ASPECTS OF THE GLACIATION AND SUPERFICIAL DEPOSITS OF PEMBROKESHIRE

Submitted for the degree of D.Phil.

in the University of Oxford, August, 1965.

B.S. John,
Jesus College,
Oxford.

VOLUME I.

TEXT.

(including Abstract).

ACKNOWLEDGEMENTS.

I would like to thank above all Dr. Marjorie Sweeting, my supervisor, for her invaluable advice and encouragement during the past three years. I am also especially grateful to Miss Gillian Groom and Mr. D.F.W. Baden-Powell, each of whom supervised me for a term. Miss Groom willingly taught me the techniques of mechanical analysis and gave me the benefit of her close personal knowledge of the coastal drifts of Pembrokeshire; while Mr. Baden-Powell gave up many hours of his time to teach me the identification of marine mollusc fragments and raised many cogent points from his great experience of Pleistocene problems in the British Isles. I am deeply indebted to Mr. F.M. Synge for many fruitful discussions, and I would also like to thank Mr. N. Stephens and Dr. G.F. Mitchell for willingly giving their advice. I am grateful to Mr. E.A. Colhoun and Mr. and Mrs. J.G. Cruickshank for their hospitality and for showing me some of the drift features of the east coast of Ireland.

Dr. H.G. Reading of the Oxford Department of Geology and Mineralogy kindly allowed me to participate in departmental field excursions, and advised me on some of the geological problems encountered. Professor L.R. Wager allowed me to use the facilities of the department of Geology and

Mineralogy for sieving analyses, and Professor W.G.V. Balchin of the Department of Geography at Swansea University kindly gave me permission to use similar equipment and facilities. I have had valuable discussions in Pembrokeshire with Miss G. Lass, Miss J. Joy, and Mr. D.E. Sugden, and have received much advice from Mr. and Mrs. E. Watson and Dr. K.J. Gregory. To each of them I offer my grateful thanks.

Many people have assisted me with advice and information during the last three years. It is not possible to mention them all by name, but I am especially grateful to Mr. J.T. Andrews, Mr. J.H. Barrett, Dr. D.Q. Bowen, Professor A. Cailleux, Professor J.K. Charlesworth, Dr. G.Y. Craig, Mr. J. Donovan, Professor J. Dylik, Dr. C. Embleton, Dr. E.A. Fitzpatrick, Professor O.T. Jones, Dr. H.H. Lamb, Professor D.L. Linton, Professor G. Manley, Mrs. N.F. McMillan, Dr. A.R. Orme, Mr. L.F. Penny, Dr. R.J. Price, Professor F.W. Shotton, Mr. T.N. Thomas, and Dr. R.G. West.

I would like to thank Mr. G.A. Dickman, the Pembrokeshire County Librarian, for his help during the course of the research work, and Mr. J.A. Price of the Pembrokeshire County Planning Department for allowing me to consult a complete aerial photograph cover for North Pembrokeshire. I thank the many farmers and landowners who allowed me to walk over and dig holes in their land, and my fieldwork benefited greatly from all those people in the area studied who were kind enough to give me information about drift characteristics and exposures.

I am grateful to Miss Potter and Mr. B.S. Purvis for their help with maps and diagrams, to Mr. P.C. Masters of the Oxford Department of Geography for undertaking most of the photographic work, and to Mrs. B.J. Smith for typing my manuscript quickly and expertly. The radio-carbon dating of organic samples was undertaken by Isotopes Inc. and by the National Physical Laboratory; to the latter I am especially grateful for their advice at all times.

The research work on which this thesis is based was carried out during the tenure of a Science Research Council studentship, and further financial assistance was received from the Royal Society, the Oxford University Committee for Advanced Studies, Jesus College, and the Trustees of the Vaughan Cornish Bequest. To these I record my thanks.

Finally I would like to thank my parents for their constant understanding, support, and encouragement during the preparation of this work.

Abstract

"Since the publication of the work of Jehu and Charlesworth the distribution and significance of the glacial deposits of the Irish Sea have remained in a somewhat confused condition." So said Professor W.D. Evans in 1964. This thesis represents an attempt to remove the confusion from one small corner of the Irish Sea basin; it is concentrated largely in North Pembrokeshire, and aims to resolve some of the stratigraphic and chronological problems concerned with the Pleistocene deposits of the region.

There is a long history of research into the glaciation of North Pembrokeshire. Most of the early work was undertaken in Dewisland (the St. David's Peninsula), but in the major contributions of Jehu (1904) and Charlesworth (1929) something was revealed of the Pleistocene history of North Pembrokeshire as a whole. Subsequent work has been greatly influenced by these two authors, and there has been no detailed field study of the area since Charlesworth. As a result, many controversies have arisen in recent years; these range from the purely stratigraphic problems of the classic tripartite drift succession and the nature of the Upper Boulder-clay to the absolute age of the Pembrokeshire drifts. Again, there is doubt concern-

ing the number of glaciations represented in North Pembrokeshire; about the existence of the South Wales End-moraine, the pro-glacial lakes, and the so-called overflow channels of Charlesworth; and about the age and origins of the coastal features of the county. These are among the problems that this thesis attempts to answer.

Some space is devoted to a discussion of the methods and techniques used during the drift studies in North Pembrokeshire. The techniques include the interpretation of head deposits, using some of the criteria of such workers as Dylik and Büdel; the field mapping of drifts; stone-counts for the recognition of drift boundaries and the differentiation of drifts in composite exposures; the mechanical analysis of drift matrices in order to establish whether the different drifts have diagnostic grain-size distributions; the measurement of preferred stone orientation in order to recognise soliflucted deposits and perhaps to establish accurately the direction of ice-movement across North Pembrokeshire; and the analysis of pebble-roundness in order to recognise the mode of transport and deposition of certain drifts. A brief outline is given of the potential and problems of dating drifts on the basis of their derived assemblages of marine mollusca, and of the uses and methods of radiocarbon dating of organic material in order to assess the absolute age of drifts.

Twelve of the most important coastal localities in West Wales are analysed in detail. The localities in North Pembrokeshire are grouped under the broad categories of North Pembrokeshire coast, West Dewisland coast, and South Dewisland coast, while related sections from the coasts of South-west Pembrokeshire and South Cardiganshire are also examined. Drift stratigraphy is virtually identical in all these areas; although the tripartite drift succession of Lower Boulder-clay, Intermediate Sands and Gravels, and Upper Boulder-clay is still accepted by many workers, it is not supported by evidence in the field. The term "Lower Boulder-clay" is unsatisfactory, for it includes drifts of several facies that are not always the stratigraphic equivalents of one another. There is no evidence from any coastal section that sands and gravels are overlain by a till of a later glaciation, and nowhere are they "intermediate" between two tills. The Upper Boulder-clay is not a till at all in most localities, although the term has been used in the past to describe some of the land facies of the Irish Sea till; in general, the Upper Boulder-clay is seen from detailed fabric analyses to be a rubble-drift of head, till, and sands and gravels soliflucted during or after the wastage of the last ice-sheet. It is always closely associated with the Irish Sea till.

There is no evidence from the coastal sections in support of Charlesworth's "South Wales End-moraine", and no trace of any large pro-glacial lakes. The sequence of deposits exposed in the coastal drift cliffs is the same well to the south, and to the north, of the so-called Newer Drift limit.

From the coastal studies it seems that there have been two glaciations of West Wales. These glaciations are not the equivalents of the Older Drift and Newer Drift Glaciations of earlier authors. An Early Glaciation, which may have been powerful and prolonged, apparently had an ice-gradient sloping down from the north-east; however, few traces of it remain apart from the erratic boulders which rest upon the raised beach platforms of North Pembrokeshire. After the Poppit Interglacial, in which the raised beaches of the area were deposited, there occurred a Dewisland Glaciation from the Irish Sea. The ice of this glaciation extended at least as far south as Milford Haven, and deposited Irish Sea tills where it assaulted the coast and local land facies where it moved off the land. Fluvio-glacial deposits were laid down in some coastal localities during the wastage of this ice. During the first phase of the Dewisland Glaciation the Irish Sea ice failed to reach North Pembrokeshire, and there is abundant evidence for a prolonged period of fluctuating periglacial climate. From the association of coastal features with the drifts it is suggested that the drowned valleys of West Wales, the configuration of the coastline, and the raised beach platforms of the area were all features of the landscape prior to the Early Glaciation.

The characteristics of the drift cover are examined in Western Dewisland and in the Fishguard area in order to establish whether the coastal sections are truly representative of the complete drift succession. In Dewisland, after an examination of the drift characteristics, several quantitative techniques are employed to test the Lower Boulder-clay/Upper Boulder-clay subdivision, assuming, as a working hypothesis, that the moorland tills of the area are Lower Boulder-clays and the sandy tills elsewhere Upper Boulder-clays. The findings confirm those for the coastal sections, and suggest that the surface drifts on the moors are simply remanié drifts which are no different from those on the rest of the land surface. There is but one till sheet in Western Dewisland; it is thin and sandy, and has no "ideal" preferred stone orientation which indicates the direction of ice-movement across the sea. Although the Irish Sea ice was at least 600 ft. thick over Dewisland, it appears to have been relatively weak at the time of till deposition.

In the Fishguard area there is hummocky topography of sands and gravels; this is dead-ice topography with interspersed and interbedded patches of ablation till. As indicated in the coastal sections, there is no true Upper Boulder-clay in the area, no trace of the South Wales End-moraine, and no trace of Glacial Lakes Manorowen, Gwaun, and Nevern. All the depositional features of North Pembrokeshire, including the hummocky topography and the valley sandur remnants, are related to the wastage of the extensive Dewisland Ice-sheet.

The meltwater channels of North Pembrokeshire are analysed in some detail in Part V of the thesis. A re-examination is made of Professor Charlesworth's hypothesis that the meltwater channels of the Gwaun-Jordanston system are Newer Drift features cut by overflows from pro-glacial lakes. It is suggested that there are many inconsistencies in the hypothesis, and that there are difficulties in accepting that lake overflows, even in a highly complex sequence, could have been responsible for the cutting of the channels. On the other hand the channel system has characteristics which suggest that it was cut predominantly by sub-glacial meltwaters. In association with the Gwaun-Jordanston channel system there are several features which can be attributed to meltwater flow marginally or sub-marginally alongside downwasting ice. These features provide support for the conclusions reached on the basis of depositional evidence concerning the mode of ice-wastage at the end of the Dewisland Glaciation.

The orientation of the Gwaun-Jordanston channel-system is something of an anomaly. The sub-glacial meltwaters of the Dewisland Glaciation should have flowed approximately parallel with the direction of maximum ice-surface gradient, i.e. towards the south-east. However, the channels are orientated for the most part towards the south-west, possibly indicating that they were cut during the Early Glaciation when Welsh ice may have been dominant and the ice-sheet gradient sloping N.E.-S.W. There is other evidence in the Fishguard area for the Early Glaciation age of the channels, but the most convincing evidence comes from Dewisland; here the deep coastal meltwater channels (previously thought to be features of sub-aerial stream rejuvenation) support head beneath till of the Dewisland Glaciation. The channels cannot therefore date from the Dewisland Glaciation.

After a tentative reconstruction of the Pleistocene history of West Wales on the basis of all the lines of evidence pursued, the proposals made are considered in the wider context of the Irish Sea Basin as a whole. The drift stratigraphies of South-East Ireland, Lleyn, Gower, and the north coast of Devon and Cornwall are compared with that of Pembrokeshire. In spite of minor differences of opinion between various authors, it seems that the drift stratigraphy is consistent as far south as the Scilly Isles. The Irish Sea till is a good datum for correlation, and it seems that the chronology proposed for North Pembrokeshire may hold good for all areas except South-East Ireland and Lleyn, where later glacial fluctuations may be represented. The Dewisland tills are probably the equivalent in age of the Eastern General and Fremington tills.

Pleistocene sea-level movements in Pembrokeshire are considered briefly in the light of evidence from further afield. Little attention has been paid in the past to low Pliocene and Pleistocene sea-levels, for the scheme of a high regressive sea appears to have been widely accepted, Several of the findings from Pembrokeshire contradict recent viewpoints: the prolonged period of low sea-level prior to the Early Glaciation, the great age of the coastline, and the separation of the periods of rock platform cutting and raised beach deposition by a full glacial stage appear to support the findings of Orme rather than Zeuner and Bowen.

In the final part of the thesis an attempt is made to establish an absolute chronology for the Pleistocene of West Wales. Faunal analysis suggests that the shell content of

Irish Sea till and outwash gravels is the same, indicating that they are the products of the same glaciation. The mollusc assemblages of the drifts may also be correlated with that of the Wexford Manurial Gravels and some other Pleistocene shelly deposits. Some of the implications of the mixing of mollusc species in drift deposits are discussed, and it is concluded that the shell assemblages in the Pembrokeshire drifts probably represent temperate to cold conditions, and are of Last Interglacial age or younger. The Dewisland Glaciation, which dredged up the shells from the floor of the Irish Sea, may therefore be the Last Glaciation.

This dating is confirmed by C14 dates for four organic samples from drift. Shell samples from outwash gravels yielded the dates

$$37{,}960\ ^{+1700}_{-1400} \text{ years B.P.}$$

and $37{,}310\ ^{+1515}_{-1275}$ years B.P.

and samples from till yielded the dates

$> 36{,}300$ years B.P.

and c.40,000 years B.P.

The glacial drifts of Pembrokeshire were probably deposited within the last 38,000 years; it is probable that the Eastern General till of Ireland, and other tills as far south as the Scilly Isles, are of the same age. Since the Dewisland Glaciation was the Last Glaciation of the Irish Sea Basin, it follows that neither the South Wales End-moraine nor the Midland General - Clynnog Fawr moraine can be considered true terminal features; the latter feature may represent a local readvance during overall deglaciation.

By correlation with Europe, it is suggested that the dated shells were alive during the Middle Würm period of fluctuating interstadial climates, while the Dewisland Glaciation was the equivalent in time of the European Main Würm Glaciation. There is no evidence in West Wales to support the so-called Early Würm Glaciation of other areas in Western Britain; during the Early Würm in Pembrokeshire there was intensive solifluxion, perhaps culminating in a local mountain glaciation at New Quay. By further correlation, the Poppit Interglacial is probably the equivalent of the North European Eemian, while the Early Glaciation may be equated with the Continental Riss.

In the Midlands it has been proposed by some authors that the Main Irish Sea Glaciation was Early Würm, while in Ireland several workers have mentioned that the Eastern General Glaciation was the equivalent of the Riss; it is suggested that neither of these datings is compatible with the evidence from Pembrokeshire, and that careful stratigraphic studies and further C14 dating of Irish Sea drifts may resolve this difficulty.

Contents

List of Tables

PREFACE

This study attempts to resolve some of the Plesistocene problems of Pembrokeshire. Detailed fieldwork has been restricted to North Pembrokeshire, which holds a comprehensive Pleistocene record in many ways representative of the southern Irish Sea margins which lay within the theatre of action of the Irish Sea Ice-sheet (Fig. 1).

The greater part of the thesis is devoted to a close stratigraphic study of drifts, for this is the only means by which the patterns of glaciation can be disciphered in the area. However, drift distributions and associated landforms do not pass unnoticed, and it is hoped that the studies of drifts, when combined with the absolute dating of glacial events, may establish a reliable stratigraphy and Pleistocene chronology for West Wales which may serve some useful purpose for extrapolation to the Irish Sea Basin as a whole.

It is hoped that the text will be read only in close conjunction with the illustrations contained in Volume II.

Tables are numbered separately and are contained in Volume I. Figures, plates and appendices are contained in Volume II, which also contains five folded maps. One of these maps (Map 2) is an O.S. 1" sheet which will be useful for locating sites mentioned in the text. Grid references are not given in the text, for wherever possible sketch-maps are used to indicate the positions of important localities. However, a list of grid references to critical sites is given in Appendix II. Appendix I is a short list of some of the terms used in the text and their meanings.

PART I

Chapter 1.

The Physical Background.

(A) Structure and Geology

(B) Landscape

(c) The erosion surfaces of North Pembrokeshire.

Chapter 1

THE PHYSICAL BACKGROUND.

(A) Structure and Geology.

Geologically, North Pembrokeshire is a complex area of Pre-Cambrian and Lower Palaeozoic rocks whose structure was determined for the most part during the Caledonian orogeny. The two major anticlines of West Wales are the Towy Anticline and the Teifi Anticline (Fig. 2); extensions of the latter may be traced into western Pembrokeshire as the St. David's Anticline and the Hayscastle Anticline (Pringle and George, 1948). In Central Wales the Teifi Anticline pitches from the south-west to the north-east, but in North Pembrokeshire, where Armorican earth movements may have had some influence, the orientation of the main structural axes is in places east-west. In spite of the effects of the Armorican earth movements, North Pembrokeshire is structurally quite distinct from South Pembrokeshire, where Armorican trends are dominant in the Upper Palaeozoic rocks (Fig. 2). The whole of the southern coastline of Cardigan Bay runs closely parallel to the main structural trends (Jones, 1912).

The structural complexities of the area, arising from its position in the zone of contact between Caledonian and Armorican trends, have still not been completely disciphered (McQuillan, 1958). However, it is possible to recognise two major structural regions, as proposed by Brown (1960). These regions are shown in Fig. 2. The western region, which is dominated by the St. David's and Hayscastle Anticlines, may be loosely termed Dewisland[1], while the eastern region incorporates the areas dominated by the intrusions of Prescelly and Pen Caer. To the east of these regions is the Teifi Anticline, while immediately to the south is the westward extension of the Towy Anticline.

Dewisland. In this region, described in detail by Cox et al (1930a)[2], there are, apart from the St. David's and Hayscastle Anticlines, major folds at Llanrhian and Aber-castle.

---

1. "Dewisland" is the ancient name for the St. David's Peninsula. It is named after Dewi Sant, the patron saint of Wales, who established his ecclesiastical centre at Menevia, now called St. David's.

2. Most of the geological studies in north Pembrokeshire have been concentrated in the St. David's Penineula. A full list of papers written before 1930 may be found in Cox et al (1930a), and a list of later references appears in Pringle and George (1948). Apart from the references mentioned in this chapter some important works on the geology of North Pembrokeshire are as follows: Cox (1915); Cox and Thomas (1924); Elsden (1905); the numerous works of Hicks; Nicholas (1933); Thomas and Jones (1912). There are no Geological Survey "New Series" sheets of North Pembrokeshire, although a useful geological map has been printed for Dale Fort Field Centre. A copy of this map (Map I) is folded into the back of the thesis.

Strike faults are common throughout the area, and thrusting and folding often causes repetition of beds, while others may be cut out. Strata may dip at high angles; in places they stand vertically, while elsewhere over-folding can be seen. Basic igneous material has flooded many ancient faults, and igneous masses further confuse the structural picture.

The most noticeable geological feature of Dewisland is the anticlinal exposure of Pre-Cambrian "Pebidian" volcanic rocks, which extends north-eastwards from the southern end of Ramsey Sound for a distance of c. eight miles (Fig. 3). The rocks within the Pebidian group are tuffs of various colours, with greenish acid rocks, conglomerates, and halleflinta[1] (Green, 1911a). The anticline is flanked across an unconformable contact by steeply-dipping Lower Cambrian rocks, which pass outwards into Upper Cambrian and then Ordovician sedimentaries. Of these, the Lower and Middle Cambrian sedimentaries are easily-recognisable on account of their bright green, purple, and red colouring. On the other hand it is often difficult for someone with an inexperienced eye to distinguish the dull shales and mudstones

---

1. Halleflinta is a translucent volcanic rock with blue and green tints; its outcrops are of limited extent, and it is an excellent erratic indicator if found in drifts.

of the Upper Cambrian from the various series of the Ordovician. Pre-Cambrian "Dimetian" intrusive masses (usually of granophyre, diorite, or quartz-porphyry) are found within the area of Pebidian volcanics, while basic Ordovician intrusives are found within many of the other formations of the area.

The Hayscastle Anticline displays a very similar sequence of rock-types (Fig. 4), although there are larger outcrops of Pebidian extrusives than in the St. David's Anticline; conversely, the Hayscastle area appears to be almost devoid of Ordovician intrusives (Williams, 1934).

Prescelly and Pen Caer Region. In the Prescelly and Pen Caer region, the structure is not well-known; however, the overall ENE-WSW structural trend can still be discerned, especially in the north-westward extension of the Hayscastle Anticline. Intrusive and extrusive igneous outcrops indicate the dominant strike trends of the soft Ordovician rocks (Fig. 5). Some of the complexities of the structure of the isolated upstanding mass of Mynydd Prescelly[1] have been elaborated by W.D. Evans (1945), while Cox (1930c) and Thomas and Thomas (1956) have examined the geological

1. Mynydd Prescelly is the largest of the mountain masses which constitute the Prescelly Mountains. The latter term, as used in this thesis, incorporates all three of the main mountain masses of North Pembrokeshire.

features of Pen Caer. There have been few other studies of the upland areas of North Pembrokeshire.

Geologically, the region is made up largely of Lower Ordovician sedimentary rocks (Pringle and George, 1948). Both the major folds of the Ordovician system in this area trend NE-SW, and expose shales, mudstones, ashes, sandstones, limestones, and some lavas of the Arenig, Llanvirn, and Llandeilo Series. Large intrusive masses, probably of Ordovician age, occur in Pen Caer, and in the Prescelly Mountains is an extensive series of tuffs, lavas, and dolerites which outcrop conformably with the strike of the sedimentary outcrops (Evans, 1945). ~~On the coast between Dinas Island and the Teifi estuary is the only known outcrop of Silurian shales in North Pembrokeshire (Myers, 1950).~~

Thus North Pembrokeshire may easily be sub-divided on the basis of structure and geology. In the west is a region of complex structure and complex geological outcrops; it has been hallowed ground for geologists ever since the investigations of De la Bêche, Geikie and Hicks almost a century ago. In the east is a region of lesser geological interest; it is characterised by Ordovician sedimentary rocks and intrusive masses whose lithology and structure, being relatively uniform over a wide area, have failed to excite detailed geological investigation.

(B) Landscape.

In aereal extent, the major landscape regions of North Pembrokeshire are broadly similar to the structural regions, as indicated on Fig. 6. However, at this point correlation must cease, for over most of Pembrokeshire erosive processes have been the dominant controls in landscape evolution. Only in isolated localities in lowland Pembrokeshire has planation been resisted, so that the major landscape features of the county are undoubtedly its erosion surfaces.

Dewisland (A1), the region of greatest geological complexity, is the region of greatest topographic simplicity. It is considered by Brown (1960) to be the westernmost portion of the "North Pembrokeshire and North Carmarthenshire" coastal plateau, one of a broad zone of coastal plateaux flanking the Welsh Upland massif. Topographically, it is related to the coastal plateaux of Lleyn and Anglesey in the north and to South Pembrokeshire, Gower, and the Vale of Glamorgan in the south and south-east.

As long ago as 1188, Giraldus Cambrensis described Dewisland as "situated in a most remote corner of land upon the Irish Ocean, the soil stony and barren, neither clothed with woods, distinguished by rivers, nor adorned by meadows, ever exposed to the winds and tempests";[1] this description would not be out of place today, for the flat landscape is still wild and treeless. The south coast of Dewisland is diversified by deep channels such as Merry Vale and the Solfach Valley, while inland there are extensive areas of waterlogged moorland. Near the north coast the steep-sided carns[2] of Carnllidi and Penbiri, their summits less than 600 ft. above sea-level, assume the proportions of sizeable mountains as they stand sentinel above the plateau on low undulating ridges of Ordovician intrusive rock (Plate 1). Other carns occur on igneous outcrops in the coastal area to the west of St. David's and in Pen Caer (B1).

In the east the region of relative geological simplicity emerges as a region of great topographic diversity. The land rises gently eastwards from the broad upper basin of the Western Cleddau through low foothills to Mynydd Prescelly, a rounded and undulating mountain ridge (C1). Other masses of Mynyddcaregog (C2) and Freni-fawr (C3) have been separated from Mynydd Prescelly by deeply-cut channels. Further diversity is encountered in region A3, where a complex

---

1. "The Itinerary through Wales", translated by R.C. Hoare; in Wright, T. (ed.) 1863 "The historical works of Giraldus Cambrensis." London. P. 415.

2. "Carn" is Welsh for a rock or mountain.

network of channels (which may be called the Gwaun-Jordanston channel system) has imparted strong relief to the landscape south of Fishguard (Plate 2). Other deeply-entrenched valleys run southwards from the Prescelly Mountains to the Eastern Cleddau river-system. On the north coast the isolated upland mass of Mynyddcaregog is flanked by a narrow coastal plain (A4). The Afon Nevern drainage-basin (A5) is in its upper part a distinct landscape unit, although further north it is difficult to distinguish on a physical basis from the lower section of the broad Teifi basin (A6).

The mountain[1] masses, which are generally under 1500 ft. high, owe their distinctive character more to exposure than to altitude. Mynydd Prescelly, a ridge with an east-west extent of over ten miles, is a treeless and undulating bleak moorland of sparse grasses, heather, gorse, and bog (Plate 3). Its slopes are seldom steep, and rock outcrops are rare; where rocky crags do appear they are more fragile in appearance than the Dewisland - Pen Caer carns, and are called true tors by Linton (1955). Mynyddcaregog and Freni-fawr are of lesser extent than Mynydd Prescelly, but

1. In Pembrokeshire anything which remotely resembles a hill is called a mountain. There appears to be no good reason for discontinuing this practice!

are similar in all their physical characteristics. Extending south-westwards from Mynydd Prescelly is the low windswept Treffgarne Ridge (B2)[1], breached only by the Treffgarne Gorge and supporting a tongue of moorland which extends almost to the coast of St. Bride's Bay. Above this ridge stand more rocky carns, of which the most spectacular are Maiden's Castle and Poll Carn.

There are further contrasts between the two major landscape regions when the drainage-pattern is considered. In Dewisland the drainage-pattern is simple; most of the small streams rise at altitudes beneath 300 ft. O.D. in broad inland depressions characterised by waterlogging and bog and moorland vegetation (Fig. 7), and later plunge into the deep coastal channels in which they are clearly misfits. Examples are the River Alan in Merry Vale, and the small stream in the Caerbwdy channel. In the St. David's area the largest of these channels run southwards, and drainage to the north coast is negligible. Further east, however, several channels run to the north coast between Abereiddy and the Pen Caer peninsula.

The river-system in the eastern landscape region, in contrast, is exceedingly complex. In the Gwaun-Jordanston

---

1. The effectiveness of this ridge as a physical divide is witnessed by its coincidence with the Pembrokeshire Landsker, a cultural and linguistic divide which has persisted for almost a thousand years.

channel-system (A3) all the streams appear to be misfits, and valley-bottom divides[1] are common. The Gwaun River (which collects its tributaries from the southern flanks of Mynyddcaregog and the north-western slopes of Mynydd Prescelly) reaches the sea at Fishguard, and the Afon Nevern drains a broad basin north of the Prescelly Mountains before reaching the sea at Newport. On the western flanks of the mountains the Western Cleddau river-system is dominant. The main stream rises at Penysgwarn (near Mathry) and flows north-eastwards for about five miles before swinging southwards to collect the most important streams of Mynydd Prescelly. It leaves its upper basin and breaches the main watershed of the county through the deep Treffgarne Gorge (Fig. 6).

The coastline of North Pembrokeshire is one of high, rugged cliffs. Although there are sandy bays at Newgale, Whitesands, Aber-mawr, Abereiddy, Goodwick and Newport, coastal inlets are generally rocky, with deep and sheltered anchorages as a legacy of post-glacial drowning. For example, Solva, Porth-clais, Porth-gain, and Abercastle are excellent small "ria" harbours which are beloved of lobster fishermen

---

1. The term "valley-bottom divide", which is used frequently in the thesis, indicates the presence of a major water-parting on the floor of a through channel.

and artists. Between these widely-separated inlets the coastline is rugged and spectacular (Steers, 1946). Cliffs are commonly 150 ft. high, but rise to over 250 ft. at several localities in the north. At Pwllderi and Dinas Head cliffs are over 400 ft. high, and they rise to over 500 ft. at Foel-goch, north of Newport. Over long stretches of coast the cliffs maintain an approximately even height, since they truncate the extensive erosion surfaces which give North Pembrokeshire its distinctive character (Plate 4).

(C) The erosion Surfaces of North Pembrokeshire.

There appears to be no clear agreement on the number of surfaces to be found in North Pembrokeshire. North (1929) recognised a surface sloping westwards from 250 ft. O.D. to 150 ft. O.D. in Dewisland, while Miller (1937) recognized higher surfaces at 600 ft. O.D. and 400 ft. O.D. From this threefold sub-division of surfaces Burton (1952) elaborated further, recognising levels at 490, 435, 390, 335, 295, 240, 190, 140, 75, and 45 ft. O.D.

A dominant feature of most of the extensive literature on these features is the conclusion that they are of marine origin.[1]

---

1. For the development of thought on the erosion surfaces of West Wales see Ramsay (1846), McKenny Hughes (1885), Davis (1909), Jones (1911), Keeping (1882), and Sawicki (1912). The lower surfaces of North Wales were studied by Dewey (1918) and Greenly (1919). For examinations of the lower surfaces of West Wales see Goskar and Trueman (1934), George (1938), and Brown (1960). Jones (1951) considered that all the lower surfaces were cut initially by Triassic pediplanation.

Further, it has been suggested in the recent literature that the surfaces, be they three or thirty in number, were cut during the Pliocene or Pleistocene periods. The dating of the platform surfaces as Early Pleistocene[1] derives in part from the fact that the surfaces are unwarped (suggesting that they were not cut until after the mid-Tertiary earth movements), and in part from the interpretation of the Red Crag beds found upon the 600 ft. bench in South-East England (King, 1955). It has been proposed that since Red Crag times sea-level has fallen spasmodically from at least 600 ft. O.D., with transgressions coinciding with interglacial stages and regressions coinciding with glaciations. According to Zeuner (1959) and Fairbridge (1962) each of the major transgressions attained a lesser altitude than its immediate predecessor (Fig. 8). If these ideas are correct, then many of the erosional features of Pembrokeshire beneath 600 ft. O.D. may be the products of a regressive sea and of river-patterns graded to it.

---

1. A Pleistocene age has been given to the so-called marine platforms by Wood (1959) in Cardiganshire; Orme (1964a) in South-East Ireland; Kidson (1962) and Brunsden (1963) in Devon; Embleton (1964) in North Wales; Driscoll (1958) in the Vale of Glamorgan; and Bowen (1965) in Central South Wales.

A discussion of the age and origins of the North Pembrokeshire erosion surfaces lies outside the scope of this thesis. The development of thought on this topic has already been examined by Burton (1952) in the context of a detailed study of denudation chronology in Pembrokeshire, and Bowen (1965) has completed a study of the erosion surfaces and landscape evolution of Central South Wales; both studies are relevant to any examination of the Pembrokeshire landscape, for the evolutionary history of most of lowland South Wales must have been similar. However, at this stage all that need be said concerning the Pembrokeshire surfaces is that the concept of a regressive Pleistocene sea renders it impossible to divorce a study of glaciation from some consideration of sea-level movements and landscape development.

In Pembrokeshire glaciation appears to have had little effect upon the erosion surfaces; there are no diagnostic forms of glacial erosion. Even in the Prescelly Mountains there are no characteristic glacial landforms apart from a doubtful cwm and several doubtful nivation hollows. Although the carns of Dewisland may have been slightly modified by ice, and although many of the deep river-channels of North Pembrokeshire may have been eroded by glacial meltwaters, it would not be unreasonable to assume that the forms of the mountains and low plateaux of North Pembrokeshire owe more to long-continued sub-aerial denudation than to glaciation.

On the other hand the effects of platform cutting can be over-emphasised; Miller (1937) and Burton have called some of the drift-filled depressions of Dewisland platform fragments, whereas their surfaces consist of recent glacial drifts. Again, one cannot be certain of the extent to which glaciation has removed minor irregularities on the platform surfaces, while there is even greater doubt concerning the influence of glaciation upon the drainage pattern.

It is probably true to say that in spite of the small-scale erosional effects and the depositional activity of the Pleistocene ice-sheets in North Pembrokeshire, no major landscape changes can be attributed to the action of ice.

PART I

Chapter 2.

Past Investigations and Problems concerned with the Glaciations of North Pembrokeshire

(A) The History of Research

(B) Recent opinions and unanswered problems

Chapter 2.

PAST INVESTIGATIONS AND PROBLEMS CONCERNED WITH THE GLACIATIONS OF NORTH PEMBROKESHIRE.

The depositional record of the Pleistocene glaciations of North Pembrokeshire is poor. The drift cover over most of the land surface is less than three feet thick, and thick deposits of till[1] may occur inland only in inaccessible waterlogged depressions. Even in coastal exposures, which occur for the most part at the mouths of deeply-cut valleys, drift seldom attains a thickness of more than 30 ft. Only in scattered localities near the north coast are drifts seen with a marked surface expression; in Dewisland the drift lies as a thin featureless veneer upon the flat erosion surface.

Erratic boulders from beyond the shores of Pembrokeshire are common throughout the area; in most cases they have been built into the high banked hedges or stone walls which demarcate the stony fields. Here and there, where rock outcrops at the surface, striations give a clue to the direction of former ice-movements.

The drifts of the area may be simply categorised as till, head, and outwash sand and gravel. In many coastal localities

1. Definitions of the more important terms used in this thesis may be found, arranged alphabetically, in the Glossary (Appendix I).

is found a stiff blue calcareous till which contains shell fragments, and which has been recognised for over 300 years as having been carried southwards from the floor of the Irish Sea. For many years this till has been called the "Irish Sea till". Inland, a stiff clay till is also encountered at depth in the waterlogged moors. Sands and gravels occur in isolated patches, and in many localities is a sandy and stony "rubble-drift" full of angular and rounded stones in a loose matrix; both these drifts are frequently seen to overlie the clay till.

At some localities on the coast rock platforms varying in altitude from sea-level to 50 ft. O.D. support raised beach gravels; these features are often overlain by glacial drift, and their importance has long been recognised in attempts to establish the chronology of the Pleistocene period in West Wales.

In North Pembrokeshire several important localities have figures prominently in the literature. At Ogof Golchfa (Porthclais)[1] is a drift succession of raised beach gravels, till and head resting upon a fine rock platform; at Whitesands is a comprehensive section which displays erratic pebbles, head, till, and other drift deposits upon a rock platform; and at Druidston and Porthmelgan are thick exposures

1. Grid references to all the important localities mentioned in the thesis are given in Appendix II.

of clay till. These and other important coastal exposures are located on Fig. 6.

For many years, correlations have been attempted between the North Pembrokeshire drifts and those of Gower; the reason for this lies in the common occurrence of a well-developed raised beach platform and a similar drift succession in each area. Correlations with the adjacent coastline of Cardiganshire have also been made at frequent intervals. In view of the proximity of the coastline of South-East Ireland it is perhaps surprising to find that it has been mentioned infrequently for the purposes of comparison until recent years.

With these points in mind, a brief summary of previous work on the glaciation of North Pembrokeshire, and a statement of some of the more urgent problems which need to be answered, are important preludes to this thesis.

(A) THE HISTORY OF RESEARCH.

(1) A description of till in 1603. The earliest description of the superficial deposits of Pembrokeshire was that of George Owen, a native of North Pembrokeshire who was renowned 250 years after his death as the "patriarch of English geologists". In an unpublished treatise on clay marl (1599) and in his "Description of Penbrokshire" (1603)

he described with great accuracy the calcareous blue clay till of the area. Referring to the till as "Claye Marle", he wrote:

> "This kind of Marle is digged out of the Earthe where it is found in great quantitie and thought to be in rounde great heapes and lompes of Erthe as bigg as round hills, and is of nature fatt toughe and clamye...(p.71). This marle is of couler with vs most commonlie blwe and in some place redd.... It is verie hard to digg by reason of the toughness, much like to waxe, and the pickax or mattock beinge stroken into it, is hardlie drawne out againe, so fast is it holden; it is also verie heavie as ledd." (p. 72-73).

> "Also in the harte of the Marle is founde diverse sortes of shells, of fishe, as Cogle shells, Muskell shells, and such like, some altogether rotten and some yet unrotted as also you shall therein finde peaces of tymber that ben hewen with edge tooles & fire brandes, the one ende burned and diverse other thinges which hath ben before tyme vsed, & this XXtie foote and more deepe in the Earth in places that never haue ben digged before, and over the which great oakes are now growinge: and this seaven or eight myles from the sea so that it is verie probable that the same came into these places at the tyme of the great and generall flood." (p. 71-72).

Turning his attention to the origin of the marl, Owen was prompted by all his carefully collected evidence to accept the current theory that the drift had been deposited catastrophically by the sea:

> "The opinion of the Countrie people where this Marle is founde is that it is the fattnes of the Earthe gathered at Noes flood, when the Erthe was Covered withe the said flood a whole yeare, and the surginge

and tossinge of the said flood, the fattnes of the Earthe being clamye & slymie of nature did gather together, and by rowlinge vpon the Earthe became round in forme, and when the flood departed from the face of the Earthe, the same was left drie in sondrie partes, which is nowe this Marle that is found. and how the Comon people Cam to this opinion I knowe not but it is verye like to be true, for wheresoever the same is founde, it is loppie (loose) and covered with sande gravell and rounde pebblestones such as you shall finde at the sea side verie plaine, appearing that the stones hath ben worne by the sea or some swift river." (p.71).

Owen noted the widespread, intermittent distribution of the till, and wrote further:

"This Marle is founde in Kemes and both Emlyns from Dynas vpp to Penboyr in Carmarthen sheere, beinge about twentie myles in lengthe and fowre myles in bredeth in most places to the sea syde, and out of this compasse I cannot heare that the same ys founde: I think more for want of Industrie then otherwise..." (p.73).

Owen's work was quite outstanding for its accuracy, and his description is such that one has no difficulty in recognizing his "claye marle" as the Irish Sea till which is found in both eastern Ireland and west Wales. He was correct in his observation that the till contains shell and wood fragments, and he also clearly recognized that it is everywhere characterized by a tough, compact clay matrix. He even noticed the subtle colour difference between the calcareous unweathered blue clay and the weathered and decalcified red clay which overlies it. Significantly, he recognized the till's most important stratigraphic relationship, namely, that it is often overlain by water-deposited sands and gravels.

Jehu (1904), who quoted Owen's work at length in his classic paper on the glacial deposits of north Pembrokeshire, stated that his 1599 pamphlet on the clay marl contained "perhaps the earliest attempt to give a full description of the boulder-clay". Indeed, it may represent the earliest attempt to differentiate on a stratigraphical basis between the "Lower Till" and the "Middle Glacial Sands and Gravels" of Britain, the lower members of a tripartite glacial succession which has excited the attention of British geologists and glaciologists for so many years. (John, 1964).[1]

(2) Early Observations. Between 1839 and 1916 information on the North Pembrokeshire drifts was slowly accumulated as the tempo of geological investigations in the area increased. This information is scattered throughout the literature, usually in the form of one or two relevant sentences in longer geological articles. Nevertheless, the sum total of these observations remains invaluable.

---

1. A copy of a short note on George Owen's description of till is bound into the back of the thesis as Appendix III.

Murchison (1839) recorded the presence of much "detritus" and gravel in Pembrokeshire, but the first specific reference to erratics in North Pembrokeshire appears to be that of Symonds in 1872. He noted the widespread occurrence of "trap" boulders in the St. David's area and invoked transport "over a slope of ice and snow which once reached from the Trap Hills of Precelly down to the sea" (p.53) in order to explain their distribution. In 1887 the presence of gravel and flints in Dewisland was noted by McKenny Hughes. In 1885 Hicks had recorded striations and erratics in Dewisland which indicated ice-movement from the north-west, apparently becoming the first worker to ascribe a true glacial origin to the drifts of the area. He went further, and stated in 1891 that the lowland parts of the county were covered to a great depth by the ice of an Irish Sea glacier flowing from the north and north-west.

Prestwich (1892) was the first worker to describe the exposure at Ogof Golchfa (Porth Clais); his section included head but not till above the raised beach gravels. At Whitesands, however, he noted till and mentioned blown sands beneath new head. The relation of the till to other deposits was not given clearly, but the work of Prestwich probably represents the earliest attempt to differentiate the glacial drifts of Dewisland from those formed periglacially.

After Prestwich many workers turned their attention briefly to the glacial features of Pembrokeshire. Cowper Reed (1895) noted some of the topographic features of the Fishguard area, and in 1896 Howard and Small recorded evidence of ice-action around Marloes. Codrington (1898) postulated the erosion of certain drowned valleys of Milford Haven by land-ice from the Prescelly Mountains, and suggested that till might be present on the floor of these valleys.[1] In 1900 Tiddeman, although he worked in Gower only, showed that till overlies raised beach gravels there -- a fact of importance for later work in Pembrokeshire. In 1911 Green contributed further observations on the Whitesands sections and demonstrated some of the depositional characteristics of the St. Davids area to the Geological Association (1911b), and Cox (1915) briefly considered the origin of the deep valleys of the North Pembrokeshire coast.

By 1905 the workers of the Geological Survey were in the county, and Dixon's "Summaries of Progress" for 1905 and 1906 mention several valuable South Pembrokeshire localities.

---

1. This idea has received confirmation in recent years as a result of industrial borings in Milford Haven and on the floor of the Daucleddy (Soil Mechanics Ltd., 1958).

He suggested that on Caldey Island glacial materials overlie raised beach gravels, but admitted that his evidence was inconclusive. He noted the apparent similarity between the Pembrokeshire raised beach platform and the "pre-glacial" platform of the Cork district. The Geological Survey memoirs (Strahan et al 1914 and Cantrill et al 1916) contain much useful information on Pleistocene sites. The important Druidston section was discovered, and erratic trains from the Prescelly Mountains and the north and west are recorded in the area east of Haverfordwest. In the Milford Haven area, sections revealing plant remains in loamy clay above till and beneath sands and gravels prompted speculation on a possible climatic amelioration between two cold phases. Organic remains in the Pembrokeshire drifts are rare, and no subsequent stratigraphical work has attempted to investigate this suggestion.

At intervals throughout this period of small-scale observations, attempts were made to portray the maximum extent of the "Irish Sea Glacier", as it was termed by Carvill Lewis. Geikie (1894) clearly considered that the whole of Pembrokeshire was ice-covered, although his failure to note Hicks' evidence of striations led him to indicate ice-movement across the county from north-east towards south-west. Nevertheless, his line coincides very closely with that of Charlesworth (1957) showing the southern limit of older drifts (Fig. 9a). The "Edge of the Ice-sheet", as portrayed by Carvill Lewis (1903) passed west to Ireland from the Lleyn Peninsula, leaving Cardigan Bay supposedly ice-free. The presence of till in Dewisland was accounted for by a glacier extending westwards from Cardiganshire and the Prescelly Mountains, perhaps in support of Symonds' (1872) idea of an ice-slope extending westwards to the sea (Fig. 9b). Carvill Lewis' limit for England appears to have been drawn on the basis of fresh drift topography, and correlates very closely with the Smestow (Newer Drift) limit as held today by Charlesworth and Mitchell; in Pembrokeshire his "west-flowing glacier" even affects a compromise between the divergent views of these latter authors concerning the Newer Drift limit in the Irish Sea area, for it accounts for the presence of apparently fresh drift on the North Pembrokeshire coast without invoking the presence of Irish Sea ice in the vicinity! (Penny, 1964). Bonney's (1903) "extreme view as to the extension of the land-ice" was something of a compromise between Lewis' line and that of Geikie, while Wright's (1914) line approximates rather more closely to that of Geikie. His map (p. 49) incorporated the ice-flow directions suggested by Hicks. As early as 1914 Wright was making a distinction between the Older and Newer drifts, and postulated tentatively that most of South Wales was glaciated during the Last Glaciation. (p. 76)[1]

(3) Major Contributions. The works of Jehu (1904), Leach (1911), Williams (1927) and Charlesworth (1929) have had the greatest influence upon contemporary opinions on the Pleistocene period in Pembrokeshire.

(a) Three centuries after Owen, Jehu (1904) published his fine paper on "The glacial deposits of Northern Pembrokeshire". To this day it remains the most skilful, carefully-stated, and comprehensive analysis of the North Pembrokeshire drifts. He proposed for the area a "typical" tripartite succession of Lower Boulder-clay, Intermediate sands and gravels, and Upper Boulder-clay and rubble-drift. He described in detail the characteristics of each of these drifts, and although he produced no map, he examined and recorded innumerable localities where exposures were to be found (Fig. 10). He agreed with earlier workers that the Irish Sea glacier had over-ridden most of North Pembrokeshire. He stated that the direction of ice-movement was roughly NNW-SSE. He recognized many erratics from Ailsa Craig, Galloway, North-East Ireland, North Wales, and the Lake

1. In the 1937 edition of his work he changed his mind and accepted Charlesworth's Last Glaciation limit for the area, some 35 miles to the north.

District, and dispelled the idea held by earlier workers that the erratics of Dewisland were derived from the Prescelly Mountains. Like Owen (1603) he noted the presence of shells in the Lower Boulder-clay and in some of the sands and gravels, and remarked on their absence from the Upper Boulder-clay. He stated that there was a general thickening of the drifts from west to east, and concluded that the glaciation in which the Lower Boulder-clay was laid down was of greater extent than any other. He considered that the sands and gravels were the fluvio-glacial products of a melting ice-sheet, and although he tentatively suggested a readvance of the ice in order to deposit the Upper Boulder-clay he was more inclined to consider it a rubble deposit of frost-shattered bedrock, moraine, and outwash material "re-arranged, and in places sifted by the waters." (p. 87). With the exception of this last viewpoint, Jehu's theory of the glaciation of Pembrokeshire is that accepted in outline at the present day.

(b) In 1911 Leach wrote an important short paper which suggested a relationship between the raised beach sections of Gower and Pembrokeshire. At Ogof Golchfa, which has since become a classic locality, he showed that till and head overlie the local representatives of the raised beach series. Although part of the Gower succession is not present at Ogof Golchfa, he had no hesitation in correlating its platform and raised beach gravels with the Patella beach of Gower.

Thus by 1911 there had been accumulated a large body of information, which was not augmented substantially until a further sixteen years had passed. The Irish Sea ice was accepted as the major agent in the glaciation of the area, and two distinct glaciations separated by an inter-glacial period had been postulated. Most of the critical Pleistocene sections were already well recorded, and Jehu's succession was firmly established. The deep rock channels of the north of the county were attracting attention. In outline and in many details the current viewpoint on the glaciation of Pembrokeshire was already formulated.

(c) In 1927 Williams worked in western Cardiganshire, and recorded a succession similar to that of Jehu (1904). He proposed that the Upper Boulder-clay of Cardiganshire was deposited by local ice following some retreat of the Irish Sea ice which had laid down the Lower Boulder-clay. He did not consider that the "Intermediate" sands and gravels represented an interglacial period.

(d) The last major contribution was that of Charlesworth (1929), who worked in the Fishguard area. He proposed two glaciations for North Pembrokeshire -- an Older Drift glaciation which affected the whole of the county, and a Newer Drift glaciation which affected only the Pen Caer-Cardigan coastal area, impounding a complex series of pro-glacial lakes which cut deep "overflow channels" during the course of their drainage. He suggested that many of the sand and gravel patches of the area constituted remnants of the "South Wales End-moraine", dating from the last glaciation (Fig. 11). Charlesworth's work was of great value, for he was the first person to progress beyond the cautious description of the North Pembrokeshire drifts and suggest correlations of drift boundaries with those of Ireland, the Welsh borderland, and England. He was also the first person to venture an opinion on the origin of the North Pembrokeshire channels.

(4) <u>New Statements and Old Ideas.</u> Between 1929 and 1950 most of the studies of glaciation in Pembrokeshire appear to have been by-products of geological investigations or of studies in adjacent areas; consequently a characteristic of the period was an acceptance of the overall drift stratigraphy proposed by earlier workers.

In 1929 North repeated the established drift sequence of South Wales and proposed an interglacial origin for the raised beach; in 1930 Cox recorded the exposure of shelly till at Porthmelgan, and found striations at 500 ft. O.D. on

Penbiri and Carnllidi. George (1932) established the complex nature of the raised beach platforms and deposits in Gower, and two years later Leach worked on the Caldey Island raised beaches and suggested a marked fall of sea-level after the formation of the platform. This fall was considered to have coincided with a possible glaciation.

Griffiths (1939) studied the mineralogy of drifts in Carmarthenshire and West Glamorgan, and accepted Charlesworth's ideas on the glaciation of North Pembrokeshire. However, he considered that Charlesworth's lake-system was formed in Older Drift times. His thesis (1940) contained useful maps of erratic trains and inferred ice-directions over Pembrokeshire (Fig. 12), and he suggested that there had once been a local ice-cap over Mynydd Prescelly. However, most of his work was concentrated in the region to the east of Pembrokeshire, and his statements do not seem entirely clear concerning the stratigraphy and distribution of drifts.

