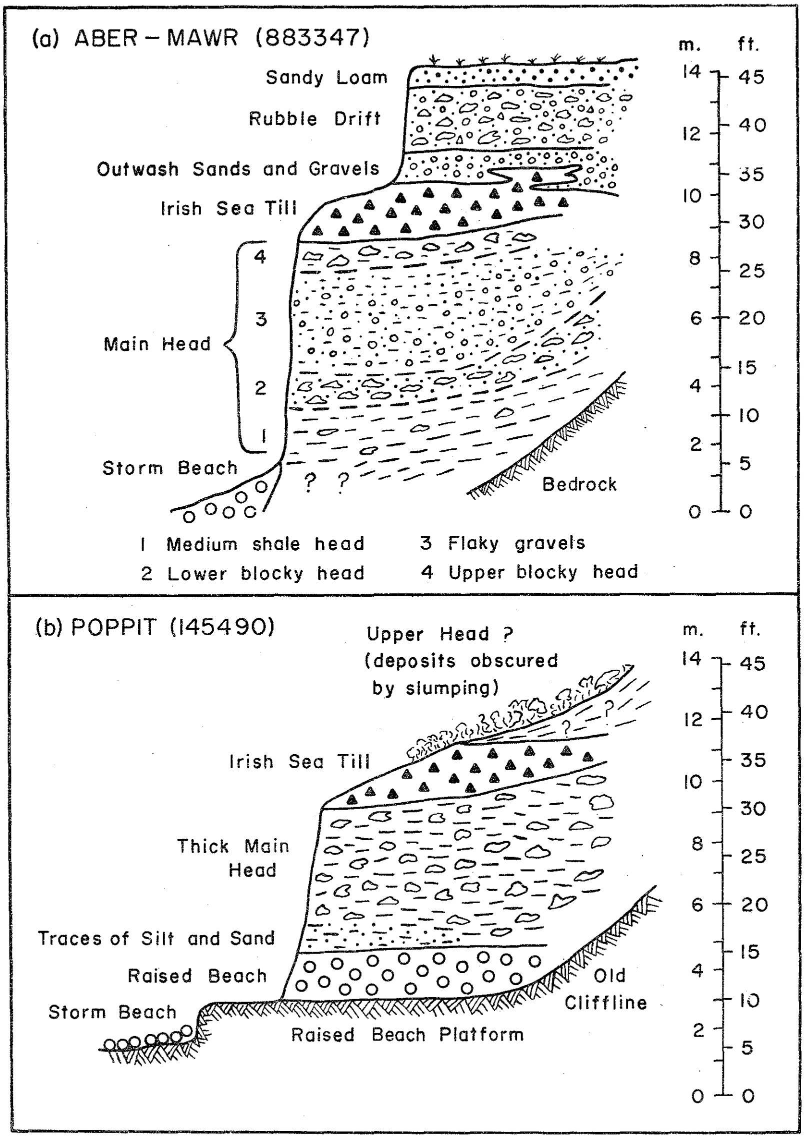


Fig. 7. Type localities for Main (lower) head in South-West Wales

Note that in each case the head is overlain by calcareous Irish Sea till. Note also the variations in facies within the head. Both sections are generalised. Parts of the Aber-mawr sequence of deposits are shown in Pls. 1, 2, and 4

even that interglacial or interstadial horizons may once have been present above the head. But however much material has been removed by ice, the head is sufficiently widespread and thick enough (up to 10 m, with even greater thicknesses possibly undiscovered beneath the level of present-day

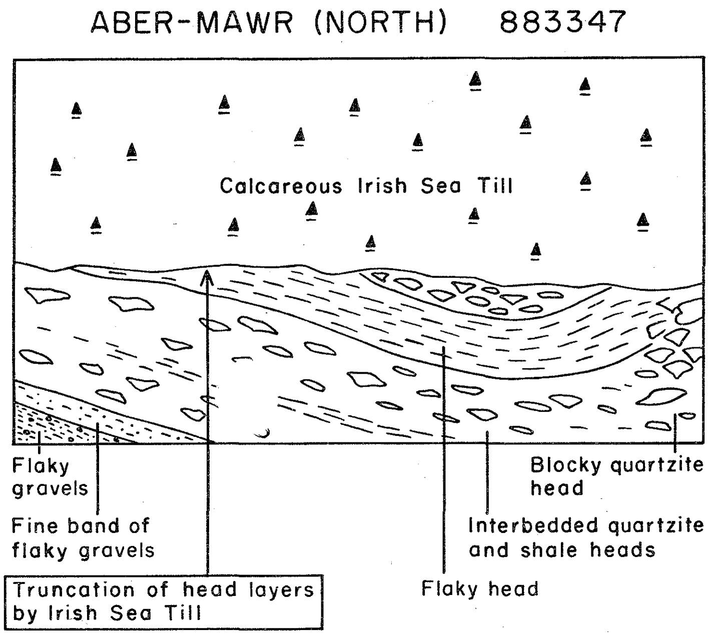


Fig. 8. Unconformity between Irish Sea till and underlying Main head at Aber-mawr

The vertical scale is exaggerated

storm beaches) to indicate accumulation during a long period of fluctuating periglacial climate.

LATE PERIGLACIAL PHASE

The head accumulations which originated at this time are widespread, but are seldom more than 2 m thick except in areas of high „solifluction potential"; that is, beneath steep cliffs or where there were plentiful supplies of unconsolidated glacial drifts on the coastal slope, as at Whitesand Bay and Druidston. The deposits are generally found directly above glacial and fluvioglacial drifts, and indicate that periglacial conditions persisted for some time after ice dissolution.

Lithologically, the true Upper head displays less variation that the Main head. It is generally moderately blocky in character, and at each exposure known to the author it remains fairly homogenous from top to bottom, as at Gwbert, Ogof Golchfa, and the south end of Aber-mawr beach. From the lack of facies variations within the head itself, therefore, it seems that climatic conditions were stable during its formation. On the other hand the rubble-drift, which is the stratigraphic equivalent of the head, does display great variations in character. Above all its nature is influenced by the nature of the superficial deposits from which it is derived. For example, at Druidston it is a thick variable deposit composed of till masses, outwash sands and gravels, and head fragments in varying proportions. At Aber-mawr and Pen Deudraeth headland it is composed of angular bedrock fragments mixed with outwash sands and gravels. As at Whitesand Bay and Porthmelgan most of the extraneous material in the rubble-drift is derived directly from the underlying calcareous Irish Sea till. Clearly, in view of the range of lithological variations encountered in examinations of the rubble-drift, it is unsuitable for use as a periglacial climatic indicator.

Several valuable inferences may be drawn, however, from the relationships between the Upper head and other periglacial phenomena. In the foregoing descriptions of ice wedge features, it was proposed that frost cracking, and possibly even ice wedge growth, occurred before the final dissolution of Irish Sea Ice. Certainly the evidence cited from Mathry Road suggests that permafrost was present before the aggradation of fluvio-glacial outwash terraces in the main river valleys was complete. A severe periglacial climate must have persisted for some time after final ice dissolution also, in view of the widespread occurrence of fossil ice wedges and related phenomena in the surface horizons of fluvioglacial sands and gravels (Fig. 3). Furthermore, it can be seen from the two sites in Figure 6 that this phase of permafrost probably preceded the phase of Upper head accumulation, since fossil ice wedges are seen to occur at the base of the uppermost head horizons.

Cryoturbation traces are also instructive when considered in their stratigraphic context. By no means all of the Upper head horizons are frost-heaved, but where conditions were favourable (as at Caerfai and Pen Dal-aderyn) severe cryoturbation does appear to have affected the uppermost head. Although there is no unequivocable supporting evidence, it may be suggested that head accumulation was followed by a deterioration of climate in which there was local cryoturbation and possibly further ice wedge development in sands and gravels.