In 1940 Evans mapped the distribution of head and till around the Prescelly Mountains in the context of wider geological studies; he agreed with Griffiths that there had probably been a Prescelly ice-cap. M. Jones (1946) reconsidered the formation of glacial lakes in the Teifi valley, and while he considered that minor local lakes were formed at different stages of deglaciation, his views did not differ greatly from those of Charlesworth.

In 1948 Pringle and George (in the "South Wales" regional geology handbook) gave a concise summary of the ideas accepted on the glaciation of South Wales at that time. This summary still appears in its original form today, and is accepted as authoritative by many people.

(B) RECENT OPINIONS AND UNANSWERED PROBLEMS.

"Since the publication of the work of Jehu and Charlesworth the distribution and significance of the glacial deposits of the Irish Sea have remained in a somewhat confused condition".

(W.D. Evans, 1964, P. 99).

"A major divergence of opinion ......exists. Perhaps the complexity of the Würm has not always been appreciated".

(J.B. Sissons, 1964, P. 142).

(1) The Development of Controversy. While little work has been achieved since Jehu's critical analysis of the drift stratigraphy of North Pembrokeshire, a great divergence of opinion on the Pleistocene problems of West Wales has emerged during the last decade.

Charlesworth's glacial lake hypothesis has received recent heavy criticism. Bowen and Gregory (1965) consider that it contains many weaknesses, and have proposed a sub-glacial origin for the meltwater channels of North Pembrokeshire as an alternative hypothesis. In an undergraduate thesis Joy (1963) found no evidence of pro-glacial lakes in the area, and also postulated a sub-glacial origin for the channels. On the other hand O.T. Jones (1964) produced evidence in support of Charlesworth's glacial lake in the Teifi valley, and Evans (1964) in supporting the same hypothesis suggested that a Prescelly ice-cap had assisted in the damming and supply of meltwaters to Glacial Lake Nevern (Fig. 11).

Several authors have expressed opinions on the age of the Pembrokeshire drifts and their relations with elsewhere. Charlesworth (1929) and George (1932; 1933) considered that the Older Drift of Pembrokeshire is "Mousterian" in age and the Newer Drift "Magdalenian". In 1942 Bull considered that both these drifts were deposited in stages of a single prolonged Last Glaciation, which he correlated with the Wisconsin Glaciation of North America. In 1943 Arkell suggested that the Older Drift of South Wales is "Cornovian" in age (the equivalent of the East Anglian Gipping), while the Newer Drift is "Cymrian", but by 1946 he had altered his view and considered that both the drifts of Wales are of Würm age. Zeuner (1959) considered that the raised beach platform of the area is of Last Interglacial (Monastirian) age, and while accepting the basic division of the West Wales drifts into an Older Drift and a Newer Drift, he followed Bull in the view that both drift deposits date from the Last Glaciation.

On the other hand Wirtz (1953) considered that the drifts of two distinct glacial periods are represented in West Wales. He thought of the Patella beach platform and its equivalents as Mindel/Riss, while accepting the Older Drift as Riss and the South Wales End-moraine as Würm. Mitchell (1960) advanced the view that West Wales was covered by the Irish Sea glacier during both the Lowestoft (Mindel) and Gipping (Riss) glaciations, but not during the Last Glaciation. Like Wirtz, he considered that the Older Drift of West Wales is of Riss age; however, unlike Wirtz he considered that the Patella beach platform was cut in pre-Mindel times, for, as he reasoned, the erratics on the raised beach platform and beneath Riss till must have been deposited in a glaciation earlier than the Riss. In 1961 Synge supported the scheme of Mitchell when correlating the South Wales drifts with the Eastern General drifts of Ireland and the Continental Riss. In 1962 and 1963 Mitchell and Synge restated their views and used evidence from the Porth-clais and Aber-mawr sections in North Pembrokeshire to aid their interpretations. However, Charlesworth (1963) disagreed with their Midland General ice-limit (Fig. 13), and insisted that Irish Sea ice of the Last Glaciation reached the North Pembrokeshire coast, as suggested in his 1929 paper.

Recently D.Q. Bowen (1965) has re-examined the drift deposits of Central South Wales and Gower, and has followed Bull in the suggestion that the Older Drifts of the area are in fact of Early Würm age. He considers that during the Main Würm there occurred a more limited valley glaciation in South Wales, which he terms the "Welsh Readvance". Like Charlesworth, he considers that the Irish Sea ice of the Last Glaciation impinged upon the North Pembrokeshire coast.

Concerning the absolute age of the Newer Drifts of Britain, there have been several other relevant expressions of opinion during the last decade. Godwin (1960) considered that the maximum advance of the British ice during the Last Glaciation occurred between 57,000 and 42,000 years ago, i.e. prior to the Main Würm glaciation of Europe; this dating is supported by Coope, Shotton and Strachan (1961) for the maximum advance of the Irish Sea glacier. Likewise Peake (1961) has suggested that the Welsh Readvance is Main Würm in age, with the Main Irish Sea Glaciation possibly of Early Würm age. On the other hand Penny (1964) has argued that the Newer Drift Maximum in Britain is probably of Main Würm age, with the Welsh Readvance and other events relegated to the status of minor retreat stages.

Thus there are many differences of opinion concerning the number of drift deposits represented in Pembrokeshire, their distributions, and their ages. Perhaps more than anything else, the multiplicity of viewpoints expressed on these topics points to the need for careful stratigraphic analysis and absolute dating of the drifts of North Pembrokeshire.

(2) <u>The Nature of the Problems.</u> In view of the major divergences of opinion mentioned above, there seem to be several pertinent questions which may be posed:

a) Is Jehu's tripartite drift division justified?

i) Is the "Lower Boulder-clay" one deposit? Jehu grouped coastal and inland clay tills together as "Lower Boulder-clay", while later workers (e.g. Mitchell and Synge) have noted a coastal distribution only for the calcareous Irish Sea till. It has not been established whether the terms "Lower Boulder-clay" and "Irish Sea till" are synonymous.

ii) Do the "Intermediate sands and gravels" exist, and do they represent an interglacial deposit? Jehu and Williams were inclined to think not, but Griffiths and Pringle and George have accepted that they lie stratigraphically between Older Drift and Newer Drift.

iii) What is the nature of the "Upper Boulder-clay"? Mitchell and Synge agree with Williams that it is a local Welsh till. On the other hand Groom (personal communication) follows Jehu in considering it a mixed solifluxion rubble which is not necessarily the representative of a local glaciation.

b) Does the "South Wales End-moraine" of Charlesworth really exist? It is accepted by Zeuner and some later workers, but its existence as a terminal or readvance feature has been doubted by Synge.

c) What is the age of the North Pembrokeshire drifts? Charlesworth, Jones and Evans believe that the South Wales End-Moraine is the representative of the Newer Drift and the Last Glaciation. Synge and Mitchell consider all the Pembrokeshire drifts to be Older Drift, and categorise them with the stages of the Eastern General (Riss) Glaciation of Ireland. Zeuner and lately Bowen incline to the idea that all the Pembrokeshire drifts are Newer Drift (Wurm/Weichsel) in age.

d) How old are the raised beach platforms of North Pembrokeshire? Zeuner considers them to be Last Interglacial in age; Wirtz considers them to be Great Interglacial in age;

and Mitchell considers them to be pre-Mindel in age.

e) What is the origin and age of the North Pembrokeshire meltwater channels? They are considered to have been cut as lake overflow channels by Charlesworth, Jones, and Evans, and as sub-glacial channels by Joy, Bowen, and Gregory. Griffiths considers them to have been cut during the Older Drift glaciation, while the above-mentioned authors think of them as features of a Newer Drift Glaciation.

Among the minor problems which need investigation the four most interesting appear to be:

f) The "Prescelly Ice-cap". Griffiths and Evans believe in its existence, whereas Pringle and George (1948) consider the Prescelly Mountains to have been over-ridden "at least in great part" by the Irish Sea Ice-sheet; they make no mention of local ice in the mountains.

g) The directions of ice-movement in Pembrokeshire. From Griffiths' map of erratic distributions it seems that ice-streams may have moved in different directions at different glacial stages (Fig. 12). It is not known how violent these swings in movement were, and to what extent they were controlled by topography or the location of the ice-cap centres.

h) The reason for the negligible thickness of the drift cover in North Pembrokeshire and the absence of topographic features in the drift over most of the county.

i) The eastern limit of the Irish Sea ice in West Wales. This has been mentioned by Griffiths, but more detailed work is needed.

(3) The Scope of the present study. The research work for this thesis was undertaken in the hope that some of the problems outlined above could be resolved. Detailed stratigraphic studies were undertaken, and several quantitative techniques were employed in an effort to propose which of the ideas expressed to date are most reliable. Radiocarbon dating has been used to provide new chronological data of sufficient reliability for correlations with other parts of Britain.

As a preliminary, a detailed description of the techniques used during the course of the study is given in Part II. The larger part of the thesis (Part III) is devoted to close examinations of coastal sections; observations are made on drift stratigraphy, and also on specific points concerning the origins of drifts and associated topographic features. In addition, some suggestions are made on relative chronology in so far as it can be disciphered from coastal features and the stratigraphic record. In Part IV this restricted study is broadened to encompass the whole of Dewisland and the

the area south of Fishguard, and detailed investigations are undertaken concerning specific problems of drift distributions and origins. Part V is devoted entirely to a study of the meltwater features of North Pembrokeshire, and suggestions are made concerning their origins and age.

In Part VI attempts are made to sum up the evidence collected and to describe the most important Pleistocene events which can be discerned in North Pembrokeshire. The drift stratigraphy of other areas in South-Western Britain is examined in order to assess how far the Pleistocene events of Pembrokeshire are typical of a wider area. In Part VII several independent lines of evidence concerning the age of the drifts are persued before an absolute chronology is suggested and correlations are made with other parts of Britain.

Within this broad framework it is hoped to suggest answers to most of the questions outlined in the foregoing pages. Some of these answers may subsequently be proved unreliable, but perhaps this thesis will contribute something towards the growth of interest in the many Pleistocene problems of George Owen's "little Countie of Pembrokesheere".

PART II.

METHODS AND TECHNIQUES USED IN DRIFT INVESTIGATIONS IN NORTH PEMBROKESHIRE.

This part of the thesis is devoted to the description of techniques used during the fieldwork in North Pembrokeshire. Few of the techniques are new, for drift fabric analyses of various types have been essential components of geomorphological and geological research for many years. In some cases adaptations and simplifications of older techniques have been made to suit conditions in Pembrokeshire; the reasons for these changes are discussed in the text. Fabric analysis has by no means been the raison d'être of this work; no detailed studies of process have been made, and all the techniques employed have been intended only to assist the field interpretation of drifts. Simplicity and rapidity have therefore been important characteristics of all the techniques employed; however, it is thought that the loss of accuracy resulting from the modifications of elaborate techniques has been negligible.

For each technique a brief outline of its earlier use is given, along with a discussion of its value. Detailed accounts are given of the field and laboratory methods employed. Where a new technique is developed a short note is given on the results obtained.

In Chapter 3 the techniques of fabric analysis are discussed, while Chapter 4 is devoted to a short discussion of the usefulness of marine mollusca for absolute dating.

Chapter 3

FIELD ANALYSIS OF DRIFTS.

Chapter 3 (A)

THE INTERPRETATION OF HEAD DEPOSITS.

"Although various periglacial phenomena have been reported in Britain....., little work has been done on their stratigraphy and climatic indications". "The close observation of periglacial phenomena can give much information on environmental conditions, as has been shown by Professor Dylik and his school in Poland".

(R.G. West, 1963, P. 177)

In many areas head[1] deposits provide the only evidence available of periglacial climatic fluctuations during the Pleistocene period. Although the presence of till, raised beach gravels and other deposits in Pembrokeshire means that climatic changes can be disciphered with relative ease, the characteristics of head deposits are used in this thesis to provide supplementary data on the nature and length of periglacial phases before and after the last glaciation of the area. It is recognised that there have been several phases

---

1. The term "head", which is now officially accepted by the Geological Survey, is preferred to older terms such as "rubble-drift" and "trail", and to more recent terms such as "congelifractate" (Bryan, 1946). "Head" is used here to incorporate all deposits which are composed largely of local bedrock materials and which have been soliflucted under periglacial conditions (see Dines *et al*, 1940).

of head formation in Britain; in the same way I hope to suggest that there have been distinguishable periods of head formation in West Wales, with each generation displaying specific characteristics which may be related to specific stages in the Pleistocene history of the area.

There are innumerable descriptions of head deposits of various types in the British literature, and innumerable attempts to explain the origin of head. The major advances towards the interpretation of head as a periglacial solifluxion deposit appear to have been made by Godwin-Austen (1851), Wood (1882), and Andersson (1906); an exhaustive summary of the rest of the early literature is given in Dines _et al_ (1940). The last-named paper contains a general survey of head characteristics and origins, and analyses the significance of head deposits in selected areas.

Head characteristics are immensely variable. Plates 5, 6, and 7 illustrate the three most easily-distinguishable head types found in Pembrokeshire, namely:

1. Flaky gravelly head with fine pseudo-stratification (Plate 5).
2. Moderately blocky head with pseudo-stratification (Plate 6).
3. Coarse blocky head without pseudo-stratification (Plate 7).

Of these types, Type 1 is not widespread, being well-exposed only at Aber-mawr and Whitesands. Similarly, although Type 3 does occur in some localities around the Irish Sea (e.g. at Porth Neigwl in Lleyn and Garryvoe in South-East Ireland), it appears not to be common in Pembrokeshire. On the other hand moderately blocky heads similar to that shown in Plate 6 are widespread, and occur with some variable characteristics at virtually every coastal exposure of head in North Pembrokeshire.

In general, head may be distinguished from other deposits on the following grounds:

1. Its fragments are generally angular or sub-angular, unless its parent material contains rounded pebbles.
2. It is found on or at the base of gentle slopes.
3. It consists entirely of material derived from upslope in the immediate vicinity.
4. Its constituent fragments may cover a regular size-range, and may be set in a silty or sandy matrix. This matrix may be derived from upslope parent material.
5. It often displays a rough "pseudo-stratification", which may be parallel with the surface slope.[1]

---

1. From a distance a head deposit may appear to be well-stratified; this is generally an illusion, for upon close inspection true strata are seldom encountered.

6. Elongated fragments generally have their long axes orientated in the direction of maximum slope.

In view of this combination of characteristics it is usually possible to distinguish head from till, hillwash, and fluvial and wind-blown deposits; however, it should be borne in mind that in some areas the products of temperate humid mass wasting are difficult to distinguish from head, and great difficulties of interpretation may be encountered where bedrock weathers into soft flakes of fine material, as in chalk (Kerney, 1963).

There have been few attempts to define the conditions under which head accumulates. It seems, however, that solifluxion is most effective where the following conditions are satisfied:

(a) Frequent freeze-thaw cycles. Dylik (1964) has stressed the importance of alternations across freezing-point in a periglacial environment, but has also noted that oscillations below freezing-point are required for effective frost-cracking of bedrock fragments. However, there appears to be some doubt about whether the frequency of cycles is a more important control on frost-shattering than cycle amplitude. Tricart (1956) has suggested that a "Siberian" cycle regime (characterised by a small number of cycles of large amplitude, i.e. $-30^{\circ}C$ to $+15^{\circ}C$) is most effective for shattering. Galloway (1958) has agreed with this, and considers that the amplitude of freeze-thaw cycles experienced by a locality is as important as the actual number of cycles experienced. However, these views are disputed by Wiman (1963), who has conducted experiments on the rate and effectiveness of frost-shattering. He found that shattering was more rapid under an "Icelandic" cycle regime, characterised by numerous small cycles between -7°C and +6°C. Thus, in view of the contradictory nature of this evidence it may be as well to keep an open mind about the respective merits of cycle frequency and amplitude until further field and experimental data are available.

The work of Visher (1945) and Fraser (1959) is of great importance to this topic, for their maps of freeze-thaw frequencies in North America may reflect great differences in solifluxion potential. In the high latitudes of the Canadian Arctic, only nine or ten freeze-thaw cycles are experienced annually in some localities; passing southwards, the Hudson Bay area experiences c. 35 cycles, and the Great Lakes area over 60 cycles. The highest totals are recorded in the Rocky Mountains, with over 130 cycles per annum. It is possible that the efficiency of solifluxion is more closely related to the number of freeze-thaw cycles than to the mean annual temperature of a locality.

(b) Adequate moisture. It is frequently stressed in the literature (e.g. Peltier, 1950; Paterson, 1940) that a great deal of moisture in the "active" layer is essential for effective solifluxion. Wiman (1963) found in his experiments that frost-shattering did not occur under any cycle regime without the presence of adequate moisture. Field observations have shown that in periglacial areas of low precipitation (i.e. under 6" per annum) solifluxion may be negligible, in spite of abundant freeze-thaw cycles. An example is the McMurdo Sound area of Antarctica; this contrasts greatly with the Marguerite Bay area of Graham Land, where precipitation is c. 20" per annum, and where solifluxion features are well-developed (Hoskins, 1963). Peltier (1950) suggested that a mean annual precipitation of 10" to 50" is most likely to favour active solifluxion, but this has been criticised by Fraser (1959) on the grounds that in Arctic regions total precipitation bears little relationship to the amount of groundwater available for freeze-thaw; low evaporation and the impermeability of permafrost can render a precipitation of 10" per annum adequate for rapid frost-shattering. The downslope movement of meltwater from pre-existing snow or ice-patches may further contribute to the amount of water available.

There may be reason to assume that more moisture is required for the production of blocky head than for flaky head (Dylik, 1964), since small bedrock flakes may be moved downslope in a thin active layer with little surface run-off.

(c) The presence of permafrost. While mass-wasting and soil creep can proceed under a large variety of climatic regimes (Leopold et al, 1964), it seems that a deep-frozen permafrost layer which is subject to surface melting is especially favourable for large-scale solifluxion (Williams, 1960). Head fragments migrate downslope within the melted "active" layer, which may vary in thickness from a few centimetres to several metres; migration is more effective upon a permafrost surface than on a surface of solid bedrock, and in favourable circumstances all bedrock above the permafrost level will be "shaved" off (Te Punga, 1957). Indeed, the presence of a shaved bedrock surface is considered by Cotton to be one of the diagnostic features of areas of periglacial solifluxion. It should be noted in the context of this discussion that given an identical bedrock slope and a seasonal active layer only 3" thick, solifluxion may be possible in a flaky head deposit, but not in a very blocky head.

(d) Negligible snow-cover. In view of the "blanketing" effect of a thick snow-cover, a permanently snow-covered landscape is seldom underlain by effective permafrost (Annersten, 1964). Solifluxion may therefore be more effective in areas where annual precipitation is considerably lower than annual ablation, or where wind-action can keep solifluxion slopes largely free of thick snow-banks.

(e) Suitable parent lithology. In general, rocks which are resistant to freeze-thaw (such as highly permeable or impermeable rocks) yield coarse head fragments, while weak rocks yield abundant fine material (Galloway, 1964). Among rocks which are susceptible to freeze-thaw, Leopold et al (1964) list fine-grained and moderately permeable rocks such as shales, slates, schists, and some sandstones, while Czeppe (1964) has emphasised the variable weathering characteristics of different sandstone facies in Spitsbergen. It seems that lithology alone may be responsible for variable head formation in an area of variable rock-type but identical environmental conditions. If the head is derived from earlier drift deposits such as till or raised beach pebbles (as at Ogof Golchfa and Poppit, North Pembrokeshire), the processes of solifluxion may be speeded up as a result of the ample supply of loose fragments.

(f) Ample bedrock slope. Solifluxion can proceed on slopes as low as 1° (Galloway, 1958), but is likely to be more effective on slopes of 2° to 5° (Büdel, 1960). Solifluxion may be rapid on slopes of 10°, but on steeper slopes it may be replaced by scree or talus formation; these deposits lose some head characteristics, and probably form much faster than head (Rapp, 1960). On some slopes there is a gradation between head and talus. Jahn (1960) has noted that in Spitsbergen the solifluxion zone at the foot of frost-shattered cliffs lies beyond zones of solifluxion terraces and talus formation, each of which has a successively steeper gradient; he stated that the deposition of fines by surface meltwater is an important process in the solifluxion zone, where slopes are between 2° and 5°. Head of fine bedrock flakes may develop continuously on a low slope; under identical environmental conditions a blocky head probably needs a much steeper slope for its formation.

(g) Suitable head matrix. Since the active layer may be highly mobile during the summer season, head fragments tend to move more easily if they are embedded in a supersaturated matrix of fines (Galloway, 1958; Péwé, 1964). The silt, sand, and gravel for this matrix may be derived from wind-blown periglacial deposits (Dylik, 1960), from upslope fluvial or glacial deposits, or from shattered bedrock itself. Wiman's experiments in 1963 suggested that certain rock-types produced an ample supply of fines under freeze-thaw, whereas others did not. Even without the presence of fines, flaky head fragments may themselves act as a mobile matrix.

(h) Elimination of vertical frost-heave movements. In some areas, the periglacial climate is too severe for solifluxion; instead, if the mean annual air temperature is below -6°C, it may favour ice-wedge cracking and frost-heaving (Péwé, 1964). However, it is possible that on slopes of c. 10° and over vertical frost-heave movements may be eliminated and solifluxion maintained (Czudek, 1964). Head may accumulate on a steep hillside, therefore, while neighbouring low slopes may experience only the disturbance of existing deposits (Paterson, 1940).

(i) Lack of vegetation. Where a vegetation cover is able to establish itself on a solifluxion slope it will naturally tend to bind head fragments together and arrest the rate of head formation (Dines et al, 1940). Upslope vegetation will also diminish the amount of fines available for incorporation in the head matrix; this will also tend to slow down the solifluxion process (Dylik, 1964).

(j) Maintenance of periglacial conditions. Head forms slowly, subject to the conditions listed above. Jahn (1960) found that head fragments in Spitzbergen moved down a slope of 4° at a rate of only 3 cm. per annum; similarly

Rudberg (1958) reported that the mean movement of 22 stones on a 5° solifluxion slope in North Sweden was only 3.5 cm. in one year and as low as 0.9 cm. in another year. Rather higher rates of head movement have been recorded (up to 2 ft. per annum in places; Leopold et al, 1964), and it is possible that the rate of movement may be even faster in some unrecorded localities.[1] In any case, it appears to be very much faster than soil creep and other gradual mass-movements.

The maximum rate of head formation is a much debated point, but thick accumulations of head possibly need many centuries in which to form. It may be misleading, however, to assume that Western Europe under periglacial conditions experienced the same rates of head formation as present-day permafrost areas; the effects of lower latitude, more numerous freeze-thaw cycles, and greater precipitation under an oceanic regime may have facilitated more rapid head formation. (Büdel, 1960).

From the above summary of factors it may readily be appreciated why head characteristics vary enormously from one locality to another. Each head deposit displays its

1. Flint (1957) mentions one locality where a rate of 13 cm. per day has been recorded; however, he does not mention the period of time over which this rate was maintained.

own unique features, and until detailed studies provide a key to the interpretation of specific head properties[1] all conclusions drawn from the examination of individual head exposures must be considered tentative. The difficulties are increased because in certain cases it may be difficult to distinguish true periglacial deposits from sedimentary deposits formed under temperate or tropical humid conditions (Jahn, 1964); Paterson (1940) has stressed this difficulty after comparing Arctic solifluxion deposits with those of the Himalayan foot-hills which form seasonally during the monsoon, and Kerney (1963) has shown that many of the chalk "coombe rock" deposits of south-east England may not be true periglacial deposits.

Bearing in mind these difficulties, however, there are good grounds for assuming that some reliable inferences on past periglacial conditions may be drawn from careful studies of head. It is agreed that of all the factors which control head formation, the climatic factors are the most important (Dines _et al._ 1940), and while there are immense dangers in the long-distance correlation of heads on the basis of their characteristics it is clear that different head layers

---

1. Such properties may include size of fragments, character of matrix, degree of pseudo-stratification, thickness of deposit, and preferred orientation and plunge of elongated fragments.

within one exposure may generally be related to climatic fluctuations. Dylik (1964) has emphasised that periglacial climates are just as varied as those of temperate lands, and from the factors noted above it seems that head formed in one locality under moist, moderately cold periglacial conditions will be rather different from a later head formed under conditions of extreme cold and aridity.

While it is true to say that more attention has been paid by periglacial specialists to the phenomena of frost-heaving and cracking than to solifluxion, much work has been done in Poland and elsewhere in recent years to increase knowledge of climatic controls on head formation. Büdel (1959; 1960) has suggested that there are two distinct types of solifluxion, namely "periodic" and "episodic".

(a) "Periodic" solifluxion, where there is downslope movement in a relatively thin active layer every year; the resultant head shows good pseudo-stratification, a rather even fragment size, and a close agreement between the angle of plunge of incorporated fragments with the surface slope. This type of solifluxion is widespread, and is apparently favoured under oceanic periglacial climates.

(b) "Episodic" solifluxion is characterised by the essentially intermittent movement of a deep active layer (up to 4 m. thick), giving rise to complex "cryotectonic" structures. It occurs on shallow slopes of between 2^{o} and 4^{o}, and in view of the rigorous conditions necessary for its formation it has a restricted distribution. Heads laid down by episodic solifluxion occur largely in Central Europe.

Head deposits are apparently more common in Western Europe than in Eastern Europe (Cailleux, 1962) perhaps bearing witness to the importance of moisture and an oceanic regime for head formation. Galloway (1958) has proposed that a maritime tundra climate (as experienced by the west coast of Spitsbergen and by South Greenland today) may have existed at low levels in Britain during the Pleistocene glacial maxima. The climate may have been characterised by moderate cold, with frequent freeze-thaw cycles of small amplitude, and plentiful moisture. There appears to be some doubt about the type of head which may be expected to develop under such conditions. Galloway (1958) suggests that there was rapid head accumulation of fine fragments, while Dylik (1964) considers that there may have been rapid mass-movement, giving rise to poor pseudo-stratification and blocky head fragments. Conversely there is doubt about the type of head which would develop under a continental periglacial regime of greater aridity and infrequent freeze-thaw cycles of great amplitude. Galloway considers that larger head fragments with less fine material would result, while Dylik proposes that well-stratified thin layers of flaky head fragments would accumulate.

These two views are not compatible, but the views of Dylik appear to be supported by more field observations and experimental data (Wiman, 1963). He states that a head characterised by thin bedding and flaky fragments (Plate 5), perhaps with interbedding of thin sheets of sand and silt, may have been deposited under very severe periglacial conditions with a thin active layer and little moisture. Each thin layer of flakes would represent one year's accumulation; the permafrost level would rise with the rising surface of the head deposit, so that a large measure of protection is afforded to past accumulations. Often a thin-bedded and flaky head deposit with fossil ice-wedges lies between blocky heads with poor pseudo-stratification (Fig. 14); such a sequence is interpreted by Dylik as representing a cycle of head development, with the blocky heads at A and C representing the waxing and waning phases of periglaciation (cold, rather moist conditions) and with the climax (very cold and arid conditions) represented at B. In Poland most fossil ice-wedges are apparently associated with horizons similar to that at B; the correlation of stage B with conditions of maximum cold therefore seems to be reasonable.

If the characteristics of a sequence of head deposits in one exposure cannot be related to lithological differences in the upslope parent material, then several climatic inferences may be drawn. Weathering horizons in the head deposits can immediately be interpreted as the representatives of warmer phases, although some warm phases which may have occurred since the onset of periglacial conditions may not be represented in the head exposure. (Fig. 15). Interbedding of blocky and flaky heads may record fluctuations in periglacial climates, and major uhconformities in a head series may represent prolonged breaks in solifluxion. If erratic pebbles or blocks are present in one head horizon above a horizon which has no foreign material, then there may have been a break in periglaciation during which the erratics were introduced. If the head is severely contorted or has fossil ice-wedges in it, then there is reason to suspect a deterioration in climate and a decrease in precipitation.

It is difficult to make suggestions about absolute chronology on the basis of head accumulations. It has been suggested above (Fig. 15) that traces of interstadial conditions may be completely removed by later solifluxion; a certain thickness of head may have formed quickly in a relatively short time, or else over a period of many centuries with two or more phases of solifluxion separated by interstadial conditions. Again, the relative thickness of head layers may not be a reliable guide to age, since blocky heads may form more quickly than flaky heads with pseudo-stratification. Similarly, the thickness of a certain head layer beneath another may represent its total thickness, or else simply the remnant not removed by the subsequent phase of solifluxion. With flaky heads it may be reasonable to assume that each stratified layer represents an annual cycle, as suggested in Plate 5; on the other hand each layer may represent a short phase of freeze-thaw, such as may occur in spring and autumn each year, with the result that two or more layers may be formed in a single year. In blocky heads there is often no clear indication of the thickness of the active layer, so that no conclusions can be made regarding the number of depositional cycles represented.

In spite of these difficulties there have been several attempts at the detailed chronological assessment of head deposits. Many papers have been written in Polish, but more readily available are the papers in French and English in the "Biuletyn Peryglacjalny". Dylik (1960) has studied fine waste materials in Poland, and has proposed that weathered layers in the flaky heads of Klemencice and Parkoszowice are of Mindel/Riss interglacial age. He also states that erratic pebbles in the lower head probably date from the Mindel glaciation. Starkel (1960) has made a detailed study of blocky heads and interbedded deposits of fines in the Carpathians, and has been able to reconstruct a chronology which is in accordance with other observations from Eastern Europe. Pecsi (1964) has related solifluxion and other periglacial phenomena of Hungary to the stages of the Pleistocene, and claims to have reconstructed a chronology on this basis back as far as the Günz glaciation. Czudek (1964) has made a study of head deposits in the Bohemian massif, relating them to variations in climate and the variable thickness of the active layer.

In Western Europe van der Hammen (1952) has correlated the coversands and other periglacial deposits of the Netherlands with the Pleniglacial stages of the Würm, and with Maarleveld (1952) he has used the full sequence of deposits on the eastern fringe of the Veluwe to reconstruct seven stages between the Last Interglacial and the end of the Younger Dryas.

Head studies in the British Isles have been mainly descriptive, and knowledge has advanced little since the speculations of Prestwich (1892) and earlier workers, except in the general recognition that solifluxion deposits are in fact of periglacial origin. Some indication of the possibilities of head interpretation was given during the meetings and symposia of the International Geographical Congress in 1964. At Exeter much discussion was centred on the interpretation of head on Dartmoor and the Devon coast, and some participants emphasised the dangers in assigning thin weathered layers in head to full interglacials, as has been done in a tentative reconstruction of events at some localities by Stephens (1964). In East Anglia doubt was expressed concerning the assignment of relatively thin head layers to the whole of the Weichselian stage in support of the dating of the underlying deposits as Saale; several participants considered that such thin head layers could easily have formed post-glacially, perhaps during Zone III. In support of this, Kerney (1963) has demonstrated that thicknesses of up to four metres of solifluxion deposits may have accumulated on the south coast of England since the Allerød. At Garryvoe, in South-East Ireland, Professor Dylik opened the door to future work on the interpretation of heads around the Irish Sea with his suggestion that blocky, flaky, and contorted heads beneath till were the representatives of specific periglacial phases preceding glaciation.

Horizons in which pollen or floral remains are preserved (as noted by Prestwich, (1892) from exposures in Southern England, and by Rudberg (1958) from Sweden) are valuable aids to climatic interpretations, especially if pollen analysis or C14 dating of organic materials proves possible. However, few such horizons have been found in Western Britain, and in their absence the ideas of Professor Dylik may be used with advantage in Pleistocene studies. Following some of the ideas put forward by the workers mentioned above, I have attempted to draw simple conclusions on periglacial climates on the basis of head interpretation in Pembrokeshire.

Chapter 3 (B)

THE DRIFT MAPS.

Field mapping in North Pembrokeshire had to be undertaken without accurate prior knowledge of either solid geology or drift distributions. As far as is known, no other drift maps have been prepared by earlier authors for the areas studied in this thesis; indeed Jehu, when remarking on the rapid lateral transitions from one drift to another, was moved to state "Owing to the want of good exposures inland, it is generally impossible to mark out the limits of the different kinds of superficial detritus" (P. 63). In view of the lack of Geological Survey "New Series" sheets for the area, the Dale Fort Geological Map (Map 1) proved to be invaluable in the field, and additional information on the geology of the St. David's area was obtained from a manuscript map kindly made available to me by R. Leake.

Two areas were mapped in detail at a scale of 6" to one mile. In Dewisland, an area of c. 23 square miles was mapped on eight O.S. 6" sheets during the early part of the study, and later an area of c. 43 square miles was mapped in the Aber-mawr - Fishguard - Dinas district on a further seven O.S. 6" sheets.[1] The locations of the areas mapped in detail in the field are shown in Fig. 16. Drift boundaries were mapped in the field by frequent excavation and augering with a 3 ft. hand auger. The whole of the coastline on the field sheets was examined in detail, and inland drainage reservoirs and drift exposures proved to be particularly useful for field interpretations. Where possible, information from farmers was used to supplement field observations.

In Dewisland the pattern of drift distributions is simple. Jehu's tripartite drift subdivision (Upper boulder-clay, Intermediate sands and gravels, and Lower boulder-clay) was used during the early part of the fieldwork as a working hypothesis, but it soon appeared that it was simpler to classify the major drift types of the area on a purely empirical basis as (a) Thin sandy and stony remanié drift, and (b) Gleyed tills located on the inland moors (Fig. 7). Furthermore, sands and gravels were found to be virtually absent from the area. Accordingly a simple scheme of drifts was adopted for the drift map of Dewisland:

---

1. The numbers of the sheets used were as follows: Dewisland, Nos. XIV N.E., S.W., and S.E.; XV N.W. and S.W.; XX N.E. and N.W.; XXI N.W. Fishguard area, Nos. V S.W.; IX N.W., N.E., S.W., and S.E.; X N.W. and S.W.

(a) Thin sandy and stony remanié drifts.

(b) Gleyed stony tills.

(c) Thin head.

(d) Blown sands.

(e) River alluvium.

(f) Bedrock exposures.

In the Fishguard area (Fig. 16) field mapping was undertaken in association with a re-examination of the meltwater channels of the Gwaun-Jordanston system, and the South Wales End-moraine of Charlesworth. In this area sands and gravels are frequently encountered, and the occurrence of steep slopes, gentle waterlogged depressions, and complex channels in the Prescelly foothills has given rise to a great variety of drift soils subject to varying degrees of alteration by solifluxion and gleying. The drift categories used for the 6" field map in this area were as follows:

(a) Thin sandy and stony remanié drifts.

(b) Drift-soil with much sand and gravel.

(c) Drift-soil with much head.

(d) Gleyed stony tills.

(e) Gleyed drift-soil with sands and gravels.

(f) Head.

(g) Sands and gravels.

(h) River alluvium.

(i) Peat.

(j) Bedrock exposures.

Besides these areas mapped in detail in the field, the northern part of the Pen Caer peninsula and the Gwaun Channel district were mapped in less detail on seven O.S. 6" sheets.[1] The drift cover in these areas was plotted with the aid of vertical aerial photographs at a scale of 1:9,800[2] with field checks made at frequent intervals. Some photographs at a scale of 1:30,000 were also used. The drifts of some other small areas on the North Pembrokeshire coast were also plotted in the field at a 6" scale, while some field mapping at a scale of 2½" to one mile was undertaken in scattered localities in the Prescelly Mountains. On the north-east flanks of Mynydd Prescelly the spasmodic drift cover has been mapped by W.D. Evans; the area studied by him is indicated in Fig. 16.

In view of the simple drift pattern of Dewisland, the field sheets were easily reduced to a 2½" scale; the resultant map is discussed later in the thesis. The complex

---

1. The numbers of these sheets were IV N.W. and S.W., and S.E.; VIII N.E.; X N.E. and S.E.; XI N.W. and N.E.

2. Through the kindness of the Pembrokeshire County Planning Officer, Mr. J.A. Price, a complete cover for North Pembrokeshire was made available to me.

drift distributions plotted on the 6" sheets for the Fishguard area have been simplified and reproduced at a scale of one inch to one mile; this map is analysed in Chapter 9.[1]

The drift maps which have been prepared are subject to varying degrees of error according to the intensity of the field survey. However, when they are used in conjunction with the reliability diagram it is hoped that they may serve as a useful basis for future detailed work in North Pembrokeshire.

---

1. A set of 2½" sheets showing the drift distributions of the areas studied will be deposited in the Pembrokeshire County Library.

Chapter 3 (C)

STONE-COUNTS FOR THE RECOGNITION OF DRIFT BOUNDARIES AND THE DIFFERENTIATION OF DRIFTS.

The direction of ice-movement across North Pembrokeshire from north-west to south-east was established on the basis of erratic indicators and striations by Hicks (1885) and later confirmed by detailed analysis of erratics by Jehu (1904) and Griffiths (1940) (Fig. 12). Accordingly I undertook no further analysis of large erratics. However, I hoped that stone-counts from drift localities might aid the recognition of drift boundaries and accurately indicate directions of ice-movement. Further, it was hoped that stone-counts from adjacent exposures of "Upper Boulder-clay" and "Lower Boulder-clay" might reveal differences in stone-content and consequently indicate the source and mode of formation of these deposits. Also, it was hoped that this technique might throw light on the characteristics of the drift cover and consequently on the strength of the transporting ice-streams.

1) Horizontal differentiation of drifts.

Milthers (1909) examined pebble indicators at numerous drift localities in Denmark in an attempt to distinguish the drifts of different glaciations and the directions of ice-movement. He collected only those pebbles which could be used as good indicators, and produced effective maps showing important geological outcrops and the percentage frequency of indicators in the surrounding drifts. He portrayed the percentage frequency by means of colour tinting, and used a broad two-fold sub-division of rock-types for generalisations concerning drift distribution. Madsen (1928) used a more complex method of drift sub-division based on both stone-content and stone-types in drifts, with a coefficient figure calculated for each locality. Lundquist (1932) used proportional circles to represent the percentage frequency of certain rock-types in till. More recently Holmes (1952) undertook pebble-counts at many localities in west-central New York State, U.S.A., where glacier flow was believed to have been across the strike of the bedrock outcrops. He drew interesting conclusions regarding the distance of transport, and produced isopleth maps on the basis of points plotted with the percentage of stones of a specific type. Anderson (1955) carried out stone-counts at random grid points on the Marseilles till sheet of north-east Illinois, U.S.A., and again represented pebbles of a certain rock-type as a percentage of the individual sample. Matisto (1961) used proportional circles to indicate the percentage of certain rock-types at individual localities, and used "drift-sectors" on his maps to portray the range of sources from which such rock-types could have been derived.

In North Pembrokeshire, and particularly in western Dewisland, stone-counting techniques have proved to be of great value during drift analysis. In the St. David's area five simple rock-types were selected on the basis of the geological map (Fig. 3) as a preliminary to field sampling:

5) Ordovician Intrusive rocks: gabbros, dolerites etc.

4) Ordovician sedimentaries: shales, mudstones, grits, sandstones, ashes.

3) Cambrian sedimentaries: sandstones, shales, mudstones etc.

2) Pre-cambrian (Pebidian) extrusives: bedded lavas, gritty tuffs etc.

1) Pre-cambrian (Dimetian) intrusives: granophyre, quartz-porphyry etc.

The coarse-grained to medium-grained dark-coloured intrusive rocks of category (5) were generally easy to recognise, as were the hard gritty light-coloured intrusives of category (1). The Pre-Cambrian extrusive rocks (2) are commonly soft flaky greenish and pinkish tuffs, while vivid tints of green, red and purple characterise some of the sandstone and shale facies of category (3). The Ordovician sedimentary rocks are generally soft grey, brown and buff shales and sandstones in the St. David's area, but in certain cases they are difficult to distinguish from certain facies of the Cambrian sedimentaries.

Some reliance was placed upon the geological sketch-map during the investigation of drift boundaries, and although certain unexplained anomalies occurred during the field-work[1] the relationship between sample stone-counts and geological outcrops was usually logical. In the field very few erratic pebbles from beyond the shores of Dewisland were encountered; consequently any erratics which did occur were disregarded. In spite of this rejection of 1% or 2% of pebbles, it is not thought that there is a serious error in the representation of drift composition at the plotted points.

Field sampling techniques. In all, I undertook 35 stone-counts in the St. David's area. Of these, eleven counts were made at the intersection points of a superimposed random grid, and ten counts were made at random points which were also used for the collection of samples for sieving analysis. (Fig. 17). In two cases (Numbers 6 and 17), where the intersection points lay respectively on a bedrock exposure

---

1. For example, the predominance of Pre-Cambrian extrusive pebbles in drift at point 20, where the bedrock is supposedly of Cambrian sedimentaries.

and on blown sand, the points were moved southwards along the grid parallel to the nearest drift-covered area. In two cases counts were not made at grid intersection points because counts had already been undertaken in the immediate neighbourhood (Numbers 11 and 23). Fourteen further counts were undertaken at convenient coastal and inland exposures. Grid references, place-names, and stone-counting details are given in Appendix IV.

From convenient exposures, and from sampling-points used for other tests, stones were taken from a depth of 18"-24", but samples from random grid points were taken from one square foot at or just beneath the surface. Tests indicated that the surface stones at a locality are no less representative of the drift cover than stones taken from a depth of 18"-24" (Fig. 18). For some samples I recorded the percentage of striated stones, although for surface samples great care had to be exercised in view of the undoubted effects of ploughing and harrowing.

The percentage of a particular stone-type at one locality varies according to the stone-size category being investigated; for example, the percentage of Ordovician intrusive pebbles at many localities decreases noticeably from upper to lower size-categories. However, stone and boulder clearance from cultivated fields renders unreliable any stone-count on stones over 6" diameter. Since most pebbles in the drift cover fall into a size-category of c. ½" - 2" diameter each field sample consisted of 50 stones in this range.[1]

Presentation of data. The results of this investigation of horizontal differences in drift composition are presented in Chapter 8. A map of divided circles for sampling localities has been constructed to indicate the total pebble composition of drift at each point, and other maps have been constructed following the principles of the authors mentioned above. The percentages of individual stone-types in till are portrayed by proportional circles, and their relationship with parent outcrops is shown. The complexity of the geological outcrops and the small size of the area studied has made it impossible to construct effective isopleth maps; however, such maps could possibly be constructed for the area east of St. Bride's Bay, using purple Cambrian sandstone or Ordovician igneous pebbles as indicators.

2) Vertical differentiation of drifts in complex exposures.

In England Simpson (1960) has analysed the vertical distribution of erratics in an attempt to differentiate

---

1. A field test at Ogof Golchfa indicated that samples of 50 stones can yield a representative picture of the pebble-content of drift (Fig. 19, Note 3).

the Upper Boulder-clay, Middle sands and gravels, and Lower Boulder-clay of the Manchester area. Pebbles in individual samples were grouped into 15 simple categories and histograms constructed to compare the distribution of erratics in different deposits.

A similar technique was used in this study during the examination of most of the critical drift sections in North Pembrokeshire. At each locality the first sample was taken from one square foot of the face of a distinct stratigraphic horizon. The first 50 stones of size ½" - 2" were collected and grouped into 15 simple categories determined on the basis of the first 15 distinctive stone-types encountered (e.g. coarse-grained igneous pebbles, black mudstone pebbles, red sandstone pebbles, etc.) The number of stones in each category was then plotted as a percentage on a simple histogram. Stones from subsequent drift samples from the exposure were grouped into the same 15 categories and also plotted on histograms (Fig. 19). Therefore each important exposure is represented by a series of comparative histograms which may reveal similarities or differences in the stone-content of its component drifts. It is emphasised that since the 15 stone-type categories differ for each locality, no horizontal comparisons can be made; the simpler stone-counts described in the earlier part of this section serve this purpose.

Chapter 3 (D)

MECHANICAL ANALYSIS OF SUPERFICIAL DEPOSITS.

For many years mechanical analysis has been accepted as a useful technique for the identification and differentiation of drifts. For example, blown sands are known to have a very characteristic grain-size distribution (Stuart, 1924), while Boswell (1916) was able to distinguish between certain brickearths in East Anglia on the basis of mechanical analysis. Krumbein (1936) has illustrated the differences in grain-size composition between beach gravels and sands, glacial till, and inland clay samples, and many authors have used the technique to differentiate between tills of various types and outwash sands and gravels.[1] A comprehensive summary of the early literature and the uses and methods of mechanical analysis is given in Krumbein and Pettijohn (1938).

In North Pembrokeshire mechanical analysis was undertaken as part of this study for three main reasons:

(a) To determine whether there is any difference in the grain-size distributions of the gleyed drift soils (the so-called "Lower Boulder-clay") and

1. See, for example, Lundquist (1933), Hoppe (1963), Horberg and Potter (1955), Flint (1957), and Andrews (1963).

the stony sandy soils (the so-called "Upper Boulder-clay") of Dewisland.

(b) To assist in the interpretation of the various deposits exposed in the coastal drift cliffs of the area.

and (c) To assist in the interpretation and mapping of the complex drift deposits of the Fishguard area.

Collection of Samples. In Dewisland I followed the definitions of Jehu and took the areas of Lower Boulder-clay, as a working hypothesis, to coincide with the drift-filled depressions plotted on Fig. 7. For the purpose of this exercise the rest of western Dewisland (with the exception of rock outcrops and exposures of head or blown sand) was taken to be the area of "Upper Boulder-clay". When field mapping in the area had been completed, a rectangular grid was superimposed upon the 6" field map and the grid lines numbered. With the aid of a set of random tables (Gregory, 1963), twenty random grid references were obtained and plotted on the map (Fig. 20) so that ten points fell on each of the major drift areas.

At each plotted locality a hole about 18" square was dug and a sample of c. 2000 gms taken from beneath the A horizon, at a depth of 18" - 24". Although Krumbein and Pettijohn (1939) have noted that different drainage and leaching conditions can lead to significant changes in the physical properties of drifts from site to site, it seemed that sampling from a constant depth would provide sufficient data for a comparative analysis.

In the Fishguard area spot samples[1] were collected from good exposures or from the drift cover where I hoped that sampling would aid the interpretation of drifts. The analytical evidence from these samples is not used for generalisations concerning the characteristics of certain types of deposit; however, within strict limits the evidence is used for the interpretation of a deposit at a specific point. For example, the spot sampling technique has been used in order to determine whether a "yellow clay" at Rhos-y-Clegyrn, near Fishguard, is gleyed and weathered outwash material or glacial till.

At Aber-mawr, Druidston, and other coastal localities where drifts are exposed in steep cliff sections, I collected spot samples from the different stratigraphic horizons in the face in order to aid their interpretation. Again, the results obtained are used within strict limits; however,

---

1. Spot samples are isolated samples collected from particular points in a drift exposure. They are not to be confused with "compound" or "channel" samples, as defined in Krumbein and Pettijohn (1938), pp. 16 - 19.

analysis of several spot samples from the drift-cliff at Aber-mawr revealed consistent grain-size distributions, and suggested that the results based on the spot sampling technique are probably reliable (Fig. 21).

The field samples were analysed at the School of Geography and the Department of Geology and Mineralogy in Oxford, and the Geography Department at Swansea University. At each place the apparatus differed slightly, but this is not thought to have seriously affected the results. There are innumerable methods of mechanical analysis, many of them involving complex and prolonged laboratory procedures; in this study I have followed closely the method of dry sieving described by Krumbein and Pettijohn, and the method of pipette analysis for the smaller grain-sizes in each test sample.[1]

Preparation of Samples for Analysis.

Drying. Those samples which were slightly moist were dried out in a warm room after preliminary disaggregation. Samples which were collected in a wet state, however, were dried thoroughly in china containers in an oven at 100°C. Sand

---

1. Wet sieving, which may be a more satisfactory technique in that it minimises the risk of breaking fragments during disaggregation, was not undertaken because of lack of facilities.

and gravel samples needed no preliminary disaggregation, but it was found that fine-grained tills could only be oven-dried quickly if they had been subjected to prolonged disaggregation beforehand.

Sample splitting. Once dried, each complete field sample of c. 2000 gms was disaggregated further and passed through a B.S. No. 5 sieve until all stones over 4 mm. were removed. The remaining sample was then passed through a Jones sample splitter until a test sample of just over 500 gms was obtained. Where no sample splitter was available, simple hand-quartering was undertaken.

Disaggregation of test samples. The test samples were shaken for a preliminary period of five minutes, and each sieve load subjected to disaggregation with rubber pestle or wooden rolling-pin. At all stages particles were examined under a binocular microscope to ensure complete disaggregation. For loosely-consolidated samples of sand and gravel a rubber pestle was generally found satisfactory; however, the pestle was inadequate for the disaggregation of fine-grained plastic tills, and a rolling-pin had to be used instead. As soon as it became clear that individual particles in the 2 mm - ¼mm fraction were being broken, or that compaction was replacing disaggregation, the process was stopped. As a consequence, some aggregates remained at the onset of analysis of some samples. However, it was considered that they were compensated for approximately by the breakage of rock fragments, so that the error in the plotted grain-size distribution may have been small. In a few cases (sandy loam and plastic till samples) the impossibility of complete disaggregation with the facilities available may mean that there are larger errors in the plotted curves. Once disaggregation was completed, as nearly as possible, the test sample was mixed and weighed to exactly 500 gms.