From these various lines of evidence, the author considers that the wastage of the Irish Sea Glacier in South-West Wales was accompanied and succeeded by severe periglacial conditions, leading to the development of ice wedges, frost fissures and frost cracks. Later there was a slight amelioration of climate with the accumulation of the Upper head, and later still some of the deposits were disturbed by a phase of severe cryoturbation (and possibly further ice wedge development). This sequence of events must remain tentative; but it is supported by related evidence from several critical coastal and inland sites. Above the periglacial deposits there occurs only the sandy loam and surface soil. As suggested above part of the loam may be of periglacial aeolian origin.

It is difficult to assess the length of time represented by this "late-glacial" periglacial phase. If the thick Main head is taken to represent a prolonged periglacial phase, the thin Upper head should be taken to represent a considerably shorter phase. However, the most severe periglacial conditions may have occurred during the latter phase.

CHRONOLOGICAL SIGNIFICANCE OF PERIGLACIAL PHENOMENA

A major problem of interpretation concerns the age of the periglacial features discussed above. In order to assign these features to specific stages or sub-stages of the Late Pleistocene it is first necessary to review current opinion concerning the West European chronology. In spite of different uses of stage names by different authors, there appears to be a broad concensus of opinion concerning the climatic sequence. Working back down the time-scale, the following brief points can be made.

Flandrian Interglacial (recent). Slight climatic fluctuations but overall temperate climate. No occurrence of arctic or sub-arctic conditions at low altitudes, although evidence of a "Little Ice Age" (1580–1850 A.D.) in mountain areas (Grove, 1966).

Late-glacial[1] (10,000–14,000 years B.P.). Rather violent climatic fluctuations, the most important being as follows:

Pollen zone III was a very cold sub-stage of sub-arctic climate, with glacier readvances in many parts of the northern hemisphere. Severe periglacial activity in extra-glacial areas, even at low altitudes.

Pollen-zone II was a warmer sub-stage generally known as the Allerød oscillation. Conditions possibly as warm as the present day. Widely recognized in the stratigraphic records of Western Europe, but not in North America (Mercer, 1969).

Pollen-zone I was a sub-stage of gradual climatic amelioration after the last major glaciation. But climate still sub-arctic or arctic, with fluctuations. Many organic deposits known from this stage; also widespread periglacial features. Traces of a Bölling oscillation at about 12,300 years B.P.

Late Vistulian[2] (26,000–14,000 years B.P.). Last major glaciation of North-western Europe. Major ice-sheet growth over Scandinavia, and smaller ice-sheets over northern British Isles and Alps. Speed of build-up

[1] This term is used in the sense of Zagwijn & Paepe (1968)

[2] Equivalent to the western European Late Weichselian. This and subsequent terms are used broadly in the sense of Flint (1971).

variable, but probably rapid ice dissolution. Most extensive glaciation of the Vistulian.

Middle Vistulian (50,000–26,000 years B.P.). Fluctuating interstadial conditions. Two distinct interstadials (Hengelo and Denekamp interstadials) known from the continent, but not differentiated in the British Isles. Whole sub-stage generally referred to in Britain as "Upton Warren Interstadial complex". Climate as inferred from organic remains (mainly in the English Midlands) generally sub-arctic, with some approximations to boreal.

Early Vistulian (70,000–50,000 years B.P.). Cold for the most part, with severe sub-arctic to arctic conditions prevailing at times on the continent. Possibly a considerable expansion of Scandinavian ice, but recently held view of an extensive British glaciation not now supported. At least one cold--temperate (forested?) interstadial known as Chelford interstadial in Britain (Worsley, 1970).

Eemian interglacial (more than 70,000 years B.P.). Attainment of fully temperate conditions. Many interglacial deposits (organic and inorganic) known from Continental Europe and Britain (West, 1968). Also raised beaches widely referred to this stage.

Rather than elaborating on pre-Eemian stages, it is worth considering the extent to which the South-West Wales stratigraphy can be equated with the events of the Vistulian. A tentative correlation is made on Figure 9, with the right-hand column showing the south -West Wales stratigraphy set against a suggested climatic curve for Western Britain. Overall, the correlation appears to be excellent between the British stages and sub-stages and the West Wales stratigraphy.