Choice of Grade Scale. A set of six sieves was used during mechanical analysis. These sieves (to British Standard specification) were chosen to coincide closely with the lower grade limits of Wentworth's (1922) categories. The table below gives the mesh sizes used and their relation to the Wentworth scale:

Mesh No.	Mesh Size	Grade limits (Wentworth)	Name
B.S. No. 8	2.06 mm.	4 - 2 mm.	Granule (Gravel)[1]
No. 16	1.00 mm.	2 - 1 mm.	Very coarse sand
No. 30	.500 mm.	1 - $\frac{1}{2}$ mm.	Coarse sand
No. 60	.251 mm.	$\frac{1}{2}$ - $\frac{1}{4}$ mm.	Medium sand
No. 120	.124 mm.	$\frac{1}{4}$ - $\frac{1}{8}$ mm.	Fine sand
No. 240	.064 mm.	$\frac{1}{8}$ - $\frac{1}{16}$ mm.	Very fine sand

1. The term "gravel", as used by Boswell (1916) is preferred to "granule".

After sieving the amount of material resting on any one mesh coincided with one of Wentworth's categories.

Sieve analysis. The 500 gm. test sample was usually shaken for a period of ten minutes in the set of sieves on an automatic shaking machine.[1] However, test cases suggested that a five-minute period was long enough for most outwash sands and gravels, but that fifteen minutes was necessary for fine-grained tills. (Fig. 22)

At the end of 15 minutes' shaking of fine-grained till samples, it was found that a small amount of fines had still not passed through the No. 240 mesh, but in view of the large size of the test sample (500 gms), the percentage error remaining was considered to be negligible.

Pipette Analysis of Fines.

The material which passed through the No. 240 mesh (i.e. the silt and clay fractions) was subjected, in the case of 18 test samples, to pipette analysis.[2] For those samples which produced few fines, the whole fines fraction was used;

---

1. Wentworth (1927) concluded that a five- or ten-minute period is usually sufficient.

2. Krumbein and Pettijohn (P. 136) recommend that $\frac{1}{16}$ mm may be conveniently used as the upper limit of sedimentation analysis and the lower limit of sieving analysis.

but in most cases the fines fraction was reduced to c. 50 gms by careful quartering. Each analysis was undertaken in a controlled temperature room at 20°C with apparatus, dispersing agent and water which had been previously stored in this room. Thus conditions were as constant as could reasonably be achieved.

For each sample the weighed fines were poured into a litre measuring cylinder. 40 ml. of 2% sodium hexameta-phosphate solution was added to aid dispersion of fragments, and the mixture was then made up to 1000 ml. with de-ionized water. Before each pipette sample was taken the whole suspension was thoroughly stirred with a stirring rod. A stopwatch was used to ensure that pipette samples were withdrawn at the correct time intervals, as below:

Diameter of grains.	Depth of sampling.	Time.
1/32 (.0312)mm.	10 cm.	1 min. 56 secs
1/64 (.0156) mm.	10 cm.	7 min. 44 secs
1/128 (.0078) mm.	10 cm.	31 mins.
1/256 (.0039) mm.	10 cm.	2 hrs. 3 mins.

It was considered that in the time available and for the accuracy required, four readings per sample were sufficient.

Each pipette sample of suspension was transferred to a

50 cc. beaker and dried till evaporated in an oven at 100°C. The residue in each beaker was then weighed to 3 decimal places on an analytical balance and the results computed as outlined by Krumbein and Pettijohn on P. 168.

Graphic presentation of data.

The weights of material resting on each sieve after mechanical analysis and in each of the grade-categories computed from pipette analyses were converted to percentages of the total test sample, and then to cumulative percentages.

A cumulative curve for each test sample was then plotted on graph paper having a logarithmic scale on the horizontal axis and an arithmetic scale on the vertical axis. The advantage of this paper is that the grade-size limits chosen can be plotted at equal intervals along the horizontal axis, while a frequency scale from 0 - 100% can be plotted on the arithmetic axis.

On samples where only sieve analysis was carried out, the cumulative curve covers the range 2 mm - $\frac{1}{16}$ mm., but where pipette analysis of the fines fraction was undertaken a complete cumulative curve (covering the size range 2 mm. - $\frac{1}{256}$ mm.) was constructed. The "break" in the curve at the $\frac{1}{16}$ mm. point in most of these composite curves is the result of the change of process from sieving to sedimentation analysis.

For further analysis data were plotted on triangular graph paper. For those samples which did not undergo pipette analysis the sieved fractions were grouped into three categories, namely:

1. Gravel and coarse sand (4 mm. - $\frac{1}{2}$ mm.)
2. Medium and fine sand ($\frac{1}{2}$ mm. - $\frac{1}{16}$ mm.)
3. Fines - silt and clay (under $\frac{1}{16}$ mm.)

On each triangular graph, each apex represents 100% of one of these categories, so that each sample, when subdivided into the three categories, may be plotted as a single point.

For those samples which did undergo pipette analysis, the three categories used on the graph were as follows:

1. Sand (2 mm. - $\frac{1}{16}$ mm.)
2. Silt ($\frac{1}{16}$ mm. - $\frac{1}{256}$ mm.)
3. Clay (under $\frac{1}{256}$ mm.)

For these samples, direct comparison of sediments with the categories of Lakin and Shaw (in Krumbein and Pettijohn, P. 203) was possible (Fig. 23).

Chapter 3 (E)

THE PREFERRED ORIENTATION OF PEBBLES IN DRIFT.

For many years preferred orientation diagrams have been used to assist in the interpretation of drift deposits. In areas which have a thick cover of till a network of diagrams showing the preferred orientation of till pebbles can be used, subject to critical analysis, for the determination of ice-movement directions. Accordingly I have undertaken detailed drift-fabric studies in Dewisland, and 42 preferred orientation diagrams have been prepared in an attempt to determine the genesis of the drifts of the area.

Richter (1936) confirmed earlier beliefs that most stones contained in till have their long axes parallel to the direction of ice-flow. Holmes (1941) added that some stones (depending on their size and shape) can be orientated transverse to the direction of ice-flow, and showed that the most "ideal" orientation diagrams are obtained in lodgement till in areas of low relief where solifluxion and cryoturbation have not disturbed the initial till fabric. In drumlins, for example, both Hoppe (1951) and Wright (1957) have demonstrated that stone orientation reliably follows the direction of ice-movement and the axis of the drumlin ridge. Again, Hoppe (1953) has produced "ideal" orientation diagrams for ground moraine adjacent to active Icelandic glaciers (Fig. 24B).

However, it has been revealed on many occasions that the long-axis orientation of pebbles need not always parallel the direction of regional ice-movement. Galloway (1956) found that stones in englacial moraine in Lyngsdalen, North Norway, had their long axes parallel to ice-movement, but that stones in lateral moraine were orientated transverse to the ridge crest (Fig. 24D). In terminal moraine stones were orientated parallel with the crest. Portmann (1960) added to these findings by stating that crevassing could induce orientation of englacial stones perpendicular to the crevasse. Hoppe (1952) showed that in regions of hummocky moraine preferred orientations are rarely "ideal", but are usually transverse to individual morainic crests and parallel to the direction of maximum surface slope. (Fig. 24C). Dumped dead-ice ablation or englacial moraine may field fabrics which are completely chaotic (Fig. 24A), and in 1953 Hoppe concluded that diagrams from parallel morainic ridges, shear-plane moraines, and crevasse fillings are likely to be unreliable.

It seems, on the basis of this evidence, that interpretations based on fabric diagrams of several types may lead to erroneous conclusions concerning the direction of regional ice-movement.

It is important that post-depositional modification of till should be recognised as such, for it is often considerable. Rudberg (1962) has shown that solifluxion can be severe in the surface layers of a till sheet, and suggests that even at a depth of several feet the till fabric may have been disturbed. Watson (1964) has described masses of till on the Cardiganshire coast which are completely soliflucted. Lundquist (1949) and Harrison (1957b) have established criteria for the recognition of head and soliflucted till on the basis of orientation diagrams; preferred orientation of pebbles is generally parallel with the maximum surface slope or else with the slope of the underlying bedrock.

Field Analysis Technique. Wadell (1936) and Krumbein (1939) have evolved complex methods for the marking and collection of pebbles from the till face and for analysis in the laboratory. Karlstrom (1952) and Harrison (1957a,b) have added further refinement by cutting blocks of till in the field and extracting pebbles from the re-orientated block in the laboratory. Harrison's method requires about six hours per sample. In contrast, simple field analysis, in which pebbles are extracted from the till face and orientated by means of a hand-held compass, has been employed by MacClintock (1959) in Canada, and West and Donner (1956) and Norris (1962) in England. MacClintock considers that the loss of accuracy in his field analysis is negligible, so for rapid field measurements the refinements of American workers seem unnecessary.

In Dewisland I undertook preferred orientation studies at the random grid points used also for stone-counts. Visual selection of suitable sites, as used by West and Donner (1956), was thought unsuitable in Pembrokeshire because of the scarcity of flat areas of thick till; it seemed that random sampling might yield a truer indication of the processes responsible for the formation of the drift cover. In addition, sample studies were also made inland where good exposures were available, and on the coast at all critical drift sections.

At inland sites, pits c. 1 ft. square were dug to a depth of 2' 6" and the orientation of the first 50 undisturbed stones of size 1" - 3" from the bottom of the pit was recorded.[1] Orientations were obtained by loosening each pebble until its long-axis orientation was visible for measurement with a hand-held prismatic compass. Frost-heaving and rootlet disturbance may have been effective at this depth, but it was often found that deeper holes

1. Holmes (1941) stated that 50 stones from till are sufficient to determine statistically the direction of ice-movement.

encountered the shattered bed-rock zone; a standard sampling depth of 2' 6" was therefore adopted. On coastal sections one square foot of the drift face was cleaned and the orientation of the first 50 undisturbed stones recorded.

In this study I measured the orientation of rod-shaped pebbles only, and rejected all pebbles whose long-axes were difficult to estimate visually. Harrison (1957b) has shown that disc- and blade-shaped pebbles yield a more reliable preferred orientation, but other writers (e.g. Norris, 1962) have found rod-shaped pebbles quite reliable; furthermore, they are easy to recognise in the field and facilitate the rapid recording of orientation.

Orientations were read in the direction of long-axis dip, and were recorded to the nearest 5^{o}. They were then plotted on a duplicated form (Fig. 25) which enabled rapid assessment of the preferred orientation and dip to be made. Before each field measurement was made, the estimated direction of maximum surface slope was recorded as a 30^{o} sector, here called the "Sludge Sector". From each completed form, therefore, it was quickly apparent whether the deposit had been subjected to solifluxion since deposition. For plotting on the orientation diagram, stones were grouped into 10^{o} categories and the percentage in each category plotted on each side of the diagram. The 30° sector with the greatest percentage of pebbles was then plotted as the "dominant 30° sector", which effectively shows the dominant dip direction of pebbles in the drift fabric. In many studies (e.g. West and Donner, 1956; Norris, 1962; Stevens, 1959) orientation diagrams have not shown either the dominant dip direction or the sludge sector; however, both sectors are portrayed on all the diagrams in this study (Fig. 26).

Some workers (e.g. Harrison, 1957a; Baumont, personal communication, 1965) have used the Chi-square test to assess mean stone orientation and the "strength" of the diagram. However, Galloway (1958) and Watson (1964) have used a 30° sector to illustrate satisfactorily the strength of diagrams; following the simple method of these authors, the strength of diagrams in this study is expressed as the percentage of pebbles in the dominant 30° sector.

A note on the use of preferred orientation diagrams for the recognition of head.

It has been noted in Chapter 3 (A) that head deposits are generally characterised by strong preferred orientation maxima in the direction of maximum surface slope. Watson

(1964) found that in Morfa Bychan he could distinguish certain solifluxion deposits on the basis of the percentage of pebbles orientated in the dominant 30° sector; for example, he found that true head generally had 85% to 75% of its pebbles in the dominant 30° sector, while soliflucted till had only 60% to 75% in the sector and a blue head 44% to 60%.

From a collection of preferred orientation diagrams it is quickly apparent that there are several distinct diagram types (Fig. 27), as noted by Holmes in 1941. With this in mind some examination of head diagrams was made in Pembrokeshire to assess whether there is a "typical" head diagram. In Fig. 28 preferred orientation diagrams for twelve head deposits and three soliflucted till deposits have their orientations standardised for comparison. The strength of the diagrams varies considerably; for example. sample D has only 28% of pebbles orientated in the dominant 30° sector, compared with 56% in sample C.

Holmes (1941) attempted to construct a "composite" orientation diagram for till from ten individual diagrams, and found that the resultant diagram was of great use for defining certain characteristics of till diagrams. Accordingly, I attempted to construct a similar composite diagram from fifteen individual diagrams for head.

The mean preferred orientation diagram on Fig. 28 proved to have 37.8% of its pebbles in the dominant 30° sector; it is also characterised by its lack of a strong transverse element and the presence of several minor oblique peaks. It is an inconclusive diagram, however, and nothing new has emerged from its construction. From the field diagrams it appears possible that oblique peaks may be more characteristic than transverse peaks in head diagrams, although the range of diagram types is very wide. Until head studies have progressed considerably, and a detailed statistical study is made of the variable factors in head formation, it would be dangerous to claim that diagrams of a certain type in Pembrokeshire are characteristic of head. In the future it may be possible to relate diagram type to such factors as aspect, type of periglacial climatic regime, and angle of slope.

Chapter 3 (F)

THE ANALYSIS OF PEBBLE-ROUNDNESS.

It has long been recognised that the degree of roundness[1] of detrital particles is dependent to a large extent upon their mode of transport; for example, beach pebbles are generally well-rounded, river pebbles tend to be moderately rounded, and head fragments are almost invariably angular.

In any deposit, however, there is a certain range of variation in the roundness of particles, and it would be unusual to find no angular fragments on a beach or no rounded fragments in head. Clearly, the mode of transport is not the only factor which influences the degree of roundness. Some of the important factors which affect pebble-roundness are as follows:

(1) Rock Type. The resistance of pebbles of a certain rock-type to erosion during transport varies according to the mode of transport. For example, limestone pebbles may be resistant to rounding in a glacier, whereas Tricart (1959) has emphasised that they are rather susceptible to diminution

---

1. Pebble-roundness is quite distinct from pebble-sphericity. "Roundness" is concerned with the degree of sharpness on the corners and edges of a pebble, while sphericity is concerned with the degree of approximation to a sphere. For a further discussion of terminology see Wadell, 1932.

in a fluviatile environment, i.e. where chemical action may be an essential attribute of the transporting agency. Tricart and Schaeffer (1950) have said that chalk seldom forms pebbles except under arid or semi-arid conditions.

Again, if pebbles of quartzite and micaceous sandstone are transported by ice from adjacent outcrops and deposited in moraine two miles away, it may be found that the quartzite pebble is still angular, while the micaceous sandstone pebble may be rounded. The resistance of quartzite pebbles in a fluviatile environment has been emphasised by Kuenen (1958).

A factor which is closely associated with rock type is rock structure, which can have a significant effect upon rounding (Krumbein and Pettijohn, 1938). For example, in Pembrokeshire shale fragments frequently break down into flattened pebbles under transport; breakage along small bedding-planes is so frequent that an angularity is imparted to the pebble which counteracts the rounding process.

It is unsatisfactory to assign the resistance of pebbles to rock "hardness", since rocks which are "hard" and resistant to abrasion in one environment may prove to be susceptible to abrasion in another.

(2) <u>Form of the original fragment.</u> Pebbles which are transported and eroded under any agency owe their degree of round-

ness in part to their original shape when removed from the bedrock. This principle may be well illustrated from Haytor in Devon, where the granites weather sub-aerially in different ways; the coarse-grained granite produces rounded "core-stones", whereas angular blocks are derived from the fine-grained granite at the base of the tor. Clearly, if these blocks are incorporated into solifluxion deposits they will display rather different original forms.

One cannot be sure that pebble-roundness as discerned in the field is not an "inherited" characteristic, for the pebble may have been transported and deposited several times by different agencies (Tricart and Schaeffer, 1950). Fluvio-glacial pebbles may owe a large proportion of their rounding to the action of ice, and Tricart (1959) has stressed that even river pebbles are difficult to analyse in view of the fact that they may have been rounded and deposited initially under a very different climatic regime than that prevailing at present. In North Pembrokeshire, if secondary deposition is not recognised as such it could lead to grave misinterpretations. Near St. David's well-rounded and spherical pebbles of reddish quartz may be found in glacial deposits; these owe their form not to glacial erosion but to erosion prior to their initial deposition in the Cambrian basal conglomerate of the area.

(3) Size of particle. Although the influence of stone-size on the efficiency of rounding is doubted by some, in the field it is often noticeable that in one deposit there is a close correlation between size and roundness. In morainic debris in Kaldalon, North-West Iceland, large boulders of basalt are often well-rounded, while smaller basalt stones may retain their angularity. A similar relationship between size and roundness has been noticed in moraines in the Cairngorm Mountains of Scotland by D.E. Sugden (personal communication), and by Godard (1961) in Morvern.

Tricart (1959) has shown from the limestone Causses of France that different rock-types attain their optimum resistance to erosion in a certain environment in different size-ranges; while limestone pebbles of 1 - 4 cm. survive best, quartz tends to survive most effectively in the silt range. Godard (1961) has also shown from Scotland that granite pebbles are generally smaller than granidiorite pebbles in moraine. Thus there appears to be a close interplay between rock type and particle size.

(4) Distance of Transport. The marked angularity of head fragments is in part a reflection of the negligible distance they have travelled, for they may move no more than ten yards from the bedrock outcrop before coming to rest. In

contrast beach pebbles may have been moved thousands of miles on a beach by the constant attentions of waves and tides. Thus the distance of transport is closely associated with the process involved.

However, there are often gradations in roundness within one extensive deposit. Holmes (1960) has shown that in a till sheet in Central New York pebbles from one outcrop decrease markedly in angularity with distance from the outcrop. Galloway (1956) noted that the evolution of pebble roundness in an area of glacial outwash bears a direct relationship to distance from the glacier snout; he considered that this relationship is so constant that roundness analyses on terrace material can enable estimations to be made of the position of the ice-front at the time of terrace formation.

(5) Variability of Process. There is a temptation to assume that such phrases as "transport by ice" imply a relative uniformity of process. However, if a pebble is transported within a morainic mass it may retain its initial angularity for many miles during transport (Tricart and Schaeffer, 1950); alternatively, if part of the journey is spent at the base of the glacier or in a sub-glacial stream, the pebble may be rounded quickly. Similarly Tricart and Schaeffer have shown that there is a great

variability in hydrodynamic conditions in a temperate fluvial environment, making generalisations about fluvial processes extremely difficult.

(6) Availability of fines. Tricart and Schaeffer have suggested that in an environment where there is an abundance of fine material, particles will tend to be abraded and rounded at a faster rate than in environments where fines are lacking.

(7) Climatic Conditions. In some environments "external" climatic factors may influence pebble roundness. For example, in a periglacial fluvial deposit pebbles which are exposed above water during periods of seasonal low flow may be shattered by frost processes.

From the above summary it may be suggested that a sample of pebbles from one deposit may display a large range of roundness and shape characteristics. So great can this range of variation be that Gregory (1915) was led to deny that reliable criteria for distinguishing different deposits could ever be established. Certainly, many authors may have over-emphasised the reliability of roundness analyses, and Holmes (1960) has given a warning in showing that a long-held view on the "typical" wedge-form of glacial pebbles is incorrect; in reality, it may be that ovoid and rounded pebbles are the end-products of glacial transport.

While one must have some reservations, a great deal of work has shown that roundness is related most closely to the transportation process[1], and many writers have concluded that statistical studies of pebble-roundness should indicate clearly whether pebbles have been transported by water, ice, periglacial solifluxion, wave-action, or other processes (e.g. Tricart and Schaeffer, 1950). For example, Alimen (1958) has shown that alluvial pebbles in the Sahara are not as well-rounded as fluvial pebbles in humid areas, and Cailleux (1945) noted that beach pebbles show a greater degree of roundness than fluvial pebbles. Holmes (1941) has illustrated the differences in roundness between glacial pebbles and river pebbles, and Tricart and Schaeffer, in the context of a study of many types of deposit, have shown that the degree of angularity on pebbles from a periglacial alluvial environment is higher than on fluvial pebbles. From these and many other examples in the literature it appears that roundness analysis of pebbles can be a reliable method for distinguishing between deposits.

---

1. For a summary of work prior to 1938 see Krumbein and Pettijohn (1938); later references are given in Reichelt (1961).

Method of Analysis.

Many attempts have been made to express the roundness of pebbles in meaningful terms, for such qualitative expressions as "angular" and "well-rounded" are vague. Wentworth (1919, 1922a, 1922b) may have been the first worker to develop a quantitative system of shape analysis, which incorporated studies of roundness and flatness. After further studies on roundness by, for example, Lamar (1927), Pentland (1927), Cox (1927) and Tester (1931), Wadell (1932) added refinement by differentiating between "shape" and "roundness" of pebbles[1], and devising a simple quantitative method of measurement. After Wadell there have been many works on roundness analysis, the most widely-accepted scheme being that of Cailleux (1945, 1947).

According to the method of Cailleux, simple measurements of the dimensions of a pebble can enable three indices to be calculated: "les indices d'emoussee, d'aplatissement, et de dissymetrie". If all three indices are calculated for a sample of pebbles from a deposit, it is possible to describe accurately in quantitative terms the characteristics of the pebbles and to evaluate their history. Many workers in

---

1. The degree of roundness is here considered as synonymous with the degree of smoothness or abrasion or the "indice d'emoussee" of Cailleux.

Europe have used the method with success[1], but since it involves the accurate measurement of pebble axes and curvatures it is often too complex for rapid field sampling.

In 1961 Reichelt suggested that the roundness of pebbles could be determined visually by comparison with a set of four major standards. Similar visual analysis had been employed by Trowbridge and Mortimore (1925), and "classes of roundness" had been used in work by Krumbein (1941), Plumley (1948), and Pettijohn (1949). However, Reichelt considered that four major roundness categories (as in Fig. 29) were sufficient for field analysis, in contrast to the five categories previously used. He proposed that pebbles from any sample from a deposit could be grouped quickly into the four categories and a histogram constructed which would indicate the mode of transport of the pebbles.

Reichelt realised that the major weakness in this method of roundness analysis was its subjectivity, but in a series of statistical tests he found that the grouping of pebbles differed little from one person to another; furthermore, the

---

1. Among recent works see Boye (1960), who gives a good summary of the method and its applications; also Tricart (1959), Galloway (1956), Cailleux (1955) and Alimen (1958).

average error which appeared in the course of analysis was only ± 2%, and thus negligible. In a detailed comparison of his method with that of Cailleux he found that there was a very close agreement, and that his simple categories were closely related to groups of categories plotted from the "indice d'emoussee". The total error in Reichelt's method (made up of the subjective error, the error from counting only a small sample of pebbles, and the error derived from differences in gravel composition) is proved to be less than ± 5%.

Since the publication of Reichelt's work the method has been used by Magerud (1963) to distinguish between morainic and fluvio-glacial material in the Gudbrandsdal, Norway, and by Sollid (1964) to identify fluvio-glacial material which was incorporated in moraine. Price (1964) has also used a simple four-fold scheme of roundness for stone-counts to distinguish between till and outwash gravels at the Casement Glacier, Alaska.

The inadequacy of the method for distinguishing clearly between fluvio-glacial and fluvial deposits was admitted by Reichelt, and has been emphasised by the inconclusive nature of histograms constructed from stone-counts on the upper terraces of the Thames (Miss S. Scott, personal communication). However, this deficiency appears to be inherent even in the other methods of roundness analysis, and Professor Cailleux has said that he considers the Reichelt method quite reliable (personal communication, 1964).

The Field Method.

Roundness analyses were undertaken in North Pembrokeshire using the simple method of Reichelt. Samples of 50 pebbles[1] were collected from one square foot on the face of drift exposures or from inland pits one foot square and c. 2 ft. deep. The pebbles counted were generally in the size-range ½" - 2", and incorporated the first 50 pebbles encountered, regardless of rock-type. Once collected, the pebbles were compared visually with the categories in Reichelt's diagram (Fig. 29) and grouped into these categories.

There are undoubted dangers in using samples consisting of many rock-types for roundness analysis, for few of the factors which can influence roundness will be eliminated. However, if samples consisting entirely of one rock-type

---

1. Tricart and Schaeffer (1950) used samples of 150 pebbles, and considered this number too small for accurate work. Reichelt, however, suggests that the error in using 50 pebbles is small (not greater than ± 5%).

were to be used in Pembrokeshire, several difficulties would be encountered:

(a) It is often difficult to find 50 pebbles of a pre-determined rock-type at each sampling-site. If only the commonest pebbles at each site were to be used, they would often prove to be angular bedrock fragments which would reveal nothing of the mode of transport of the bulk of the drift.

(b) Holmes and Galloway have suggested that rounding of pebbles increases with distance from the rock outcrop; it follows that if pebbles are taken of one rock-type only in an extensive till-sheet, the resultant histograms may be characteristic of till close to the rock-source, but characteristic of a fluvial deposit twenty miles down-glacier.[1]

(c) It is not always easy to distinguish pebbles from a specific outcrop. For example, if one decides to use only Ordovician igneous pebbles for roundness analyses in Pembrokeshire, one may be analysing pebbles from widely-separated outcrops.

Since most drift deposits contain assemblages of pebbles

---

1. There appears to be some disagreement on this point, for Tricart and Schaeffer (1950) and Reichelt (1961) have found that "optimum roundness values" are attained quickly in any environment, and are approximately maintained regardless of the distance of transport.

from different sources and which have been transported for varying distances and varying lengths of time, it seems that a more representative picture of overall roundness characteristics will be gained if entirely random samples of 50 pebbles are analysed. In the results obtained there will inevitably be variations which may be related to the characteristics of the dominant rock-type and to other factors, but as Tricart and Schaeffer proposed, the overall roundness characteristics of a sample are determined above all by the transporting process, so that the variation will remain within narrow limits.

The Use of Criteria.

The histograms constructed by Reichelt on the basis of his roundness analyses are shown on Fig. 30. It can be seen that there is a major distinction between the diagram-types for solifluxion material (A) and river-pebbles (E), while the diagrams for till (B and C) are themselves characteristic. From information in Price (1964) two mean histograms have been constructed for till and outwash gravel deposits near the Casement Glacier, Alaska (Fig. 31); both histograms bear a close resemblance to the related diagrams of Reichelt.

Before basing detailed field interpretations upon histograms constructed by the Reichelt method, I undertook an extensive programme of field sampling in order to construct diagram "types" for North Pembrokeshire, and to test the reliability of counts which included different pebble-types. Twenty samples were analysed from outcrops of head, twenty from non-calcareous till, and twenty from fluvio-glacial outwash. Ten further stone-counts were made on exposures of -calcareous till, which is encountered less frequently in the field. From these samples (listed in Appendix VI) "mean" histograms for North Pembrokeshire were constructed (Fig. 32). Each histogram is based upon the average percentage of pebbles in each roundness category, although the highest and lowest percentages recorded for individual samples are also plotted. The histograms for head, till and outwash gravels are rather similar to those of Reichelt, and they compare well with the histograms for Casement Glacier.

The major characteristics of each histogram appear to be as follows:

1. <u>Head.</u> Most of the pebbles (58.3%) are angular, while there are only 3% in the rounded categories. None of Reichelt's samples had less than 70% angular pebbles, but the correlation of the diagrams is still close. The rather high number of pebbles in the sub-angular category in Pembrokeshire (38.7%) is in part the result of the lack

of resistance of the Ordovician shale pebbles which made up the bulk of many samples; the relatively high percentage of rounded pebbles (up to 16% in one sample) derives from the fact that most of the head deposits of North Pembrokeshire contain some erratics.

2. Till. The two histograms for till are characterised by a peak in the sub-angular category, with moderate percentages in both the angular and rounded categories. Both histograms have some well-rounded pebbles. These characteristics appear to accord well with the conclusions of Tricart and Schaeffer concerning moraine. The calcareous till histogram (C) has a higher percentage (29% against 18.5%) of rounded pebbles than the non-calcareous till, and a correspondingly lower percentage (16.5% against 27%) of angular pebbles; these features may be diagnostic, but in view of the smaller number of samples on which the calcareous till histogram is based, they must be used with caution.

3. Outwash Sands and Gravels. The histogram is characterised by rather low percentages of angular and well-rounded pebbles, with an approximate equality of the percentages in the sub-angular and rounded categories. The percentage of angular pebbles is higher than that in the other diagrams for outwash, but may be explained by the ease with which

shale fragments in the Pembrokeshire outwash appear to have been broken in transport.

On the basis of these histograms it may be concluded that the Reichelt method of roundness analysis appears to be useful for drift deposits in Pembrokeshire, and there is a reasonable chance that the diagrams produced from individual drift horizons may be diagnostic, to some extent, of the mode of transport and deposition. In spite of the errors involved in analysing the roundness of pebbles of different rock-types in each sample, the results of the experiment in histogram construction are satisfactory. Many histograms are analysed in the course of this thesis, and are generally compared with the mean histograms for North Pembrokeshire, rather than with those of Reichelt.

PART II

Chapter 4.

The use of Marine Mollusca in Drift Interpretation.

A. Faunal analysis of derived marine mollusca in outwash and till.

B. Radio-carbon dating of Organic Material from Drifts.

Chapter 4 (A).

FAUNAL ANALYSIS OF DERIVED MARINE MOLLUSCA IN OUTWASH AND TILL.

"...a faunal assemblage is not quite the same as a fossil population. A variety of causes operate which may result in the addition of exotic elements to an existing population. The result may be confusing."

A.E.M. Nairn, introduction to Chapter 12, "Palaeontology and Climate", in "Problems in Palaeontology", 1964. P. 581.

The potential of fossil marine mollusc faunas of Pleistocene age for the recognition and tentative dating of raised marine and other deposits in Britain has long been known. In West Wales the subdivision of the Patella and Neritoides beaches[1] by T.N. George (1932) was a much-discussed work, but in spite of the development of the study of marine mollusca in the context of Pleistocene studies by D.F.W. Baden-Powell, this line of research has been sadly neglected in recent years (West, 1963). It is given only passing reference in both Zeuner (1959) and Charlesworth (1957); a surprising fact in view of the relative ease with which marine molluscs can be identified in comparison with freshwater and land mollusca (Sparks, 1961) and foraminifera (Funnell, 1961).

---

1. So called after the dominant shell constituents of the beaches.

It is now considered possible to recognise faunas as representative of certain interglacial phases on the basis of the altitude at which the fossils are discovered (Zeuner, 1959, P. 307), and the number of extinct, "warm" and "cold" species represented (Baden-Powell, 1955). Under certain conditions, the faunal community of a raised beach deposit may be expressed as a "climatic equivalent" of a present-day community elsewhere (Baden-Powell, 1927), although care must be taken that the fauna does represent one community (Chatwin, in George, 1932). There is a danger that a so-called "community" in a raised beach may consist of easily-transported valves thrown up by wave-action, or else of valves re-deposited by solifluxion or stream-action (Sugden and John, 1965); in none of these cases would one be justified in calling a raised beach fauna a community. Craig (1964) has stressed that even in a comparatively undisturbed marine environment, and especially in estuarine conditions, there may be large-scale mixing of valves after the death of the inhabitant animals; a preserved fossil fauna, therefore, may be made up of valves from several different communities, unless it can be proved that all the valves are *in situ*. Critical stratigraphy has to be employed to indicate the reliability of all conclusions (Baden-Powell, 1928).

Even greater difficulties are experienced in the interpretation of faunas found in till or glacial outwash:

1) Glacial deposits cannot contain faunas truly representative of preceding interglacial conditions. Any shell assemblage in a pro-glacial area will tend to contain mixed warm and cold species as a result of deteriorating marine conditions as the glacier advanced (Fig. 33), but in glacial deposits a further complication results from the fact that a glacier advancing over an old sea-floor (as in the Irish Sea Basin) is capable of mixing faunas dredged up from innumerable localities with different depth, salinity, temperature, and bottom conditions.[1] A derived shell assemblage in till or outwash, therefore, may include faunas originating in localities hundreds of miles apart and differing in age by many thousands of years.

2) Gravel remnants at a particular altitude with a particular fauna could be mistakenly fitted into a preconceived system of sea-levels and faunas. For example, the Wexford Manurial gravels were thought by Baden-Powell (1955) on the basis of their fauna to be marine beds equivalent in age with the Tyrrhenian

---

1. For a discussion of the factors influencing the distribution of present-day shell communities in a typical sub-arctic environment see Ockelmann, 1958.

beds of the Mediterranean; it now seems possible that the gravels are glacial outwash (Mitchell, 1962) with a mixed fauna of derived shells, including some Crag fossils (McMillan, 1964).

3) The frequency of a certain mollusc species in a glacial deposit may represent not so much its abundance in immediate interglacial times as its resistance to comminution during transport in the glacier. Therefore fragile shells such as *Portlandia artica* which may not be represented in a shell assemblage may have been abundant in the interglacial sea. On the other hand strong, compact gasteropods such as *Nucella lapillus* and *Littorina littorea* may remain unbroken after prolonged glacier transport.

In spite of these difficulties faunal analysis may yield valuable results if assemblages are considered strictly in the context of critical stratigraphic studies. Great errors can be made, for example, if a terrace of glacial outwash is mistakenly interpreted as a raised beach. The absence of extinct species in an assemblage may be tentatively accepted as an indication of the deposit's recent age; and in Pembrokeshire the presence of "warm" species in a derived assemblage in glacial deposits probably indicates that interglacial warm conditions extended into Cardigan Bay at some time preceding glaciation.

With these points in mind collections of shell fragments have been made from till and glacial outwash wherever possible, so that some attempt could be made to establish the age of the drift on the basis of a derived fauna dating from the preceding interglacial period or periods. Shell identifications have been made with the very kind advice and help of Mr. D.F.W. Baden-Powell. For shells which occur in Pembrokeshire waters at the present day the specific names recommended by Bassindale and Barrett (1957) are used. For other species the specific names used are those of Winckworth (1932-3). Jope (1960) has estimated percentages for species found in different horizons at Ringneill Quay, Ireland, and Jehu (1904) recorded species as "rare", "abundant", or "common" in sands and gravels at Manorowen. However, in view of the dangers of making such estimates in till and outwash, analysis in this thesis has been based solely on the record of species for a locality, and not upon estimates of relative abundance.

Chapter 4 (B).

RADIO-CARBON DATING OF ORGANIC MATERIAL FROM DRIFTS.

The dating of late-glacial and post-glacial events by the C^{14} method has now received widespread acceptance. It has been used for the construction of absolute chronologies in, for example, North America (Flint and Deevey, 1951; Broecker, Ewing and Heezen, 1960), the British Isles (Godwin, 1960), and Denmark and the Netherlands (Andersen et al, 1960; Zagwijin, 1961). It has helped to elucidate post-glacial movements of sea-level (Godwin, Suggate and Willis, 1958; Ewing and Donn, 1961), and has added accuracy in the context of wider-scale investigations of chronology by Emiliani (1955) and Kulp (1961). There is a useful short summary of C^{14} dates for Europe by Flint (1957), and British chronologies are suggested on the basis of C^{14} dates by Coope, Shotton and Strachan (1961) and West (1963). Sissons (1964) summarises the C^{14} dates for the Weichselian period in Britain, and emphasises the apparent complexity of the chronology.

The radio-carbon dating system was developed by W.F. Libby in the United States, using the assumption that all living organisms contain a minute equilibrium concentration of C^{14}, a radioactive isotope of carbon. This isotope is formed in the atmosphere by the action of cosmic-ray produced neutrons on atmospheric nitrogen; until the 1850's it appears to have maintained a roughly constant level in the biosphere, its rate of production being balanced by its rate of radioactive decay (Callow, 1962). It appears that the equilibrium concentration of C^{14} is maintained even in organisms living in an environment slightly deficient in C^{14}, for example in the sea. Libby calculated that C^{14} atoms decay at such a rate that their concentration in organisms is reduced by half every 5568 $\pm$ 30 years; consequently he thought it possible to measure the residual activity in dead organisms and calculate the time which has elapsed since death. Exhaustive tests on organic objects of known age were carried out, and the coincidence of sample dates with the curve calculated for the half-life of C^{14} proved the reliability of the method (Libby, 1961).

Since 1950 the method has been refined considerably, and a large number of C^{14} dating laboratories are in operation throughout the world. At present there is a practical limit of 40,000 to 50,000 years for the method, although counting systems may shortly be devised which can date events back to 100,000 B.P. (Oeschger, 1963).[1] Already a method of isotopic enrichment has been devised at Groningen to date events back to 70,000 B.P. (Haring et al, 1958). Dating results from each laboratory are reported annually in the Radiocarbon Supplement published by the American Journal of Science.

Short outlines of the radiocarbon dating method are given by Kulp (1963) and Callow (1962), and the standard exhaustive work on the subject is that of Libby (1955). Fergusson (1955) and de Vries and Barendsen (1953) have given technical accounts of the method. Ault (1964) gives a shorter account of the techniques involved in the pre-treatment of samples, the measurement of residual C^{14} in the laboratory, and the calculation of sample age. Johnson (1955) has contributed a general consideration of the significance of C^{14} dating.

There appear to be four basic assumptions on which the C^{14} method of age determination depends:

1. that the rate of C^{14} formation in the atmosphere is constant,
2. that the rate of mixing of C^{14} in the biosphere

---

1. If it proves possible to extend the potassium-argon dating technique into the Early Pleistocene and to about 50,000 B.P., then absolute dating techniques will span the whole of the Pleistocene period.

is rapid relative to the rate of decay,

3. that on the death of an organism no further C14 is added,

4. that the C^{14} present in a dead organism decays at a known and constant rate (Kulp, 1963).

These assumptions have been proved approximately valid by the reliability of most of the dates obtained so far, but some serious dating anomalies have led to much discussion on the effects of sample contamination. It is known that C^{14} atoms of greater or lesser age than the sample may find their way into the sample after its death. "Old" C^{14} may occasionally find its way into a sample, giving it an apparent age in excess of its correct age; but more frequently "new" C^{14} derived from percolating ground-water or humic acid may give the sample too young an age (Godwin and Willis, 1959). Further contamination may result from isotopic exchange of the "dead" C^{14} with environmental C^{14}, or from isotopic fractionation since decay (Olson and Broecker, 1958).

While these sources of error are recognised, it is exceedingly difficult to identify samples which are contaminated. Careful collecting and washing can eliminate possible sources of contamination, and pre-treatment of the test sample to eliminate possibly contaminated fractions is now accepted practice in dating laboratories. Charcoal, in spite of its tendency to absorb humic acids, is considered to be the best dating material; wood and peat have also proved reliable. In these materials possible carbonate contamination can be removed with ease, and their chemical composition allows fractions (cellulose and lignin) to be isolated. Further, their non-ionic nature excludes the possibility of chemical exchange of carbon atoms with their environment. On the other hand it is often difficult to remove modern rootlets from these materials, so that contamination leading to a falsely young age determination is still possible (Callow, 1962).

Shell has proved to be the most practicable dating material from the Pembrokeshire drifts, and it will be worthwhile to consider a little more fully its susceptibility to contamination. Since shell is composed of calcium carbonate, it is liable to be exchanged with bicarbonate carried in ground-water. This will usually result in an age determination which is falsely young, unless the ground-water has assimilated dead carbon. A detailed study of the problems of C^{14} dating of shells has been made by Olsson and Blake (1961). It appears that the same percentage contamination with "modern" carbon will affect a very old sample much more than a younger one. On a sample 100,000 years old a 1% contamination with modern carbon would lead to an apparent age of 37,000 years (Olson and Broecker, 1958), while a sample 22,000 years old would yield an apparent age of 21,000 years if contaminated with 1% modern carbon (Olsson and Blake, 1961). Even a contamination of 0.1% can lead to an apparent age of 51,000 years for a sample which is in reality 57,000 years old. On the other hand contamination with dead carbon leads to smaller errors, and 10% contamination will lead to an error of only 800 years in samples of all ages. For a date to be in error by 5,000 years the sample would have to be contaminated with about 50% dead carbon (Olsson and Blake, 1961).

Accepted laboratory procedure is now able to minimise the effects of contamination in shell samples. After initial scraping and cleaning, the outer parts (those most likely to be contaminated by ground-water) are removed by leaching in hydrochloric acid. The inner part of the shells is divided into two fractions which are separated by further leaching; an age determination is carried out on each fraction. If the ages of the fractions agree within small limits of error it can be assumed that the cores of the shells have not been contaminated.

The presence of pitting on shell surfaces may be an indication of contamination (Olsson and Blake, 1961), and thin shells will be more liable to contamination than thick ones. Kulp (1963) emphasises that samples with ages in excess of four half-lives (23,000 years) should be subject to question until the absence of contamination has been demonstrated, although appreciable contamination (several per cent) of buried samples appears to be the exception and not the rule (Olsson and Broecker, 1958). Furthermore, Libby (1955) stated that "shells which appear well preserved physically have a good chance of being authentic." (p. 44), and large numbers of dates back to 35,000 B.P. from shells in Arctic raised beaches and till appear to be quite reliable (Blake, 1961; 1964).

Four samples of organic material from glacial deposits in Pembrokeshire have been submitted for C^{14} dating. Two samples of shells from glacial outwash and one wood sample from till, have been dated at the National Physical Laboratory, and one shell sample from till dated at Isotopes Inc.; the dating methods used at these laboratories are outlined by Callow (1962), Callow, Baker and Pritchard (1963), and Ault (1964). For each age determination the C^{14} half-life used was 5,569 $\pm$ 40 years, although new work indicates that a value about 5,730 $\pm$ 40 years should now be used (Godwin, 1962). The reliability of the dates obtained is discussed in Chapter 15, when they are used in a tentative attempt to reconstruct an absolute chronology for some of the Late Pleistocene events in West Wales.

PART III

THE INTERPRETATION AND CORRELATION OF SELECTED COASTAL SECTIONS.

In this part of the thesis the most useful coastal drift sections in North Pembrokeshire and adjacent areas are analysed in some detail. The exposures examined are located on Fig. 34. The stratigraphy of the larger exposures is described, and attempts are made to answer specific stratigraphic problems with the aid of some of the techniques described in Part II. Smaller and less clearly-exposed sections (e.g. Pen Dal-aderyn and Parrog) are described in less detail, but for every exposure an attempt is made to establish the sequence of events portrayed through the drift stratigraphy.

In Chapter 5, three groups of exposures are examined:

(a) The North Pembrokeshire coast,

(b) The west coast of Dewisland,

and (c) The south coast of Dewisland.

At the end of each group an attempt is made to summarise the drift succession and sequence of events apparently represented on that particular stretch of coast.

In Chapter 6 two groups of sections are described from beyond the confines of North Pembrokeshire:

(a) The coast of South-west Pembrokeshire,

and (b) The coast of southern Cardiganshire.

This has been done in order to establish whether there is any major difference in drift stratigraphy between North Pembrokeshire and adjoining areas. Not least, comparison with areas well within and well beyond the zone of Charlesworth's "South Wales End-moraine" may establish whether there are any features of drift stratigraphy to support the hypothesis.

In Chapter 7 an attempt is made to answer some of the questions posed at the beginning of the thesis, and the evidence presented in Chapters 5 and 6 is brought together and used for the construction of a correlation table of discernible Pleistocene events in West Wales.

Note.

In the following chapters many coastal exposures are described with the help of sketched sections. The symbols used in these sketches have been standardised, and a key to their interpretation is given in Fig. 35. For convenience, this key is folded into the thesis in such a way that it can be opened and consulted alongside individual sketched sections.

PART III.

The interpretation and Correlation of selected coastal sections.

Chapter 5.

Coastal Sections in North Pembrokeshire.

Chapter 5 (A)

The North Coast of Pembrokeshire.

A1. The drift succession exposed in the cliffs at Aber-mawr.

A2. Features on Pen Deudraeth Headland, Aber-mawr.

A3. The drift exposures in the Afon Nevern estuary.

Summary of Conclusions.

Chapter 5 (A1)

THE DRIFT SUCCESSION EXPOSED IN THE CLIFFS AT ABER-MAWR.

The Northern Drift Cliff (Fig. 36).

On the north side of Aber-mawr beach, where the path descends from the cliff-top, a complex and valuable section is clearly displayed (Fig. 37). The drift cliff is some 40 ft high at its northern end, falling towards the south-west to c. 5 ft in height where the footpath reaches the beach. The whole exposure is being actively eroded and undercut by the sea, so that the face is always fresh; consequently the boundaries between individual horizons are clearly displayed. The section has been mentioned in the literature by Jehu (1904) and Synge (1963). After numerous examinations of the section, the following succession has been recognised:

Bedrock. At the northern end of the drift cliff the contact between bedrock and the overlying drift deposits is revealed. Bedrock consists of thin beds of Upper Cambrian Lingula Flags, which dip northwards. They are folded and contorted and are overlain by massive quartzites, possibly of the Ordovician Arenig series (Cox, 1930). Although the contact with the overlying drift is generally sharp and the dip of the rock surface regular, there is evidence in places that the beds have been shattered and bent downhill by head movement. The bedrock surface appears to have been eroded and smoothed prior to the formation of the lowest head. Some of the smoothed slabs are scratched, but the freshness of these scratches appears to indicate that they have been formed by loose angular blocks which have slipped downslope as a result of present-day processes.

1. The Lowest Shale Head. This deposit, which attains a maximum visible thickness of c. 9 ft, is a well-stratified head with some frost-heave structures, consisting largely of small flakes of Upper Cambrian grey shale derived from the bedrock outcrop. In the flaky matrix are some angular slabs up to 6" in diameter, and the whole deposit displays good pseudo-stratification. There are some erratics in the head (namely small pieces of Cretaceous flint, rounded pebbles of vein quartz, and some pebbles of igneous rock), but it is generally characterised by a high proportion of local material and a virtual absence of rounded fragments.

The bedding in this head is clearly truncated by an erosional and weathering contact. (Plate 9B). The upper 6" of the weathered horizon is a buff-reddish stained head in a sticky and silty matrix of small flakes. Beneath this, 6" of olive-green head passes down to a band of bright orange-staining 4" - 8" thick. The main stratigraphic break appears to occur at the base of the green band, which becomes a 2" wedge of bright grey clay at the lowest part of the exposure. This is possibly a washing deposit derived from the weathered layer above.

2. The Lower Blocky Head. Above the weathering break is another layer of stratified head, which attains a maximum thickness of c. 5 ft. It is a blocky deposit with disordered pseudo-stratification. It consists largely of mixed shale and quartzite fragments, but has a much higher proportion of foreign rounded pebbles than the lowest head.

3. The Flaky Gravels. The lower blocky head grades upwards into 12 ft. of flaky gravels which dip at c. 8° towards the south-west. The deposit makes up the bulk of the drift-cliff at its northern end (Plate 9A), where it is being actively eroded by the sea at the back of the storm-beach. The gravels are somewhat disturbed near their base, where they contain much angular blocky material, but upwards this material disappears as pseudo-stratification becomes well-marked. The bulk of the gravel consists of angular local shale flakes, but there are great numbers of small well-rounded foreign pebbles present. Most pebbles and shale fragments are under ½" diameter, although some embedded quartzite stones are over 6" in diameter (Plate 5).

Occasional bands consisting almost exclusively of shale flakes are present, and some layers have a much higher proportion of foreign pebbles than others.

At the top of the horizon is a distinctive band of flaky gravel 12" thick where the fragments are of unusually uniform size; hardly any stones in this layer are over ½" diameter, and most are ¼" - ½". It may be this layer, and perhaps the heads above and below it, which Jehu (1904) described as showing "some tendency to a rough kind of bedding, and ...... full of small flakes and little stones, more or less pebbly." (P. 75). George's (1933) Plate xv, photo 3, shows a deposit from Kilboidy which may be similar, and another such deposit is described by Synge (1964) from Porth Neigwl, Lleyn. In Pembrokeshire flaky bedded gravels have also been seen at West Dale and Whitesand North.

4. <u>The Middle Blocky Head.</u> Through a somewhat irregular junction the flaky gravels grade upwards into c. 5 ft. of blocky head. Above the flaky gravels the deposit consists of chaotically-arranged sub-angular slabs of local quartzite up to 12" in diameter embedded in a rich sandy and shaly matrix. The head displays good pseudo-stratification, and its stones project in spectacular fashion from the cliff-face. Towards the centre of the drift-cliff inter-bedded patches of blocky shale head appear, and one continuous

layer of this head is again overlain by quartzitic head. (Fig. 38). The southernmost exposure of this head consists of chaotically-slumped angular masses of quartzite in a matrix of shale flakes. In places the matrix is clearly-stratified. Foreign rounded pebbles are again frequent in this deposit.

5. The Massive Purple Irish Sea Till. Overlying the heads is c. 8 ft. of massive till containing numerous fragments of marine mollusca and carbonized wood. The till contains very few stones, although there are occasional well-rounded and striated pebbles up to 4" in diameter. It is tenaceous and plastic, although there are occasional thin lenses of sand and irregularly-bedded bands of silt; a concentration of these thin beds in the upper part of the till exposure gives it a foliated appearance.[1] The till is highly calcareous, although its upper surface is decalcified and weathered to a rich red colour to a depth of 12" - 18"; the lower 9" of the till is weathered (presumably as a result of ground-water percolating upwards from the permeable head below) but is not properly decalcified, and still contains shell fragments. Similar basal weathering of Irish Sea Till is seen at Garryvoe in Ireland. In

---

1. An Irish Sea Till with similar characteristics is seen at Wexford Harbour, Ireland.

places the basal weathered layer is cemented by iron-pan. Among the erratics in this till I have found many pebbles from Ailsa Craig, while Jehu recorded pebbles of Galloway granite, Scottish Silurian grits, Borrowdale volcanics, and Antrim quartz-porphyry.

Excavation revealed that the contact between the weathered till and the overlying deposits is sharp. In contrast, the contact between the lower surface of the till and the underlying head is confused; the basal layer of the till contains a noticeably higher proportion of shale fragments than the till above, and some small blocks of local quartzite are found in the till c. 24" above the junction with head. Interbedding and contortion of the deposits indicates that some head material was caught up and incorporated in the till during deposition, and there are "drag" features in the head which also bear witness to ice-movement (Plate 10).

The bedding in the underlying deposits is truncated by the till, reinforcing the impression that some erosion of the underlying head was achieved by the Irish Sea Ice. (Fig. 38).

6. Fluvio-glacial sands and gravels. The purple till is overlain in the southern part of the section by rich red-brown sands and gravels, which attain a maximum thickness of c. 15

ft. In places there are zones of well-rounded foreign boulders up to 2 ft. in diameter. Lenses of gravels are common, and there are frequent signs of stratification. Several contorted slump features may be observed, with uninterrupted stratification above and below them. (Plate 11). On a minute scale similar contortions and some "flow " features may be observed within sand layers, as if the sands were deposited in a super-saturated state under pressure from above. There are many small iron-pans in the sands and gravels, possibly reflecting a fluctuating water-table during and after deposition.

The contortions in these fluvio-glacial deposits and the sudden and chaotic juxtaposition of fine silts, boulder beds, gravels, and sands gives the impression that they were laid down as ice-contact deposits. This impression is strengthened by the recent exposure of discontinuous patches of weathered Irish Sea Till within the sands and gravels (Fig. 39). The till is stony and gravelly and is severely-gleyed, although in places it is still slightly calcareous. It contains no shell or wood fragments.

7. The Upper Rubble-drift. Capping the cliff-tops to the north and overlying the purple till in the northern part of the section is a deposit of what may best be called rubble-drift. For the most part it consists of angular fragments

of local quartzite in a sandy and gravelly matrix, although in places outwash sands and gravels seem to be interbedded. Jehu (1904) called it "a rubbly clay, full of boulders of all sizes, most of which are angular or sub-angular, and derived from rocks in the locality". (P. 75). He did not differentiate between the purple Irish Sea till and the rubbly deposit above, and considered the whole to be "Upper Boulder-clay". Its maximum thickness is c. 7 ft; it is everywhere very stony, and is chalky brown to rich red in colour. It is nowhere clearly stratified, but stones project downslope from the drift face as in the lower heads. Most of the stones in the rubble-drift are angular or sub-angular local Ordovician quartzites or shales, usually less than 12" in diameter. Rounded and striated foreign erratics are occasionally found, and large boulders up to 4 ft. in diameter occur near the base of the deposit, resting on what may be a glacially-smoothed rock surface. The deposit is strikingly similar to a so-called upper local till at Garryvoe in Ireland and to a thick blocky head at Red Rock, in Co. Dublin (Stephens and Synge, 1958).

8. <u>The Sandy Loam.</u> Capping the drift cliff and also capping local rubbly material along the coast to the north is a fine sandy loam which may be up to 2 ft. thick. It is generally less stony than the rubble-drift below, although

in places it contains small rounded foreign pebbles. Its colour grades from rich red near the surface to chalky brown just above the junction with underlying material. Above the sands and gravels in the southern part of the drift cliff the contact is particularly sharp, and the presence of occasional bands of "lag concentrate" pebbles suggests that some erosion of the underlying deposits took place before deposition. In places the loam has the colour and texture of blown sand, but for the most part it is similar to the loam capping virtually all the clifftop drift deposits of North Pembrokeshire. A similar deposit has been described from the Gower by George (1933) and from West Dale Bay by Groom (1956).

The Southern Drift Cliff.

At the southern side of the bay a smaller and simpler drift section is exposed. (Fig. 40). At its southern end the section is c. 20 ft. high, and although some slumping obscures part of the face it is being actively eroded by the sea. Storms early in 1965 exposed till in this section for the first time since 1961.

The section in January 1965 was as follows:

Bedrock. Steeply-dipping Upper Cambrian shales are shattered by present-day weathering, and the downward movement of loosened slabs has resulted in scratches on solid bedrock beneath. There are no eroded surfaces of demonstrably pre-drift age, although as in the Northern Drift Cliff the rock exposure appears to be part of an old marine cliff on the valley-side.

1. Lower Shale Head. The lower head is derived from the denuded shale bedrock cliff. The orientation of flattened angular blocks is parallel with the surface, and the great majority of fragments are 3" - 6" in diameter. Occasional slabs of shale attain a diameter of 18". There are no large foreign stones in the head, although some small pebbles of vein quartz, grey sandstone, Cretaceous flint and igneous rock are encountered. The deposit is c. 8 ft thick, and appears to grade upwards without a break to the upper head close to the bedrock contact. The head appears to be homogenous, and it bears no sign of a weathering break.

2. Decalcified till. Above the lower head is a small wedge of rich red decalcified till. It is gravelly in places, but is marked by an absence of large erratics. It contains a few rounded and striated erratic pebbles, but apparently no shell or wood fragments. It has been severely weathered, and its appearance is similar to that of the patches of decalcified Irish Sea till among the sands and gravels in the northern drift cliff. It is still slightly calcareous, so it appears to be a true Irish Sea till.

3. <u>Fluvio-glacial sands and gravels.</u> The till is overlain by fine reddish sands which attain a maximum thickness of c. 6 ft. They are badly contorted, and in places are interbedded with the weathered till. In the upper part of the section they are intercalated with head, and this phenomenon is observed on a smaller scale at the base of the section. The irregular bedding of sand and gravel layers and the appearance of slump features in places (Plate 12) suggests that these outwash materials were deposited in an ice-contact environment.

4. <u>The Upper Shale Head.</u> This head consists predominantly of small shale slabs displaying a pseudo-stratification parallel with the surface. At the base of the head is c. 5 ft of fine flaky head, and there are slight traces of a discontinuity between it and the rather more blocky head above, which is c. 4 ft thick. However, this discontinuity is not obvious enough to permit a subdivision of the head into two horizons. At the base of the head a small fossil ice-wedge c. 2 ft. deep passes from head into the sands beneath.

5. <u>Sandy loam.</u> Above the blocky head is c. 18" of rich foxy-red sandy and silty material. In its upper part it has become a soil layer, with much humus, but beneath it has similar characteristics to the surface deposit on the northern drift cliff.

Interpretation of the Deposits.

The bedrock surface on which the lowest head rests does not appear to have been glaciated, although its slope is regular enough to permit the assumption that it is an erosional surface. Examination of vertical aerial photographs revealed that the steep bedrock slope of the coastline is continued beneath the drift cover towards the southeast, where it eventually emerges as the valley-side. (Fig. 36). This indicates that the rock surface was perhaps initially part of a valley-wall; it follows that the present form of the Aber-mawr valley was established before the Irish Sea glaciation of the area and even before the formation of the lowest heads. In view of its width, steep sides, and negligible catchment area, it is tempting to attribute the cutting of the valley to melt-water during an earlier glaciation.

The lowest suite of head deposits (horizons 1 - 4) presents a great problem in interpretation, for the included heads differ greatly in character. In part, this is due to the particular bedrock stratum being attacked periglacially during head formation; as a rule in this exposure, head derived from shale bedrock is finer and more flaky than head derived from the quartzite outcrop higher up the cliff.

It is clear, however, that lithology cannot wholly explain the differences between heads, for shale fragments vary in size from one shale head to another, and in the stratified flaky gravels very few shale flakes attain a diameter of 3".

The lowest shale head contains some erratic pebbles; they are often rounded, so before head deposition commenced fluvial, fluvio-glacial, or marine gravels must have been available for solifluxion on the old valley-side. The presence of Cretaceous flint among these pebbles strongly suggests that the gravels contained glacial erratics, for flint pebbles could not have occurred inland (i.e. upstream from this coastal area) if water had been the sole agent of deposition. It is tentatively suggested, therefore, that a glaciation pre-dated the formation of the lowest head; from the evidence available it would be reasonable to assume that this glaciation introduced the erratics and deepened the Aber-mawr valley.

The lowest shale head appears to have been laid down during either a late or early stage of a severe cold period, or at the maximum of a period of moderate cold. The reason for this speculation lies in the moderately blocky appearance of the head and the presence of slight frost-heave features for c. 3 ft beneath the weathered horizon; this would imply that the climate during head deposition was only moderately severe[1] (with much moisture available for freeze-thaw shattering of bedrock), and that the active layer above permafrost at the end of this phase may have been at least 3 ft. thick.

The truncation of the pseudo-bedding in the lowest head and the presence of an undoubted weathered layer implies a break in head deposition at this point. No impression can be gained of the length of time represented by this break, for it is not known how much weathered material has been removed by later solifluxion. Conversely, the thickness of the weathered layer (over 12" at the base of the wedge) may not be representative of the weathered layer *in situ*, but may contain much weathered material sludged from upslope. The severity of the rotting in this layer may indicate the onset of full interglacial conditions, but in view of its limited thickness it may be more reasonable to suggest that it was formed in an interstadial period.

The lower blocky head, above the weathering break, is a mixed and rather chaotic deposit which seems to indicate formation in a milder period of periglacial activity than

---

1. Dylik, 1964 (in a discussion on head deposits, I.G.C. Symposium S7a, Exeter) considered that rather blocky heads with poor pseudo-bedding may be deposited during rather moist, moderately severe cold conditions.

the lowest head. The disordered nature of the bedding and the inclusion of blocks and flakes of all sizes implies rapid mass-movement, and it is possible that the head developed in relatively few years. Climatic conditions may have been mild enough to permit a deep active layer, perhaps with "episodic" solifluxion (Büdel, 1959). This head contains a higher proportion of foreign pebbles than that beneath; this may perhaps be explained by the increased availability of gravels on the flatter ground above the steep valley-side.

The head grades upwards into the flaky gravels, perhaps indicating a phase of waxing cold. The grain-size curve for the flaky gravels is strikingly similar to curves for the rubble-drift and outwash materials in the area (Fig. 41). However, fabric analysis revealed that the deposit bears much closer affinities to head than to till or outwash (Fig. 42), confirming that it is lithologically and stratigraphically part of the suite of head deposits. According to the suggestions of Professor Dylik, the flaky head may represent very severe and rather dry periglacial conditions; each thin layer of flakes possibly represents an annual cycle, with the permafrost surface within a few inches of the ground surface at all times. The maximum of this cold phase, which may have lasted for many centuries, may be represented by the layer of very fine flakes at the top of the deposit.

The presence of quartzite blocks and 32% of small erratic pebbles in the flaky gravels may be accounted for by the occasional loosening of blocks from upslope quartzite outcrops, and the incorporation of erratic gravels from extensive gravel patches on the upper parts of the valley-side.

The middle blocky head which overlies the flaky gravels is a chaotic and variable deposit which may indicate a rather rapid amelioration of climate after the cold maximum indicated below. Many of the characteristics of this head (for example, the interdigitation of shale and quartzite heads, the occasional occurrence of erosional contacts, and the slumped appearance of quartzite masses) are indicative of rapid mass-movement. The role of surface washing is witnessed by finely-stratified silty layers in the upper part of the deposit.

Irish Sea till directly overlies this head, and evidence already cited (c.f. Fig. 38) indicates that the ice responsible for its deposition achieved some erosion of underlying head. And yet why is this head seemingly representative of a phase of <u>waning</u> cold? If the till is truly the culmination of the suite of head deposits beneath, it should theoretically overlie the topmost 12" layer of flaky gravels. Yet the flaky gravels grade into what is possibly a less severe periglacial deposit, which would seem an unconvincing herald of glaciation. It is possible, therefore, that the deposits of a further period of waxing cold have been entirely removed by the ice, leaving till in contact with the middle blocky head.

The origin of the overlying deposit as a glacial till is confirmed by fabric analyses (Figs. 41 and 42), although the preferred orientation of pebbles in the till is somewhat erratic (Fig. 43). The content of marine mollusc fragments and Scottish erratics indicates that the till was deposited by ice which moved onshore from the floor of Cardigan Bay. The wood fragments in the till were possibly dredged up by the ice from an interstadial or interglacial forest which had grown on the floor of Cardigan Bay at a time of lower sea-level;[1] or alternatively from banks of driftwood along offshore interstadial shorelines. The comminuted and rounded nature of the wood fragments, and the presence of bark, precludes any possibility that they are post-glacial root fragments.

---

1. Over-ridden wood fragments are common in the Wisconsin tills of the United States (Flint and Deevey, 1951), and an inter-glacial forest covered by glacial gravels is known in North Wales (George, 1932).

Since the till is weathered only to a depth of 12" - 18", it is probably of recent age. It contrasts greatly, for example, with the deeply-weathered Eastern General till at Brackenagh, Northern Ireland (weathered and decalcified to a depth of 12 ft; E.A. Colhoun, personal communication), and with the Illinoian till of the United States (Flint, 1957).

From the fabric analyses of the sands and gravels above the till (Figs. 41 and 44) there is little doubt that they are the product of the same ice-sheet.[1] This impression is strengthened by the presence of ice-contact features and included lenses of till, as described above.

The rubble-drift into which these outwash deposits grade laterally presents an important problem. It has been mentioned above that it may be interpreted either as a "local till" or as a solifluxion deposit. Mitchell (1962) correlates the "angular rubbly non-calcareous boulder-clay" at Porth Clais (Ogof Golchfa) with the Pencoed till and a so-called upper till at Manorowen; and Synge (personal communication) considers the Aber-mawr

1. From other evidence in North Pembrokeshire Griffiths (1940) came to a similar conclusion regarding the close relationship of the "Lower Boulder-clay" and the "Middle Sands and Gravels".

rubble-drift to be the equivalent of these. He suggests that Welsh erratics in the drift were transported along the flanks of the Irish Sea glacier between it and the hills. Stone-counts and roundness analyses, however, seem to indicate that the drift is a blocky head consisting of angular bedrock fragments and incorporating outwash gravels and perhaps till (Fig. 44). This is supported by the down-slope orientation of drift pebbles. (Fig. 43). From the evidence available there is no justification here for proposing a separate advance of local Welsh ice (as proposed by Mitchell 1960 for the upper rubble drift at Pencoed and New Quay) in order to deposit the rubble-drift. Neither does it appear to be an ablation till, for the quartzite blocks of which it is composed are essentially derived from upslope in the immediate vicinity; unless the ice-surface lay beneath an altitude of 40 ft. O.D. there could be no gravitational slipping of frost-shattered blocks onto the ice surface.

The stratigraphic position of the rubble-drift at the junction between bedrock and Irish Sea till gives a further clue to its origin. Synge (1964) has stated with reference to the Ardmore Point-Carnsore Point sheet of Eastern General till that wherever it "abuts against one or other of the rock hills or ridges, it is buried beneath a fan or sloping terrace of solifluxion debris. For example, at Ballyguile, on the north side of Wicklow Head, over 6 ft. of "rubble-drift" - a mixture of soliflucted till and head - overlies the weathered surface of the Eastern General till." (P. 78). This situation appears to exactly match that at Aber-mawr. All the evidence, therefore, supports Jehu's contention that the upper boulder-clay is partly a deposit formed by "ordinary weathering processes".

The blown sands and silts capping the drift cliff must post-date the erosional period responsible for the removal of any drift which once plugged the centre of the valley, for they cap the whole drift section from the cliff-top in the north down to storm-beach level in the south. The present valley stream rises less than 1½ miles away at an altitude of under 200 ft. O.D; it is a misfit today and it seems unlikely that even in a wetter climatic phase it would have been powerful enough to remove all the drift from the valley-floor. If stagnant ice filled the floor of the valley during deglaciation it is possible that the sands and gravels in the drift cliffs were laid down on its flanks; alternatively powerful melt-water stream-flow during deglaciation could account for the present lack of visible drift in the centre of the valley.

Table I . A tentative reconstruction of events at Aber-mawr.

Events.	Climate.
Soil development and till leaching	Warmer
Sandy loam	Cold and dry?
Rubble-drift/Head	Moderately cold
Sands and gravels	Deglaciation
Irish Sea Till	Glaciation
Middle Blocky Head	Moderately cold
Top 12" of flaky gravels	Very severe cold
Flaky gravels	Severe cold
Lower Blocky Head	Moderately cold
Weathered layer	Warmer
Lowest head	Cold

Aber-mawr Valley Erratics }	Glaciation ?

The southern drift cliff may be correlated with the northern section as shown in Fig. 45. There is no great variation in head characteristics in the southern section, but it seems on stratigraphic grounds that its upper head must correlate with the rubble-drift in the north. Similarly, the rather blocky nature of the lowest shale head in the south makes correlation possible with the middle blocky head of the north. The lower members of the head suite may be represented in that part of the section covered by the present-day storm-beach.

From a consideration of the deposits at Aber-mawr, it seems possible to propose a sequence of events for the area, as laid out in Table I. It is hoped that the examinations of subsequent major exposures and evidence from less important inland sites may supplement and perhaps indicate the reliability of this suggested chronology.

Chapter 5 (A2).

FEATURES ON PEN DEUDRAETH HEADLAND, ABER-MAWR.

On the small headland of Pen Deudraeth, between Aber-mawr and Aber-bach, 8 - 10 ft. of rubble-drift rests upon a shattered rock platform (Fig. 36). The drift is a continuation of that capping the Aber-mawr North section, and its examination reveals much concerning the nature of the rubble-drift. Further evidence concerning the relative age of the rock platforms and deeply-entrenched valleys of Pembrokeshire may be seen on the headland.

Bedrock. Bedrock on Pen Deudraeth is of Ordovician quartzites and sandy shales of the Arenig series, dipping northwards towards Aber-bach (Cox, 1930c). On the outer part of the headland is a sill of intrusive dolerite, possibly also of Ordovician age. In places, the quartzites and shales appear to have been smoothed (Plate 13), and above this smoothed area two bedrock slabs, which may or may not be *in situ*, have polished and striated surfaces. Many small striations trend towards 122° and 148°, although deeper grooves trend towards 173°. The smaller grooves apparently pre-date those trending due south.

On the outer part of the headland a dissected rock platform over 50 yds. in length is capped by rubble-drift.

The platform has a steep seaward slope of 11°, although its upper part slopes at only 5°; its altitude lies between 18 and 27 ft. O.D. At an altitude of c. 20 ft. O.D. on the main part of the platform are several deep hollows which may owe their existence in part to gouging. The southern edge of the platform appears to be truncated by a low cliff which may be a continuation of the old valley-side of the Aber-mawr valley; unfortunately a large part of the platform is still covered with drift, so this impression is difficult to substantiate.

1. Basal deposits. Lying directly on the rock surface on the outer part of the exposure is a rotten and weathered layer of fine bedrock fragments and silt (Fig. 46). The silt is discontinuous, but is occasionally present as a stoneless layer 3" - 6" thick. Above this layer is c. 2 ft. of fine flaky bedrock head which has good traces of pseudo-stratification; when viewed from the outer part of the rock platform this stratification appears to be horizontal.

2. Blocky rubble-drift. The stratigraphic relationship of this drift with the basal deposits is not clear, for it is seen to rest directly on bedrock near the Aber-mawr North drift-cliff. It consists of angular blocks of quartzite and shale between 3" and 1'6" in diameter. The matrix is loose and gravelly, again consisting largely of bedrock

fragments. The drift is 4 - 5 ft. thick above the quartzite slabs (Plate 13), but a few yards to the west its upper part consists of an "openwork" deposit of quartzite blocks without a matrix (Fig. 46). Above the rock platform the relationship between the blocky rubble-drift and the bedrock is well-displayed, for above the dolerite sill most of the blocks in the drift are of dolerite.

3. Compact rubble-drift with erratics. Lying directly upon the striated bedrock slabs and elsewhere upon blocky rubble-drift is c. 3 ft. of drift with a sandy and silty compact matrix. In places patches of clay up to 9" long and 2" thick are interbedded with the drift. There are many erratic pebbles in this layer, although most blocks are again of angular quartzite. Some erratics retain striations, although many appear to be rotten. There is one distinct layer of rotten igneous erratics c. 12" thick. This drift is non-calcareous.

The distinctions between this drift and the blocky rubble-drift are not always clear, especially on the 50-yard frontage of drift on the outer part of the rock platform. Here the drift exposure is often over 10 ft. high; erratics appear to be scattered throughout the deposit, although shattered bedrock masses are common. Often there are traces of frost-heaving and pseudo-stratification.

4. <u>Sandy loam.</u> Capping the whole of the drift-cliff is up to 5 ft. of sandy loam. In places it incorporates patches of rich sand and gravel, and well-rounded erratic pebbles are common. At its base there is a good erosional break, overlain by a "lag concentrate" of well-rounded pebbles. South of Aber-bach there are excellent traces of stratification in the deposit, and interbedded bands of flaky head are common along the whole length of the exposure.

Interpretation.

The rock platform may be an ancient raised beach platform, in spite of its rather steep slope; if so, it may represent a sea-level as high as 27 ft. O.D. The platform correlates well in altitude with other raised beach platforms at Ogof Golchfa and Pen Dal-aderyn, and is likewise shattered and dissected. The presence of striations on the platform and re-worked till in the drift exposure indicate that the cutting of the platform pre-dated the last glaciation of the area. It is also possible that it pre-dated the cutting of the Aber-mawr valley.

The reason for this conjecture lies in the fact that the present cliff-line at the southern edge of the platform appears to be a continuation of the old valley-side (Fig. 36);

it has smoothed rock surfaces on its upper part, indicating that it may not be a product of post-glacial marine erosion. The raised beach platform appears to be truncated by this cliff-line, so that the cutting of the valley wall may have post-dated the erosion of the platform. At the moment this seems to be a logical suggestion, although it is possible that the thick drift cover masks an extension of the platform into the valley itself. Until the processes of erosion have removed a little more drift from the cliff-top, the question will have to remain unanswered.

At first sight, the continuation of the rubble-drift of Pen Deudraeth southwards to the upper part of the drift-cliff at Aber-mawr North seems to indicate that the whole of the deposit post-dates the last Irish Sea glaciation. Furthermore, the presence of striations on some of the bedrock slabs beneath this drift could be interpreted as further evidence of an "upper boulder-clay" glaciation (Mitchell, 1962). However, the presence of flaky gravels, silts, and a possible weathered horizon at the base of the deposits invites correlation with the lower head deposits at Aber-mawr North. A similar correlation may be suggested between the blocky rubble drift (overlain by compact rubble-drift with erratics) and the middle blocky head at Aber-mawr (overlain by till). The compact rubble-drift here may therefore be the equivalent of the calcareous till, in view of its content of striated erratics and lenses of clay. It is possible that the bulk of the rubble-drift above this horizon consists of a soliflucted thin layer of till mixed with masses of sand and gravel, local head, and shattered bedrock. The high degree of angularity on bedrock blocks in the drift and their apparent downslope orientation leaves a strong impression that they have been deposited primarily or secondarily in head; the upslope gradient of 8^{o} (and in places 10^{o}) is ample for large-scale solifluxion.

The sharpness of the contact between the sandy loam and the underlying rubble-drift is probably of little significance; it may be no more than a surface eroded by slope-washing processes towards the end of the periglacial phase responsible for the deposition of the rubble-drift. The well-rounded pebbles at the base of the sandy loam present a problem, for they look suspiciously like beach pebbles. They may have been re-deposited after incorporation in glacial drift; they may have reached the cliff-top in the hands of human beings, to be buried beneath recent hill-wash; or they may represent a high relative

Table II. **A Tentative reconstruction of events at Pen Deudraeth.**

Events.	Climate.
Sandy loam/head fragments	Cold and dry ?
Compact rubble-drift	Moderately cold
Clay lenses and striations	Glaciation
"Openwork" rubble-drift Blocky rubble-drift	Moderately cold
Flaky head	Severe cold
Weathered layer ?	Warmer ?
Silt etc.	Cold ?

Aber-mawr Valley	Glaciation

Rock platform	Sea-level 18-27 ft. O.D. Warm

post-glacial sea-level.[1]

After an investigation of the features at Pen Deudraeth it is suggested that the "rubble-drift" is a composite deposit containing pebbles laid down before, during, and after the last Irish Sea glaciation of the area. It is basically a solifluxion deposit; there is no evidence that it was laid down by ice as a true till after the deposition of the calcareous till, as suggested by Mitchell and Synge for other sections.

The sequence of events apparently represented at Pen Deudraeth is portrayed in Table II.

---

1. A "Post-Older Drift" platform at c. 50 ft. O.D. in Gower was tentatively attributed to marine action by George (1932).

Chapter 5 (A3).

THE DRIFT EXPOSURES IN THE AFON NEVERN ESTUARY.

(A) South Side (Parrog).

Along the south side of the estuary of the Afon Nevern is a discontinuous and rather poor drift exposure; nevertheless, its details are worth recording, for it throws light upon several stratigraphic and chronological problems. The drift cover is never more than 6 ft. thick, and rests upon remnants of a rock platform. The generalised succession seems to be that recorded in Fig. 47.

Bedrock and rock platform. For a distance of about half a mile small sections of a rock platform are preserved along the Parrog front, cut across thin-bedded Ordovician shales and mudstones. In places, the weak shales have been bent over towards 300° - 310° by solifluxion. The platform surface varies from c.5 to 10 ft. O.D. in the east to 18 - 20 ft. O.D. near the lifeboat station; remnants are so discontinuous, however, that it cannot be said with any certainty that they represent one platform, or that the feature rises in altitude westwards.

On the small point west of the lifeboat station polished slabs of bedrock are seen between 14 and 26 ft. O.D. (Plate 14). The hummocky slabs on this surface still retain their polished appearance, although they are often badly weathered and covered with lichen. It is still possible to distinguish faint grooves and striations trending to between 113° and 173°, with the most common direction apparently 160°. These striations are distinguishable from joint planes and fractures.

1. Rounded pebbles. On the lower parts of the platform at the eastern end of the exposure well-rounded pebbles may sometimes be seen in an earthy and sandy matrix. There are few exposures of these pebbles, however, and in view of the large amount of made-up ground in the vicinity (houses have been built within a few yards of the platform edge) it is not certain that these pebbles are in situ.

2. Contorted lower head. No thick and continuous head is seen in the section, although in Traeth-y-Bettws a layer of contorted head fragments may be seen above shattered bedrock. The head fragments are in part incorporated in the overlying gravelly till. In several sites thin head with well-rounded erratics rests directly upon bedrock; at one site 18" of flaky shale head has a sandy matrix with silt bands and well-rounded pebbles and pieces of Cretaceous flint.

3. Gravelly reddish till. In patches this till is up to 2' 6" thick. Its lower part has a high proportion of head

fragments, but upwards the proportion of rounded stones in a gravelly matrix increases. The till is non-calcareous and contains no shell fragments. Here and there a higher proportion of well-rounded pebbles and boulders gives the deposit the appearance of fluvio-glacial outwash. Thus in appearance it is similar to some of the lower gravelly decalcified till masses at Aber-mawr.

Above the till there are isolated masses of red non-calcareous clay which are up to 2 ft. thick. The clay contains no laminations or bedding features, but is occasionally gravelly, with rounded and sub-angular pebbles up to one inch in diameter. Among the erratics in the clay are rounded pebbles of medium-grained igneous rock and Cretaceous flint. The clay resembles the highest decalcified till mass in the outwash gravels at Aber-mawr.

4. Head and sandy loam. The section is capped with up to 2 ft. of sandy reddish loam with interspersed layers of fine flaky shale head. In places made-up ground is mixed with the deposit, and it contains some derived *Patella* fragments. These fragments may have been carried by birds or human beings; such are frequently found in sandy loam on the high cliffs of St. Bride's Bay. In places the flaky upper head cuts out the till deposits and rests directly upon the older flaky head and the rock platform.

(B) North Side (Newport Sands).

To the north of the estuary, where bedrock outcrops beneath the sand-dunes, there are traces of a shattered bedrock platform and solifluxion deposits which appear to correlate with those at Parrog.

The bedrock at this locality consists of steeply-dipping faulted and folded black shales which are soft and easily-shattered; it is understandable that slight traces of a rock platform at c. 11 ft. O.D. have been virtually destroyed by frost-shattering.

The maximum thickness of the periglacial deposits in the vicinity is c. 8 ft, in a wedge of head on the beach close to the car-park. The lowest deposit is a thin contorted head of shale flakes lying directly above shattered bedrock. On the low cliff this head is c. 18" thick, but it thickens southwards to attain a maximum thickness in places of c. 3 ft. A stony reddish till occurs in one or two small patches above the shattered rock platform; it is never more than 18" thick, but contains erratics of all shapes and sizes in a matrix of silt and clay. Some of the erratics are up to 12" in diameter, and the rock-types represented include coarse sandstones, Cretaceous flints, and igneous rocks. The upper part of the till is soliflucted, and contains head flakes and lenses of silt and sand. Where no till is seen in section there is generally an indistinct break between head without erratics below, and head with erratics above. In the head wedge near the car-park there is no true till, but instead there is a variable head deposit with lenses of silt and gravel interbedded with layers of stony erratics and flaky head. This upper head is up to 4 ft. thick,and is overlain by up to 4 ft. of blown sands.

Interpretation.

The platform remnants on either side of the estuary are at similar altitudes, and probably correlate. However it is unlikely that all the remnants belong to one raised beach platform, for the large height range of the feature (5 - 26 ft. O.D.) may preclude an origin under one phase of marine erosion.

It is valid to note at this point that the platforms are cut inside the mouth of the estuary; the configuration of this coast must therefore have been determined before the platforms were cut. This indicates that the Afon Nevern must have cut its broad estuary before sea-level rose and fluctuated at the time of platform cutting. A reconstruction of the cross-profile of the estuary reveals that the valley-floor is probably graded to a sea-level at least 75 ft. lower than at present (Fig. 48). It may be related in time to the deeply submerged rock floors of Milford Haven (Codrington, 1898), the River Tawe (Jones, 1942), and other valleys in south-west England (McFarlane, 1955). It is interesting that the reconstructed long-profile of the Teifi also indicates a sea-level at least 75 ft. lower than at present (Allen, 1960).

The incorporation of raised beach pebbles in the lower head is not at all unusual. There is an intimate association of head and raised beach gravels at Ogof Golchfa, Whitesands, and elsewhere in Pembrokeshire, as at Pencil Rock in Devon and Garryvoe in South-East Ireland. A phase of solifluxion must have followed the formation of the raised beach; the contortions in the head may indicate that following solifluxion the climate became more severe, with cryoturbation predominant.

Striations and probable polishing of bedrock slabs indicate that ice moved onshore towards 160°. In view of the similarity of the till with that at Aber-mawr there is good reason to suppose that the ice was Irish Sea ice. There is no true calcareous till in the section, but this is not surprising in view of the limited thickness of drift and subsequent susceptibility to leaching and decalcification. The red clay above the till is not laminated, so it does not appear to be a lacustrine or basal washing deposit. Both gravelly till and red clay appear to be glacial deposits associated with the last glaciation of the area; if there had been a later glaciation there would surely be traces of it in this northern coastal locality. In view of this it seems safest to assume that the weathered appearance of the smoothed rock slabs is simply the result of long exposure to sub-aerial weathering.

The position of the drift exposures in the Nevern estuary invites a brief examination of Charlesworth's (1929) hypothesis of Newer Drift glacial lakes. According to his map (Fig. 11), a so-called Lake Nevern was dammed up in this estuary for a long period during ice-retreat, with a lake-level falling from over 300 ft. O.D. to near present sea-level. If meltwater had been entering this lake from a wasting ice-front in the vicinity of Parrog and also from inland meltwater streams, then at least some stratified sands and gravels or lake clays should be present above the till. There are no such deposits, strongly suggesting that a large lake did not exist in this locality at the close of the last glaciation.

The ice-stream of this last glaciation was perhaps relatively weak, for it did not entirely remove the raised beach gravels or the thin flaky head from the platform

Table III. **A Tentative reconstruction of events at Parrog and Newport Sands (Afon Nevern Estuary).**

Events.	Climate.
Decalcification of till	Temperate ?
Sandy loam/head	Cold and Dry.
Gravelly Till Striations on platform	Glaciation
Lower Head	Moderate cold ?

Raised beach pebbles?	Sea-level 13 ft. O.D. Warmer

Erratics	Glaciation ?

Raised beach platforms	Sea-level 5-26 ft. O.D. ? Warmer

Erosion of Afon Nevern Valley and Drowning of Estuary	Sea-level below O.D. ? Temperate ?

surface, and itself left only thin till deposits. Following the deglaciation of the area, further peri-glacial action appears to be represented by the head with erratics north of the estuary, and the sandy loam and interbedded head at Parrog.

In Table III tentative suggestions are made concerning the sequence of events at Parrog and Newport Sands.

Chapter 5 (A).

SUMMARY OF CONCLUSIONS.

The sections at Aber-mawr, Pen Deudraeth, and the Afon Nevern estuary are representative of coastal exposures lying to the north of the "South Wales End-moraine". If the end-moraine is a true terminal feature of the last Irish Sea Ice-sheet, the sections should bear some features which are not found further south in the area of "Older Drift" in Pembrokeshire.

1. Stratigraphy.

An attempted correlation between the sections described is made in Fig. 49. The best datum for use in this correlation appears to be the calcareous Irish Sea till, which is present (in varying states of preservation) at Aber-mawr North and South and in the Afon Nevern estuary. It may be argued that the thin gravelly red till at Parrog and Newport Sands is neither thick enough nor plastic enough to be called an Irish Sea till; however, it can hardly be anything else, for its stratigraphic position between two heads is similar to that of the calcareous till at Aber-mawr, and there is abundant evidence further east that the Irish Sea ice impinged upon the whole northern coastline of Pembrokeshire.

Once this till is established as a datum, the upper head with erratics in the Afon Nevern estuary can safely be correlated with the rubble-drift at Aber-mawr North, the upper shale head at Aber-mawr South, and the compact rubble-drift with erratics at Pen Deudraeth. Again, the overlying sandy loams and blown sands at each locality can be correlated. Ice-contact fluvio-glacial sands and gravels lie above the till only at Aber-mawr North and South. However, there are slight traces of outwash above the till at Parrog, and it is suggested that the upper solifluxion deposits at Pen Deudraeth and the Afon Nevern sections contain pebbles possibly derived from old outwash.

Correlation of the deposits beneath the Irish Sea till becomes more difficult, for the complexity of the lower head suite at Aber-mawr North is matched nowhere else. It seems plausible, however, to relate the middle blocky head at Aber-mawr North with the lower shale head at the south of the bay and the blocky rubble-drift at Pen Deudraeth; all three heads are apparently indicative of moderately cold and moist periglacial conditions. The stratified flaky gravels at Aber-mawr North may exist beneath the present-day storm-beach at Aber-mawr South, and they seem to be related to the fine flaky bedrock head on Pen Deudraeth. The weathered horizon at Aber-mawr North may be related in time to the rotted layer of silt and bedrock fragments at Pen Deudraeth.

The raised beach pebbles at Parrog have no correlatives in the other sections analysed, but the similarity of the drift successions lying above the raised beach platforms at Pen Deudraeth, Parrog, and Newport Sands is well-marked, suggesting that the history of drift deposition at each locality has been broadly similar.

2. Variable drift thickness.

While the drift successions of the five sections correspond, some comment on the variable thickness of deposits may be made. For example, the section at Newport Sands (which is seldom over 4 ft. thick) displays a very similar four-fold drift division of head - till - head with erratics - blown sands as Aber-mawr North (where the drift is at least 40 ft. thick). At Aber-mawr the complex lower head series, which is over 20 ft. thick, appears to correlate with the lowest head at Parrog, which is everywhere less than 18" thick. This discrepancy is possibly due to a great difference in "solifluxion potential" from one locality to another; at Aber-mawr the steep rock walls of the old valley were particularly favourable sites for solifluxion, while at Parrog the gentle surface slope (less than 4^{o}) above the section and the lack of a marked break of slope for c. 200 yards inland may have precluded rapid solifluxion. The negligible thickness of till at Parrog does not present a great problem, for the locality lay directly in the path of the advancing ice; in such localities in Pembrokeshire till seldom appears to have been deposited thickly. On the other hand localities in the lee of headlands or in valleys running transverse to the direction of ice-movement are often filled with thick till. Aber-mawr North was one such locality.

3. <u>The mode of deposition of some drifts.</u>

In the foregoing studies several points have been made concerning the mode of deposition of some of the exposed drifts. These points may be summarised as follows:

(a) In view of the limited thickness of the calcareous Irish Sea till and its stratigraphic position above relatively undisturbed head deposits at all the localities studied on this coast, it may be suggested that the ice-stream was rather weak and the glaciation perhaps short-lived.

(b) The interbedding of fluvio-glacial sands and gravels and till masses at Aber-mawr indicates that stagnant ice was probably present while these deposits were laid down. It seems reasonable to propose that on a small scale, at least, ice-wastage in the area was by disintegration of ice-masses in situ, rather than by the retreat of a steep ice-sheet face, as envisaged by Charlesworth (1929).

(c) The nature of the "Upper Boulder-clay" or rubble-drift is revealed from evidence at Aber-mawr North and Pen Deudraeth. There is reason to suppose that it is a mixed and variable solifluxion deposit which has incorporated head fragments and remnants of outwash gravels and till. There is no reason to suppose that it is the deposit of a Welsh Readvance.

(d) At this point it may be worth noting that there is no evidence in the coastal sections of the Afon Nevern estuary in favour of a "Lake Nevern", as postulated by Charlesworth. There appear to be no lacustrine deposits in the sections studied.[1]

4. Evidence for climatic fluctuations.

In the analysis of the drift sections several suggestions have been made concerning climatic fluctuations.

The climate during the formation of the raised beach at Parrog was probably somewhat warmer than that of today,

1. Charlesworth's hypothesis of glacial lakes will be examined in detail in Chapter 10.

for unless there is tectonic or isostatic interference a high sea-level is possibly a reflection of high interglacial temperatures (West, 1963). Therefore the raised beach may be a representative of an interglacial period.

Following the formation of the raised beach, three main climatic phases appear to be represented at Aber-mawr:

(a) a long periglacial phase, itself divisible into a period of waxing cold, a period of severe maximum cold, and a period of waning cold. This may be called the "Main periglacial phase".

(b) a glacial phase of limited strength.

(c) a shorter periglacial phase of moderate intensity.

The evidence from the other sections suggests an identical sequence, and although there is little stratigraphic evidence from the Afon Nevern estuary for the climatic fluctuations in the main periglacial phase, the thin contorted head does seem to indicate a period of moderate cold (solifluxion) followed by severe cold (frost-heaving).

The weathered horizon above the lowest head at Aber-mawr North invites some speculation. The phase may have been a short interruption of periglacial conditions, and may thus have coincided with a rather lower sea-level than at present. It is tempting to suggest that the wood frag-

TABLE IV. STRATIGRAPHIC CORRELATIONS AND INTERPRETATIONS FOR THE COAST OF N. DEWISLAND.

Aber-mawr S.	Aber-mawr N.	Pen Deudraeth	Parrog	Newport Sands	Sea-level	Climate	Events
S. loam	S. loam	S. loam	Head and Sandy loam	B. sand	Low - rising	Cold arid?	Wind action & sOlifl.
Upper shale head	Upper RD	Compact rubble-drift and erratics		Head with erratics		Mod. cold	Solifluxion
Fl-gl S&G	Fl-gl S&G					Warmer	Deglaciation
De-calc I. Sea till	Irish Sea till		Gravelly red till	Gravelly till	Very low	Glacial	Dewisland Glaciation
Lower shale head	Middle blocky hd.	Blocky rubble-drift	Contorted lower head	Contorted lower head	Low - falling	Moderate cold	Rapid solifluxion?
	Strat. flaky gr.	Basal deposits				Severe cold, dry?	Slow solifluxion?
	Lower blocky hd					Mod. cold	Rapid solifluxion?
	Weathered					Warmer?	Weathering? Forest?
	Lowest shale hd.					Mod. cold	Solifluxion
			Raised B.		High	Warm	Beach deposition
Erratics & Aber-mawr valley			Erratics		Very low	Glacial	Early Glaciation
		RB plat	RB plat	RB plat	High	Warm	Platform cutting
Establishment of coast					As pres?	Temp?	Coast erosion
			Afon Nevern Valley		Low	Temp?	Sub-aerial erosion

ments in the till above were derived from a forest which was growing to the north of the present coast-line at this time; the trees would certainly not have grown there during a cold periglacial phase, or at the peak of an interglacial stage, when sea-level may have been too high. On the other hand the wood may have been derived from a submerged forest dating from the beginning or end of an earlier interglacial.[1]

5. Table of Correlation and Interpretation.

The points made above, concerning the correlation of sections and the interpretation of sea-levels and climatic changes, are summarised in diagrammatic form in Table IV. In this table no attempt is made to represent the relative thickness of stratigraphic horizons, or the length of time which elapsed during any particular depositional phase. The earliest events traceable are plotted at the bottom of the diagram, and the most recent at the top; the most westerly locality is plotted on the left, and the most easterly on the right.

---

1. There is a submerged forest in Aber-mawr Bay today; it probably dates from the submerged forest period of the present interglacial, when sea-level was lower than at present. There is no reason why similar forests should not have grown in this locality in the early parts of previous interglacials.

It is realised that certain parts of the table (especially the interpretations of sea-level) are directly contradictory to some of the theories widely accepted in the literature. However, in a study of this type it is preferable to interpret sea-level and climatic fluctuations purely in the light of field evidence, without reference to a preconceived scheme of events. Later in the thesis, when a Pleistocene chronology for Pembrokeshire has been proposed, it will be worthwhile to assess the relationship of this chronology with other schemes.

The lines of reasoning behind the interpretations are simple. The drift deposits are correlated as in Fig. 49, and the interpretations are summarised from the text; however, the lower half of the diagram may need some explanation.

(a) The raised beach platforms. As suggested in the section on the Afon Nevern estuary, the variations in altitude of the rock platforms may imply that they were cut at different times by a fluctuating sea-level. There is no evidence to suggest that all the platform-cutting was achieved in one interglacial; the process may have spanned several interglacials.

The raised beach pebbles resting on the platform at Parrog may have been deposited by the interglacial sea which cut the platform. However, the presence of erratics in the beach invites some speculation. If, as seems likely, they were introduced by a glaciation which pre-dated the deposition of the beach pebbles, two possibilities emerge:

(a) This early glaciation pre-dated the cutting of the platform, so that any erratics on the platform must be derived from older glacial deposits.

(b) The early glaciation intervened between the cutting of the platform and the deposition of the raised beach.

Some difficulty is encountered in case (a), for it requires erratics to have been preserved at the raised beach site throughout a prolonged period of platform-cutting which may have lasted for many thousands of years. The second case, therefore, appears to have more to commend it, for glacial deposits actually resting upon a pre-existing platform (as at Gwbert and Ogof Golchfa today) will provide abundant erratics for incorporation in the raised beach, if sea-level happens to rise to the old platform-level. On this basis the postulated early glaciation is placed tentatively between the cutting of the raised beach platform and the deposition of the raised beach.

This is supported by the fact that the Pen Deudraeth platform is apparently truncated by the wall of the Aber-mawr valley. There is some evidence that the valley may have been cut during the glaciation which introduced the lowest erratics at Aber-mawr. If this glaciation was the "early glaciation", as suggested in the table, then it follows that the platform must have been cut even earlier. In view of the doubt concerning the nature of the Pen Deudraeth platform and its position, it may be best at present to treat the above suggestion with caution until it is supported or contradicted by other evidence from elsewhere.

(b) The Afon Nevern Valley. The Afon Nevern valley definitely pre-dates the Parrog rock platforms, and appears to have been graded sub-aerially to a sea-level at least 75 ft. lower than at present. The gentle, open slopes of the valley sides do not seem to indicate erosion by glacial meltwaters (Plate 15). A prolonged period of sub-aerial river-erosion, however, presumably requires an inter-glacial period; at such a time, assuming relative stability of the land-mass, sea-level should theoretically be high. It may be best to assume that the valley is an ancient feature which pre-dates the establishment of the present coast-line and the cutting of the raised beach platforms; it is therefore placed at the base of the table, prior to two glaciations.

6. The Age of the Deposits.

The relative age of the North Pembrokeshire coastal drifts is relatively simple to determine. Clearly the calcareous till must date from the last glaciation of the area, while the erratics in the raised beach and head deposits may date from an earlier glaciation or glaciations. There appears to be good evidence that an interglacial period intervened between the last two glaciations. Already it seems reasonable to suppose that the last glaciation of North Pembrokeshire may be synonymous with the "Last Glaciation" of Britain, for the tills are leached to no great depth and head deposits above them are thin. If the "Last Glaciation" is represented in the sections by the upper head only, the limited thickness of this head must give rise to some misgivings. However, at this stage any attempt at absolute dating will be unwise, and some confusion over terminology may be prevented if the glaciations of Pembrokeshire are assigned local names.[1] Perhaps the glaciation which introduced the erratics may be

---

1. In Ireland Dr. Farrington (1944) proposed local names for the glacial stages of Co. Wicklow which have subsequently been widely-accepted and correlated with glacial stages elsewhere.

called simply the "EARLY GLACIATION"[1], while the last Irish Sea glaciation of North Pembrokeshire may be called the "DEWISLAND GLACIATION", using Aber-mawr as a sample locality. These names are not proposed out of any desire to increase the multiplicity of terms already existing for glacial stages in Britain, but because at the moment the use of local terms may minimise the risks of making rash correlations before reliable criteria have been established.

There appear to be no deposits in the area which pre-date the Early Glaciation. All that can be said concerning the age of the raised beach deposits is that they were laid down between the two glaciations. On the other hand all the head in the sections may be related to the waxing and waning phases of the Dewisland Glaciation.

The suggestions made above concerning the correlation, interpretation, and age relationships of the drifts and other coastal features of North Pembrokeshire must be very tentative at this stage; however, they appear reasonable in the light of the field evidence. The sequence of events proposed in Table IV may be used as a working hypothesis during the examinations of other coastal sections in West Wales, in the following pages of the thesis.

---

1. D.Q. Bowen (1965) has used the term "Early Glaciation" for the glaciation which introduced the erratics to the Gower raised beaches.

Chapter 5 (B)

The west coast of Dewisland.

B1. The drift exposures at Whitesands.

B2. The Porthmelgan channel and drift-cliff.

B3. The head deposits at Pen Dal-aderyn.

Summary of Conclusions.

Chapter 5 (B1).

THE DRIFT EXPOSURES AT WHITESANDS.

In Whitesand Bay[1], the most westerly sandy bay in Dewisland, two long exposures reveal important stratigraphic evidence concerning the Pleistocene period in Pembrokeshire. Two major drift cliffs, one to the north and the other to the south of the car-park, are close to H.W.M., and are kept fresh by wave-attack. The two exposures were separated originally by stream-erosion, and the picture is further complicated by the presence of made-up ground in the car-park. Since the exposures are not strictly comparable, it is difficult to tie them together stratigraphically.

The section was first mentioned by Prestwich (1892), who noticed that south of the car-park there is an exposure of raised beach and blown sand sealed beneath head. In 1904 Jehu visited the exposures, and in his paper there are illustrations of the sections at the north and south ends of the beach. There is till to the north of the stream and head to the south; he included both drifts in

1. Whitesand Bay stretches from St. David's Head to Point St. John, at the northern end of Ramsey Sound. The local term "Whitesands" is used for the main sandy beach in the bay.

his overall category of "upper boulder-clay and rubbly-drift". Green (1911a) gave a section from the south side of the bay as follows:

5) Blown sand.

4) Head.

3) Lenticles of blown sand.

2) Boulder-clay with varied erratics.

1) Layer of great boulders.

Cleaved Cambrian rock.

Since the investigations of Green, only Cox (1930) appears to have made more than a passing reference to the drifts at Whitesands.