(6) The soils and slope-washing materials at the ground surface must be of Flandrian age. There is abundant archaeological evidence for this (Lacaille and Grimes, 1955), and indeed Bowen (1966) has cited biological evidence that some of the sandy loams of nearby Gower are also recent or recently redeposited.

(5) The Upper head and rubble-drift are best envisaged as the products of a Late-glacial periglacial climate in view of their limited thickness and position close to the top of the drift stratigraphic column. If any of the wind-blown materials are in reality of periglacial origin, they are also most conveniently assigned to the Late-glacial, for aeolian action on a large scale has already been proved for this time by Kerney (1963) in South-East England. It is tempting to suggest that the traces of climatic fluctuations during this periglacial phase may to related to the well-known oscillations of pollen--zones I–III.

(4) and (3) The glacial deposits of South-West Wales are relatively thin.

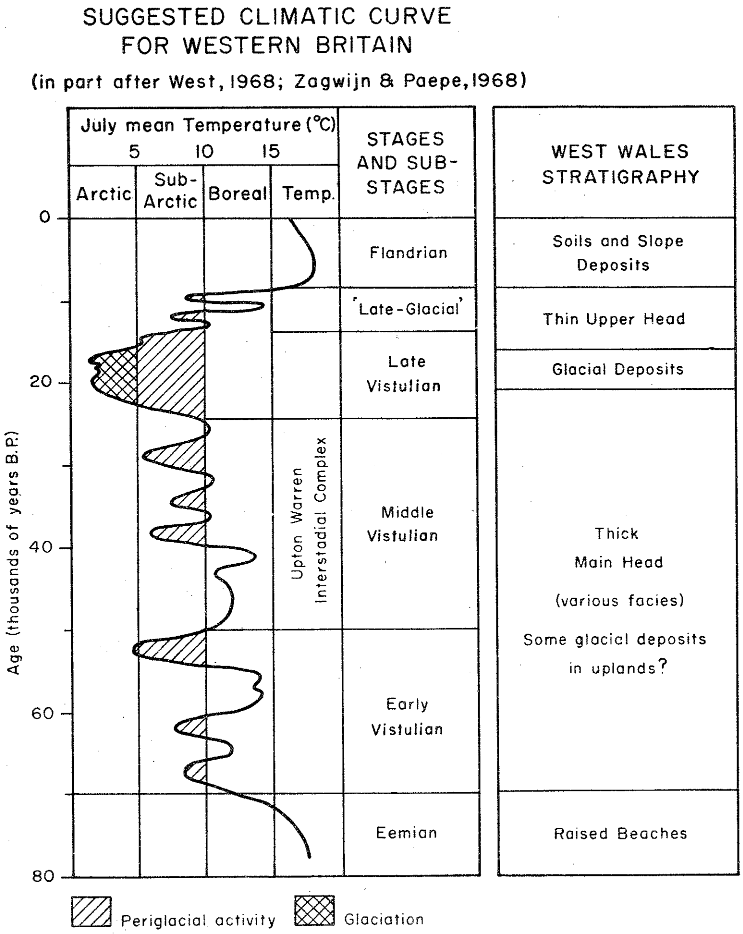


Fig. 9. A suggested correlation between a climatic curve for Western Britain and the South-West Wales stratigraphy

Full glacial conditions are thought to have affected the area only during the Late Vistulian. (The stage names and boundaries are not closely defined, but are believed to represent a broad concensus of opinion)

but are nevertheless coherent and largely unmodified by weathering (John, 1970a) ; they appear, therefore, to relate to a recent glaciation, which must have been that of the Late Vistulian. As noted above, the Irish Sea glacier at this time did achieve some erosion of pre-existing deposits, but the overall impression is that it was not a particularly powerful erosive force, and that it may have been close to its southern limit. However, the ice did extend at least as far south as Milford Haven (John, 1965b; John and Ellis-Gruffydd, 1970).