(A) <u>The Northern Drift-Cliff.</u>

At the northern end of the beach, where the coast curves towards Trwynhwrddyn headland, there is a drift exposure c. 40 yards long. The maximum thickness of the drift is c. 18 ft. where it is seen in contact with bedrock; the section decreases in altitude to c. 4 ft. at its southern end. The stratification of the cliff is shown in Fig. 50.

<u>Bedrock.</u> Bedrock at this point is of vertically-dipping sandy shales and thin hard sandstone bands of the Lingula Flags (Upper Cambrian). Hummocky and striated bedrock shales may be seen (Jehu, 1904) and the greater part of

the rock surface above the reach of storm-waves is polished by ice. The best striated slabs may be found within 4 ft. of the corner-pole (Plate 16A). Jehu noted that the striations commonly indicate ice-movement from the north-west; in general, this is true, although striations may be found on the slabs trending at all orientations between 100° and 160°. There is some evidence of an older set of striations trending 180° - 230°, with the most common direction c. 223°. These may represent local swings in ice-movement in sympathy with bedrock and coastal configuration before the ice-stream became dominant in its movement towards c. 133°.

Near the corner-pole the rock surface has the appearance of a rock platform c. 14 ft. above O.D., although it is not as convincing as the platform mentioned by Cox et al (1930b) from south of the car-park. On the "col" of Trwynhwrddyn headland there are traces of a much-shattered platform at 14 - 17 ft. O.D. Further platform remnants are found at c. 14 ft. O.D. west of the stack in Pwlluog bay, and there are slight remnants of a higher platform on the cliffs around the bay at c. 25 ft. O.D.; however, all these remnants are intimately associated with joint-planes in the bedrock, so they may be unreliable indicators of past sea-levels.

Between the corner-pole and Trwynhwrddyn headland there are no traces of a rock platform, but above a low cliff of steeply-dipping soft shales the strata are seen to be "over-folded", with rock fragments carried towards 145°. This could be a solifluxion effect, but the direction of the "folding" seems to indicate rather the influence of over-riding ice. This impression is reinforced by over-folding on the clifftops above Craig y Creigwyr in a direction c. 90° different from the sludge sector. A similar distortion of bedrock beneath Midland General till, and attributed to ice-movement, is seen at Sutton, Co. Dublin (Stephens and Synge, 1958).

1. Lowest Shale Head. In the main drift section (Fig. 50) a thin wedge of well-stratified head is seen overlying the polished bedrock and underlying calcareous shelly till. The head is up to 3 ft. thick, and is a gravelly deposit consisting largely of small flakes of bedrock shale but incorporating some foreign pebbles. It is non-calcareous, and displays moderate pseudo-stratification. The wedge occupies the same stratigraphic position as the trail of bedrock fragments beyond the "over-folded" shale beds, and ~~in many hollows exposed~~ in the cliffs 50 yards to the north angular contorted head is seen in bedrock hollows (Fig. 51). In other places also, a gravelly head-like deposit is found lying on the rock platform beneath till.

It may be significant that clearing of the overlying head and washing of the polished rock surface in the main drift exposure revealed that striations pass beneath the head (Plate 16B). This situation is matched at Ringabella, in Southern Ireland, where striations and glaciated channels on a "pre-glacial" raised beach platform are seen to pass beneath a supposed head.

2. The Calcareous Shelly Till. A wedge of calcareous shelly till up to 4 ft. thick overlies the head above the lowest bedrock exposure in the northern drift-cliff (Fig. 50). The till is generally blue-grey in colour, although at its upper and lower margins a few inches are decalcified and coloured red. The till is cracked and fractured; it appears to be fissile, and signs of layering are seen here and there. The till matrix is stony and gravelly, and its upper margin grades through a stony decalcified layer up to 2 ft. thick into the overlying rubble-drift. As at Aber-mawr, the calcareous till does not form an unbroken horizon. It is terminated above the upper part of the "head" wedge and replaced by stony non-calcareous till in contact with bedrock.

3. Upper Rubble-drift. This rubble-drift attains a maximum thickness of c. 18 ft. It is sandy and gravelly,

and is full of locally-derived angular stones and rounded erratics. On the northern part of the main section there are traces of interbedded sands and gravels. Stones are generally under 12" in diameter, although some igneous striated boulders up to 3 ft. in diameter protrude from the face of the cliff. The angular boulders which make up the storm-beach at the base of the section are largely derived from the rubble-drift. Where the cliff is c. 8 ft. 6" high a boulder over 6 ft. long rests upon the storm-beach; its upper face is covered with striations, and it has clearly fallen from the drift above. In the southern part of the main drift section the proportion of bedrock fragments seems to increase, and pseudo-stratification gives the impression of solifluxion.

Near the corner-post the rubble-drift attains a thickness of c. 10 ft., and assumes a more variable nature (Fig. 51). In a small gully lies a wedge of severely-contorted head, overlain by a reddish gravelly deposit which contains striated stones; the reddish deposit is non-calcareous and contains many flaky bedrock fragments, but it appears to be related to the calcareous till in the main drift-cliff. Above this deposit is a layer of large igneous boulders up to 3 ft. thick, which is in turn overlain by a stony head with striated erratics, and then blown sand.

4. <u>The Blown Sand.</u> The whole drift exposure is capped by a deposit of blown sand which attains a thickness of 5 ft. in places. Here and there it is severely-gleyed, and it has been weathered and disturbed by soil-forming processes. It is non-cemented, and is similar to the sands in the stabilized sand-dunes south of the car-park. Its surface is completely vegetated today. At its base there is occasionally a "lag concentrate" of large angular and rounded boulders and pebbles.

(B) <u>Trwynhwrddyn Promontory.</u>

At the base of the Trwynhwrddyn Promontory, where the path descends from the cliff-top to the rock platform, 7 - 12 ft. of drift is exposed. Seen from the north side, the deposit consists largely of small flakes of bedrock in a rich brown sandy matrix. Jehu (1904) said of the locality "....the drift shows a rough sort of stratification, and has much sandy and pebbly material intermingled with the boulder-clay". (P. 75). On closer examination, this stratification is seen to be restricted to one horizon, which makes up the greater part of the exposure (Fig. 52). Above and below the sandy and gravelly deposit there are more variable drifts, as indicated in the sketch section.

Seen from the south, the drift sequence on the promontory is somewhat simpler, and the lowest contorted head is not exposed. Instead, up to 5 ft. of stony and gravelly non-calcareous till is seen to lie directly upon the broken platform surface of soft shales. The till itself contains a few bands of fine sand, but is overlain by c. 3 ft. of reddish sands and flaky gravels.

(C) Whitesands South.

To the south of the broad, open Whitesands Valley there is a long exposure of head deposits lying above a raised beach. Since Prestwich mentioned this section in 1892, it has been well-known to generations of geologists for the erratic boulders resting in the raised beach and on a shattered rock platform (Green, 1911a). The drift succession over the greater part of the drift-cliff appears to be that suggested in Fig. 53A.

Bedrock. A few yards to the south of the car-park bedrock emerges through the pebble-beach; its shattered surface steadily rises in altitude eastwards until it is exposed as a high cliff near the steps at the southern end of the section. Upper Cambrian soft shales and sandstones are seen to dip steeply towards the north; however, the exposures are frequently trucated by an undulating rock platform surface which is generally at 10 ft. O.D. This surface is badly-shattered, and only where the drift-cover has recently been removed are fresh slabs seen. Slabs are occasionally polished, apparently by ice-action, and striations add weight to this view. Striations are poorly preserved, but several may be discerned trending to between 115° and 190°. The clearest striation trends to 135°, and striations on a large erratic block which appears to be <u>in situ</u> trend towards 128°. On one rock slab, just above H.W.M., there is a series of deep gouges apparently unrelated to the cleavage of the shale bedrock; it is possible that these features, like the striations, are legacies of glaciation.

1. <u>Large rounded boulders.</u> Resting on the rock-platform and embedded in the basal deposits of the drift-cliff are large numbers of well-rounded igneous boulders. These boulders may be up to 3 ft. in diameter, although most are under 12" in diameter. Many of the boulders are of coarse-grained igneous rock similar to that of the St. David's Head - Carnllidi intrusions (Elsden, 1905), although they show much variation in grain-size. One or two of the large boulders which appear to have been over-run by ice are striated, but I have not seen striations on the boulders and pebbles which are securely embedded at the base of the drift-cliff.

2. Basal Deposits. The lowest drift deposit at Whitesands South is a thin heavily-stained layer of head and raised beach material set in a sandy matrix (Plate 17A). It is exposed in several short sections, in each of which it rests directly upon the rock platform. Generally, there is a lower layer of bedrock fragments, beach boulders, and iron-stained sand beneath a layer of disturbed head with rounded pebbles, which is stained by manganese oxide. The combined thickness of these two layers is seldom more than 9". In places boulders and head fragments are cemented to the platform by iron and manganese oxides. There do not appear to be any traces of raised beach *in situ*.

It is interesting that these basal deposits lie in exactly the stratigraphic position of Green's "boulder-clay with varied erratics" - i.e. apparently above the large boulders and beneath blown sand and head. I have found no till at Whitesands South, and it is possible that the boulder clay of Green was in fact the basal suite of deposits; however, it is quite possible that till was exposed in the locality in 1911, but has since been removed by wave-attack.

3. Stained sand. At the southern end of the exposure (Fig. 53B) a wedge of coarse red-stained sand lies above the basal deposits and beneath shale head, as figured by

Prestwich in 1892. He interpreted this deposit as a blown sand, as did Green (1911a). It contains blocks of shale bedrock from the old cliff-line, and also some lenses of fine shale head. It attains a maximum thickness of c. 8 ft. In view of the fact that it is stained, it may be related closely in age to the severely-stained deposits below.

4. Flaky shale head. Overlying the stained sand at the southern end of the section and elsewhere resting upon the basal deposits or directly on the rock platform is a fine flaky head of shale fragments (Plate 17B). Jehu (1904) called this deposit a sandy and earthy rubbly-drift which is "choke-full of small flakes of slaty and other rocks, which have a rude kind of arrangement, especially towards the lower part". (P. 75). Embedded in the head are rounded pebbles and angular erratic blocks, so that comparison is invited with the lower flaky gravels at Aber-mawr North. The shale fragments in the head are seldom more than 2" in diameter, although they appear to be somewhat larger just above the basal deposits. The head has a maximum thickness of c. 10 ft., although slumps of blown sand over the upper part of the drift exposure may mask a somewhat greater thickness.

5. Sandrock.[1] On the main part of the southern drift cliff the head is overlain by up to 6" of sandrock. In places it has resisted erosion and protrudes from the drift-face above the head, and here and there blocks have broken off and slumped down the drift-face. The deposit thickens inland and near the caravan-park sandrock outcrops through the blown sand in places.

6. Blown Sands. The southern drift-cliff is capped with a variable thickness of blown sand, which passes inland for almost a mile as the Burrows. The sands rise to an altitude of c. 200 ft. near Carn Croeswdig. The undulating surface of the dunes is now largely vegetated, although there are a few small blow-outs close to the coast. It is interesting that Green (1911a) recorded a hard-pan, "marking the site of an old marsh", at a height of 140 ft. on both sides of the Whitesands Valley; unfortunately he did not state whether this hard-pan occurred in or beneath the blown sands. It is possible that this hard-pan may have been simply a higher exposure of sandrock.

---

1. This deposit, strictly termed an "aeolian calcaronite", is probably a cemented blown sand. It is commonly found in association with head deposits on the North coast of Devon (Stephens, 1964).

Correlations.

There are difficulties in correlating the sections which lie to the north and south of the car-park, but this is attempted in Fig. 54.

The three sections to the north of the valley are themselves difficult to correlate. The blown sand is an easily-recognizable deposit which has a characteristic grain-size curve (Fig. 55); it occurs above all four sections, and so can be correlated with ease. Similarly the upper heads at Trwynhwrddyn and the gully seem to correlate with the upper rubble-drift in the northern drift-cliff. The line of boulders above the gully is a counterpart of the boulder-bed above the calcareous till at Porthmelgan, and is probably a glacial deposit related to a decalcified Irish Sea till beneath. This reddish till could conceivably be a much older deposit, but it is less than 5 ft. thick and its complete decalcification may be attributed to its particularly moist situation; the gully appears to collect much of the sub-surface drainage of the clifftop, for even in dry weather it may be seen streaming with water. The lower head in the gully appears to correlate satisfactorily with the lower shale head in the main cliff.

The glacial deposits at Trwynhwrddyn are more difficult to correlate, for two till masses appear to be represented there (Fig. 52). The upper till mass could be interpreted as the equivalent of the Irish Sea till, with the lower mass of greater age. This appears to be supported by the fact that the lower till mass is very thin (not over 9" thick), and appears to be less stony than the upper mass. However, if the lower mass does represent an earlier glaciation, it should be separated from the upper till by head or other sub-aerial deposits from a succeeding warmer phase; this is not the case, for the sandy and gravelly drift between the till masses is best interpreted as a stained outwash deposit, incorporating till and older head fragments. Furthermore, it is not necessary to assign the tills to different glaciations, for they are weathered in very similar fashion, their erratic content is similar, and they are not separated by a weathering front or erosional break. It is logical to assume that the tills, and the sandy outwash between them, are the product of one glaciation, and therefore correlate with the Irish Sea till. If this correlation is correct then it is best to correlate the lowest head at Trwynhwrddyn with the lowest heads in the gully and in the main drift-cliff.

Correlations across the valley from Whitesands North to Whitesands South are more difficult, for there is no till in the southern sections to use as a datum. The only safe correlation appears to be at the top of the sections, where blown sand is a common horizon. Beneath the blown sands, however, real problems are encountered for it is difficult to say whether the flaky head at Whitesands South is the equivalent of the upper rubble-drift in the northern drift-cliff. If it is, why is it overlain by sandrock, and why is it not underlain by till?

The flaky head at Whitesands South appears to be a close equivalent of the flaky gravels at Aber-mawr North, which lie beneath the Irish Sea till; but if it is correlated accordingly with the lower head at the main northern drift-cliff one has to explain the apparent absence of a suite of glacial deposits from above the head. It is unlikely that the sandrock is the equivalent of the Irish Sea till less than 300 yards to the north! On the contrary the sandrock is a thin deposit which may represent a previous generation of blown sand or else simply a "fossil" water-table.

Perhaps the problem will be solved by referring to Green (1911a), who recorded till from beneath the lowest sand lens at Whitesands South; if the Irish Sea till is wedged out in this position in the stratigraphic column the flaky head with erratics must be the correlative of the upper rubble-drift (Fig. 54). The presence of angular erratics in the head supports this interpretation.

The sand itself is difficult to interpret. Since it is interbedded with head fragments it is logical to suggest that it accumulated sub-aerially under cold, arid periglacial conditions - i.e. is a blown sand. However, if it is related to a destroyed till deposit, it could be interpreted in part as outwash.

<u>Interpretations.</u>

The lowest head at Whitesands North (Fig. 56 No. C) is a difficult deposit to interpret. Its orientation diagram has the dominant 30° sector within 10° of the sludge sector, apparently justifying its interpretation as head; however, there are only 30% of stones in the dominant 30° sector, and the diagram is unusual in that it has a strong transverse peak.[1] Furthermore, stone-counts from the wedge of head in the northern drift-cliff revealed that 38% of stones in the drift are striated, while only 76% of the stones are derived from the immediate upslope area (Fig. 57). Whereas the mean diagram for North Pembrokeshire heads has 58% of angular stones, this

1. For comparison with other head diagrams, see Fig. 28.

deposit has only 12% in the category, suggesting that the stones have been abraded during transport. There are 6% of rounded pebbles in the deposit, most of which are erratics.

When it is borne in mind that striated bedrock appears to pass beneath this head, there do seem to be grounds for suggesting that it is an old head re-deposited by ice (perhaps as a basal till layer). On the other hand, if the erratics were introduced into the head during transport at the base of a glacier, it could surely not have retained its preferred orientation. Stratigraphically, the head is the equivalent of the lower head suite with erratics at Aber-mawr, and the possibility must be borne in mind that the head is in situ. If this is so, then the erratics and the bedrock striations may date from the Early Glaciation.

The field interpretation of the Irish Sea till is confirmed by fabric analyses. From Fig. 55 this till is seen to have a somewhat shallower grain-size curve than the Aber-mawr Irish Sea till (see Fig. 41), but it is comparable to the curve for calcareous till from nearby Porthmelgan and appears to be simply a gravelly facies of the till. Its curve is nevertheless quite distinct from that of the rubble-drift, which has only 21.1% fines compared with 32.9% in the calcareous till.

Although the exposure of calcareous till is small, three preferred orientation counts were undertaken at three spot sites. Each count yielded a very different result (Fig. 58), with only no. (3) displaying any sort of affinity with the direction of ice-movement as indicated by striations. However, even this diagram has its dominant 30° sector dipping down-glacier, and the diagram appears to have been influenced in part by solifluxion. In diagram (2) there is a close relationship between the dominant 30° sector and the sludge sector, while diagram (1) has a dominant 30° sector which is apparently related to neither the sludge-sector nor the direction of ice-movement. This great variation in preferred orientations within one small exposure must be due in part to local sludging and slumping during deposition; this sludging may have been controlled in part by the underlying bed-rock surface, and in part by the configuration of dead-ice masses beneath the till. There is no evidence that the till has been "plastered" (Holmes, 1941).

The upper rubble-drift at Whitesands North is a highly variable deposit. From the cumulative curve in Fig. 55 it will be seen that it is comparable in grain-size composition with the Aber-mawr rubble-drift, with a coarser matrix than the Irish Sea till. However, it grades gradually upwards from this till, and the boulder-beds and sand and gravel lenses within the drift indicate that in part it consists of undisturbed outwash and till masses. However, stone-counts revealed that it contains almost as many sub-angular fragments (76%) as the lower head, while the percentage of bedrock fragments is somewhat higher than in the Irish Sea till (Fig. 57). Again, the preferred orientation diagrams in Fig. 56, based upon readings taken from two sites at the base of the rubble-drift exposure, apparently indicate that solifluxion has been an active depositional process at least 8 ft. beneath the ground surface. These figures reinforce the impression that the deposit is partly a solifluxion drift.

There is little doubt that the flaky head at Whitesands South is a true solifluxion deposit, for its preferred orientation diagram has 34% of stones in the dominant 30° sector; furthermore, this sector is only 20° removed from the estimated sludge sector (Fig. 56).

Relative Chronology.

The most recent glacial deposit at Whitesands seems to be the calcareous Irish Sea till, which has resisted complete decalcification and may therefore be assigned to the Dewisland Glaciation. The upper rubble-drift at Whitesands

North and the flaky head at Whitesands South apparently represent a prolonged period of solifluxion after the retreat of the ice - a conclusion supported by the thickness of upper rubble-drift at Aber-mawr and Porthmelgan. On the other hand something of a problem is presented by the negligible thickness of lower head at Whitesands, in contrast to the great thickness which has accumulated at Aber-mawr. Perhaps this discrepancy can be accounted for in part by the lower "solifluxion potential" of the Whitesands sites.

It appears most reasonable to suggest that the erratic pebbles in the lower head and perhaps the rounded erratics on the rock platform south of the car-park were introduced into the area during the Early Glaciation. This glaciation may have been responsible for some of the striations at Whitesands North. Following this glaciation there was a prolonged period of beach deposition on the platform, and later still a phase of solifluxion.

The staining of these beach and head deposits may have occurred in a subsequent period when the water-table was high in the valley, or in an interstadial phase of weathering such as that represented at Aber-mawr North. The sands beneath the flaky head at Whitesands South, and the sands on Trwynhwrddyn Promontory between the two till lenses,

Table V. A tentative reconstruction of events at Whitesands.

Events.	**Climate.**
Blown sands	Arid, cold ?
Flaky Head Rubble-drift	Moderate to severe cold.
Sand and gravel in rubble-drift	Deglaciation
Irish Sea Till	**Glaciation**
Blown sand Lower Head	Moderate cold ?
Raised Beach	Sea-level 8-10 ft. O.D.? Warm?

Erratic boulders	**Glaciation** ?

Platform-cutting Establishment of coast	Sea-level 8-10 ft. O.D.? Warm-temperate
----------------	
Cutting of Whitesands Valley	Temperate ?

are also stained by iron and manganese oxides. It is difficult to decide whether <u>all</u> the staining in the area occurred at the same time; if so, then the stained sands and lower till lens at Trwynhwrddyn must have been *in situ* while the beach and head deposits were being stained. In other words, the lower deposits at Trwynhwrddyn may date from the Early Glaciation. The implications of this could be important, for the rock platform on the promontory, on which the deposits rest, must then pre-date the Early Glaciation.

However unreliable this speculation, it is suggested in Table V that the platform-cutting phase occurred before the Early Glaciation. The other suggestions made above are also summarised in the table.

Chapter 5 (B2).

THE PORTHMELGAN CHANNEL AND DRIFT-CLIFF.

At the western end of the small valley of Porthmelgan, just east of St. David's head, c. 20 ft. of drift is exposed in a drift cliff and in a stream cutting where a small stream descends to the beach. The clearest part of the exposure lies just to the east of a small waterfall. The locality is mentioned in the literature by Green (1911) and Cox et al. (1930). Jehu noted the presence of striations at Porthmelgan, but did not record the drift section. Several examinations of the site have revealed the drift succession shown in Fig. 59.

Green (1911b) noticed that the drift at Porthmelgan fills the deep valley which runs south-westward from Porth Uwch (Plate 18). The stream in this valley at the present day is a misfit, flowing upon the drift fill. Near the drift exposure the valley has a deeply-cut form, with its floor below sea-level (Cox, 1930a). It is cut across the St. David's headland, and has a humped long-profile, with a col at c. 180 ft. O.D. In cross-profile the drift is seen partly to fill a deep channel incised into an earlier, gently sloping valley-floor. (Plate 19).

Bedrock. Ordovician shales of the Arenig series are exposed at the northern end of the section beneath the drift cover (Cox et al, 1930), and again to the south of the Porthmelgan stream. Just above the beach in this vicinity are several smoothed and striated bedrock slabs. Three yards beyond the end of the pebble beach and just above H.W.M. sloping and eroded shale slabs reveal striations trending towards 120° and 160°. One of the striations takes the form of a series of crescentic gouges strung together for a length of 7". On the next smoothed slab to the west striations are seen trending between 140° and 190°; and one deep gouge swings through 80° till it trends towards 230°, parallel with the vertical face of the slab above. Apparent chatter-marks (Harris, 1943) and other series of small pits in the eroded rock surface also appear to be the result of glacial gouging, for, like the striations, they are unrelated to the bedding or fractures of the shale bedrock. Some striations trend in sympathy with the bedrock configuration, but the overall trend appears to reflect ice-movement towards 160°; this agrees well with the direction of ice-movement inferred by Jehu (1904) from striations near the stream. The preservation of striations on slabs only 4 ft. above the sandy beach and within easy reach of storm waves is something of a problem; it is possible that until recently the slabs in question were buried beneath beach sand.

1. Lowest Head. Directly above bedrock, although poorly-exposed in the section, is a thin head of angular shale fragments which are generally 2" - 6" in diameter. The head displays some pseudo-stratification, although since it is near the stream it is wet and possibly subject to some present-day sludging; the stratification cannot with certainty be called an initial characteristic of the head. The contact with underlying bedrock is not clearly seen. An initial examination of the head suggested that it contains no erratics; an intended more thorough search for erratics in April 1965 was frustrated because the head was nowhere to be seen. Even extensive excavation failed to reveal any satisfactory exposure.

2. Laminated silt. Just south of the stream a wedge of calcareous grey and buff-grey laminated silt overlies the lowest head or a smooth bedrock surface (Plate 20). The silt is generally clean, although it contains a few thin gravelly layers and some head fragments near its base. Some bedrock shale fragments occur in the upper part of the silt. The layer is up to 4 ft. thick, and displays minute traces of current-bedding, which may indicate a water-deposited origin. There are no shell fragments in the silt.

3. Purple calcareous till. Up to 15 ft. of shelly calcareous Irish Sea till overlies the laminated silts. It

is relatively stoneless, although striated erratic pebbles and boulders over 2 ft. in diameter are stuck in the compact plastic matrix. Among the erratics are boulders from Scotland and Antrim (Cox, 1930), vein quartz, Cretaceous flint, coarse-grained igneous rocks, and grey shales. The till is often fissile, and irregular veins of silt and clay are common (Plate 21). There is little appearance of decalcification at the base of this till, although it is weathered and decalcified in its upper part to a depth of c. 5 ft. Near the stream several huge igneous erratics are observed in the till. One, which has a diameter of c. 10 ft., has been washed out of the till and has been frost-shattered into several distinct "slices" since exposure.

Possibly related to the exhumed boulders near the stream is a distinct layer of large sub-angular igneous boulders which are interbedded with the till; the layer is c. 4 ft. thick, and dips southwards across the drift exposure. The matrix of this boulder-bed is still strongly calcareous, but is more sandy and gravelly than in the purple till above and below. The layer has a grey-brown colour, but does not appear to be separated by an erosional or weathering break from the calcareous till either above or below. It seems that it is essentially a part of the single suite of glacial deposits.

4. Rubble-drift. Above the calcareous till lies up to 5 ft. of rubble-drift which consists in part of decalcified lower till and in part of soliflucted and sludged deposits. It contains several easily-identified patches of stratified shale head from the valley-side above; this characteristic is seen both in the main drift cliff and in a small exposure on the clifftop south of the stream. Rounded and striated igneous stones 6" to 9" in diameter are found alongside angular shale fragments in a gravelly and stony matrix. The drift is coloured chalky brown, although where it outcrops at the surface it is weathered dark brown to a depth of 12". Augering above the drift-cliff revealed that the rubble-drift is in places severely gleyed, with a high silt content, although it is everywhere non-calcareous and non-shelly.

5. Upper head. Probably related to the lenses of head in the rubble-drift, but generally lying near the top of the section is c. 2 ft. of stratified local head consisting of angular shale flakes and erratics in a silty matrix. It is clearly derived from the valley-side above, which slopes at over 20° in places. Most of the fragments in this head are 3" to 12" in diameter, and are stratified approximately parallel to the slope.

6. Sandy loam. At the top of the section is a sandy loam up to 2 ft. thick. It contains few stones apart from some incorporated head flakes. The upper few inches of the deposit are weathered to a soil.

Interpretation.

Cox (1930a) suggested that the deep valleys in this area are graded to sea-level; presumably he considered them to have a sub-aerial origin. Regarding the formation of the Porthmelgan channel, however, it is difficult to imagine sufficient water ever having been available for its cutting by normal fluvial processes. The humped bedrock profile, the steepness of the channel sides, and the fact that it is cut across the headland all suggest that the valley has a fluvio-glacial origin (Sissons, 1961). The fact that head which predates the Porthmelgan till is found on the floor of the channel indicates that it must have been cut during an earlier glaciation.

If the channel is sub-glacial, as is suggested by its form and relations with the surrounding topography,[1] then it would be difficult to associate it with ice moving south-eastward (as is indicated by striations of the last

1. A fuller consideration of the diagnostic features of sub-glacial channels is given in Chapter 10.

glaciation). Sollid (1964) and other workers have shown that sub-glacial meltwater flow is controlled above all by the ice-gradient; if this is so, then ice-directed drainage associated with the last glaciation should have been orientated towards the south or south-east. It may tentatively be suggested at this stage, therefore, that the ice-gradient of the early glaciation rose towards the north-east. It is worth bearing the possibility in mind in later discussion that the two glaciations which appear to be represented at Porthmelgan may have originated in different source-areas.

The earliest representative of the drift suite at Porthmelgan is the lower head, which is moderately blocky and which may have been deposited under rather cold and moist periglacial conditions (Dylik, 1964). Its original thickness cannot be estimated, for while it has not been contorted by over-riding ice, head fragments are found in the base of the till; at least some erosion of the head must therefore have been achieved by the over-riding ice. There is no evidence in this section of striated bedrock passing beneath the lowest head.

The laminated silts, in view of their calcareous nature, gravelly layers, and gradation upwards into calcareous till, appear to be part of the glacial deposits. The presence of bedding-structures suggests that they were laid down at the base of the ice before large-scale deposition of the till, perhaps as a result of basal washing of fines (Carruthers, 1939; 1948). The silts do not appear to be a sub-aerial stream-deposit or hillwash; they are too compact and stoneless, and are quite different in character from such deposits in the area today.

The till appears to be a true Irish Sea till in view of its calcareous matrix, shell content, and grain-size distribution (Fig. 55). The striations in the area suggest that the ice must have passed over the high ridge of St. Davids Head (over 200 ft. O.D.) before depositing the till. While it appears from the preferred orientation of till pebbles that the ice which deposited it may have moved from the south-west (Fig. 60A), it is difficult to imagine an ice-gradient which would have permitted ice-movement in this direction. Furthermore, ice moving up the Porthmelgan valley would surely have left striations on the exposed bedrock slabs above the beach; in contrast, the striations, and the erratic content of the till, indicates ice-movement during this glaciation from the north-west.

The transverse nature of the orientation diagram seems to indicate that "plastering" was not the process responsible for the deposition of the till. The presence of near-vertical veins of silt and clay (Plate 21) and sand and gravel patches may indicate that the till was laid down at the time of deglaciation by the slow melting-out of the basal glacier zones, with associated faulting and slumping of local till masses (Harrison, 1957b).

The concentration of large sub-angular igneous boulders in a broad layer within the till presents a slight problem of interpretation, for most of them are derived from the ridge of St. David's Head to the north. However, they do not appear to have been soli-flucted from the valley slope, for the bedrock beneath the greater part of this slope is Ordovician shale, frag-ments of which are rare in the deposit. The lack of a weathering contact or erosional break in association with the layer, and its calcareous matrix, strongly suggest that it is part of the till suite. It seems plausible that the layer owes its existence to an unusually inten-sive phase of glacial erosion on the ridge to the north, while for some reason the ice carrying the upper and lower till layers achieved relatively little local erosion. Perhaps the idiosyncrasies of shear-plane formation could account for this.

The fabric characteristics of the rubble-drift are seen on the basis of fabric analysis to be markedly different from those of the calcareous till beneath. The preferred orientation diagram for the drift (Fig. 60B) displays a very strong peak, with its dominant 30° sector closely coinciding with the sludge sector. The sample was taken c. 7 ft. beneath the clifftop, so it seems that the rubble-drift has been soliflucted at least to this depth since deposition. This is supported by the presence of interbedded shale head. Roundness analyses on pebbles from the calcareous till and the rubble-drift (Fig. 61) revealed that they have rather similar histograms, all approximating to the North Pembrokeshire mean diagram for moraine. However, the lower proportion of rounded pebbles in the rubble-drift (24% compared with 32%, 26%, and 30% for the calcareous till samples) is consistent with its higher proportion of upslope bedrock fragments (60% as against 34% in the calcareous till). Stone-counts revealed a much higher percentage of erratic pebbles in the calcareous till, and a greater variety of stone-types. Further tests on samples from the two drifts revealed that the calcareous till contains 48% striated pebbles compared with only 36% in the rubble-drift.

From the convergence of evidence, therefore, it appears that the rubble-drift at Porthmelgan has been subjected to considerable local sludging since, and perhaps

Table VI . A tentative reconstruction of events at Porthmelgan.

Events.	Climate.
Surface soil	Temperate
Sandy loam	Cold and arid ?
Upper Head	Moderately cold
Rubble-drift	Deglaciation
Calcareous Till }	Glaciation
Laminated Silt }	
Lowest head	Moderately cold

Valley erosion	Glaciation ?

during, deposition. This sludging was effective to at least a depth of 7 ft. beneath the ground surface. In spite of downslope movement it still retains most of the characteristics of a till. There is, however, no evidence to suggest that it was laid down by a different ice-sheet than that responsible for the calcareous till, for the deposits grade into one another.

The stratified head above the rubble-drift probably represents a short phase of moderately severe periglacial solifluxion, followed by a phase of wind-action and hill washing, probably still under periglacial conditions. (Dylik, 1964).

From an interpretation of the deposits at Porthmelgan the sequence of events shown in Table VI may be represented.

Chapter 5 (B3).

THE HEAD DEPOSITS AT PEN DAL-ADERYN.

At Pen Dal-aderyn, on the south-western extremity of Dewisland and overlooking Ramsey Sound, a rock platform is capped with complex head deposits. These deposits are exposed in a much-eroded state at the base of a small peninsula, but are most easily examined in a small drift cliff c. 30 yds. long and 10 - 12 ft. high (Plate 22A). The locality has not previously been mentioned in the literature.

The Rock Platform. The rock platform has a total length of c. 50 yds, and a maximum visible width of c. 15 yds. Its northern part may be much wider, but the covering of head makes estimation of its total width impossible. The southern part of the platform consists of a broken rock surface at an altitude of c. 34 - 37 ft. O.D. The surface is cut across fine-grained soft gritty Pre-Cambrian tuffs (probably of the Ramsey Sound (Pebidian) series), and is deeply weathered and pitted as a result of long exposure (Cox *et al*, 1930a). Many loose fragments and angular boulders of bedrock lie on the platform surface and in recently-exploited rock clefts (Plate 22B). The whole surface is well-covered with lichen, and grasses are established on the northern end of the platform.

The platform falls in altitude to c. 29 ft. O.D. on a col in the vicinity of spectacular pillars of blocky head (Plate 22A). On this col the platform is narrow and dissected, but northwards it becomes a distinct feature c. 10 yds. wide and rising to an altitude of c. 36 ft. O.D. at its northern end. Beneath the drift cliff its broken surface slopes seawards at c. 4°, although loose blocks and debris from the drift-cliff face cover the slope.

Fine silts and gravelly materials lie in the hollows on the northern part of the platform. However, gravel particles are angular, and there is no evidence to suggest that they are raised beach gravels. It seems more likely that all loose fragments on the rock platform are derived from the drift cliff or from sub-aerial weathering of the surface itself.

<u>The Head Deposits.</u> The head deposits exposed in the drift cliff consist largely of angular blocks and flakes of purple, green and buff Pre-Cambrian tuffs derived from upslope. Certain horizons are recognised in the drift-cliff, as indicated in Fig. 62.

1) <u>Blocky green-buff head.</u> This head is c. 12" thick at its maximum, and is only observed at the base of the head

pillars. It consists largely of soft sub-angular blocks of green-buff tuffs c. 3" - 6" in diameter. Some blocks attain a diameter of 12". The matrix is sandy and red-brown in colour, and some erratics are found at the base of the head just above the contact with the rock platform.

2) Lowest head with many erratics. This head is found in a 12" layer between the blocky green-buff head and the purple blocky head at the base of the head pillars. It contains many small greenish bedrock blocks, and is distinguishable on the basis of its high content of erratic pebbles in a matrix of gravelly and silty mud. The erratic pebbles are up to 3" in diameter, and are often striated and rounded.

3) Purple blocky head. This is a massive head up to 5 ft. thick which is found throughout the length of the exposure. It is most chaotic in the head pillars, where particles vary from large angular blocks up to 4 ft. diameter to gravelly particles ¼" in diameter (Plate 23). There is no sorting in the deposit, and little pseudo-stratification. Most of the blocks in the pillars are of red, purple, blue or green tuffs in a brown sandy matrix; northwards most of the blocks are of purple tuff, possibly reflecting a gradation to a more uniform upslope outcrop.

There is a notable absence of erratics in this head, and only one piece of Cretaceous flint has been found to date. Some blocks are sub-angular, although this appears to be the result of sub-aerial weathering. One large angular boulder of bedrock appears to have one faceted surface (Plate 23). Slight grooves on this surface do not have the appearance of striations and appear to have resulted from the weathering of joint systems. However, one or two deeper grooves trending to 145° are visible, and these may have originated as glacial gouges.

In the southernmost part of the drift cliff the top of this layer is seen to be weathered to a depth of c. 6". This weathered layer is discontinuous, however, and it is difficult to estimate its significance.

4) <u>Buff blocky head with erratics.</u> This layer is seen along the drift cliff overlying the purple blocky head. The junction is irregular but gradual, and there is no appearance of truncation. The constituent blocks of the head are of coarse buff tuff with chlorite and quartz crystals, and although the fragments are soft and rather rotten, there is no reason to suppose that the head is a weathering product of the head below. Rounded and striated erratic pebbles are common, and sandstones and quartzites, Cretaceous flints, rounded red quartz pebbles from

the Cambrian basal conglomerate, blue Pre-Cambrian halle-flinta, and coarse-grained igneous rocks have been found. Some erratics up to 2 ft. in diameter are clearly striated. This layer appears to have two slight and discontinuous weathering zones, neither of which is more than 3" deep.

5) Purple-green blocky head. This is an unweathered rather blocky angular head up to 4 ft. thick. Like the purple blocky head it consists of soft flaky tuffs, but its fragments are smaller (with few flakes over 6" diameter) and its pseudo-stratification better. There are few erratics in this head.

6) Purple-buff finer head. This layer consists largely of purple-green soft tuffs, and is distinguishable on the basis of its colour and high erratic content from the head beneath. It is 3 ft. thick in places, and most of its fragments are between 2 ft. and 3" in diameter. It has a buff-brown sandy matrix. Fragments are much-disturbed by frost, and a good fossil ice-wedge passes from the base of this head into the purple-green head beneath.

7) Sandy loam. A typical sandy loam caps the drift cliff, being c. 12" thick and with few stones except bedrock flakes. It is similar to the sandy loam at Porthmelgan.

Interpretation.

The rock platform at Pen Dal-aderyn appears to be of marine-cut origin, in spite of its lack of raised beach gravels. In its characteristics it is similar to the rock platforms at Trwynhwrddyn (14 - 17 ft. O.D.). over 2½ miles to the north-east, and at Ogof Golchfa (15 - 35 ft. O.D.) 1½ miles to the east. Like these platforms, it has a similarly shattered and lichen-covered surface. While it differs somewhat in altitude, this may be accounted for in part by its exposed position which may have resulted in higher platform cutting initially and greater erosion during recent times.[1] In the absence of other evidence, it is reasonable to assume that the Pen Dal-aderyn raised beach platform is possibly of approximately the same age as others in the area.

The heads are difficult to interpret, for the subdivisions are based simply upon differences of block size and colour. The colour and rock-type of individual layers probably reflects the lithology of the upslope bedrock outcrop at any stage of head formation, although the interbedding of buff and purple layers is something of a problem.

---

1. Stephens (1957) points out that rock platforms on headlands can be correlated with lower platforms in more sheltered positions.

It is difficult to explain the high erratic content of the buff head layers; upslope bedrock exposures cannot be seen, so it is not known whether the buff exposures could have coincided with patches of till at one time. This may suggest that the purple heads are of soliflucted bedrock fragments, while the buff heads bear more of the characteristics of soliflucted till. Against this may be cited the fact that the erratic content is still low even in those heads characterised by erratics.

A glaciation prior to the head development is indicated by the presence of erratic striated pebbles even in the lowest head. In this sense the situation is similar to that at Aber-mawr. But the lack of till in the Pen Dal-aderyn section means that the head cannot safely be claimed to pre-date the most recent Irish Sea Glaciation. Thus it is possible that:

1. Some of the head pre-dates and some post-dates this glaciation.
2. All the head pre-dates the last glaciation.
3. All the head post-dates the last glaciation.

The first of these possibilities is rendered unlikely by the lack of a real weathering break or erosional truncation in the section. The depositional process appears to have been relatively continuous, for the slight weathered zones in layers 3) and 4) could have been formed during very short climatic oscillations lasting just a few seasons.

There are great difficulties to be answered if the second possibility above is considered. Relatively unweathered Irish Sea till occurs at an altitude of c. 40 ft. O.D. at Druidston on the eastern shore of St. Bride's Bay, implying that the ice of the last Irish Sea glaciation reached that point. Evidence of erratics (Cantrill, 1916) and striations (Hicks, 1891) indicates that the ice which deposited the Druidston till probably passed over the western part of Dewisland, so it would seem unlikely that Pen Dal-aderyn could have escaped glaciation. If the heads pre-date this glaciation, why is there no evidence of till above them?

It therefore seems more likely that the head deposits at Pen Dal-aderyn post-date the most recent Irish Sea glaciation of Dewisland, and are the equivalent of the thick upper heads at Aber-mawr and Whitesands.

The conditions under which the Pen Dal-aderyn heads were laid down seem to have been only moderately severe. There are no fine flaky gravels in the section which might represent conditions of extreme cold and high permafrost levels (Dylik, 1964). On the other hand the blocky nature of most of the head may have resulted in part from the rock lithology and in part from effective and rapid frost-shattering in a moist, cold periglacial environment. In spite of the relative rarity of erratics in the purple blocky head (Plate 23), its chaotic and unsorted nature is reminiscent of certain ablation moraines in East Greenland; so it may tentatively be suggested that some of the lower heads were laid down either on wasting glacier ice which filled Ramsey Sound, or in an immediately pro-glacial environment. Above the chaotic head the appearance of pseudo-stratification may indicate slower head formation under slightly colder conditions, culminating in a very cold phase of ice-wedge cracking at the end of phase 5). (Péwé, 1964). During phase 6) there may have been a return to less cold conditions, followed by intense frost disturbance to a depth of c. 2 ft.

Thus the possibility emerges that this suite of head deposits represents a post-glacial period of fluctuating climate. The moderately severe nature of this climate appears to correlate with the climatic conditions suggested for the formation of the Aber-mawr and Whitesands upper heads. Initial rapid mass-wasting at Pen Dal-aderyn was

Table VII. **A Tentative reconstruction of events at Pen Dal-aderyn.**

Events.	Climate.
Sandy loam	Cold and dry?
Frost disturbance	Severe cold ?
Purple-buff finer head	Cold and moist
Ice-wedge cracking	Severe cold
Purple-green blocky head	Cold and moist
Weathering horizons ?	Warmer phases ?
Lowest blocky heads	Cold and moist

Erratics	Glaciation

Raised beach platform	Sea-level 34-37 ft. O.D. ?
	Warm

followed by a phase of less moist and rather colder climate, interrupted by short weathering phases. An eventual deterioration to very cold climatic conditions was followed by a later amelioration (Table VII).

The Pen Dal-aderyn heads possibly correlate with only the post-glacial part of the sequence at Aber-mawr.

Chapter 5 (B).

SUMMARY OF CONCLUSIONS.

Although the sections at Porthmelgan, Whitesands and Pen Dal-aderyn all lie to the south of the "South Wales End-moraine", at Porthmelgan and Whitesands North are drift successions which are comparable to those of the North Pembrokeshire coast. As at Aber-mawr and the Afon Nevern Estuary, there is evidence of an Early Glaciation which achieved some meltwater erosion and introduced erratics into the area. Following a period of raised beach deposition and then a periglacial phase, a glaciation occurred from the Irish Sea; all the stratigraphic evidence suggests that the Dewisland Glaciation, which was responsible for the deposition of the calcareous till at Aber-mawr, was also responsible for the deposition of the tills at Porthmelgan and Whitesands.

1. Stratigraphy.

In Fig. 63 an attempt is made to correlate the sections from the west coast of Dewisland. The calcareous tills at Porthmelgan and Whitesands North are easily correlated, as are the upper rubble-drifts at both localities. The boulder-bed and the laminated silts at Porthmelgan appear to be related to the calcareous till, and it seems that the lower shale heads at each locality are of similar age.

The difficulties of correlating the drifts to the south of Whitesands stream arise from the fact that no calcareous till is seen there; however, there appears to be good reason for assuming that the beach deposits and lowest head at Whitesands South may be older than the Irish Sea till, while the flaky shale head with erratics may be the equivalent of the rubble-drifts to the north of the stream. Again, it has been argued that the whole suite of head deposits at Pen Dal-aderyn post-dates the Dewisland Glaciation, although the absence of calcareous till from the rock platform remains something of a problem. However, when it is considered that there is no calcareous till on the similarly exposed headland of Pen Deudraeth (Chapter 5A), while it is found at Abermawr North less than 40 yards away, it may not be unreasonable to attribute the lack of till to Pen Dal-aderyn's unfavourable site. Indeed, the till exposures at Porthmelgan and Whitesands North are both in particularly favourable sites in the lee of rock-masses which lay across the path of the advancing Irish Sea ice.

2. <u>The Mode of Deposition of Some Drifts.</u>

Some of the main points made in the preceding pages concerning drift deposition may be summarised as follows:

(a) The lowest head at Whitesands North appears to be <u>in situ,</u> although it contains erratics and is seen to overlie striated bedrock.

(b) Pebbles in the calcareous Irish Sea till do not show a strong preferred orientation which accords with bedrock striations, and it is probable that the till was subjected to local slumping and sludging during or shortly after deposition. The calcareous tills at Whitesands and Porthmelgan are coarser than the equivalent till at Abermawr, and the boulder-bed at Porthmelgan indicates that the till is by no means homogenous; in places there is considerable variation in till lithology.

(c) The upper rubble-drifts at Porthmelgan and Whitesands North are not thought to be tills dating from a later glaciation than that which deposited the calcareous till. There is much evidence to suggest that the drift is a mixture of till, outwash sand and gravel, and solifluxion debris. The proposal that the drift is no younger than the Irish Sea till is supported by the fact that the two are intimately associated; calcareous till and stony rubble-drift occur at both Porthmelgan and Whitesands North, while neither deposit is found at Whitesands South or Pen Dal-aderyn. If the rubble-drift is an independent glacial deposit there is no reason why its coastal distribution should be identical to that of the calcareous till. The evidence suggests that the Dewisland Glaciation was the last glaciation of the area.

(d) The sandrock beneath the recent blown sands is a thin layer which may represent no more than a "fossil" water-table. It is not comparable stratigraphically with the thick sandrock deposits of North Devon (Stephens, 1964).

3. The Valleys of Whitesand Bay.

The valley at Whitesands appears to be an ancient feature cut sub-aerially and graded to beneath present sea-level. Today it is drift-filled and supports a small, misfit stream. It has a raised beach platform cut across its southern flank, so the valley itself must have been in existence before the period of platform-cutting and before the establishment of the present coast. It must also predate the postulated Early Glaciation (which introduced the beach erratics) and all the other events which are represented in the drift sections.

The Porthmelgan Channel, which is also filled with drift, appears to pre-date both the Dewisland glaciation and a sub-aerial periglacial phase which preceded it. It is suggested that the channel may be a sub-glacial feature; it is certainly unlikely to have been cut sub-aerially. Tentatively, it may be dated to the Early Glaciation.

4. Evidence for Climatic fluctuations.

The raised beach platforms at Pen Dal-aderyn and Whitesands South are unlikely to have been cut during the same marine stillstand, for their respective lowest altitudes differ by 26 ft. At both platform-cutting phases, however, the climate may have been warmer than that of today, as reflected by the higher sea-levels. Again, the climate may have been warm during the deposition of the raised beach, although the association of head with the stained beach deposits may indicate that periglacial conditions immediately preceded or post-dated the raised beach period.

The lowest head is thin in all the drift localities on this coast; it provides no clues to periglacial climatic fluctuations such as are represented at Aber-mawr.

Following the Dewisland Glaciation there appears to have been another period of solifluxion. From the blocky rubble-drifts around Whitesand Bay little information can be gained concerning this period, but at Pen Dal-aderyn a comprehensive record is preserved. The periglacial climate appears to have been only moderately severe, for blocky heads predominate; however, there appears to have been at least one short weathering break, followed some time later by a severe periglacial phase represented by flaky head and fossil ice-wedges. The flaky head at Whitesands South appears to correlate with the Pen Dal-aderyn head series, and yet its flaky nature may indicate prolonged conditions of climatic severity; in this case, therefore, stratigraphic and lithological correlations are in conflict, and it may be advisable to remain cautious on the climate of this periglacial phase.

Following the deposition of the upper heads, there is evidence from all the sections for hillwashing and some wind-action, with subsequent climatic amelioration.

5. Older Drift or Newer Drift?

The coastal exposures considered in the foregoing pages all lie to the south of Charlesworth's "South Wales End-moraine" and yet the drift stratigraphy is no different from that of coastal sections to the north of the moraine. Even at this stage of the thesis there are grounds for suggesting that the end-moraine is not a terminal feature of a Newer Drift glaciation. If the Irish Sea till is the product of the Newer Drift ice, then the glaciation was more extensive than Charlesworth envisaged; on the other hand, if the till is the product of Older Drift ice, then no later ice-sheet appears to have over-ridden the Pembrokeshire coast.

TABLE VIII CORRELATION AND INTERPRETATION OF EVENTS IN WESTERN DEWISLAND.

STRATIGRAPHIC CORRELATIONS				SUGGESTED INTERPRETATIONS		
Porthmelgan	Whitesands N.	Whitesands S.	Pen Daladeryn	Sea-level	Climate	Events
S. loam	B. sand	B. sand	S. loam	Low - rising	Cold-arid?	Wind-action etc?
Upper head	Rubble-drift	Sandrock?	Fine hd.		V. cold	Solifluxion and ice-wedges
Rubble-drift		Head with erratics	Blocky heads		Cold?	Solifluxion
			Weathering horizon		Warmer	Weathering
			Blocky head		Cold	Solifluxion
Irish Sea till	Irish Sea till	B. sand	↓ ?	Very low	Warmer	
					Glacial	Dewisland Glaciation.
Lowest head	Lowest head	Lowest head		Low-falling	Cold	Solifluxion
		Raised beach		High	Warm	Beach deposition
Channel	Erratics			Very low	Glacial	Early Glaciation
	Raised beach platform			High	Warm?	Platform-cutting
Establishment of coast				As pres?	Temp?	Est. of coast
	Whitesands Valley			Lower?	Temp?	Sub-aerial valley erosion.

The stratigraphic correlations and suggested interpretations for the coastal sections in West Dewisland are summarised in Table VIII.

Chapter 5 (C)

The south coast of Dewisland.

C1. The Ogof Golchfa raised beach and associated deposits.

C2. The drift sections at Caerbwdy.

Summary of Conclusions.

Chapter 5 (C1).

THE OGOF GOLCHFA (PORTH-CLAIS) RAISED BEACH AND ASSOCIATED DEPOSITS.

Between Porth-clais harbour and Ogof Golchfa, a cave some 300 yards to the west, there is a small headland on which is preserved an excellent drift section. The section is preserved on an extensive raised beach platform, and has been described by Prestwich (1892) and Leach (1911). It is mentioned more recently by Synge (1963) and Mitchell (1962).

Beneath a degraded cliff-line at the base of the headland a vegetated terrace of drift some 50 yards wide slopes seawards at c. 2°. It is in the small cliff on the seaward edge of this terrace that the drift succession to be described is visible (Plate 24A). Many visits to the locality between 1962 and 1965 have confirmed the presence of the section shown in Fig. 64.

1. The Raised Beach Platform. The well-displayed rock platform of Ogof Golchfa extends for c. 40 yards on the headland, and is only partly covered with superficial deposits. It appears to extend landwards for c. 40 yards beneath a drift cover to the base of a degraded cliff-line. Leach (1911) placed the altitude of the platform at 15 - 20 ft. A.H.W.M.; but in places it is as much as 30 ft. A.H.W.M.

(c. 35 ft. O.D.). The main body of the platform is never less than 25 ft. O.D., although in the cove to the west there are traces of a platform at c. 15 ft. O.D. This lower platform is inaccessible, but seems to support a sequence of deposits similar to that on the higher platform remnants.

The greater part of the platform is cut across a fine-grained dolerite sill (Cox et al, 1930b) bounded by near-vertical strata of greenish Lower Cambrian shales and sandstones. Parts of the sill have resisted erosion to form slight ridges running across the platform. The seaward margin of the platform is much-dissected, and even parts of the inner platform surface are breaking up rapidly. Loose angular blocks of bedrock litter the surface, and as at Pen Dal-aderyn the surface is well-colonised by lichen. In places ice-smoothed surfaces are preserved, with innumerable striations up to 9" long. On the stacks to the east of the platform there are traces of deep glacial grooves 2" wide and trending almost due south, but good striations on the platform indicate a general ice-movement direction towards 125°. There are signs of ice-movement between 90° and 140°, and more local swings in direction towards 80°, 33°, and 25° are indicated.

Boulders on the Rock Platform. Leach (1911) noted the presence of large, well-worn and ovoid boulders on the rock platform and sometimes embedded in beach shingle. Most of the boulders on the higher part of the platform are angular blocks of local Cambrian sandstone, shale, or igneous rock, which could easily have been derived from the platform itself or from the degraded cliff-line. Other smaller boulders (up to 2 ft. in diameter) of purple Cambrian sandstone, red shale, and Cambrian basal conglomerate, are all well-rounded, and could quite easily have been derived from a buried storm-beach at the back of the platform. They are not far-travelled, and are typical components of other storm-beaches in the area such as Caerfai and Caerbwdy. The only accessible boulder foreign to the area is the huge diabase boulder which projects from the drift cliff (Leach, 1911). It lies on till, and although weathering has removed any striations it was probably deposited by glacier ice.

On the lower and inaccessible part of the platform several large boulders lie on the rock platform or are embedded in raised beach deposits. These boulders are rounded and some are foreign, but in view of their inaccessibility it has not been possible to decide whether they could have fallen from the till above, or whether they could be "normal" storm-beach boulders (Plate 25).

1. <u>The Raised Beach Shingle.</u> The raised beach materials attain a maximum thickness of c. 3 ft. on the inaccessible western part of the platform. There are few traces of gravels on the main platform surface, although one small exposure may be seen beneath a large boulder just to the west of the vegetated "col". Here pebbles were found to be well-rounded and generally less than 3" in diameter. Most pebbles were derived from local red Cambrian shales and purple sandstones, and other pebbles of grey Cambrian shale, vein quartz, local white Dimetian granophyre, Cretaceous flint, and other Dewisland igneous rocks were discovered. gravelly and silty material In low depressions on the eastern part of the platform may be a mixture of raised beach shingle and flaky fragments washed from the till exposure above (Plate 24B).

Leach noted the presence of concreted raised beach shingle on the platform, sometimes cementing erratic boulders to the rock surface. In spite of a prolonged examination of the deposits, I have not found any cemented shingle; all the shingle exposed is sandy, loose, and friable. It is possible that some of the cemented patches seen by Leach have since been removed by storm-waves.

2. <u>Lower Head of Beach Pebbles.</u> Above the raised beach

shingle in the western part of the exposure lies up to 8 ft. of well-stratified head. Stones in this head are generally 6" - 12" in diameter, and are almost always well-rounded. The stone-types represented in the head are identical to those in the raised beach deposits below, and are set in a red-brown sandy matrix. While some of the pebbles have a somewhat angular and flaggy appearance, and some appear to have been derived from purple sandstone outcrops on the degraded cliff-line, a clear impression is gained that the head consists almost entirely of fragments from a now-invisible "pre-glacial" storm-beach at the back of the platform. Leach mentioned that raised beach deposits were 10 ft. thick on the western part of the platform, and it is clear that this figure includes the 8 ft. of soliflucted beach material (Plate 25). Soliflucted beach material is known in Islay, West Scotland (McCann, 1964), and from localities in Devon and Eastern Ireland.

3. Non-Calcareous Local Till. The Lower head is overlain by up to 8 ft. of red-brown non-calcareous till. It attains its maximum thickness in the western and eastern parts of the exposure, and near the vegetated col it appears to have cut its way through the lower head (Cox *et al*, 1930b). The till is generally stony, and has a

sandy and gravelly unstratified matrix. It has a high content of angular pebbles of local purple and red Cambrian sedimentary rocks, and although there is a larger variety of striated foreign stones than in the underlying beach deposits the erratic types are rather similar. Many angular blocks in the till are over 12" in diameter, and some boulders are over 2 ft. in diameter. In the eastern part of the section there are few stones over 6" in diameter in the till. At this point the till outcrops at the surface, and is weathered to a depth of 2' 6". In places the till rests directly on the striated raised beach platform.

4. Upper Local Head. This was not mentioned by Leach, although Mitchell (1962) and Synge (1963) mention its presence. It is well-exposed only in one locality, along-side the small footpath which descends from the drift terrace above Ogof Golchfa cave. The head is no more than 2 ft. thick, and is a distinct and colourful layer as a result of its high concentration of Cambrian purple sand-stone and shale fragments (Plate 26). Most of the frag-ments in this head are probably derived from uphill bedrock outcrops and from the underlying till.

5. Sandy Loam. This deposit, which is up to 2' 6" thick, covers the greater part of the terrace. It is of yellow

to red-brown colour, and is often silty and stoneless. It does, however, contain bands of flaky bedrock fragments and pebbles derived from till. It may therefore have been deposited in part while solifluxion was still active. It has a "honeycomb" appearance similar to that of sandy loams at Aber-mawr and in the Gower Peninsula (George, 1933).

Interpretation.

Preferred orientation studies reveal that the field interpretation of the Upper and Lower Heads is probably correct. The Lower Head (Fig. 65-1) yields a very strong downslope peak, although not in the direction expected. The difference of 90° between the centre of the sludge sector and the centre of the dominant 30° sector indicates that the slope which controlled the solifluxion of the Lower Head was rather different from the present surface slope. Nevertheless, the solifluxion characteristics of the deposit are such that it seems improbable that the deposit is an undisturbed storm-beach. The Upper Head (Fig. 65-2) does not have a strong peak, but is nevertheless clearly soliflucted.

From the diagrams in Fig. 65 it seems that only Nos. 3 and 5 have "ideal" forms for basal till, i.e. with most pebbles dipping up-glacier. The loose friable till matrix and the disturbed nature of the till at sampling-site 3, however, indicate that the sample may simply represent a local depositional sludge direction. In the case of diagram 5, 32% of the pebbles dip up-slope and up-glacier, but again the matrix bears no appearance of true plastering, even though the sample was taken from 6 ft. beneath the till surface. Diagram 6 has a moderately strong preferred orientation, and diagram 4 is less strong; but both appear to have been sludged. The former sample, taken from 6 ft. beneath the surface, has most stones dipping northwards, but ten yards to the west, at site 4, most stones are dipping towards 120° at a depth of 8 ft. beneath the surface. Thus four diagrams from within one small till exposure reveal three quite distinct sludging directions; perhaps significantly the only close coincidence of estimated sludge sector and dominant 30° sector occurred in the deepest sample. The impression is gained from this evidence that the till was not deposited or overridden by a powerful ice-stream, but was possibly deposited in a dead-ice environment with local sludging directions dependent upon downwasting masses of dead-ice. Alternatively the till may have been laid down sub-glacially by a rather decadent ice-stream. The till does not appear to have been completely soliflucted since deposition.

Roundness analyses and stone-counts undertaken on spot samples further reinforce field impressions (Fig. 66). The raised beach shingle is found to have 90% rounded and well-rounded pebbles, a far higher percentage than has been found in any other drift deposit of North Pembrokeshire. It contains a good spread of stone-types, with very little bedrock derived from the immediate vicinity. The Lower Head had a smaller range of stone-types and a higher percentage of bedrock pebbles, but its storm-beach origin is indicated strongly in the roundness analysis histogram. This histogram is markedly different from the North Pembrokeshire mean diagram for head deposits, so that the rounding of pebbles must have been achieved before the onset of periglacial conditions (Fig. 66-2). The Upper Head is a typical periglacial deposit, with a high percentage of sub-angular bedrock fragments; and the till, although it has fewer well-rounded and rounded pebbles than might be expected, leaves little doubt as to its origin.

The sandy surface loam at Ogof Golchfa may be classified tentatively as a windblown deposit laid down under waning periglacial conditions, although the presence of isolated head and till fragments in it may suggest that it has been subjected to later slope-washing and re-deposition under cold conditions (Czudek, 1964).

The altitude of the rock platform at Ogof Golchfa invites correlation with the platform at Pen Dal-aderyn, 1½ miles to the west, and with other small platform remnants at Ogof Henllys and west of Ogof Lle-sugn. Leach (1911) and Mitchell (1962) have correlated the platform with the Gower raised beach platform.

Much discussion has centred upon the so-called "drifted erratics" which rest upon the platform. Leach considered that they may have been dropped by drifting ice-floes before and during the deposition of the beach. This seems unlikely, however, for if one assumes that the immediately pre-glacial land-mass in this area was relatively stable, it would be difficult to envisage a sea-level at +30 ft. O.D. when conditions were cold enough to permit ice-rafting of boulders. While the presence of large erratics older than the raised beach pebbles remains unproven, it is true that the shingle itself does contain foreign pebbles. These foreign pebbles are all well-rounded, and can hardly all have been drifted in on ice-floes; they appear to have been in the area prior to the deposition of the raised beach. It therefore seems reasonable to accept Mitchell's (1962) view that these erratics may be derived from older glacial deposits. In view of the suggestions made in the earlier part of this chapter, these deposits were probably laid down during the Early Glaciation.

Thus it seems that two glaciations are represented in the Ogof Golchfa section. The later of these is simply fixed by its stratigraphy, but it is difficult to decide at this locality, as at Whitesands and the Afon Nevern Estuary, whether the first glaciation occurred before or after the cutting of the raised beach platform. It must certainly have occurred before the deposition of the raised beach shingle and buried storm-beach. In the absence of other evidence it may be best at this stage to follow the earlier suggestion that the raised beach platform and deposits are not contemporaneous, and that the Early Glaciation intervened between platform-cutting and beach deposition.

The length of time represented by the Lower Head is impossible to estimate without further evidence, for it is derived not from shattered bedrock outcrops but from easily-sludged pebbles of the raised beach. Thus it may have formed more quickly than an equivalent thickness of bedrock head under identical climatic conditions. From

Table IX. **A tentative reconstruction of events at Ogof Golchfa.**

Events.	Climate.
Soil formation	Temperate
Sandy loam/Head	Cold, arid ?
Upper Head	Moderately cold
Non-calcareous till	Glaciation
Lower Head	Moderately cold
Raised beach	Sea-level 15-30 ft. O.D.? Warm

Erratics	Glaciation

Raised beach platform	Sea-level 15-35 ft. O.D.? Warm
Establishment of coast	Temperate ?

the rather blocky appearance of the head, it seems that the climate may have been moderately cold and rather moist. The Upper Head is thin but again blocky, and may have been formed under similar conditions.

The lack of calcareous Irish Sea till at Ogof Golchfa has been ascribed by Synge (personal communication, 1962) to the deflection offshore of Irish Sea ice by local Welsh ice which was moving along the North Pembrokeshire coast. This would seem unreasonable, for Irish Sea till is probably present on Trefeiddan Moor, less than one mile to the north-west (Jehu, 1904). Irish Sea till appears to be absent from all the localities on the South Dewisland coast, and it seems probable that the essentially local characteristics of the Ogof Golchfa till may reflect more the weakness of the ice-stream than its source. The striations on the platform and the evidence of preferred stone orientations cited above tend to support this hypothesis.

The complete drift succession and sequence of events at Ogof Golchfa appears to be that suggested in Table IX.

Chapter 5 (C2).

THE DRIFT SECTIONS AT CAERBWDY.

Important evidence concerning the nature of the "Upper Boulder-clay" or rubble-drift may be found in good sections in the Caerbwdy valley. This valley, which has a deeply-entrenched cross-section for the lower 900 yards of its course, carries a small stream which drains the Dowrog and Waun Vachelich moorlands towards the south coast of Dewisland. In places, the valley sides are broken by rocky outcrops of Cambrian basal conglomerate, from which innumerable large blocks have slipped downslope. Downstream from Pont Clegyr conspicuous mounds of Pre-Cambrian (Pebidian) halleflinta stand above the valley-floor. Head is exposed above old quarry-cuttings on the upper parts of the eastern valley side, and near the bungalows there are good exposures of thin till, sand, and gravel with interbedded head. The main cliff section has been mentioned by Jehu (1904) as a locality for "Upper Boulder-clay".

The Stream Cutting.

In the lower part of the valley a recent slump on the stream bank has revealed sands and gravels underlying a stony rubble-drift (Fig. 67). The gravels at the base of the exposure are fine and irregularly bedded; they are non-calcareous, and consist of rounded pebbles less than ½" in diameter. These pebbles are of mudstones, shales, red and purple Cambrian sandstones, vein quartz, buff local sandstones, and halleflinta derived from up-valley outcrops. The sands are also stratified and non-calcareous; they contain very few pebbles and have no interbedded gravels. They are red-brown in colour, possibly as a result of iron-staining.

The rubble-drift above the sand and gravel is bright brown in colour, and is full of a variety of local and foreign stone-types. There is no sorting according to size, and some of the larger stones attain a diameter of 18". The matrix is non-calcareous compact sand and gravel. At the southern end of the cutting there are traces of interbedded sands and gravels in the rubble-drift. The upper part of the drift appears to be soli-flucted, and contains patches of sandy loam and stratified local sandstone head.

Other small exposures reveal that a similar till may blanket much of the floor and sides of the valley. Near the bungalows one cutting reveals that at least 3 ft. of gravelly till is overlain by 6" to 9" of fine sand, which is in turn overlain by 3" of outwash gravel, 12" of flaky head, and up to 9" of sandy loam. In the area of the halleflinta outcrops on the valley-floor innumerable angular and rounded erratics litter the ground surface, and some of the mounds on the valley floor may consist of drift.

The Main Drift Cliff.

At the mouth of the valley the stream reaches the sea through a breach in a broad barrier of outwash and till capped by local purple sandstone head (Fig. 68A). The lower part of this drift cliff is obscured by slumped material, but a recent cutting on its flank reveals the deposits clearly.

1. Stratified sands and gravels. On the flank of the drift cliff well-stratified sands and gravels are seen to underlie, and in part interdigitate with, stony non-calcareous till (Fig. 68B). The bedding of these sands and gravels is highly irregular, in both angle and direction of dip; their upper margin is 3' 6" higher at the southern end of the exposure than at the northern end. The deposits vary from fine sands to coarse gravels containing large rounded erratic pebbles. The most interesting feature of the exposure is a 6" band of cemented gravels which is stained black by manganese oxide. The band consists of well-rounded pebbles ½" to 3" in diameter,

with hardly any matrix of finer gravel or sand; this latter characteristic is unique in the exposure. Beneath this band there is at least a further 12" of moderately-stained gravel, with irregular bedding. The whole band is truncated at its northern end by a slump of reddish upper gravels (Plate 27). The stained layer appears to be a local feature, for it is not seen 10 ft. to the north in the same exposure; nor is there any sign of staining in stratified outwash at a lower level 10 yards further south.

2. Stony non-calcareous till. Overlying the outwash sands and gravels, and in places interbedded with them, is c. 10 ft. of stony brown till which is similar in all its characteristics to that exposed in the stream-cutting 70 yards to the north. Most of the stones in the till are under 6" in diameter, but it contains many striated boulders up to 3 ft. in diameter (Plate 28A). The matrix of the till is sandy and gravelly, and is foxy-red in colour. Jehu (1904) noted "pockets of rather fine sand" in the till. In places on the cliff-face the top 3' 6" of this till appears to be soliflucted; this layer is marked by a fissile appearance, traces of stratification, and a higher proportion of purple Cambrian sandstone fragments than in the drift below.

3. Purple sandstone head. Above a somewhat irregular junction with the till lies a purple local head, consisting largely of angular fragments of Cambrian sandstone and shale (Plate 28B). These fragments are generally flattened, and vary in diameter from ½" to over 12". It does, however, contain some rounded foreign pebbles and boulders. It displays a moderate pseudo-stratification. It attains a maximum thickness of c. 5 ft.

4. Sandy loam. At the top of the section is 3" to 6" of sandy reddish loam and interbedded head flakes. It is much thinner than in many of the North Pembrokeshire drift sections, and in places does not appear at all on the clifftop.

Interpretation.

The form of the Caerbwdy Valley is similar to that of Merry Vale, the Porth-y-rhaw valley and the Solfach valley. Its steeply-incised lower portion cannot with confidence be attributed to pre-glacial rejuvenation at a time of lower sea-level (Cox, 1930); the present stream is a misfit, and even in pre-glacial times it is difficult to envisage a runoff from the limited lowland catchment area capable of cutting the valley. Therefore the valley may tentatively be attributed to the action of glacial meltwaters.

There is some evidence concerning the age of the valley. The drift deposit which blocks the valley-mouth must post-date the cutting of the valley, although it is possible that valley-cutting and drift deposition could have occurred during the same glaciation. Against this some evidence may be quoted from the valley-slope c. 40 yards south of the drift-cliff; here, over 3 ft. of blocky and flaky angular head underlies c. 12" of soliflucted till (Fig. 69). If the valley was cut by the glaciation which deposited the till, then head could not be preserved on its flanks. It may be proposed on this basis that the valley is the same age as the channels at Aber-mawr and Porth-melgan.

The irregularity of the bedding in the sands and gravels indicates that they are probably of fluvio-glacial origin. They are interbedded with the till, and the fact that they occur at markedly different altitudes even within the same exposure appears to invalidate the hypothesis that they represent a valley sandur later buried beneath soliflucted till or till of a later glaciation. It seems, also, that the sands and gravels have not been soliflucted; their bedding structures remain intact. Neither do they appear to have been laid down under "normal" fluvial conditions, for the percentage of rounded pebbles appears to be too low (Reichelt, 1961); indeed, the stone roundness histograms (Fig. 70) are closer to the North Pembrokeshire mean diagram for till than to that for fluvio-glacial outwash.

The manganese-stained band represents a problem, for it could be interpreted as a weathered layer. Detailed comparison of the band with the gravels above, however, reveals that their roundness characteristics and stone-content are very similar (Fig. 70). The stained band has a slightly higher percentage of local pebbles, and perhaps as a consequence of this, also a higher percentage of sub-angular pebbles. However, the similarity of the two deposits is well-marked, and it appears reasonable to postulate that the manganese-staining was achieved by a temporary local water-table (perhaps controlled by the permafrost level) during or just after gravel deposition.[1] The truncation of the stained band by a slump-fault (Plate 27) may also bear witness to the approximate contemporaneity of all the gravels in the section.

The most unusual feature of the Caerbwdy sections is that outwash sands and gravels underlie till, whereas at

---

1. Similar staining is known in Scandinavian eskers (Wadell, 1936) and in Ireland in outwash sand and gravel beneath ablation till (E.A. Colhoun, personal communication).

Aber-mawr, Druidston and other coastal sections outwash deposits overlie the till to which they are related. To the casual observer, therefore, it may be tempting to ascribe the till to a later glaciation. Indeed, the outwash and till could be interpreted as the upper two members of the classic tripartite glacial succession in the area (Jehu, 1904; Griffiths, 1940).

Investigation of the till fabric reveals that this hypothesis has little foundation in fact. The till was deposited by ice moving towards the south and south-east; this is indicated by its erratic content, which includes halleflinta fragments from the north and boulders of St. David's Head gabbro (Jehu, 1904). The histograms in Fig. 71 for the basal tills and clifftop till at Caerbwdy reveal that there is an apparent increase in stone angularity as one passes upwards. Even so, the clifftop till has as many rounded stones as one of the bedded outwash samples in Fig. 70, so the two deposits may have marked affinities. The basal till samples have 56% and 58% rounded and sub-rounded stones (higher percentages than for the outwash gravel samples), so it appears not to be a true till, and the possibility must be considered that the deposit has been severely washed and mixed with outwash material during deposition. It does not consist of over-ridden outwash, for there is no erosional break or change of matrix between the deposits. The clifftop till has a stone roundness histogram similar to that for the North Pembrokeshire mean histogram, and it also has a greater spread of stone-types than either of the basal till samples; it may not have been subjected to such severe washing and intermixing with outwash as the till below.

The impression that the till and underlying fluvioglacial deposits are related is reinforced by an examination of the preferred orientation diagrams for four till samples (Fig. 72). Only diagram 3 has a strong preferred orientation, and the dominant 30° sector differs markedly for each diagram. Diagram 1 (a sample from only 2 ft. beneath the ground surface) appears to have a preferred orientation in sympathy with the sludge sector; the other diagrams reveal that the bulk of the till has probably been neither "plastered" by moving ice nor sludged subaerially under valley-side control. The lack of strength and discordant directions of sludging in the till could be attributed to intense periglacial disturbance which has destroyed the original till fabric since deposition. There is some evidence of disturbance near the top of the cliff, but it is unlikely that any periglacial active layer could have extended through 20 ft. of drift to the basal till, which is no less chaotic in its preferred orientation than the till above.

In view of the combination of fabric characteristics, it appears reasonable to propose that most of the Caerbwdy till was deposited by sludging and slumping on dead-ice masses during deposition (Holmsen, 1963), or by sub-glacial flowage of saturated till (Hoppe, 1952). The deposition of en-glacial till and ablation till by slumping upon dead-ice is common around all the glacier snouts which I saw in East Greenland in 1962, and Flint (1929) proposed a similar mechanism for drift deposition during the melting of the last North American ice-sheet. It is reasonable to propose similar conditions of wastage at the close of the glaciation which deposited the Caerbwdy till.

The field interpretation of the purple head at Caerbwdy is apparently confirmed by the roundness analysis and stone-count histograms (Fig. 71) and by the preferred orientation diagrams (Fig. 72, Nos. 1 and 2). The fact that neither dominant 30° sector coincides with the sludge sector is of little importance, for both diagrams display moderate strength and a reasonable preferred orientation for head. The moderately blocky nature of the head may indicate that it was formed during a phase of moderately cold and oceanic periglacial conditions (Dylik, 1964); conditions must

Table X . A tentative reconstruction of events at Caerbwdy.

Events.		Climate.
Soil formation		Temperate
Sandy loam/Head		Cold, arid ?
Purple head		Moderately cold
Non-calcareous till		Deglaciation
Fluvio-glacial outwash		Glaciation
Contorted head	on valley-side	Very severe cold
Flaky head	on valley-side	Severe cold
Blocky head	on valley-side	Moderate cold
Caerbwdy Valley		Glaciation

certainly have been less severe than those responsible for the flaky and contorted heads beneath the glacial deposits on the cliff to the south (Fig. 69).

In spite of the limited thickness of the sandy loam, it appears to be the equivalent of the deposits at Abermawr, Porth-melgan and elsewhere, for it is interbedded with head. It may be in part a temperate deposit, but it seems likely that its lower layers at least were laid down under conditions of alternating wind-action, hill-washing, and solifluxion.

It appears from the foregoing evidence that the bulk of the deposits at Caerbwdy may date from the same glaciation, with the sands and gravels laid down sub-glacially by melt-waters using a pre-existing Caerbwdy valley, and with the overlying till laid down by slumping and sludging in a dead-ice environment. The till does not appear to have been re-sorted since deposition, for in the stream-cutting interbedded sand and gravel layers remain in situ. Post-glacial periglacial activity has been responsible only for some disturbance of the upper till layers, and the deposition of the purple head and sandy loam.

The apparent sequence of events represented at Caerbwdy is set out in Table X. It is still possible that head and perhaps more till may be preserved beneath the deposits described.

Chapter 5 (C).

SUMMARY OF CONCLUSIONS.

The most important fact to emerge from the studies at Ogof Golchfa and Caerbwdy is the apparent absence of Irish Sea till from the south coast of Dewisland.[1] However, non-calcareous till is represented at both sections, and it is clearly of importance to establish whether or not this till is the equivalent of the Irish Sea till of the Dewisland Glaciation.

1. Stratigraphy.

As indicated in Fig. 73, the lateral correlation of the drifts at Ogof Golchfa and Caerbwdy appears simple. The non-calcareous local till may be used as a datum at each locality, for in both the main exposures it is a gravelly and sandy deposit full of striated stones. Passing downwards from the ground surface there is an identical sequence overlying the till at both localities: namely sandy loam with head pebbles and then upper head with erratics. Thus there are good grounds for correlation.

---

1. This is confirmed by examination of the whole of the nine-mile coastal stretch between Pen Dal-aderyn and Cwm-mawr. The only till found on this coast is stony gravelly till like that at Ogof Golchfa and Caerbwdy.

Beneath the local till correlation is not so simple. At Caerbwdy a suite of fluvio-glacial sands and gravels of unknown thickness lies at the base of the drift-cliff, while at Ogof Golchfa a raised beach and thick lower head of raised beach pebbles rest upon a rock platform. However, some correlation is afforded when the Ogof Golchfa section is compared with the Caerbwdy clifftop section, where a thin head is seen to underlie glacial deposits. A solifluxion phase prior to the glaciation appears to be represented by this head and by the Ogof Golchfa lower head.

As far as can be determined from the present exposure, there is no raised beach deposit or rock platform at Caerbwdy. Both these features of the Ogof Golchfa section are therefore assumed to pre-date the lowest deposit at Caerbwdy.

2. The Mode of Deposition of some Drifts.

(a) The fieldwork at these two localities involved the detailed examination of the nature of the non-calcareous till. From the work at Ogof Golchfa it was suggested that the till is a variable deposit which in places was subjected to local sludging during or shortly after deposition; only occasionally does this sludging appear to have been controlled by the underlying bedrock slope. A similar conclusion has been gained from fabric analyses of the Caerbwdy till, which bears signs of having been deposited under very moist conditions in association with fluvio-glacial material. There is good evidence that the tills are largely in situ, and are not soliflucted remanié drifts derived from older Irish Sea till deposits.

It is tempting to relate the non-calcareous till to the rubble-drifts at Aber-mawr and Porthmelgan. However, its stratigraphic position is not comparable, and it does not have the solifluxion characteristics of the rubble-drifts.

(b) The lower sands and gravels at Caerbwdy are thought to be fluvio-glacial deposits intimately associated with the non-calcareous till. They are not considered to be "intermediate sands and gravels" lying between two tills.

(c) The lower head at Ogof Golchfa consists largely of raised beach pebbles. Its stratigraphic counterpart is the thin head on the Caerbwdy clifftop, illustrating in an extreme way the variable characteristics of head deposits which may have accumulated under identical climatic conditions.

(d) The raised beach at Ogof Golchfa appears to have been initially a thick deposit upon an extensive raised beach platform. The raised beach which rests in situ on the outer part of the platform is sandy and gravelly with small pebbles, while beneath the degraded cliff-line there appears to have been a storm-beach of large pebbles and boulders (which has since been destroyed by solifluxion to form the lower head). These thick beach deposits must have been deposited during a prolonged still-stand of sea-level possibly as high as 30 ft. O.D.

3. The Age of the Deposits.

Stratigraphically, the sections at Ogof Golchfa and Caerbwdy are comparable with the sections at Aber-mawr. The non-calcareous till lies above a thick lower head (the "main" head) and beneath a thinner upper head; the calcareous Irish Sea till elsewhere lies in an exactly equivalent position. The Irish Sea till has been dated to the Dewisland Glaciation, so there is good evidence for suggesting that the non-calcareous till of the South Dewisland coast is the same age.

As indicated in Chapter 5 (A) there are grounds for assigning the lower head on this coastal stretch to a

TABLE XI

CORRELATION AND INTERPRETATION OF SECTIONS IN SOUTH DEWISLAND.

STRATIGRAPHIC CORRELATIONS			SUGGESTED INTERPRETATIONS		
OGOF GOLCHFA	CAER-BWDY	CAER-BWDY CLIFF	Relative sea-level	Climate	Events
Sandy loam	S. loam	S. loam	Low - rising	Cold-arid ?	Wind-action etc.
Upper head	Upper head	Upper head		Moderate cold	Solifluxion
Non-calc. Till	Non-calc Till	Solifl. Till	Very low	Deglaciation	Dewisland Glaciation
	Sands and Gravels			Glaciation	
Main		Flaky head	Low - falling	Severe cold	Solifluxion - slow?
Head		Blocky head		Moderate cold	Solifluxion-rapid?
Raised beach			High	Warm?	Deposition of raised beach
Erratics	Caerbwdy Valley		Low	Glacial	Early Glaciation
Platform Establishment of coast			High	Warm	Platform-cutting Coast erosion

prolonged period of fluctuating periglacial conditions which preceded the Dewisland Glaciation.

The raised beach appears to have been deposited by a high interglacial sea prior to the onset of cold conditions, as suggested in Table XI. As mentioned in the discussion of the Afon Nevern sections, the erratics in the raised beach were probably introduced by the Early Glaciation prior to the formation of the raised beach, but there is no means of telling whether the glaciation preceded or followed the cutting of the platform. In the table it is again tentatively suggested that the Early Glaciation followed the cutting of the platform, although this suggestion may have to be revised when evidence from a wide area is brought together in Chapter 7.

It is reasonable to assume that the Caerbwdy channel was cut by glacial meltwaters prior to the accumulation of the lower (main) head. Like the raised beach erratics, it seems to be a legacy from the Early Glaciation.

Some comment may be made here concerning the age of the coastline of South Dewisland. In Chapter 5 (A) it was noted that the Afon Nevern valley is an ancient feature, for raised beach platforms are found on the sides of its drowned estuary. The same may be said of the cliffs at Ogof Golchfa; the raised beach platform must post-date the establishment of the high cliffs, which may have been cut when sea-level was at present O.D. or lower. If the coastline was established after the Early Glaciation, it would be most surprising to find large erratics from this glaciation still in the vicinity. It seems more reasonable to suggest that the Early Glaciation followed the establishment of the coastline, as suggested in the table.

Overall, the sequence of events proposed in Table XI bears many similarities with the table for events in North Pembrokeshire, in spite of the absence of Irish Sea till.

PART III

The interpretation and Correlation of selected coastal sections.

Chapter 6.

Related sections elsewhere in West Wales.

Chapter 6 (A)

The coast of South-west Pembrokeshire.

A1. The drift section at Druidston Haven

A2. The sections at West Angle Bay

Summary of Conclusions.

Chapter 6 (A1).

THE DRIFT SECTION AT DRUIDSTON HAVEN.

At Druidston Haven, on the west-facing coast of St. Bride's Bay a drift cliff c. 60 yards long and up to 80 ft. high is exposed at the mouth of a pre-glacial or inter-glacial valley (Cantrill, 1916). Above the storm-beach in the haven erosional processes are degrading the cliff rapidly, so that the face is kept clean; examination of the stratigraphy is therefore relatively simple. Further erosion has been achieved by two small streams which join to enter the sea at the southern end of the section (Plate 29). The section has been mentioned in the literature by Cantrill (1916), Davies (1939), and Griffiths (1940). The latter author used the locality as a type exposure for Pembrokeshire, with supposed sands and gravels of Older Drift age overlying typical "Lower Boulder-clay" of the same glaciation. The full section appears to be somewhat more complex than this, as indicated in Fig. 74.

Druidston Valley. The form of the bedrock on the north and south sides of the valley, and a marked "step" running inland from the drift cliff, indicate that the drift plugs an old valley, as recognised by Cantrill. It is difficult to follow the direction of this valley for any distance inland, for the drift fill masks the break of slope less than 400 yards to the east. The present streams which have cut through the drift flow upon bedrock close to the old valley-side; it is probable that the valley floor beneath the drift cliff lies just below sea-level.

Bedrock. The bedrock at Druidston is complex, and the bay is a well-known geological locality. The valley is cut entirely in a horst of Ordovician shales of the Bala series (McQuillan, 1958); on the clifftop to the north sandstones of the Carboniferous Coal Measures are exposed, while sandstones and shales of the Millstone Grit outcrop on the clifftop to the south. An erosion surface is cut across shales on the low clifftop south of the stream, and a much lower rock platform is seen at the northern end of the section. The latter platform lies c. 10 yards to the west of the point at which shattered bedrock is seen in contact with calcareous till; its highest point lies at c. 16 ft. O.D., and it is 10 yards long and up to 2 yards wide. It is higher and quite distinct from the present-day wave-cut platform which is exposed beneath the boulder-beach. At this point bedrock is badly-jointed and faulted, and the platform clearly coincides with a bedding-plane. It has a fresh appearance, and is not overlain by any deposits, so it is not possible to decide whether it pre-dates or post-dates the deposition of the drift at Druidston; however, it must clearly post-date the phase of valley-cutting. At this point it may be worth noting that the higher platform on the south side of the haven appears to have been cut into the old valley-wall, although since it is covered with drift it is difficult to see how extensive the platform is.

1. <u>Lower Head and possible Beach deposits.</u> At the base of the section there is c. 6 ft. of blocky quartzite head. Most of the blocks in this head are 3" - 12" in diameter, and pseudo-stratification is well-preserved. The head matrix is sandy and gravelly, and the whole deposit appears to be iron-stained. The sub-angular shape of the blocks and the soft friable character of their exposed surfaces gives the impression that the head is somewhat weathered. At times a patch of this head is observed beneath the storm-beach (Fig. 74), suggesting that it may cover the whole floor of the old valley.

Rounded erratic pebbles may be found throughout the head deposit. In the patch of head exposed in the storm-beach parts of the matrix consist entirely of small rounded flakes of shale and erratic pebbles, and in places this matrix is severely stained by iron oxide and manganese oxide. Streaks of stained gravel and sand appear to be interbedded with the head, and there is some indication that the gravels underlie the head. The gravels are similar to the raised beach gravels at Ogof Golchfa and West Angle.

2. Calcareous Irish Sea till. Overlying the head is up to 50 ft. of purple calcareous till. It is generally compact and massive, although in places gravelly and sandy patches are visible. The till is full of small broken fragments of marine molluscs, and pieces of carbonized wood have also been found. In places the till has a high percentage of bedrock flakes, but in general it contains a large variety of erratics: Cantrill (1916) recorded boulders of hornblende-porphyry from the Southern Uplands, and other erratics of grit, shale, and sandstone. There are many pebbles of Cambrian purple sandstone and red shale in the till, and rounded pebbles of Ailsa Craig riebeckite and Cretaceous flint are easily found. Many pebbles and boulders are clearly striated, and some of the boulders attain a diameter of over 6 ft. The till has occasional traces of laminations.

The till occurs close to the surface at the southern end of the section, where it is decalcified and severely gleyed to a depth of 4' 6". The decalcified till has a bright red-buff colour and a macamore profile (Gardiner and Ryan, 1964), with a mottled appearance and gleying extending down cracks in the decalcified till to a depth of 6 ft. Severe gleying is restricted to the upper 2' 6" - 3' of the till. At the base of the till is a decalcified reddish layer 2" thick, directly above a sharp contact with the underlying head.

3. Rubble-drift. Overlying the till is a variable stony and sandy rubble-drift. It varies in thickness from c. 12" near the southern end of the cliff to over 20 ft. near the northern end of the section (Fig. 74). In the south it is a thin stony and gravelly layer lying above severely-gleyed purple till; this layer has interbedded silt bands in places, and has many other traces of foliation. In places large masses of sub-angular pebbles appear to have been arched and heaved by cryoturbation. The drift contains erratic pebbles derived from the Cambrian and Ordovician outcrops of the St. David's Peninsula and elsewhere, although there appears to be a slightly higher content of quartzite bedrock than in the underlying calcareous till. The matrix of the drift is gravelly and sandy, and concentrated stony layers are interspersed throughout its thickness. There are many rounded pebbles, and undoubted patches of sand and gravel appear near the base of the deposit. From one patch of stratified fine gravel and foxy-red sand a large mass has slumped down the cliff-face (Fig. 74). At the contact between the rubble-

drift and calcareous till there appears to be an occasional erosional break, marked by the truncation of laminations in the calcareous till and a concentrated line of angular boulders at the base of the rubble-drift.

Close to the valley-side stratified outwash gravels consisting largely of local shale fragments lie above an erosional contact with the calcareous till; there are several masses of this flaky gravel in the rubble-drift above.

4. Sandy loam. Along the whole of the clifftop is c. 12" of sandy loam. At its base there is occasionally a stony layer, and small shale flakes and erratic pebbles are interspersed throughout the deposit.

Interpretation.

As recognised at Porthmelgan and Aber-mawr, the presence of blocky quartzite head at the base of the deposits means that the Druidston valley must pre-date the glaciation responsible for the calcareous Irish Sea till. If the gravels in the lower part of the head deposit are the remnants of a raised beach, then the valley must also pre-date a period of high sea-level and raised beach deposition. The broad, steep-sided form of the valley appears to be inconsistent with the limited size of the catchment area, but since so much of the valley is masked with drift it is not possible to estimate whether it could be a meltwater channel of an earlier glaciation.

The significance of the weathered appearance of the lower head is difficult to assess. The quartzite blocks may be friable and stained largely as a result of their lithology, with chemical weathering of bedrock acting contemporaneously with solifluxion processes under a periglacial environment; Czeppe (1964) has shown from Spitsbergen that such a combination of processes is possible. However, the quartzite blocks in the Aber-mawr head are not weathered, so perhaps the quartzite at Druidston was severely weathered pre-glacially or during a warm interglacial period preceding solifluxion. The preferred orientation diagram (Fig. 75A) for this head is not very strong, and the dominant 30^{o} sector does not coincide with the sludge sector on top of the drift cliff. However, there is no reason to doubt that it is a solifluxion deposit, with its preferred orientation controlled by underlying deposits or bedrock.

The thickness and characteristics of the calcareous till indicate that it must have been deposited by an Irish

Sea ice-sheet moving from the north-west across the floor of St. Bride's Bay. Griffiths (1940) noted that the till in this area derives much of its character from the Coal Measures over which its parent ice passed, but nevertheless it bears enough features in common with the Aber-mawr and Whitesands tills to be considered a correlative. The depth of decalcification at the southern end of the drift cliff is somewhat deeper than at Aber-mawr and Whitesands. But at both these latter localities the till is only seen beneath a thickness of later deposits, which have afforded some degree of protection to the upper till surface. Beneath the rubble-drift at Druidston the calcareous till is weathered only to a depth of 24", suggesting that it is the same age as the calcareous tills on the North Pembrokeshire coast. The Dewisland Glaciation must therefore have extended at least as far south as Druidston.

The stone orientation of the till is most unusual (Fig. 75B), for according to the accepted methods of diagram interpretation (West and Donner, 1956) it indicates ice-movement from the north-east. This is apparently discounted by the presence of large numbers of St. David's erratics in the till; furthermore any ice moving from the north-east in this locality could not have picked up the shelly sea-floor deposits which constitute the bulk of the till. It seems possible that the character of the orientation diagram may be the result of local sludging during till deposition.

From mechanical analysis of the matrix of the calcareous till (Fig. 76) it appears that it becomes coarser and stonier upwards. The sample from the base of the drift cliff yielded 32.1% fines, while two further samples from the calcareous till just beneath its junction with the rubble-drift yielded identical cumulative curves and only 12% fines. This change in facies towards the top of an Irish Sea till exposure is also seen at New Quay (see Chapter 6 (B2)), and may simply result from the fact that the upper layers of the moving ice may have eroded bedrock fragments from the clifftops, while the lower layers may have carried nothing but sea-floor debris and some erratics.

The rubble-drift at Druidston is unusually variable in that it contains boulder-beds, stratified sands and gravels, decalcified till masses, flaky gravels, and a coarse rubble with erratics in a sandy and gravelly matrix. Furthermore, this is the only section in Pembrokeshire which I have seen where a clear (if discontinuous) erosional contact separates rubble-drift from underlying calcareous till. The possibility must be considered, therefore, that the rubble-drift at this locality represents a later glaciation than the Dewisland Glaciation.

Apart from the fact that no trace of a later glaciation has been recorded elsewhere in Pembrokeshire, several features militate against this theory. The rubble-drift and underlying till have a very similar erratic content, and there is a good stratigraphic case to be made for the fact that the rubble-drift is simply the culmination of the upwards increase in stoniness observed in the calcareous till.

There is a higher proportion of upslope bedrock in the rubble-drift, and the stratified fluvio-glacial deposits appear to be located in a slig t channel cut into the calcareous till; on the flanks of this channel are the erosional contacts, lined above by concentrated layers of angular boulders and pebbles. These features are perhaps best accounted for by postulating a phase of stream erosion and deposition during deglaciation, accompanied by the local washing of till surfaces and the deposition of stony (ablation?) moraine in a dead-ice

Table XII. A tentative reconstruction of events at Druidston.

Events.	Climate.
Soil development	Temperate
Sandy loam	Cold, arid
Frost-heaving?	Severe cold ?
Flaky Gravels }	{ Cold
Rubble-drift }	{ Deglaciation
Calcareous till	Glaciation
Lowest head	Moderately cold
Raised beach gravels? }	Sea-level 5-10 ft. O.D.
(Doubtful rock platform) }	

Valley-cutting	Glaciation ?

environment. All these processes are common in present-day dead-ice environments, as beyond the snout of Ivar Baardson's Gletscher in East Greenland. Concentrated stony layers further south near the top of the drift-cliff may perhaps be accounted for by a washing out of fines (Flint, 1957). There are a few patches of solifluxion gravel in the drift, suggesting that solifluxion may have been active on the emerging valley-sides while ice-masses were still present above the calcareous till.[1] The preferred orientation diagram for the rubble-drift (Fig. 75C) is strong, and appears to have been controlled by a local slumping direction perhaps during deglaciation. The preferred orientation has no relationship with the present surface slope of 6^{o} towards the south.

The heaving of stony layers close to the surface may have occurred during a period of severe periglacial conditions following deglaciation; this phase may have been related to the cold, arid period which was possibly responsible for the deposition of the sandy loam above.

The sequence of events represented at Druidston is illustrated in Table XII.

---

1. This process is not unlikely; a pro-glacial gorge eroded in till and at present filled in part with slump material is strikingly figured by Boyd (1935) from Gregory Valley, East Greenland.

Chapter 6 (A2).

THE SECTIONS AT WEST ANGLE BAY.

In West Angle Bay, at the western extremity of the Castlemartin Peninsula and south of Milford Haven, may be found possibly the most useful drift exposure in South Pembrokeshire. Interesting head deposits and till occur in the coves to the north of the main beach, while at the head of the bay is a complex series of deposits which is unlike anything found to date in North Pembrokeshire. The drift succession in the old brick-pit at the back of the beach was described by Dixon (in Cantrill et al, 1916), and the locality has been mentioned by Leach (1933). As far as can be ascertained, there have been no more recent references to the West Angle drifts.

West Angle Bay has been cut in a synclinal exposure of Carboniferous limestone and limestone shales (Fig. 77), flanked to the north and south by Middle and Upper Devonian sandstones and conglomerates (Cantrill et al, 1916). In the vicinity of the coves the limestone and limestone shales are severely and spectacularly folded and faulted. In the main bay the beach is sandy, and no bedrock is seen at the base of the drift section.

A. The Main Bay.

South of the footpath onto the beach is an excellent exposure c. 150 yards long and 5-12 ft. in height (Fig. 78). A small pebble-beach marks the base of the section, but the presence of raised beach pebbles close to present H.W.M. may indicate that bedrock of lower limestone shales is not far below. Dixon has recorded an uneven platform cut across lower limestone shales c. 13 ft. A.H.W.M. (c. 19 ft. O.D.) at the southern end of the bay.

1. Raised beach. A raised beach deposit at least 18" thick passes downwards from c. 2 ft. A.H.W.M. It consists of well-rounded and severely iron-stained pebbles in a rich sandy and gravelly matrix. Most of the pebbles are under 9" in diameter. Devonian red sandstones and marls make up the bulk of the deposit, although there are also erratic pebbles. These erratics are difficult to identify, for they are severely stained and in many cases badly weathered.

2. Stiff Grey clay. A thin band of clay (c. 4" thick) overlies the raised beach in places, and is occasionally interbedded with raised beach pebbles.

3. Pebbles in organic sand and silt. Overlying the stiff grey clay, and in places interbedded with clay and the raised beach deposits below, is a variable deposit of rounded and sub-angular pebbles set in a matrix of whitish

sand and silt. On a small scale the matrix bears traces of laminations, but perhaps its most important characteristic is the presence of lenses of organic silt and wood fragments. In addition, there are a few shell fragments. The pebbles in this horizon are not clearly stratified, but appear to have been subjected to frost-disturbance. Many of the pebbles are clearly derived from the raised beach, but the angularity of some fragments may indicate the incorporation of head. The deposit has a maximum thickness of c. 24". It is possible that Dixon considered this deposit to be a till.

4. White sand and silt. Passing upwards from horizon 3 the pebbles become less prominent until c. 12" of fine white sand and silt remains. The layer contains several bright iron-stained bands.

5. Bright grey silt. This deposit lies above the lowest sharp junction in the exposure. It is c. 2 ft. thick, and consists of bright grey silt with interbedded clay bands and white silty bands. It is quite stoneless, and contains specks of organic matter and wood fragments throughout.

6. Dark grey clay. The silt grades upwards into c. 4 ft. of a darker grey clay which is still stoneless and characterised by small patches of organic matter. Towards the

top of the deposit there are a few thin gravelly layers and bands of iron-staining. The upper 3 ft. of this layer are mottled bright yellow, probably as a result of weathering aided by water percolation down rootlets from the surface.

7. Rich red sand and gravel. This deposit is variable in thickness and character. Just to the north of the exposure described above, it appears to have been deposited in a hollow cut through the silts and clays; it extends from the ground surface down to the raised beach, with a maximum thickness of 12 ft. In places, the deposit is made up of coarse gravel of Devonian sandstone and marl fragments, but greenish and greyish silts are interbedded, as are irregular bands of fine dark red gravel. Some patches of clay are seen in the drift, and the frequency of silt and clay lenses increases sharply towards the margin of the gravels with the adjoining silts and clays (Fig. 78). To the north of the contact the gravels assume some of the characteristics of till, with small unsorted angular, sub-angular and rounded stones in a matrix of fine gravel. However, stones are seldom over 3" in diameter.

8. Rich red sandy loam. Capping the drift-cliff and clearly post-dating both the truncated silts and clays and

the red flaky gravels is a bright red sandy and silty loam containing some foreign fragments. It is c. 12" thick, and its upper layers have been modified by soil-forming processes.