(2) The thickness of the Main head indicates accumulation over a period

of prolonged periglacial conditions. The Middle and Early Vistulian appears to have been such a period, for in spite of the interstadial character of certain phases the climate was probably sub-arctic for at least 50% of the time. Indeed, it is possible that the climatic fluctuations of the period 70,000–26,000 years B.P. may have caused some of the facies changes in the Main head. The glacial character of the South-West Wales climate during one part of the Early Vistulian is apparently indicated by deposits of glacial origin near the base of the drift sequence at New Quay. These drifts are of local Welsh origin, and suggest that ice from the Welsh uplands may have reached Cardigan Bay at this time (John, 1968b).

(1) The raised beaches at the base of the South-West Wales drift sequence may be interpreted as Eemian features, as suggested by Zeuner in 1949 and accepted by current research workers in the area (Bowen, 1970a; John, 1968a).

The major anomaly in this tentative reconstruction of absolute chronology is the apparent lack of interstadial traces. However these could have been soliflucted away during the periglacial phase heralding the Late Vistulian glaciation, or they may have been removed by overriding ice. They may still be present in undiscovered localities. In any case, this anomaly does not constitute an obstacle to the acceptance of the author's suggested chronology, for any alternative chronology must also account for the lack of recognizable interstadial traces. In the author's view the alternative chronologies of other authors are fraught with many more severe difficulties also (John, 1970a).

CONCLUSIONS

Finally, it will be worthwhile to reconsider the hypotheses presented at the beginning of this paper. On the whole they are seen to accord fairly well with the author's collected evidence of periglacial conditions in South-West Wales.

(1) As predicted, the phases of periglacial climate in this area during the Vistulian do not appear to have been particularly severe. Head deposits are widespread, with lithologies consistent with an origin by "periodic" solifluction under a relatively humid oceanic periglacial climatic regime (Büdel, 1959). On the other hand there seems little doubt that mean annual air temperatures were low enough (perhaps −8°C) for the creation of permafrost and for ice-wedge growth and cryoturbation at least in the phase following the Late Vistulian glaciation. Indeed, fossil ice wedges and related features are more widely encountered in South-West Wales than expected.

(2) There is good evidence that the ice of the Irish Sea glacier was in occupation of the area considered for only a short period at the peak of the Vistulian glaciation. Periglacial phases before the arrival of the ice and following its dissolution appear to have been relatively prolonged. Certainly periglacial deposits are more significant in the total drift stratigraphic record than either glacial or fluvio-glacial deposits.

(3) Predictably, the periglacial deposits related to the waxing phase of the Vistulian glaciation are thicker than those related to the waning phase. The Main (lower) head appears to have formed some time during the Early and Middle Vistulian, and appears to bear traces of climatic fluctuations during this time. The Upper head was deposited during a shorter periglacial phase; but it is interesting that this phase appears to have been a complex one including times of increased climatic severity. Late-glacial conditions in Lleyn appear to have been comparable (Whittow and Ball, 1970), but in other coastal areas around the Irish Sea there was more persistent occupation by ice. Nevertheless, in the upland areas of the Welsh mountains, the Lake District and the Isle of Man conditions were severe enough, even during a short Late-glacial periglacial phase, for the accumulation of thicknesses of head or scree (e.g. Watson, 1965 b; Thomas, 1971). It seems, therefore, that the model (Fig. 2) is an over-simplification of reality; it does not take sufficient account of the influence of altitude and topography upon the thickness of periglacial deposits, nor does it cater for the unusual nature of Late-glacial climatic fluctuations in Western Europe (Mercer, 1969).

(4) From the considerable amounts of Main (lower) head remaining in coastal sites in South-West Wales, it seems that the erosive capacities of the Irish Sea glacier were limited as it approached its Vistulian limit. However, even at the sites considered in this paper there has been some glacial removal of horizons of head ; consequently deposits of Main head are not as thick as in coastal localities beyond the Vistulian ice-margin, as in Devon, Cornwall and Western Gower (Stephens, 1970; Bowen, 1970a). In areas to the north of South-West Wales, there are records of thick head beneath Vistulian till, attesting to the highly concentrated and selective nature of glacial erosional processes. For this reason also, it may be said that the model used in Figure 2 is too simplified to be really reliable.