B. The Coves to the North.

In the first, second and third north coves[1] there are frequent exposures of decomposed bedrock and soli-flucted deposits, which differ in character according to the bedrock facies. The complete drift sequence is seen in no one locality, but the succession appears to be simple, and may be reconstructed as follows:

1. Decomposed bedrock and head. In coves two and three there are good exposures of decomposed limestone shales. In places the gradation between solid rock and its buff sandy and silty weathering products is seen; in general, the soft shales appear to have weathered completely into rich foxy-red sand, while thin sandstone beds have remained largely unweathered. The weathering-product is up to 25 ft. thick in the third north cove, where it is always stoneless and sometimes iron-stained. Decom-posed bedrock is not so much in evidence on the northern

---

1. So named in Fig. 4 of "The Country around Milford", Cantrill et al. 1916.

side of this cove, nor on the headland between the coves. Again, the southern part of the second north cove has no rotten bedrock. Thus the rotten bedrock appears to coincide only with very soft limestone shales, which are flanked by tougher limestones and calcareous shales.

In places the decomposed bedrock appears to have been soliflucted periglacially, for sandstone and shale flakes with characteristic pseudo-stratification are embedded in the weathering products. On top of a narrow anticlinal ridge between coves two and three the decomposed shales and shattered sandstone bands have been over-folded towards the south in spectacular fashion (Fig. 79A). It is difficult to determine whether the over-folding is an initial tectonic feature, but the manner in which decomposed bedrock is interbedded with head fragments suggests that the over-fold is either the result of downhill solifluxion before the cove was eroded by the sea, or else of ice-movement across the anticline.

2. Possible raised beach remnants. No raised beach deposits are seen in the coves beneath head deposits, but a pocket of raised beach shingle is recorded by Cantrill et al (1916) from a cleft in the cliffs opposite Thorn

Island, and other cemented shelly deposits may be seen in small patches just above H.W.M. in clefts between the third and fourth north coves. Since these patches rest upon highly calcareous limestones and limestone shales, some of them could have been cemented in recent years, but the possibility remains that they are the equivalent in age of the raised beach of the main bay.

3. Red Gravelly Till. The "pipe" of drift figured on the map of West Angle in Cantrill et al (1916) is perhaps the stiff till referred to by Leach (1933). The till is apparently non-calcareous, and consists of a great variety of erratic pebbles (including Cretaceous flints) set in a compact red clay and gravel matrix. Many pebbles are striated, and stone roundness is variable. Some of the blocks in the till are up to 12" diameter, but on lithological grounds it is clearly related to the flaky red gravel exposed in the Main Bay. It rests upon decomposed shales, and in places is interdigitated with the weathered material; indeed, some isolated patches of till are embedded within the weathered products. The maximum thickness of the lens of till is c. 13 ft. (Fig. 79B).

4. Flaky local head. Above the red till is 2-3 ft. of flaky local shale head mixed with patches of decomposed bedrock and a few gravelly layers possibly derived from

the till. At the northern end of cove two this head grades downwards into the decomposed bedrock. In the third cove c. 3 ft. of buff flaky shale head with erratics overlies decomposed bedrock; the erratics include rounded pebbles of red sandstone, vein quartz, and other buff sandstones up to 2" in diameter. It is characterised by good pseudo-stratification and a matrix of buff silt. In the vicinity of the first cove there are good head exposures up to 10 ft. thick; some of these head deposits contain erratic pebbles. The presence of erratics in these heads indicates that, in part at least, they post-date the red gravelly till.

5. Sandy loam. Above the head deposits there is generally a layer c. 12" thick of sandy loam and head flakes. It is similar to the clifftop loams of North Pembrokeshire, and although it differs somewhat from the rich red loam in the Main Bay, it appears to be its stratigraphic equivalent.

Interpretation.

Unfortunately I did not examine the West Angle exposures until April, 1965, and did not have time to undertake detailed fabric analyses. However, there is abundant evidence to suggest that the site may be of great importance, for the organic silts and clays in the Main Bay appear from stratigraphic evidence to pre-date the introduction of the red till. Therefore they may be of interglacial or inter-stadial age. This interpretation differs from that of Dixon, who considered that a till lay beneath the organic deposits but not above; accordingly the deposits could be post-glacial. A tentative correlation of the West Angle exposures is made in Fig. 80.

In view of the location of the raised beach platform at the south end of the bay and raised beach gravels close to the present-day storm-beach it is safe to assume that the coastline in the vicinity of West Angle had attained its present configuration prior to the introduction of the till and possibly prior to the introduction of the erratic pebbles in the raised beach. Similarly the drift-filled Angle Valley appears to be an ancient feature which may at one time have been flooded by the sea. It is difficult to determine whether the deep rotting phase responsible for the decomposition of the limestone shales in coves two and three occurred before or after the establishment of the present coast-line. The climate was possibly warmer and more humid than at the present day and may therefore have been in interglacial or pre-glacial times. Linton (1964) has suggested that deep rotting in Ireland could have occurred during the Last Interglacial, but the coincidence of the coves with the decomposed shale outcrops at West Angle may indicate that here the rotting occurred somewhat earlier.

The earliest deposit in the main drift-cliff appears to be the raised beach, although deep excavation at the base of the cliff may reveal even earlier deposits beneath the beach pebbles. The altitude of this beach, just above present H.W.M., is much lower than the raised beach at Ogof Golchfa, and the platform at Pen Dal-aderyn, but it is comparable in altitude with the raised beaches at Whitesands South, West Dale and Poppit, each of which have beach remnants only a few feet above H.W.M. In South Pembrokeshire raised beach deposits are recorded just above H.W.M. at Freshwater West (Dixon, 1921), and some of the Gower raised beach deposits (as, for example, in Caswell Bay) occur close to H.W.M. (George, 1932; Bowen, 1965). The iron-staining of the beach is not an unusual feature, for it also occurs in raised beach deposits at Poppit and Whitesands South. Again, as at other localities, the presence of erratics in the beach shingle indicates that it probably post-dated the Early Glaciation.

The presence of angular debris and raised beach pebbles in the layer above the raised beach suggests that the beach was subjected to solifluxion at some stage following deposition. The deposit is apparently frost-heaved, and may thus have experienced a rather severe periglacial climate for a while. This is by no means unique, for solifluxted and disturbed raised beach deposits are common in South Wales, for example, at Ogof Golchfa, Poppit and in Gower (Bowen, 1965). However, the presence of organic material and laminated silts in this deposit may indicate that warmer conditions intervened between the formation of the raised beach and the solifluxion of the pebbles. It is not clear whether this is the deposit which Dixon termed a boulder-clay; if so, there are some grounds for disagreeing with his interpretation. On the other hand it is possible that the section has changed greatly since 1916, and it must be borne in mind that a till may yet be discovered near the base of the section.

The deposits above the raised beach deserve closer examination than I have undertaken, but some suggestions regarding their origin may be recorded here. The suite of organic silts and clays appears to be the equivalent of a suite recorded from the old brick-pit by Dixon:

8) Angular stony loam, possibly head - 3 ft.

7) Sand with rounded flakes from Lower Limestone Shales (with erratics?) - 4 ft.

6) Well-bedded gravel and sand, rounded pebbles and some igneous rocks and flint - 2 ft.

5) Buff laminated loam, passing laterally into Lower Limestone shale debris (with erratics?) - 5 ft.

4) Dark blue loamy clay and plant fragments and some large pieces of wood - 5 ft.

3) Irregular loam, buff sand and fine gravel - 3 ft.

2) Grey clay or loam - 1½ ft.

1) Clean buff sand - 1 ft.

This interesting record of 24½ ft. of sediments confirms that the clays and silts (or "loams") underlie the gravelly drift with erratics, and indicates that the suite of deposits may extend eastwards for some distance, perhaps filling the "pre-glacial" valley connecting West Angle and Angle Bays. The surface at the southern end of the brick-pit lies at c. 40 ft. O.D., so the brick-pit record possibly does not extend down to zones 1, 2, and 3 of the cliff-face. In any case, Dixon's layer (2) may represent the base of the silty suite in the brick-pit, for the "clean buff sand" may be rotted limestone shale, and thus correlate with the decomposed debris in the coves to the north.

Plant-growth was apparently possible for periods during the deposition of the lower silts and clays, for wood fragments and organic matter are common, especially in zones 4 and 5.

The suite of silts and clays was probably deposited in still water, for each layer has an approximately regular grain-size, and laminations are characteristic.[1] If the deposits are river-laid then the lack of sands and gravels suggests that water-movement was slow and the environment estuarine. Although the silts and clays are non-calcareous they were possibly deposited in the sea, for it is difficult to envisage lacustrine conditions in this coastal locality unless there was a large storm-beach across the mouth of the bay. Another problem concerns the gradation upwards from silts into clays, matched by a decrease in organic material. The most plausible interpretation of this phenomenon is that it is the record of a transgression, with the lower silts deposited in shallow water in which plant remains (and perhaps living plants) were abundant, and the clays above representing deeper-water deposition. The environment throughout this transgression may have been periglacial, for Dixon has recorded buff laminated loam passing laterally into bedrock debris;

1. It is relevant to note that Dixon (P. 163) considered that "the horizontally laminated loams and sands represent comparatively still-water deposits".

however, at present it is not at all certain that this debris is head, and only careful analysis of the deposits and their organic content can indicate reliably what the climate was like at this time.

The red gravelly till mass in the second cove is closely related on lithological grounds to the flaky red gravels found in irregular masses in the main drift-cliff, and also to the bedded sand and gravel with erratics recorded by Dixon from the brick-pit. In West Angle valley the glacial drift bears more of the characteristics of outwash than of true till. Dixon has recorded an erratic from the St. David's district in the glacial deposits, and ice-movement from the north is further witnessed by the over-folded shales shown in Fig. 79A. The till and fluvio-glacial deposits were probably laid down by an Irish Sea Glacier which moved across the whole of Western Pembrokeshire; as noted by Griffiths (1940) the Old Red Sandstone outcrops to the north of Milford Haven are responsible for the colouring of this distinctive till facies.

The West Angle till, like other till deposits in Pembrokeshire, was apparently laid down by a relatively weak ice-stream. Masses of glacial deposits are embedded in the decomposed shale in cove two and in the silts in the main drift-cliff, and in each case the older deposits are severely contorted and in places incorporated in the till. However, the decomposed shale is a remarkably soft and rotten deposit which would surely have been removed entirely by a powerful ice-stream; again, the decomposed bands which have been overfolded by ice-action must surely have been removed completely by a strong ice-stream, for they are in a vulnerable position.

The age of the till is difficult to estimate. Although it is apparently non-calcareous, it is neither badly weathered nor buried by a great thickness of periglacial deposits. The head with erratics to the north of the main beach indicates, however, that periglacial conditions did prevail for perhaps a short period after the deposition of the till. The bright sandy loam capping the main drift cliff may be in part a wind-blown deposit and in part glacial outwash, but it appears to be related to the cliff-top sandy loams of North Pembrokeshire. Thus from the stratigraphy of the exposures at West Angle it appears entirely reasonable to propose that the gravelly till was deposited during the Dewisland Glaciation.

Conclusion.

At West Angle there appears to be a more complete interglacial - glacial sequence of deposits than anywhere else

Table XIII. A tentative reconstruction of events at West Angle Bay.

Events.		**Climate.**
Sandy loam		Arid - cold.
Upper Head		Moderately cold
Sandy red gravels		Deglaciation
Red Till		Glaciation
Grey clay	Transgression	Warmer
White organic silt		Warm
Head fragments ?		Cold ?
Raised beach gravels		Sea-level c 11 ft. O.D.? Warm ?

Erratics		Glaciation ?

Rock platform		Sea-level 19 ft. O.D.? Warm?
Establishment of coast		Temperate ?

West Angle Valley		Temperate ?

Bedrock rotting		Warm ?

in Pembrokeshire (Table XIII). From a cursory examination of the site in April, 1965 it seems that the formation of the raised beach near present H.W.M. was followed by a phase of sub-aerial solifluxion and then by a marine transgression. It is possible that a glaciation intervened between the two earlier phases. Later there was renewed solifluxion and a weak glaciation (the Dewisland Glaciation) from the north. After deglaciation there was a further short periglacial phase. Perhaps this suggested sequence of events may serve as a framework during future more detailed analysis of this valuable site.

Chapter 6 (A).

SUMMARY OF CONCLUSIONS.

From the fine exposures at Druidston and West Angle it appears that the late Pleistocene history of South-west Pembrokeshire has been very similar to that of North Pembrokeshire.

1. Stratigraphy.

At Druidston the Irish Sea till serves as an ideal datum for correlation with areas to the north, but it does not correlate lithologically with the red gravelly till and the red gravels at West Angle (Fig. 81). At West Angle the gravelly till is overlain by only a thin shale head, whereas at Druidston there is a thick rubble-drift above the till; this difference can hardly mean that the till at West Angle was deposited more recently than that at Druidston, for West Angle is some nine miles further south. Therefore it seems reasonable to propose that the two tills are the same age but of differing facies; while the Druidston till consists largely of blue-grey mud dredged from the floor of St. Bride's Bay, the till at West Angle is a local red sandstone facies which, if it was ever calcareous, has been completely decalcified.

As suggested in Fig. 81, the upper head at West Angle correlates with the rubble-drift at Druidston. At the base of the succession the stained gravels at Druidston may represent a raised beach which correlates with the raised beach at West Angle, for both deposits are stained by iron oxide and manganese oxide, and both occur close to H.W.M.

However, the organic silts and clays at West Angle are something of an anomaly, for they lie between a lower head and the gravelly till; there is no comparable suite of deposits anywhere on the North Pembrokeshire coast. If the other stratigraphic correlations are reliable it seems that the silts are wedged out at Druidston, perhaps because conditions there were not favourable enough for silt deposition.

2. The Mode of deposition of some drifts.

(a) The rotted limestone shales at West Angle appear to be largely in situ, having been deeply-weathered during a prolonged interglacial or preglacial period when the climate may have been warmer than at present. Slight traces of stratification in the rotted debris suggest that there may have been some solifluxion prior to the arrival of the ice which deposited the red gravelly till.

(b) The organic silts were probably deposited during a marine transgression after the deposition of the raised beach and prior to the last Irish Sea glaciation. From the beach deposits at Ogof Golchfa, it seems that sea-level during the interglacial prior to this glaciation may have risen to at least 30 ft. O.D.; the deposits at West Angle may therefore have been laid down in still water conditions during the waxing phase of this interglacial. This must mean that the raised beach gravels at West Angle date from an early stage of the interglacial, while those at Ogof Golchfa may date from its peak. This evidence is important, for it suggests that the raised beach deposits of West Wales are not necessarily contemporaneous, but may have formed at different altitudes at different stages of the same interglacial. In exposed coastal areas, where, the transgression did not lead to a marked retreat of the coastline, the beach deposits are generally pebbly, however, in sheltered localities such as West Angle, where the old valley was available for submergence,still water deposits are found with a record of increasing depth. Perhaps other similar deposits may be discovered just above H.W.M. within Milford Haven in sheltered localities such as the Pembroke River, Cosheston Pill, and the Carew and Cresswell Rivers.

(c) The significance of the apparent layer of head above the raised beach pebbles at West Angle is difficult to assess; it may indicate that following the deposition of the beach there was a fall of sea-level and a phase of periglacial action, followed later by a rapid transgression. Since the evidence of this phase of periglaciation is so scanty it would be unwise at this stage to speculate on either the length of time represented or the severity of the climate.

(d) The Irish Sea till at Druidston was not "plastered" by moving ice, but was possibly deposited during deglaciation when slumping and sludging of till masses in a dead-ice environment was prevalent. The till becomes stonier and its matrix coarser towards the top of the drift cliff, as the proportion of local rock-fragments increases.

(e) The rubble-drift at Druidston, as at other localities in North Pembrokeshire, does not appear to be a true "Upper Boulder-clay". It consists in part of outwash sands and gravels, in part of washed till, and in part of soliflucted bedrock fragments and till.

(f) There is much evidence to suggest that the till at Druidston and West Angle dates from the Dewisland Glaciation. Thus it appears that coastal sections c. 20 miles south of Charlesworth's "South Wales End-moraine"

TABLE XIV

STRATIGRAPHIC CORR ATIONS AND INTERPR ATION OF EVENTS IN SOUTH-WEST PEMBROKE- SHIRE.

Druidston	West Angle Bays	West Angle Beach	Sea-level	Climate	Events
S. loam	Sandy loam	Sandy loam	Low-	Cold-arid?	Wind-action
Rubble-drift	Upper head	Red gravels	rising	Moderate cold	Solifluxion Deglaciation
Irish Sea till	Red till		Very low	Glacial	Dewisland Glaciation
Lower head	Head traces?		Falling?		Solifluxion
	Rotted bedrock	Lam. clay Org. silt	High Rising	Warm	Poppit Interglacial; marine transgression
	↓ ?	Lower head?	Low?	Cold?	Solifluxion?
Raised beach?		Raised beach	Near present	Temp.	Deposition of beach
Valley		Erratics	Low	Glacial	Early Glaciation
		Platform	High	Warm	Platform cutting
Establishment of coast			As pres.	Temp.	Marine erosion
	Angle Valley		Lower than at pres?	Temp? Warm?	Sub-aerial erosion
	Rotted bedrock				Deep rotting of bedrock?

are very similar to sections to the north of the feature. The impression is reinforced that the end-moraine is not a terminal feature of a major glaciation.

3. Table of Correlations.

Most of the reasoning behind the correlation table (Table XIV) has been given in the text. As in other localities, the assumption is made that glaciations are accompanied by low relative sea-levels and interglacials by warmer climates and high sea-levels.

The juxtaposition at West Angle of the grey clay (probably indicative of a high sea-level and deep-water conditions) and the red gravels (glacial deposits probably laid down at a time of very low sea-level) is unusual, for at most other localities in Pembrokeshire there are records of a falling sea-level after the peak of the interglacial transgression. These records are generally preserved as solifluxion deposits indicative of an increasingly cold climate. A periglacial phase must surely have occurred between the two events mentioned for West Angle, and indeed at Druidston there does seem to have been a prolonged periglacial phase immediately prior to the Dewisland Glaciation. In the table, therefore, the lower head at Druidston is not correlated with that at West Angle, which appears to be a somewhat earlier deposit.

Towards the base of the table the Early Glaciation is placed later in the sequence of events than the platform-cutting phase, for the reasons adduced in earlier sections. The coastline appears to have been established after the cutting of the Angle Valley, for cliffs extend into a coastal embayment which has clearly formed as a result of the drowning of the valley. There is no good evidence for the relative age of the phase of bedrock rotting at West Angle; as argued in the text, the rotting period appears to have been prolonged, and in the table a compromise suggestion is made that some of the rotting may have been interglacial and some preglacial.

Although there are some unique deposits at West Angle, the drift succession of the coast of South-West Pembrokeshire can be related with confidence to the successions further north.

Chapter 6 (B).

The coast of southern Cardiganshire.

B1. The drift sections in the Teifi Estuary.

(a) East side (Gwbert).

(b) The drift exposures at Poppit

B2. The drift sections in New Quay and Little Quay Bays.

Summary of Conclusions.

Chapter 6 (B1).

THE DRIFT SECTIONS IN THE TEIFI ESTUARY.

(A) East Side (Gwbert) (Fig. 82).

At Gwbert, on the eastern side of the Teifi estuary, a long exposure of calcareous Irish Sea till is being eroded by the sea. Cliffs c. 60 ft. high consist largely of till in the southern part of the section, while further north the till and other deposits are seen to lie on a well-preserved rock platform (Fig. 83). The section has been briefly described by Williams (1927), Synge (1963), and Stephens (1964), and erratic indicators from the Gwbert area have been mentioned by Jehu (1904) and Hope Macdonald (1961). Jehu recorded smoothed and striated bedrock beneath drift, but did not record the presence of the rock platform. Several examinations of the section have led to the recognition of the succession shown in Fig. 83.

Bedrock and the rock platform. Bedrock in this locality is lower Ordovician thin-bedded shale, with steeply-dipping strata and many different joint-directions. In places the bedrock surface is badly weathered and shattered, but most exposures have been eroded and smoothed. The westernmost portion of the bedrock exposure is a fine rock platform with its outer edge sloping from c. 14 ft. O.D. in the north at 2° down to 6 ft. O.D. in the south. The platform is c. 50 yds. long and has a maximum visible width of 6 yards. Above a sharp break of slope at the back of the platform is a further bedrock exposure which appears to be part of the old marine cliff (Plate 30A), and which is capped with thick drift. In places the drift rests upon the rock platform itself. The northern end of the platform grades into an undulating bedrock surface which slopes towards the north at 35° (Plate 30B), and which is covered with striations. These striations generally trend towards 132°, although they are found throughout a range of c. 40°. Striations are again common on the exposed part of the rock platform, where they trend to between 163° and 183°. At the southern end of the platform some of the striations are $\frac{1}{4}$" deep and over 12" long, and deep gouges are seen here and there. In the small gully to the south of the platform smoothed and striated slabs of bedrock are again seen, and another frequent phenomenon is shattered bedrock which has been "overfolded" (presumably by ice-movement) towards the south. These overfolds are overlain by till.

No raised beach gravels have been observed on the rock platform, but it is littered with numerous striated and rounded erratic boulders. Particularly noticeable are two large boulders, of medium-grained igneous rock and black sandstone, which are covered with striations. They have clearly been left on the rock platform after the removal of part of the till cover.

1. Lowest Head. Lying at the back of the rock platform is a layer of shale head which varies in thickness from 6" to 3 ft. It consists of shale fragments which are generally under 6" in diameter, but it also contains rounded pebbles of quartzite and Cretaceous flint. Some of the erratics in the head are striated. The matrix is sandy and gravelly, and in spite of some pseudo-stratification the head is often disturbed. It is seen in several good exposures against the old rock cliff, and also in patches on the platform. The head is slightly calcareous, possibly as a result of the passage of carbonate-loaded ground-waters percolating downwards from the till above. As at Whitesands North, this head appears to overlie some of the striations on the rock platform.[1]

2. Laminated silts. Overlying the head at the base of the old rock-cliff is up to 24" of dull brownish-red laminated silt (Plate 31). It is clean, sticky, and stoneless,

---

1. A problematical head also overlies a striated rock platform at Ringabella, Southern Ireland.

although in places it appears to be interbedded with the head. The laminations dip steeply down towards the rock platform. The bottom ¼" of the deposit is coloured a richer red and is non-calcareous; the rest of the deposit reacts slightly to dilute HCL. In places the silt is overlain by recent sludged slope deposits, but where full sections are seen it appears to grade upwards into the overlying till.

3. <u>Purple calcareous till.</u> Above the silty band on the platform is c. 8 ft. of purple calcareous till. In places it is stony and gravelly, with clear traces of incorporated patches of head. For the most part, however, it is compact and relatively stoneless, with many small shell fragments as at Aber-mawr. It contains many erratic pebbles which are well-striated and derived from northern sources such as Galloway, the Isle of Man, and North-east Ireland (Jehu, 1904; MacDonald, 1961). The upper 2 ft. of this exposure are decalcified.

South of the rock platform the purple till is seen to be at least 60 ft. thick, and it extends almost from top to bottom of a degraded drift cliff c. 175 yards long. The base of the cliff lies below H.W.M., and it is being actively-eroded by wave-attack; during the winter of 1964 -

1965 the cliff retreated at least 15 ft.[1] Many rounded and striated boulders and pebbles have been eroded from the cliff and lie on the fore-shore. The lower 30 ft. of this cliff is steep and clearly-exposed, although higher up it is masked in places by large slump features and vegetation. Large contortions and apparent push-structures are visible in the till, although it is never clear to what extent these are due to recent slumping. These may be the frost-disturbance features mentioned by Synge (1963). The till is occasionally well-stratified, and thin bands of gravel are frequently interbedded. High on the cliff-face lenses of fine red sands and gravels appear in the till, which contains many different facies. There are distinct facies of clay-like, silty, gravelly, and stony tills. Everywhere the till bears traces of foliation, folding and faulting. The stratification within the till mass is highly irregular, with bedding directions different for each distinct till facies.

---

1. Other evidence or rapid cliff retreat may be seen in the fact that no rock platform was visible when Jehu visited Gwbert in 1904 or when vertical aerial photographs (1:30,000; 106G/DY/37; Nos 6057 and 6058) were taken in 1944. The platform must have emerged from beneath the till cover within the last 20 years.

At Gwbert the till is completely decalcified to a depth of 2 - 3 ft. beneath the surface, and is weathered to its usual rich yellow-foxy-red colour to a depth of 6 - 8 ft. This weathered layer displays a typical "macamore" soil profile as a result of severe gleying.

4. Stratified sands and gravels. Above the rock platform up to 8 ft. of well-stratified sands and gravels are interbedded with till in the lower part of the drift cliff. The gravels are slightly calcareous, but are weathered to a depth of c. 4 ft. at their upper margin. In appearance they seem to be fluvio-glacial outwash, for their suite of erratics is the same as that of the till; further, there is no discontinuity between the gravel and gravelly calcareous till beneath. As in the laminated silts below the lowest head, the stratification in the gravel dips down towards the rock platform. At the southern end of the platform stratified gravel is seen to overlie silt bands and then shelly calcareous gravels which contain till lenses. Here calcareous till with boulders and more silt lenses is seen to overlie and underlie the stratified gravel, so there is little doubt that it is closely associated with the till. About 30 yards south of the rock platform the long gravelly horizon disappears from the till.

At the southern end of the drift cliff, near the point at which the blown sands of Towyn Warren descend to the level of the beach, a sharp contact is seen between an irregular till surface and overlying sands and silts, which are up to 12 ft. thick. The sands are irregularly-bedded; they are stained red by iron oxide throughout, and black by manganese oxide in intermittent bands. The upper part of the exposure of sand is well-stratified, but lower down traces of current-bedding are often obliterated by severe slump-features and contortions. At the junction between this outwash sand and the overlying blown sand there is a 3" crust of stained sandrock.

5. Upper Head. In patches on the clifftop there is a thin gravelly head of greenish sandstone, probably derived from upslope bedrock outcrops. It has a maximum thickness of c. 3 ft, and contains many rounded and sub-angular erratics, including pebbles of Cretaceous flint. Part of its bulk clearly consists of soliflucted calcareous till.

6. Blown sands. Capping the drift-cliff along the whole of its length is c. 6 ft. of stoneless grey-buff sand. In places the sand has slumped down onto the cliff-face, so that in places it appears to be interbedded with

the till. To the south and east the sands are piled up into the large dunes of the Towyn Warren, so there can be little doubt of their wind-blown origin. At the southern extremity of the till exposure the stratification in the sands is surprisingly regular, giving rise to some speculation that they owe their origin in part to fluvio-glacial deposition.

Interpretation.

The rock platform at Gwbert appears to be a raised beach platform, for its altitude accords with that of raised beach platforms at Whitesands and Ogof Golchfa; the bedrock slope at the back of the platform appears to be an old cliff-line. As at other localities in Pembrokeshire, the platform pre-dates the lower head and the purple till. As at Parrog in the Afon Nevern estuary, a further clue to the age of the platform can be gained from the fact that it is cut within the estuary on the old valley-side of the Teifi (Plate 32). The estuary must therefore have been in existence before the stage of raised beach platform erosion. The old Teifi valley is graded to at least -75 ft. O.D. (Allen, 1960).

The lower head appears to be the direct equivalent of the lower heads at Porthmelgan and Whitesands, for at each locality it lies between bedrock and purple calcareous till. Furthermore, at Porthmelgan laminated silt overlies the head, and at Whitesands striations appear to pass beneath it; each situation is matched at Gwbert. The presence of striations beneath head is difficult to explain, for if the head is in situ, then the striations must clearly pre-date its formation and the deposition of the calcareous till above. Some striations, therefore, may date from an earlier glaciation. Two significant facts appear to contradict this theory: namely (a) the contorted and disturbed nature of the head, and (b) its slightly calcareous matrix. When it is also noted that patches of head are visible in the overlying till there appear to be reasonable grounds for suspecting that the head may have been moved for a short distance in the basal ice-layers, striating the bedrock surface before being redeposited as a basal till layer. This explanation seems rather tortuous, and only detailed fabric analysis of the head can indicate whether or not it is reliable. From independent evidence a similar origin has been proposed for the striations beneath the lowest head at Whitesands North.

As at Porthmelgan the laminated silts above the head appear to be associated with the overlying till, for they grade upwards into it with some interbedding. Furthermore, if the underlying head has been contorted and moved by ice then the silts are unlikely to have had a subaerial origin. While the silts may be part of a suite of glacial deposits, their compact and stoneless nature appears to preclude an origin as a true till; it is possible that they are the result of basal washing of fines, with deposition beneath the ice before the deposition of the morainic mass (Carruthers, 1939; 1948). A similar process has been observed beneath the Kaldalon Glacier, north-west Iceland.

The erratic content and shelly nature of the purple till indicates that it is probably a true Irish Sea till (Williams, 1927), and that the striations were cut by ice moving southwards up the Teifi estuary. There is no evidence in this section for ice moving northwards from a Teifi glacier. The presence of interbedded lenses of sands and gravels may indicate that the conditions of till deposition were rather moist, probably at a time of ice-wastage when englacial streams were active in the basal parts of the ice. Examples of this process on a large scale may be seen beneath the snout of the Schuchert Gletscher and the Langgletscher, East Greenland.

Regarding the age of the Gwbert till, it may be significant to note that both Charlesworth (1929) and

Griffiths (1940) consider that the Irish Sea ice of the Newer Drift glaciation over-rode this locality. The youthful age of the till may be attested by its slight degree of weathering and decalcification; and yet the degree of decalcification is no less than that at Abermawr, Whitesands, or Druidston, which are well to the south of the postulated Newer Drift limit. On this line of chronological evidence it may be tentatively suggested that the calcareous Irish Sea tills of western Pembrokeshire are the same age as that at Gwbert: i.e. dateable to the Dewisland Glaciation.[1]

There is no evidence at Gwbert of Charlesworth's "Lake Teifi", for the stratified sands and gravels and outwash lenses are best interpreted as products of ice-wastage in a sub-aerial, sub-glacial, and pro-glacial environment, rather than a lacustrine environment. Since the col in the Cippin channel lies at an altitude of 325 ft. (Joy, 1963), the channel could not have been an overflow route

---

1. Synge (1963) and Stephens (1964) consider that the till at this locality is of Eastern General (supposedly Riss) age; deep leaching and frost disturbance is cited by Synge as evidence in support of this dating. As indicated above, leaching is rather shallow and no traces of undoubted frost-disturbance have been seen in the till.

unless a lake level above that altitude existed in the Teifi estuary. Such a lake must surely have left lacustrine deposits of some sort at the top of the Gwbert section. The existence of Lake Teifi at this point is subject to considerable doubt.

The upper head at Gwbert is rather thin and has marked pseudo-stratification. It seems, therefore, that it may have accumulated under moderately severe periglacial conditions which did not last for very long.

The deposition of the blown sands may well have been rather recent, for the dunes above the drift-cliff are still only sparsely-vegetated, and blow-outs are still being actively formed, especially in the vicinity of the caravan site south of the drift cliff.

(B) The Drift Exposures at Poppit.

At Poppit, on the western side of the Teifi estuary, there occurs possibly the best-preserved raised beach deposit in West Wales (Plate 33A). The drifts which lie above the beach pebbles permit correlation with the section at Gwbert, and enable a comprehensive picture of Pleistocene events in the Teifi estuary to be reconstructed. The locality has not found its way into the literature; although it is easily accessible, neither Jehu (1904) nor Williams (1927) seem to have visited the site, perhaps because it lies on the "no-man's-land" near the Pembrokeshire-Cardiganshire boundary!

(A) Poppit East.

About 150 yards to the north-west of the car-park there is a drift-cliff c. 15 ft. high. Bedrock at the locality is revealed on an uneven rock platform cut across thin-bedded soft flaky shales with some interbedded sandstones. These rocks are part of the Silurian Llandovery Series (Pringle & George, 1948). At the base of the cliff, excavation reveals the presence of varied beach pebbles resting upon the platform just above H.W.M. The pebbles are well-rounded and generally under 3" in diameter, and are set in a sandy, iron-stained matrix. In places the pebbles pass laterally into reddish stratified sands and silts or fine white sand up to 7 ft. thick; both these deposits rest directly on the rock platform. The raised beach deposits are seldom over 2'6" thick.

In places the beach gravels are overlain by up to 3 ft. of stony red non-calcareous clay. This clay contains a large variety of angular to well-rounded erratic pebbles, some of which are striated. Although there are slight traces of laminations and some thin silt bands in the clay, it appears to be a decalcified Irish Sea till.

The thickest deposit in the exposure is a blocky head of bedrock fragments and erratics. It is of more variable composition than many of the heads of Pembrokeshire, and appears to contain masses of sand and gravel, which are especially noticeable c. 10 yards from the southern end of the section. Elsewhere angular bedrock blocks up to 9" in diameter are set in a matrix of fine gravel, and some stratified sands and silts are interbedded. Some layers contain angular blocks up to 18" in diameter. In places there are indications of a discontinuous break between a reddish blocky head in the lower part of the cliff and a darker brown head above. Towards the northern end of the section the head is seen to have cut through the underlying deposits, for it lies directly on the bedrock platform.

(B) Poppit West.

From the small point north of the car-park to Cei-Bach jetty below Penrhyn Castle there is an excellent drift exposure.

Everywhere the drift lies upon a raised beach platform which is cut across a variety of steeply-dipping folded and shattered flaky black mudstones, soft grey shales, and interbedded grey and buff sandstones. The platform has a general altitude of 8 - 11 ft. O.D., and correlates very clearly with the Gwbert rock platform which can be seen less than a mile away across the Teifi estuary (Fig. 82). The raised beach platform is probably the most extensive in Pembrokeshire, for it can be followed along the coast for almost 1000 yards. In places it has been dissected by a later phase of marine erosion, and at its seaward edge there is often an undercut ledge which appears to have resulted from present-day wave-action. No striations were discovered upon the platform; this may be due in part to the softness of the bedrock, which has facilitated considerable recent weathering of the upper surface.

On the rock platform is a long exposure of raised beach pebbles which is masked at intervals by slumping on the cliff-face. The beach is up to 5 ft. thick, and is characterised by a great deal of lateral variation in the size of pebbles and the nature of the beach matrix. Occasionally exposures are gravelly with few pebbles, but for the most part the beach consists of pebbles 2" - 6" in diameter set in a sandy and gravelly matrix which is cemented with iron and manganese oxide (Plate 33B). In places the beach consists entirely of boulders over 2 ft. in diameter. Near the boathouse at the western end of the bay is a fine exposure of a raised beach over 5 ft. thick resting upon a planed bedrock surface (Plate 34);

pebbles on this beach are often over 12" in diameter, and are set in a sandy matrix. As far as could be determined, all the pebbles in the raised beach are of local origin (sandstones, shales, and vein quartz pebbles), although the possibility must be borne in mind that some undiscovered erratics may be present.

Above the raised beach there are occasional fine gravelly layers, but generally the beach is directly overlain by a thick blocky head. In places this head is no more than 2 ft. thick, but at its thickest, near Cei-Bach, it is up to 20 ft. thick. There are a few small erratic pebbles at the head, but it is made up for the most part of local sandstone and shale fragments set in a sandy matrix. Near its base, the head contains many raised beach pebbles and at the eastern end of the exposure, where the drift cliffs are less than 15 ft. high, solifluxion appears to have removed all traces of raised beach gravels. This mixed head with raised beach pebbles may be up to 4 ft. thick. In the upper part of the main head, lenses of sands and gravels appear to be interbedded.

Directly overlying the head everywhere in the small bay is a purple shelly Irish Sea till. Near Poppit the till is less than 5 ft. thick, and in places is completely decalcified; to the west, however, the till increases in thickness and is seen everywhere to be highly calcareous. The outcrop of till is inaccessible where it overlies c. 20 ft. of head, but from the shore below it is seen to be at least 7 ft. thick. At its base the till is rather gravelly, and it appears to contain interbedded gravel layers.

In a brief examination of the exposure it did not prove possible to search for head above the till; there does not appear to be any upper head near the point, but it may occur in the west, where bedrock is near at hand and where slopes are steeper.

Interpretation.

In view of the very close association of rock platform and raised beach deposits at Poppit, there are good grounds for believing that the platform is marine-cut. On the basis of altitude and position it correlates with the platform at Gwbert and likewise indicates that the Teifi estuary was in existence before the platform-cutting period.

The Irish Sea till is a good datum for correlation across the estuary, but beneath the till there are some stratigraphic differences. For example, raised beach gravels have not been found to date at Gwbert, while they are thick and coherent at Poppit. This is hard to explain, but the greater exposure of the Gwbert platform may have resulted in scouring by storm-waves rather than beach deposition; however, it is still possible that raised beach pebbles may be exposed on the rock platform at Gwbert after further cliff erosion.

In any case the Poppit evidence indicates strongly that a prolonged period of beach deposition and sea-level stability preceded the deposition of the lowest head in the Teifi estuary. The fine white sand associated with the raised beach gravels at Poppit East may be a blown sand deposit similar to that beneath the lowest head at Whitesands South.

There is a great discrepancy in the thickness of this lower head at Poppit and Gwbert; at the former locality it varies from 2 ft. to 20 ft. in thickness, while at Gwbert it is never more than 3 ft. thick. This may be due in part to ice-erosion of the head at Gwbert, but it is more likely that differences in "solifluxion potential" are responsible; the variation in the thickness of the lower head from 2 ft. to 20 ft. at Parrog is in itself a warning to those who would make rash conclusions concerning the time-span of a periglacial phase simply on the basis of head thickness! (See Chapter 3A).

As at Gwbert, the characteristics of the lower head appear to indicate moderately cold periglacial conditions for an unknown length of time. The appearance of sandy lenses in the upper part of the head at the western end of the bay is interesting; these may be hill-washing products, or else may represent fluvio-glacial outwash incorporated in the head at the base of the Irish Sea Glacier. Unfortunately, the sandy lenses are inaccessible, so it was not possible to discover whether or not the head around them is in situ.

There do not appear to be widespread outwash deposits above the till at Poppit, although the mixed solifluxion deposit at Poppit East does contain the remnants of such outwash. If, as seems very likely, the red clay with stones at Poppit East is the equivalent of the Irish Sea till to the west, then the head with erratics and outwash masses above it must indicate that there was a phase of solifluxion shortly after the wasting of the ice-sheet. This confirms the impression gained at Gwbert. The apparent presence of a second upper head at Poppit East is unusual. It may be of little significance, indicating a change in the lithology of the material subject to solifluxion; however, the possibility must be borne in mind that there was a climatic break between the deposition of the heads.

As at Gwbert, the till does not appear to be severely

Table XV. A tentative reconstruction of events in the Teifi Estuary.

Events.	Climate.
Leaching of till	Temperate
Blown sands	Colder, dry ?
Upper Head (2) Upper Head (1)	Moderately cold
Sands and Gravels	Deglaciation
Red clay with erratics Irish Sea Till Basal laminated silt	Glaciation
Lowest Head	Moderately cold
Raised Beach Gravels - Poppit	Sea-level 3-11 ft. O.D. Warm ?

Raised Beach Platform	Sea-level 3-14 ft. O.D. Warm ?

Cutting of Teifi Valley	Sea-level -75 ft. O.D.? Temperate ?

weathered or decalcified; it may reasonably be assigned to the Dewisland Glaciation. Again, as at Gwbert there is no evidence in favour of Charlesworth's Lake Teifi.

The sections on either side of the Teifi estuary are clearly complementary, and correlations can be made with safety. The sequence of events represented in the area may be suggested as in Table XV.

Chapter 6 (B2).

THE DRIFT SECTIONS IN NEW QUAY AND LITTLE QUAY BAYS, CARDIGANSHIRE.

In New Quay and Little Quay bays, and on Llanina Point which separates them, there are many fine exposures of glacial and periglacial deposits which are typical of the south Cardiganshire coast (Fig. 84). The drift succession was described in some detail by Williams (1927); more recently Mitchell (1962) has attempted an interpretation of the deposits at New Quay and has correlated them with deposits elsewhere around the Irish Sea. The locality is also mentioned by Mitchell (1960), Synge (1961, 1963) and in Stephens (1964); these workers have proposed that at New Quay a true shelly calcareous Irish Sea till occurs between two local tills dating from the Riss-Saale glaciation.

(A) New Quay Bay (West).

Near the lifeboat station bedrock is exposed beneath the drift cover. It consists of soft grey and black mudstones of the Llandovery Series (Silurian) which are severely folded, faulted, and contorted. There are interbedded strata of soft sandstones, for the most part dipping towards 272° at 20° - 30°. Southwards from the lifeboat station the upper bedrock surface falls in altitude until it disappears beneath the beach; this surface is irregular, but in places it appears to have been eroded and parts of it may represent a rock platform.

1. Raised beach gravels (?). Although I found no raised beach gravels on the platform, they have been recorded by Synge (1963) lying immediately beneath head to the south of the lifeboat station where a small stream descends the drift cliff. Mitchell (1962) gives the grid reference to the locality as 390598. Mrs. E. Watson (personal communication) considers that the pebbles in this deposit are of doubtful origin, for they cannot be proved to underlie the deposits on the drift cliff.

2. Shattered bedrock and head. In places the upper 4 ft. of the bedrock surface is shattered and contorted, apparently as a result of periglacial processes. The shale fragments in this layer are generally under 2" in diameter, although fragments from sandstone bands may be 4" in diameter. This cryoturbated layer passes upwards into c. 2 ft. of shale head with moderate pseudo-stratification. The matrix is sandy and gravelly, and there are thin interbedded silt bands which were possibly laid down as a result of hillwash processes. Where the head consists largely of sandstone fragments a good downslope orientation of these fragments can be seen.

3. Lower Chalky-grey Rubble-drift. Lying directly upon bedrock near the lifeboat station and upon head further south is a stony and gravelly rubble-drift between 10 and 50 ft. thick. It varies in colour from rich purple to dull grey and rich grey-brown. The stones in this deposit are generally 3" - 6" in diameter, but may be up to 18" in diameter, and are often sub-angular and striated. Local sandstones and shales make up the bulk of the deposit, although there are erratic pebbles of dark grey sandstone, feldspathic sandstones, and quartzites. No Cretaceous flint pebbles or igneous erratics were found. In places the matrix of the drift contains much clay and silt, but it is everywhere non-calcareous and contains no shell fragments.

The junction between this drift and the underlying head is generally sharp, but in places there is a gradation upwards from head into c. 4 ft. of stratified layers in the base of the rubble-drift; this is best seen c. 20 yards west of the point at which the bedrock surface disappears beneath the beach. The drift contains some distinct clay bands and other bands which are packed with stones; irregular gravelly and sandy patches occur here and there. There is an irregular contact in the drift c. 10 - 15 ft. above the beach in the vicinity of the deepest gullies, although the fabric characteristics above and below this contact appear to be the same.

As one passes eastwards towards the Afon Halen stream contorted gravelly layers may be seen in the drift, and there are slump features apparently similar to those at Aber-mawr. On the top of the cliff at the western end of the bay the rubble-drift is weathered and gleyed to a depth of c. 7 ft., the upper 2 ft. being most severely gleyed.

It is not clear whether Williams considered this deposit as "Upper boulder-blay" or "Lower boulder-clay", but Mitchell (1962) considers it a true till, and has named it the "New Quay Boulder-clay".

(B) <u>New Quay Bay (East).</u>

1. <u>Calcareous Irish Sea till.</u> To the east of the Afon Halen stream and appearing for the first time at beach level near the old ruined jetty there is a long exposure of Irish Sea till. It is difficult to determine whether this till overlies the lower rubble-drift or passes laterally into it, for no complete succession can be observed in the bay. Patches of fine clay in the upper 5 - 6 ft. of the drift cliff near the lifeboat station may be the representatives of the Irish Sea till, and Mitchell (1962) and Synge (1963) appear to be in no doubt that it post-dates

the rubble-drift. Mrs. E. Watson, who has examined the section on many occasions, is likewise certain that the Irish Sea till overlies the rubble-drift, for in wet weather masses of it may be seen slipping down the rubble-drift face.

Whatever the relative age of this drift, it has all the characteristics of an Irish Sea till: a calcareous, sticky matrix of silt and clay, a chocolate brown-grey colour, many shell fragments, and relatively few erratic pebbles. The proportion of far-travelled erratics to local rock-types appears to be higher than in the rubble-drift, and rounded and striated pebbles of black mudstone and Cretaceous flint are common. The till attains a maximum visible thickness of c. 50 ft., but exposures are rendered rather complex by the presence of large-scale slump features which mask the true character of the till face. At the clifftop c. 8 ft. of till is severely-gleyed, and complete decalcification has extended to a depth of c. 6 ft. Some of the decalcified till from the clifftop (with included peaty bands) has slumped down to present high-water mark; indeed, one cannot be certain that any of the exposures are in situ.

As at Druidston, the upper part of the till exposure has a high proportion of local stones and boulders in a gravelly matrix; however, the matrix is still calcareous, and there is no evidence from the main exposures of till to suggest that it is overlain by a second local till, as suggested by Mitchell and Synge. From the sections in New Quay Bay, all that can be said is that there is a change of facies in the Irish Sea till towards the top of the cliff.

This till is the "lower Boulder-clay" of Williams; Mitchell (1962) has correlated it with other tills around the Irish Sea, and has named it the Fremington Boulder-clay.

2. Stony outwash Deposit. Immediately to the west of the mouth of the Afon Llethi stream the calcareous till is replaced at the surface in the cliff sections by a stony deposit of local and foreign stones. From a distance the deposit looks like the rubble-drift at Pen Deudraeth and Aber-mawr. The stones are up to 9" in diameter (although generally under 6") and are sub-angular and rounded; angular and striated stones are rare. In places the matrix is entirely of coarse gravel, and although the deposit is often disturbed there are frequent traces of stratification in many directions. The junction between the stony drift and the underlying calcareous till is often sharp but irregular, and in one locality c. 5 ft. of stratified fine sand separates them. In places the gravels

consist of small well-rounded pebbles which are stained by iron and manganese oxides. Occasionally, the deposit contains patches of decalcified till. The uppermost 6 ft. of the gravel are severely-gleyed. In view of its characteristics this drift appears to have accumulated in a rather different manner from the rubble-drifts at Aber-mawr and elsewhere. Perhaps the deposit is best termed a stony outwash.

3. Silty loam. On the surface of the stony outwash gravels there are a few patches of silty loam, although such patches are very rare above the till cliffs further east. In some cases the silt appears to be interbedded with the outwash gravels. It appears to have had a similar origin to the sandy and silty loams of Pembrokeshire.

(C) Llanina Point.

On the point to the east of the Afon Llethi stream mouth is a small section which provides a valuable clue to the nature of the glacial deposits in the area. The section is c. 15 ft. high and is terminated on its eastern flank by an old valley-side (Fig. 85). This is probably the locality noted by Williams where so-called Upper Boulder-clay and Lower Boulder-clay are separated by Intermediate sands and gravels.

1. Irish Sea till. At the base of the section up to 8 ft. of calcareous grey clay till is exposed. It contains striated sandstone boulders and other erratics up to 2 ft. in diameter, but for the most part it appears to contain few pebbles. It is contorted in places, and the contact with overlying sands is characterised by much interdigitation, with lenses of sand included in the till. This till must be the Lower Boulder-clay of Williams.

2. Sands and silts. The sands and silts overlying the till attain a maximum thickness of c. 7 ft. They are generally well-stratified, but also contain patches of till and gravelly and stony lenses. One of these lenses is of coarse gravel which appears to have been subjected to slumping. In the upper part of the deposit there is one distinct band of silt (2a) which is 9" thick; it is laminated and is severely contorted in places.

3. Bedded sands. The sands and silts grade upwards into a distinctive lens of medium-grained grey sand which has a maximum thickness of c. 4 ft. It is stoneless, and again is capped by 6" - 9" of grey laminated silt.

4. Decalcified till. This till, which is c. 2 ft. thick, is rather stonier than that below the sands, and is completely decalcified; however, there is no reason to suppose that it is anything but a detached mass of Irish Sea till. Again,

its stony nature matches the stony Irish Sea till further to the west on top of the drift cliffs. It is not underlain by an erosional contact or a weathering horizon of any sort, so it is best considered as part of the suite of outwash deposits.

5. Coarse gravel. The till is overlain by c. 5 ft. of coarse stratified torrential outwash gravel which is full of rounded and sub-angular local and erratic stones. This may be the "Upper boulder-clay" of Williams (there is no true till above it in this section), for it closely resembles the stony deposit to the west of the stream which Williams seemed to consider a till.

6. Sandy loam. The section is capped by c. 12" of sandy loam with a few included pebbles from the gravel beneath.

(D) Little Quay Bay.

In this bay, the coastal stretch between Llanina Point and Mount Pleasant reveals some interesting features which are not seen further west. Immediately to the west of the footpath is a badly-slumped exposure c. 200 yards long and varying in height from 10 ft. to 50 ft.

1. Calcareous till. At H.W.M. is a relatively stoneless grey calcareous Irish Sea till at least 5 ft. thick. The till contains well-rounded and sub-angular striated erratics of black mudstone, and a few shell fragments.