Arising from these points is the wider issue of the relationship between periglacial phenomena and ice margins. In the British Isles it has been assumed that the Vistulian ice limit (insofar as it is known) acts as a boundary between extensive glacial features in the north and extensive periglacial features in the south (Williams, 1965, 1969). In William's map (1969) of periglacial phenomena of Vistulian age in England and Wales, no features are shown within the presumed last glaciation limit. However, as Worsley

(1966) has pointed out, fossil ice wedges and patterned ground occur well within this limit in Cheshire and elsewhere, and it is known that there are instances of periglacial phenomena in North Wales, Scotland and Ireland which cannot by equated with the maximum phase of the last glaciation (Whittow and Ball, 1970; Galloway, 1961; Synge, 1950). Many of these features are dated to the Late-glacial and the evidence presented in this paper strongly suggests that:

(a) the Vistulian glacial limit has no significance as a line marking the northern limit of extensive periglacial features;

(b) individual periglacial features may be dated stratigraphically to any of the sub-stages of the Vistulian, and not simply to the glacial maximum; and

(c) the Late-glacial was a time of permafrost formation, with sufficient climatic severity for the production of many of the periglacial phenomena of southern England (Worsley, 1966).

Unlike Dr. Worsley, the present author does not consider it necessary to equate the main phases of periglacial activity with short-lived glacial readvances. The evidence from Mathry Road and elsewhere suggests that permafrost was present in South-West Wales even during the Late-glacial phase of rapid ice dissolution, for there was no break in time between local ice wedge growth and fluvio-glacial terrace aggradation. This is precisely the situation in many areas of ice wastage at the present day, especially in the zones of discontinuous and sporadic permafrost. For example, in the Schuchert Valley of East Greenland decaying valley glaciers, braided outwash streams, patterned ground and developing pingos can all be found in close juxtaposition (Hartshorn, 1961; Cruickshank and Colhoun, 1965; Washburn and Stuiver, 1962). There seems to be no reason why similar associations of features may not have existed in the British Isles during the glacial and periglacial phases of the Vistulian.

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DISCUSSION

Mr. D. J. Schrove asked if there were any radiocarbon age determinations which would support the Vistulian chronology proposed by the author.

The Author confirmed that there were several radiocarbon dates for organic material contained in the glacial and fluvio-glacial deposits of South-West Wales. Although there were some „infinite" ages among these, shells and other organic materials had yielded radiocarbon ages of between 30,000 and 40,000 years B. P. He suggested that these organisms were alive during the Upton Warren Interstadial complex, and were incorporated into the glacial drifts during the Late Vistulian glaciation (John and Ellis-Gruffydd, 1970). If the glacial drifts are used as a marker horizon, then the suggested dating of the Main head and the Upper head would appear to be substantially correct.

Professor S. Beaver mentioned that the author's work was largely stratigraphical and took little account of the role of water on the landscape during periglacial phases. To what extent could the deep drainage channels of Pembrokeshire be referred to these periglacial phases?

The Author agreed that water must have played an important role, not least in the process of solifluction during the summer months. In addition, there must have been sizeable rivers in the area, fed in part by the melting of intermittent snowfields. But it was difficult to assess the amount of erosion achieved by such rivers in view of the much larger part played by sub-glacial meltwater erosion during glacial stages. The most spectacular rock channels of South-West Wales all had the diagnostic features of sub-glacial meltwater channels (John, 1970), and seemed to owe little to subaerial stream erosion.

Professor F. W. Shotton agreed with the author's dating of the South-West Wales periglacial phases in view of the lack of any definite interglacial or interstadial horizons in the drift succession. The author's suggested chronology would appear to be the simplest and most reliable for the time being. However, he mentioned that while all of the South-West Wales periglacial phenomena could be assigned to the Vistulian, there was a more complex story from the Midlands and eastern England. In these areas several sites showed periglacial phenomena which could be assigned to two, or possibly three, distinct cold stages.