2. Laminated silts. At least 15 ft. of bright grey laminated silt appears to overlie the till. It is stoneless, non-calcareous, and non-shelly. In places there are irregular interbedded masses of sand and till, which are indistinguishable from the silts when viewed from a distance. The laminations are approximately horizontal, although they are buckled and faulted in places. The silts are exposed for over 100 yards in the cliff-face, and for much of this distance they are homogenous and undisturbed. In view of their interbedding and colour similarities, the silts and the underlying calcareous till appear to be intimately associated. This interpretation differs from that of Mitchell (1962), who has placed the calcareous till above the silts and has correlated the latter with the so-called New Quay (local Welsh) boulder-clay.

3. Upper variable Rubble-drift. Above the laminated silts is a variable deposit of local outwash gravel with stony till masses. In places it has cut through the laminated silts and lies in direct contact with the calcareous till. Some of the sand layers at the base of the deposit are severely contorted, and appear to have been subject to slumping during or shortly after deposition. The slump features are distinguishable from the features associated

with recent slipping on the cliff-face, and closely resemble some of the features in the uppermost drift deposit at Druidston. In places higher up the cliff the rubble-drift is stony and chaotically-bedded; it bears none of the fluvio-glacial characteristics of the outwash deposits to the west and lower down the cliff exposure. Stones in the drift are sub-angular and angular, and many are striated; most appear to be locally-derived. Near the top of the cliff, c. 45 ft. O.D., stony gravels are interbedded with a complex series of blocky layers, lenses of black cemented sand, masses of decalcified till, and layers of sands, gravels and laminated silts. The whole suite of deposits is distinguishable from the laminated silts and calcareous till below, partly on account of its rich red-brown colour. This drift certainly lays more claim to the term "Upper Boulder-clay" than do any of the drifts further west in New Quay Bay.

Interpretation.

Unfortunately I did not have time to carry out detailed fabric analyses on the New Quay drifts. However, from the stratigraphic evidence recorded above some suggestions can be made concerning the origins and relationships of the drifts. In Fig. 86 composite profiles from the four most important cliff sections are compared. Only at New Quay West do drift deposits rest directly upon bed-rock, so it is perhaps safe to assume that the rubble-drift at that locality is the oldest deposit in the area (with the possible exception of the doubtful raised beach).

If the eroded bedrock remnants represent a raised beach platform at 12 - 22 ft. O.D., and if the rounded pebbles recorded by Synge are true raised beach deposits, then correlation is invited with the raised beach series of Pembrokeshire and Gower. It is a little unusual for West Wales to find severe frost-shattering of the platform surface, but this can be explained by the incoherent bed-rock lithology of folded and faulted soft shales. There is a comparable frost-shattered rock platform at Newtown in South-east Ireland.

The head above bedrock is thin and the size of the frostflakes appears to vary according to the parent material; for example, head fragments derived from greywacke bands are several times larger than those derived from soft shales. If all the head is preserved at the present day, then it probably represents a relatively short phase of solifluxion. However, near the life-boat station it grades upwards into the roughly-stratified basal layers of the lower rubble-drift, and the possibility must be con-sidered that the thickness of bedrock head by no means represents the full periglacial phase.

The nature of the lower rubble-drift or "New Quay boulder-clay" presents a problem, for the stratification in its lower layers and its high proportion of local rock-types may mean that the deposit is a mixture of soliflucted till and head. Such deposits are apparently common on the North Cardiganshire coast (E. Watson, personal communication, 1964), and it must be borne in mind that the western end of New Quay Bay would have been a favourable locality for solifluxion in view of its aspect and the steep bedrock slope to the west. While the deposit does bear many of the characteristics of a true till, the apparent stratification of its lower layers needs to be carefully examined. Mrs. E. Watson considers the deposit to be a "solifluxion till", for its constituent stones are everywhere orientated parallel with the slope. The erratic pebbles are considered to have been derived from older glacial deposits, although the apparent lack of Irish Sea erratics in the drift may indicate that the destroyed till may have been the product of local Welsh ice. The slump features in the drift near the Afon Halen stream look like ice-contact features; however, they could equally well have formed under conditions of "episodic" solifluxion (Büdel, 1960), or as a result of unusually rapid melting of the active layer for a few seasons. Thus there appears to be much evidence to suggest that the rubble-drift is a solifluxion deposit; while there may be masses of older till in the deposit, Mitchell's assumption that it is simply a local Welsh till <u>in situ</u> seems unproven.

From the sections examined in the vicinity of New Quay there seems to be no evidence for the presence of "intermediate sands and gravels", for while outwash deposits at New Quay East and Llanina Point are seen to overlie calcareous till, they are not seen to underlie an unequivocable upper till.

The so-called upper till or "Pencoed boulder-clay" of Mitchell and Synge is a highly variable deposit. Mitchell has noted that the coarse gravel above the calcareous till near the mouth of the Afon Llethi stream at New Quay East is not in fact an upper till, as proposed by Williams. It is a torrential outwash deposit full of pebbles which appear to have been derived from inland localities. This impression is strengthened by the form of the Afon Llethi and Afon Gido valleys, which appear to have carried vast quantities of meltwater towards the coast during deglaciation. In an environment of wasting ice and intermittent pro-glacial lakes at Little Quay Bay, the meltwater from the south could have been responsible for the introduction of the sands, gravels, and masses of local stones which constitute the upper rubble-drift. The incorporated masses of decalcified till and lenses of silts bear similar witness to the process of mass ice-wasting in the locality; such features are common in present-day pro-glacial environments in the Schuchert Valley, East Greenland, and elsewhere (see, for example, Hartshorne, 1961; Price, 1964). All the exposures of the upper rubble-drift leave one unconvinced that it is a readvance till of any sort, for the characteristics of the deposit suggest that it was laid down in a dead-ice environment where melt-water from wasting ice and from the upland valleys was the major agent of deposition.

This interpretation has to be qualified somewhat by an examination of the stratigraphic position of the rubble-drift, for it apparently overlies the laminated silts. If, as seems possible, these silts are lacustrine deposits, then it is difficult to explain the presence of apparent dead-ice features and till masses above them without postulating a readvance, perhaps of local ice. Perhaps the silts were laid down in contact with glacier ice at an early stage of deglaciation when melting was on a small scale only, and were buried beneath more local dead-ice deposits during a later phase of rapid melting, when slumping and sludging were prevalent. Alternatively the relationships of these deposits may be explained far more simply. The silts may have been derived from calcareous till by recent rain-washing (Mrs. E. Watson, personal communication), and may not pass beneath the upper rubble-drift at all. Widespread slumping on the cliff face may be responsible for the discovery of thick sandy rubble-drift above the silts. This explanation is not entirely convincing, for the silts are thick and continuous along 100 yards of coast; recent rain-washing of calcareous till has produced no laminated silts elsewhere in West Wales, and there is no reason why the process should have been particularly effective at Little Quay.

Both the explanations above are somewhat unwieldy, although from a glaciological point of view they seem more satisfactory than the interpretation of the rubble-drift as a local "Pencoed boulder-clay". Perhaps it would be wiser not to propose any explanation of this dead-ice environment too strongly, for, as Flint (1957) has noted, in an ice-wasting environment "anything can happen, and it usually does." (P. 146). Where present-day slumping has confused the picture even further, one may be justified in believing anything is possible!

The lack of an upper head (which is so characteristic of the Pembrokeshire sections) at New Quay is not surprising, for many of the cliff-exposures occur over 500 yards from the nearest bedrock slope. The slope of the drift surface is often negligible (although in places, as at Llanina Point and west of Mount Pleasant, there are steep-sided drift hummocks), and even where the ground-surface slopes at more than 3° solifluxion of the drift deposits is not apparent except in isolated patches. Only accurate preferred stone-orientation counts in the drifts can determine the extent of post-glacial solifluxion at this locality.

Concerning the age of the deposits at New Quay there is little convincing evidence. Mitchell, Synge, and Stephens consider that at New Quay there are three tills which are the equivalents of the Enniskerry, Eastern General, and Brittas tills of Eastern Ireland (Farrington, 1942; 1944). These tills they equate with phases of the Riss/Saale glaciation (Stephens, 1964). Whatever the age of the deposits, there is a close correlation with the Pembrokeshire succession, and it appears reasonable that at least part of the lower rubble-drift with erratics correlates with the lower head suite with erratics at Aber-mawr, with the overlying Irish Sea till deposited during the Dewisland glaciation.

Table XVI. **A tentative reconstruction of events at New Quay, Llanina Point, and Little Quay Bay.**

Events.	Climate.
Soil	Temperate
Sandy loam	Cold, dry
Rubble-drift Sands and gravels Ice-contact drifts Laminated silts	Moderately Cold Deglaciation
Irish Sea Till	Glaciation
Lower Rubble-drift	Moderately cold
Local "New Quay" Till	Glaciation
Lowest head Frost-shattered bedrock	Moderately cold.
(Doubtful Raised Beach ?) (Doubtful Rock Platform?)	Sea-level 13-18 ft. O.D.? Warm?

Establishment of coast	Temperate

The suggestions made in this section are of limited value only in view of the lack of detailed fabric analyses, but the investigation has been of some use in that it has revealed a close correspondence between the drift succession and that of Pembrokeshire. The existence of the upper till as a representative of a local Welsh readvance may be doubted. Furthermore, the status of the laminated silts and lower rubble-drift must be open to question until more detailed field evidence is available.

From the foregoing paragraphs, it appears that the sequence of events suggested in Table XVI may have occurred at New Quay.

Chapter 6 (B).

SUMMARY OF CONCLUSIONS.

From the evidence of the sections in the Teifi estuary and at New Quay it seems that the Late Pleistocene history of South Cardiganshire has been very similar to that of North Pembrokeshire. Although at New Quay the coastal area has probably lain within the sphere of influence of Welsh Ice, this fact appears to have made little difference to the recent drift stratigraphy; the Irish Sea ice of the Dewisland glaciation appears to have been dominant in both South Cardiganshire and North Pembrokeshire.

1. Stratigraphy.

The sections examined are correlated in tentative fashion in Fig. 87. As in the coastal exposures analysed in Chapter 5, the Irish Sea till can be used as a satisfactory datum. The only locality where it does not appear as a fresh deposit is Poppit East; however, at this locality there are good lithological grounds for considering the red clay with erratics as a decalcified Irish Sea till.

The earliest Pleistocene deposit in this coastal stretch is the thick raised beach at Poppit; the platform upon which it rests may be correlated with the Gwbert platform and perhaps with the doubtful platform at New Quay West. Both platform and raised beach pebbles indicate the presence of a probable interglacial sea-level at c. 8 - 11 ft. O.D. or higher. In view of the apparent lack of erratics in the Poppit raised beach there are no grounds here for postulating separate interglacial stages for the cutting of the platform and the deposition of the raised beach.

The Irish Sea till is a suitable datum for correlation. The till itself is seen to be of variable thickness from section to section, but it appears to thicken from west to east; the till at Gwbert and New Quay is thicker than at any point on the North Pembrokeshire coast, and is only matched in Pembrokeshire at Druidston. There is good reason to believe that the Irish Sea ice which impinged upon the coast at New Quay was no less powerful than that which overran the North Pembrokeshire coast. As in North Pembrokeshire, the till has been derived from the floor of Cardigan Bay. In view of the similarities of weathering and decalcification between the Cardiganshire Irish Sea till and that of North Pembrokeshire, it is safe to assume that it dates from the Dewisland glaciation.

Above the Irish Sea till correlation is relatively simple. There are outwash sands and gravels at Gwbert, New Quay East, and Llanina Point, although at the latter two localities the outwash may not be related entirely to the Irish Sea till. In Little Quay Bay and Poppit East there is evidence that sands and gravels have been affected by later solifluxion; the upper heads in the other sections in the Teifi estuary may also be related to this late phase of solifluxion.

2. A "New Quay Glaciation"?

In spite of the similarities of the lower rubble-drift at New Quay and the thick lower head at Poppit West, there is one important difference between the deposits: namely that the New Quay drift appears to be a soliflucted till, while the Poppit head is basically a bedrock deposit containing few erratics. There are good grounds for assuming that prior to a long phase of solifluxion there was a coherent till deposit at New Quay West but no such deposit at Poppit.

Inevitably, one must wonder whether this early till was the product of the Early Glaciation which has been proposed for North Pembrokeshire. There are certainly several points in favour of this view:

(a) The early till at New Quay appears to have been entirely a local till. This suggests that Welsh ice was dominant during its deposition; in contrast, the dominant force of the Dewisland Glaciation, even as far east as New Quay, was the Irish Sea ice-sheet. It has been suggested quite independently earlier in the thesis[1] that the ice of the E arly Glaciation came from the north-east; very probably, it would have been Welsh ice.

(b) At present, there is no reason in North Pembrokeshire for postulating more than one Early Glaciation to explain the coastal melt-water channels and the presence of erratics in raised beach and lower head deposits. It seems unnatural and unnecessary to invoke a "unique" glaciation for the New Quay till.

(c) It is possible that the soliflucted New Quay till rests upon a rock platform with beach deposits. If this is so, the till itself may have been deposited after the cutting of the platform. It has been argued in Chapter 5 (A) that the erratics at Parrog may have been introduced by a glaciation which post-dated the platform-cutting stage.

On the other hand the correlation of the New Quay glaciation with the Early Glaciation of Pembrokeshire does involve one major difficulty, namely the apparent presence of thick local till prior to the main solifluxion phase at New Quay, while nothing but scattered erratics dating from

1. On the basis of the orientation of meltwater channels. See Chapter 5 (B).

this glaciation have been found in Pembrokeshire. No "early drift" has been found to date in North Pembrokeshire, apparently indicating that, if it ever existed, it has been removed by a long period of denudation prior to the Dewisland Glaciation. And yet the New Quay rubble-drift seems to have been derived, in part at least, from a till deposit which contained freshly-striated pebbles.

In view of this fact it is possible that the till was deposited during a local Welsh Glaciation (as suggested by Mitchell in 1962), immediately prior to the solifluxion phase in which it was re-sorted. It is tempting to correlate this local glaciation with the severe periglacial phase recorded in the Aber-mawr North drift-cliff, which was also succeeded by a less severe phase of solifluxion and then by a glaciation from the Irish Sea.

3. The mode of deposition of some drifts.

The important suggestions made in the sections on the Teifi estuary and the New Quay area concerning the origins of drifts may be summarised as follows:

(a) The Irish Sea till, while retaining its characteristic purple colour and calcareous matrix, is seen as a rather variable deposit. At Gwbert it is seen to be sandy and gravelly in places, with extensive lenses of interbedded outwash, while at Little Quay Bay it is closely associated with laminated silts. Furthermore, the till itself is seen to be laminated at Poppit East. As at Whitesands and other localities, the impression is gained that it was deposited under conditions of ice-wastage, with large amounts of melt-water and perhaps even small pro-glacial lakes affecting till characteristics.

(b) The upper head at Poppit East and the upper rubble-drifts at New Quay confirm the impression gained in North Pembrokeshire that the deposits above the Irish Sea till are not true tills, but mixed solifluxion rubbles containing masses of outwash, decalcified till, and head fragments.

(c) There is no evidence on the South Cardiganshire coast in support of the "intermediate sands and gravels". True, sands and gravels do overlie Irish Sea till, but in the sections examined there is no younger till over-lying outwash deposits.

(d) The sections at Gwbert and Poppit afford no support for Charlesworth's "Lake Teifi". There are no deposits at either locality which could be interpreted as lacustrine in origin. It would be tortuous in the extreme

TABLE XVII. STRATIGRAPHIC CORRELATIONS AND SUGGESTED INTERPRETATIONS FOR S. CARDIGANSHIRE

Poppit	Gwbert	New Quay Bay	Llanina Point	Little Quay Bay	Relative sea-level	Climate	Events
Sandy loam	Blown sand	S. loam	S. loam		Low-rising	Cold-arid?	Wind-action
Upper head and sands and gravels	Upper Hd.	Outwash S & G	Sands and gravels	Laminated silt		Moderate cold	Solifluxion
	Sands & gravels					Warmer	Deglaciation
Irish Sea till	Irish Sea till Laminated silts	Irish Sea till	Irish Sea till	Irish Sea till	Very low	Glacial	Irish Sea glaciation
Main Head	Thin lower head	Head	↓	↓	Falling	Cold	Solifluxion
		N.Q. till			Low	Glacial?	Local Glaciation
		Head			Falling	Cold	Solifluxion
Raised beach		Raised beach?	?	?	High	Warm-interglacial?	Raised beach deposition
Raised beach platform					High	Warm-interglacial?	Platform cutting
Establishment of coast					As pres?	Temp?	Marine coast erosion.
Teifi Valley					Very low	Temp?	Sub-aerial valley erosion

to propose that the laminations in the Irish Sea till are indicative of the presence of a lake, for till characteristics are maintained throughout the deposit.

4. Table of Correlations.

In Table XVII stratigraphic correlations are made on a similar basis to the correlations in foregoing sections. Apart from the soliflucted till at New Quay West, there appears to be nothing new in the Table; it is comparable in many ways to the tables for North Pembrokeshire.

The major problem encountered in the compilation of this table concerned the placing of the New Quay "local till". Tentatively, it is suggested that it was deposited after the depósition of the raised beach and the lower head, and contemporaneously with the main head deposits further west.

PART III

Chapter 7.

Some Conclusions based upon the Interpretation of Coastal Sections.

Chapter 7.

SOME CONCLUSIONS BASED UPON THE INTERPRETATION OF COASTAL SECTIONS.

From the evidence, correlations and interpretations in the last two chapters an attempt can now be made to answer some of the questions which were posed at the beginning of this thesis.

1. Is Jehu's Tripartite drift division correct?

(a) Is the "Lower Boulder-clay" one deposit? Jehu (1904) described exposures of Lower Boulder-clay throughout North Pembrokeshire, and considered that it thickens from west to east. However, he did not distinguish clearly between the calcareous shelly Irish Sea till and other heavy clay tills inland; furthermore, as noticed by Griffiths (1940), he classified some exposures of Irish Sea till as "Upper Boulder-clay".

The present investigation indicates that the Irish Sea till has a wide coastal distribution. It is found in localities along much of the coastline from New Quay to Wooltack Point, at the southern end of St. Bride's Bay.[1] It is best preserved where Irish Sea ice moved onshore from

---

1. South of Druidston I have found Irish Sea till at Broad Haven and Little Haven, and Miss Gillian Lass has discovered it on Nab Head (personal communication, 1964).

the floor of Cardigan Bay or St. Bride's Bay, and where deposition took place in the lee of upstanding topographic features transverse to the direction of ice-movement. Porthmelgan (behind the igneous ridge of St. David's Headland), Whitesands North (behind the low ridge of Trwynhwrddyn Promontory), and Druidston (in a deep valley bordered to the north by a high cliff-line) may be quoted as examples.

Calcareous till is not preserved where the ice moved off the land, as on the south coast of Dewisland and at West Angle Bay; in such localities the equivalent of the Irish Sea till is a "land facies" which is non-calcareous, non-shelly, and far stonier than the true calcareous till. The land facies at Caerbwdy and Ogof Golchfa may be thought, upon superficial examination, to be the equivalents of the rubble-drifts of the north and west coast of Pembrokeshire; however, it is suggested that the tills are lithologically unrelated to the rubble-drifts and are stratigraphically the equivalents of the Irish Sea till of the Dewisland Glaciation.[1]

---

1. The stratigraphic position of the land facies of the Dewisland till is shown in many clifftop sections. Some of the more important sections are described briefly in Appendix VII and located on Map 3.

Griffiths (1940) stated that there is an "absence of the typical lower boulder-clay from the St. David's Peninsula" (P. 36), but that it is replaced by a "St. David's Drift" (Fig. 88). However, the occurrence of purple shelly calcareous till within the area of "St. David's drift" at Aber-mawr, Porthmelgan and Whitesands indicates that no such generalisation can be made.

On the other hand there is some justification for suggesting that the Irish Sea till is itself subject to much lithological variation. At New Quay, Gwbert and Aber-mawr the till is plastic and relatively stoneless; it owes little to the characteristics of the underlying bedrock. The till at Druidston contains innumerable small flakes of Coal Measures shale, while that at Whitesands North is a gravelly deposit with many Cambrian shale fragments. At Porthmelgan the till incorporates a coarse "boulder-bed", while interbedded sands and gravels are seen at Gwbert and associated laminated silts at Little Quay. At New Quay and Druidston there is a gradual increase in the coarseness of the till matrix from the base of the exposure to the top. In view of all these variations it may be said that the only constant characteristics of the Irish Sea till in the coastal exposures of West Wales are: (a) a dark blue-grey to purple colour,

(b) a highly calcareous matrix, and (c) a content of marine mollusc fragments.

The term "Lower Boulder-clay" must be considered unsatisfactory for the following reasons :

(a) It has been used loosely to describe Irish Sea tills of several facies and also non-calcareous inland tills which may not be their stratigraphic equivalents.

(b) As used by Jehu, the term excluded the land facies which is the stratigraphic equivalent of the Irish Sea till.

(c) The term carries with it the implication that there is an "Upper Boulder-clay" above; it is suggested that there is no such deposit.

Perhaps it would be safer to include the Irish Sea tills and the local tills at Ogof Golchfa, Caerbwdy, and West Angle under the broad heading of "tills of the Dewisland Glaciation".

(b) Do the "Intermediate Sands and Gravels" exist, and do they represent an interglacial deposit? Jehu noticed that in many parts of North Pembrokeshire sands and gravels are found on the surface; however, he considered that the sands and gravels are often overlain by "Upper Boulder-clay and rubbly-drift", and he equated the outwash deposits with the "intermediate sands and gravels" found elsewhere in England and Wales. He was, however, not entirely convinced by his own correlation, and warned "it is not safe to assume that the Sands and Gravels always represent any definite horizon in the glacial series" (P. 82).

In none of the coastal sections examined have sands and gravels been observed between two different tills. At Caerbwdy outwash gravels are found beneath non-calcareous till, but there is much evidence to suggest that they are intimately associated with this till, and that they may have been deposited in a dead-ice environment. At Gwbert lenses of sand and gravel over 40 yards long are inter-bedded with the Irish Sea till; there is no evidence to suggest that the till above the gravels is any younger than that below. At Aber-mawr and New Quay sands and gravels are clearly seen to rest upon the Irish Sea till, and at all the localities where thick calcareous till is preserved outwash materials are incorporated into the rubble-drift.

While the sands and gravels of the coastal sections appear to be associated with deglaciation it cannot be said from the evidence that they represent a full interglacial, for glacial conditions did not return to North Pembrokeshire after they were deposited. However, there does seem to have been a later return to severe periglacial conditions for a time.

Thus there is no evidence that the sands and gravels are "intermediate" between two tills; all that can be said concerning their stratigraphic position is that they generally overlie tills which were deposited during the Dewisland Glaciation.

(c) What is the nature of the "Upper Boulder-clay"?

While Jehu considered the rubble-drift to be a mixture of morainic material, sands and gravels, and bedrock fragments, Mitchell (1962) and Synge (1963) consider it a local upper till (Plate 35).

The coastal exposures of rubble-drift examined in West Wales provide some support for Jehu concerning the nature of the deposit. At Little Quay, Aber-mawr, Porthmelgan, Whitesands and Druidston it is especially well shown as a variable rubble of head fragments, soliflucted till, and sands and gravels. The stone orientation analyses which have been undertaken strongly suggest that the drift has been soliflucted to a considerable depth beneath the surface. The high proportion of bedrock fragments in the drift, and the occasional discovery of striated erratics, cannot be taken as criteria for the recognition of a "local till".

It is worth noting that the rubble-drift is always associated with calcareous till. No rubble-drift has been recognized above the land facies of the Dewisland till, and instead the tills at Ogof Golchfa and Caerbwdy are overlain by a thin head. If the rubble-drift is a local till deposited after the retreat of the Irish Sea ice, why is it not represented at Ogof Golchfa and Caerbwdy in some form? The coastal distribution of the deposit indicates that it is the same age as the Dewisland tills.

Griffiths (1940) suggested that the "Upper Boulder-clay" occurs only within the "South Wales End-moraine", and is matched elsewhere by a soliflucted rubble. No evidence has been found in support of this contention; no "unique" deposits have been found on the north coast which can be related to a Newer Drift readvance.

2. Does the "South Wales End-moraine" of Charlesworth really exist?

From the coastal sections one cannot say that there is no such feature inland. But it has been suggested that drift stratigraphy is virtually identical in all the coastal sections of West Wales; there are anomalous deposits, but they represent no more than minor variations on a single theme.

If there was a separate glaciation as far south as the South Wales End-moraine one would expect to find a record of it in the coastal sections; there should be a fresh till to the north of the moraine, perhaps matched by periglacial deposits to the south. As suggested above, there are no such deposits, and the till of the Dewisland Glaciation (the last glaciation of Pembrokeshire) extends at least as far south as West Angle. The South Wales End-moraine must therefore be open to some doubt.

In association with this point, it may be said that there are no traces of Glacial Lake Teifi and Glacial Lake Nevern (Fig. 11) in coastal localities; lake deposits of some sort should occur in the Afon Nevern and Teifi estuaries if the lakes ever existed, but in neither area have such deposits been recorded.

3. What is the Age of the North Pembrokeshire drifts?

If there is no South Wales End-moraine, then all the till of the Dewisland Glaciation must be either Older Drift or Newer Drift in age. The stratigraphy of the coastal sections indicates that head above the Dewisland till is seldom more than two feet thick, while the calcareous till itself is seldom decalcified to a greater depth than 3 ft. At Aber-mawr the till is in places decalcified to a depth of only 12", and the greatest depth of complete decalcification recorded was 6 ft. at New Quay (Plate 36). From this evidence it is suggested tentatively that the Dewisland till may be categorized under the general term "Newer Drift".

If the raised beach gravels of West Wales are of Last Interglacial age, as suggested by Zeuner (1959) and Bowen (1965), then the Dewisland till must have been deposited during the Last Glaciation. However, at this stage no reliable evidence has been presented concerning the absolute age of the drifts; all that can be said is that two glaciations are represented in Pembrokeshire, which may or may not coincide with the "Older Drift" and "Newer Drift" glaciations elsewhere.

4. How old are the raised beach platforms and raised beaches of North Pembrokeshire?

No decisive answer has been found to this question, but there do seem to be grounds for proposing that the platforms are older than the Early Glaciation and are thus separated by a full glacial stage from the deposition of the raised beach gravels. If the platforms pre-date two glaciations (the Early Glaciation and the Dewisland Glaciation) then it follows that they cannot have been cut in the Last Interglacial, as suggested by Zeuner.

Admittedly the evidence for this tentative dating is scanty: at Pen Deudraeth a raised beach platform appears to have been truncated by the cutting of the

Aber-mawr valley in the Early Glaciation, and it has been argued that erratics from the Early Glaciation are more likely to be preserved on the rock platforms if the platforms were already in existence when the glaciation occurred. Again, it has been shown that at Whitesands North and Gwbert striations pass beneath the lowest head, and may thus date from an Early Glaciation. The stained till on the platform at Trwynhwrddyn could conceivably be an "Early till".

While the raised beach gravels may be much younger than the rock platforms on which they rest, there is evidence that the gravels in different localities and different altitudes may themselves have been deposited during different marine stillstands. It has been suggested that the raised beaches at West Angle and Whitesands South may have been deposited prior to a marine transgression while the high beach at Ogof Golchfa may date from the peak of an interglacial transgression. The stratigraphic evidence set out in the last two chapters suggests that the raised beaches were all deposited during the same interglacial stage. For simplicity it may be worthwhile to assign the term "POPPIT INTERGLACIAL" to this stage, using as a type locality the fine raised beach exposure at Poppit.

5. <u>What is the origin and age of the North Pembrokeshire meltwater channels?</u>

At this stage no detailed study of the deep coastal valleys of Pembrokeshire has been undertaken, but it is suggested that the channels at Caerbwdy, Aber-mawr, Druidston, and Porthmelgan could have been cut by glacial meltwater. The "through valley" at Porthmelgan may be a sub-glacial feature. All of these channels were cut before the Dewisland Glaciation, for they all experienced periglacial conditions and solifluxion prior to the arrival of the last Irish Sea ice-sheet. Thus it is worth bearing in mind that at least some of the channels of North Pembrokeshire may be meltwater features dating from the Early Glaciation; this conflicts with the generally-accepted view that the larger channels of North Pembrokeshire are of Newer Drift age.

<u>Some other observations.</u>

(a) There is much evidence to indicate that the larger valleys of the area were cut prior to the establishment of the coast and the cutting of the raised beach platforms. This is illustrated at Whitesands, West Angle, the Afon Nevern estuary and the Teifi estuary, where marine cliffs and raised beach platforms are found within the sides of the old drowned valleys. From the wide, open forms of these valleys it seems that they were cut sub-aerially.

(b) It is tentatively suggested that the ice of the Early Glaciation may have moved across North Pembrokeshire from the north-east towards the south-west. This idea is based upon the orientation of the Porthmelgan channel, which is difficult to explain as a legacy of an ice-sheet moving from the north-west towards the south-east (The direction of movement of the last Irish Sea ice-sheet).

(c) After the deposition of the raised beaches there was a prolonged period of solifluxion which is represented by the thick lower heads at Aber-mawr, Poppit, and Ogof Golchfa and by thinner heads elsewhere. At Aber-mawr the climatic fluctuations are excellently recorded, with the major phases as follows:

3) Moderate Cold

2) Severe Cold

1) Moderate Cold

It is tempting to correlate the period of severe cold with the local "New Quay" Glaciation further to the east.

(d) The Dewisland Glaciation appears to have been relatively weak and perhaps short-lived. In general, it altered the coastal area of North Pembrokeshire hardly at all; all the valleys pre-date the glaciation, and little erosion was achieved on the coast itself. Rock platforms were polished and striated, but older head deposits and beach pebbles remained <u>in situ</u> in spite of the over-riding ice. Fabric analyses on the calcareous till indicate that it was seldom deposited by "plastering"; rather, individual till masses appear to have been subject to slumping and sludging upon dead ice during or shortly after deposition. The ice probably wasted by stagnation rather than retreat, for ice-contact features are seen in outwash sands and gravels at Aber-mawr and Gwbert, and at Ogof Golchfa and Caerbwdy there is good evidence of the "dumping" of till masses in a moist environment of ice-wastage.

(e) Among the horizons discovered there are several anomalies which seem to occur in isolation. At Aber-mawr there is a weathering horizon in the lower blocky head which is recorded from nowhere else; at Whitesands is a unique deposit of sandrock which overlies the most recent head; at Pen Dal-aderyn there are faint traces of a weathering horizon in a suite of apparently post-glacial heads; and at Little Quay there are laminated silts (which appear to be lacustrine) in association with the Irish Sea till. None of these horizons contradict the interpretations from elsewhere on the coast of West Wales, and for the time being they may be considered as representatives

NTATIVE RECONSTRUCTION OF PLEISTOCENE EVENTS IN WEST WALES.

		North Pembs	W. Dewisland	S. Dewisland	S.W. Pembs.	South Cards.	Climate
POST-Glacial.		Soil					Pres.
		Offshore forest	Offsh. forest	Offsh. forest	Offsh. forest		Temp?
DEWISLAND GLACIATION	Phase III	Wind & solifl.	Wind Solifl. +ice-wedge	Wind Hillwash	Wind Hillwash	Wind Hillwash	Cold & dry
		Solifl.		Soli-fluxion	Solifl.	Solifl.	Perigl.
			Weathering				
		De-glac	De-glac.		De-glac	De-glac	Warmer
	Phase II	DEWISLAND GLACIATION					Glacial
	Phase I	Solifl. rapid?		Soli-			Periglac.
		Solifl. slow?		flux. Slow?		Local Glaciation	Very cold
		Solifl. rapid?		Soli-flux. rapid?	Soli-flux-ion.		Periglac.
		Weathering					Warmer?
		Solifl.					Periglac.
POPPIT INTERGLACIAL				Raised beach	Marine trans.		Warm
			Solifl.?		Solifl.?		Cold
		R.B.	R.B.		R.B.	R.B.?	Warm
(RECORD INCOMPLETE)		E A R L Y G L A C I A T I O N					Glacial
		RB plat	RB plat	RB plat	RB plat	RB plat	Warm
		Establishment of coast					Temp
		Valley erosion	Valleys	Valleys	Valleys	Valleys	Temp
					Bedrock rotting		Warm?

of phases which may be unique to one locality, or else (as in the case of the weathering horizons) as possible indicators of widespread climatic fluctuations of which all traces have been removed elsewhere.

From the coastal sections of West Wales much stratigraphic evidence has been accumulated. On the basis of the interpretations of this evidence in Chapters 5 and 6, it has been possible to correlate the events recorded at each group of coastal sections, as set out in Table XVIII. The complete sequence of events can be interpreted from no single group of sections, for inevitably there are stratigraphic gaps here and there. However, these gaps are surprisingly few in number, and all the major Pleistocene events which are discernible are widely represented. The Pleistocene record at the base of the table is scanty, and it is probable that the events portrayed occurred over a span of many thousands of years. The erratics dating from the Early Glaciation are widespread, but the fact that no undoubted Early Glaciation tills have been discovered on the coast of West Wales suggests that the Poppit Interglacial may have been prolonged enough to destroy them completely in the coastal zone.

The most important conclusion to be drawn from this table is that coherent drift deposits of only one major glaciation - the Dewisland Glaciation - are represented. This glaciation may be subdivided into an early, prolonged periglacial phase, a glacial phase, and a third phase in which deglaciation and renewed solifluxion occurred. This three-fold subdivision may be open to criticism, for the three phases represented in the drifts may have been quite unrelated in time. However, the table attempts to present the evidence in its simplest form; since there are no widespread weathering horizons or unequivocable interglacial deposits to justify the separation of the phases, it seems reasonable at this stage of the thesis to group them together.

to present the evidence in its simplest form; since there are no widespread weathering horizons or unequivocable interglacial deposits to justify the separation of the phases, it seems reasonable at this stage of the thesis to group them together.

PART IV.

THE DISTRIBUTION OF THE NORTH PEMBROKESHIRE DRIFTS.

This thesis would be open to severe criticism if it concentrated entirely on the analysis of coastal sections and failed to examine the extent to which the coastal drifts are representative of those inland. Accordingly the next two chapters are devoted to a brief analysis of the characteristics of the inland drift cover.

In Chapter 8 the major drift categories of Western Dewisland are examined, and the classic tripartite drift succession is subjected to close scrutiny; and in Chapter 9 some of the drift features of the Fishguard area are discussed. In both chapters some space is devoted to the question of the so-called "Upper Boulder-clay", and in Chapter 9 Charlesworth's hypothesis of the South Wales End-moraine and its associated lakes is examined.

Chapter 8.

The Inland Drifts of Dewisland

(A) Field Evidence

(B) Quantitative investigations of the classic "tripartite" drift succession

(C) Other Investigations in Dewisland

Chapter 8.

THE INLAND DRIFTS OF DEWISLAND.

(A) Field Evidence.

There are few good inland exposures in Dewisland, but the evidence available lends support to the conclusions based upon the coastal sections. The drift map (Map 3) shows a simple drift distribution, with gleyed tills in the waterlogged depressions and sandy and stony remanié drifts elsewhere. Inland of Whitesand Bay there is a large area of blown sand; in the north, Carnllidi, Carn Trelwyd, and Penbiri are upstanding rock masses with "aprons" of head and slumped blocks, and separated by patches of sandy and stony till; and in the west there is an area where carns intrude through a mixed mantle of stony till and head. These are the only major interruptions in the overall simple pattern.

It is important at this point that some discussion should be undertaken of the more characteristic features of the area.

1. The inland drift-filled depressions. For the most part, the depressions of Dowrog Common, Trefelly and Trefeiddan Moors, and the other moors of the area are flat and featureless with waterlogged floors and moorland

vegetation (Plate 1). The surface drift in these depressions is severely gleyed, and on a soil auger appears to have a sticky and plastic matrix, with a high clay content.

One of the most urgent questions which needs to be answered is whether or not there is calcareous Irish Sea till at depth on these moors. Unfortunately, the only exposures on the moors today are the drainage-reservoirs which have been opened during the past few years (Plate 37). Generally, the till exposed in the sides of these reservoirs is grey-blue in colour, with many local stone-types and erratic pebbles set in a sticky plastic matrix. Occasionally massive blue non-calcareous clay is seen, but there are also sand and gravel patches interbedded with the till. The surface layers of the till are generally weathered to a buff or bright brown colour to a depth of c. 5 ft.[1]

Frequent augering and excavation throughout the moorland area of Dewisland confirmed the impressions gained at the drainage reservoirs, and nowhere was calcareous Irish Sea till encountered. Severely-gleyed stony tills

1. The reservoirs are located on Map 3. Brief notes on the drifts exposed at each locality are given in Appendix VIII.

predominate over the whole moorland area, although the till matrices vary from stiff clay to friable sands and gravels. Large igneous erratics are commonly scattered over the whole of the moorland area.

At many localities on the flanks of the moors there are sharp breaks of slope between the moorland and the higher cultivated areas of stony sandy loams. For example, on the north side of Trefelly Moor is a steep face up to 6 ft. high and accentuated by spring-sapping on the gleyed moorland, while other marked breaks of slope occur on the flanks of Treleddyd-Fawr Moor and on the south side of Tre-tio Common. Augering in these areas shows that up to 8" of sandy loam overlies gleyed purple-blue till. The significance of this fact is difficult to assess; it may indicate that the sandy loams are stratigraphically younger than the gleyed tills, but it is just as likely to have resulted from slight sludging of loamy soil onto the lower gleyed areas on the moorland margins.

In view of the undoubted effects of agriculture in the area, it is also difficult to decide whether the areas of gleyed till are purely natural phenomena. The margin between sandy loam and gleyed till is generally sharp, but this margin frequently coincides with a hedge or wall. One cannot help wondering whether the field boundaries were established to coincide with the margins of the well-drained areas, or whether such areas have become well-drained simply because of good agricultural practice! In view of this suggestion it is worth bearing in mind that the moorland tills may be lithologically identical with those of well-drained areas in Dewisland; their gleyed and waterlogged appearance, which led Jehu to distinguish them as "Lower Boulder-clays" may be no more than the results of poor surface drainage.

In spite of this there is good reason to assume that calcareous Irish Sea till may be present at depth in the moorland areas. While on Treleddyd-fawr Moor and on the eastern side of Dowrog Common bedrock is seen to outcrop on the moorland surface from time to time, the impression is gained from most of the moorlands that bedrock lies far beneath the surface. Some of the drainage reservoirs indicate a minimum depth of non-calcareous till in the order of 10-15 feet, and farmers in the Trefeiddan Moor area have told me that the deep clay pits on the moor once extended down to at least 30 ft., at which depth the clay was blue and relatively stoneless. George Owen (1603), whose observations on the "Claye Marle" seem to be reliable in every respect, was in no doubt that the marle with shells and wood fragments occured "seaven or eight myles from the sea". Until a programme of deep boring can be undertaken on the moorland areas, the question of the inland extent of calcareous Irish Sea till must remain *sub judice*.

2. Sands and Gravels. Glacial outwash materials appear to be virtually absent from Western Dewisland. Nowhere in the area examined was an extensive cover of sand or gravel encountered, although it was often difficult to distinguish between sandy and gravelly surface soils and remanié till deposits with a high content of bedrock fragments. For example, in the area between Whitchurch and Waun Vachelich, which was greatly disturbed as a result of wartime airfield construction, there are traces of gravelly soils full of well-rounded erratic pebbles; these soils could be outwash remnants.

There are some small patches of possible outwash in the area of stony sandy tills; the outwash at Caerbwdy has already been mentioned, and at Clegyr Boia at least 12 ft. of fine sand was encountered in 1962 beneath sludged soil. There appear to be sandy and gravelly layers in the till at Treleddyd-fawr reservoir, and a patch of ferruginous sand (which may simply be weathered bedrock) occurs on the green at Whitchurch.

It is interesting that patches of sand and gravel appear to be more common on the moorland areas (Map 3). In part, the fact may be explained by the lack of agriculture on the moors; it may well be that similar small patches of outwash occurred throughout the whole of Dewisland upon deglaciation, but have since been removed by constant ploughing. Near the drainage-reservoir at Treleddyn-isaf, and again on the patch of moorland near Upper Treginnis, sandy and stony hummocks up to 6 ft. high stand above the general level of the gleyed drift surface. To the north of Dworog Pool there are a few gravelly patches on the waterlogged surface, and at Waun Caerfarchell, just to the west of the cottages, there is an area of pits and ridges of fine ferruginous sand and rounded pebbles which passes laterally into gleyed till. Other slight mounds of sand and gravel may be seen on the patch of moorland at Caerfai, while there is a broad area of hummocks and hollows on the western side of Spite Moor.

Some of these features undoubtedly owe their form to spring sapping or human excavation, but it is probable that many of the hummocks are depositional features which may have been formed upon ice-wastage.

3. Stony and sandy drifts. The greater part of Dewisland is covered by a veneer of stony remanié drift which seldom

appears to be more than 3 ft. thick (Map 3). At one time large erratics littered the whole land surface, but most of these have long since been built into hedges and walls, and only the smaller stones may still be found in the fields. Among the erratics which may be found are frequent pebbles of Cretaceous flint, faceted pebbles of Carboniferous limestone, and a great variety of igneous rocks derived, for the most part, from the St. David's Head - Penbiri igneous intrusions. Many erratics from the area are listed by Jehu (1904). On the west side of Caerbwdy Bay there are several large dumps of erratic boulders from the fields; some are over 6 ft. in diameter, and many are well-striated. Striated and polished erratic pebbles may also be seen in the fields near Caer-farchell, in the Porthlysgi area, and to the east of Carnllidi. All the evidence of erratic movement that I have seen tends to support Jehu, Hicks and Griffiths in their conclusion that the ice moved from the north-west.

There are few exposures of unaltered till in the area, but at Porth-clais roadside, Castell roadside, and above a small quarry at Emlych (Plate 38) there are exposures of silty and stony tills with erratic pebbles. At each locality the till is weathered to a depth of c. 12"; however, the tills remain coherent, and it is possible that coherent non-calcareous tills may cover much of the Dewisland land-surface, in spite of the effects of agriculture. The youthful appearance of the exposed tills is supported by the discovery of fresh striations on many boulders and pebbles in the fields, and fresh limestone erratics with faceted faces are frequently encountered. It is reasonable to propose that the tills, in spite of their lack of surface expression, date from the Dewisland Glaciation. They appear to be related to the stony non-calcareous land facies of the Dewisland till at Ogof Golchfa and Caerbwdy.

4. How thick was the ice? Hicks, Cox, and Green recorded striations at over 500 ft. O.D. on Carnlidi, and it has been proposed on several occasions that the monadnock has a roche moutonnée form. In spite of a long search on the rock I have found no undoubted striations, while the impression is gained that post-glacial weathering has been severe; many quartz veins stand out ½" on the exposed surfaces, and it is possible that all the striations have been destroyed. Also, the roche moutonnée form of Carnllidi is open to some doubt; from certain viewpoints the steepest rock face appears to be that facing up-glacier. However, more convincing evidence that the rock has been glaciated occurs just to the west of the summit, where smoothed slabs may be

seen; further polished slabs are found at an altitude of over 400 ft. on the north-east flank of the rock.

Other evidence of glaciation is found in the form of superficial deposits. Most convincing are patches of till with striated erratic pebbles at an altitude of 425 - 450 ft. O.D. above the quarry at Penbiri (Plate 39). Here soliflucted till and head seem to lie in hollows in the shattered bedrock surface.

On Carnllidi rounded erratic pebbles of soft grey shale, Cretaceous flint, fine-grained igneous rocks and grey sandstones occur on the northern side of the rock up to the summit at 595 ft.

In view of the fresh striated pebbles and coherent till at Penbiri it seems likely that the rock was over-ridden during the Dewisland Glaciation. The erratic pebbles and ice-polished slabs on Carnllidi reinforce this impression, and indicate that the ice of this glaciation must have had an upper surface at least 600 ft. above present sea-level.

Conclusions. Thus from the evidence of superficial deposits in western Dewisland, the following suggestions may be made:

1. The surface till in drift-filled depressions is non-calcareous and severely-gleyed. It may be underlain in

places by calcareous Irish Sea till, and may be the stratigraphic equivalent of the rubble-drifts of the coastal sections.

2. Outwash sands and gravels are rare in the area, but some slight hummocks preserved on the moorlands may be dead-ice features.

3. The featureless remanié drifts of Dewisland contain fresh striated erratics, and in places coherent tills are exposed. The drift can be attributed to the Dewisland Glaciation.

4. There is little doubt that the ice of the Dewisland Glaciation over-rode the monadnocks of the north coast.

(B) <u>Quantitative investigations of the classic "tripartite" drift succession.</u>

Several lines of research have been employed in order to test the working hypothesis mentioned earlier in the thesis: namely that gleyed inland tills are stratigraphically "Lower Boulder-clays", and the stony sandy tills "Upper Boulder-clays". In this area the lack of sands and gravels has made it virtually impossible to contribute anything reliable on their stratigraphic position; all that can be said on the evidence from Dewisland is that they overlie gleyed tills and are sometimes interbedded with them.

Tests of the Lower Boulder-clay - Upper Boulder-clay subdivision.

It was tentatively suggested in the last section that the only difference between the Lower Boulder-clay and the Upper Boulder-clay is that the former occurs in waterlogged depressions. Mechanical analyses of the deposits, and roundness analyses of drift pebbles were used in order to test the reliability of this field observation.

(a) Roundness analyses. At 28 localities roundness analysis of pebbles from the two drift categories was undertaken. The results of this investigation[1] are illustrated in Fig. 89. It will be seen that both the Upper Boulder-clay histograms (A and B) and the Lower Boulder-clay histogram (C) approximate closely to the mean histogram for non-calcareous till in North Pembrokeshire. All three histograms have a peak in the sub-angular category at c. 50%, and all three have a higher percentage of angular than either rounded or well-rounded pebbles. On this basis there is no foundation for differentiating between the Lower Boulder-clay and the Upper Boulder-clay.

---

1. The samples used for the construction of the Upper Boulder-clay histogram are Nos. 3 - 8, 10, 11, 13, 14, 18, 19, and 20 in Appendix VI (B). For the Lower Boulder-clay histogram, Nos. 1, 2, 9, 15, 16 and 17 from Appendix VI (B) were used, and a sample from Rhos-y-Clegyrn (No. 1b in Fig. 105). For histogram A see Appendix IX.

(b) Mechanical Analyses. Mechanical analysis was undertaken on ten random samples from the Lower Boulder-clay and eight from the Upper Boulder-clay. These random samples are located on Fig. 20 and listed in Appendix X (A and B), and the cumulative curves showing grain-size distribution are plotted in Figs. 90 and 91. Further cumulative curves for samples in the two drift categories are plotted in Figs. 92 and 93. In Fig. 94 the extreme range of curves for each set of random samples is plotted, and in Fig. 95 an indication is given of the extreme range of curves for all the stratified samples listed.

From an examination of these diagrams it will be seen that there is a large degree of overlap between the curves, although some of the curves for Lower Boulder-clay have a more marked concavity and a higher percentage of particles smaller than 0.25 mm. Nevertheless, the curves for Lower Boulder-clay cover a wide range on the graphs: the percentage of fines varies from 45% to 9.9%. Somewhat unexpectedly, the curves for Upper Boulder-clay cover a smaller range and fall completely within the range of the Lower Boulder-clay curves; the highest percentage of fines for Upper Boulder-clay is 34.8%, and the lowest 12.0%. Thus from this evidence it could not be said that there is any important difference between the grain-size distributions of the two drift categories.

As a further test for differences between the Upper and Lower Boulder-clays, the grain-sizes for 28 samples (15 Lower Boulder-clay and 13 Upper Boulder-clay) were grouped into three categories and plotted on triangular diagrams (Fig. 96). Again, the overlap between the categories is emphasised. The Lower Boulder-clay samples are clustered about a point with approximately 50% medium and fine sand, 20% gravel and coarse sand, and 30% fines. The Upper Boulder-clay samples, in spite of a wayward sample with over 60% gravel and coarse sand, are clustered about a point with approximately 50% medium and fine sand, 30% gravel and coarse sand, and 20% fines.

When the inland samples are compared with samples from the coastal Irish Sea tills of the area and with sands and gravels from further east, several important facts emerge. In Fig. 97 the cumulative curves for five samples of plastic calcareous till are plotted.[1] These samples have a relatively small range of variation, with low percentages of gravel and coarse sand; the highest fines percentage is 37.4% and the lowest 28.9%. While it cannot be pretended

1. These samples are listed in Appendix X (C).

that all the coastal calcareous tills have similarly high percentages of fines[1], it does appear that the plastic calcareous tills display less variation than either of the drift categories inland. This is illustrated when the calcareous till samples are plotted, together with a sample from Cahore Point, Ireland, and with five other samples from Aber-mawr, on a triangular diagram alongside the inland till samples (Fig. 98). The samples occupy a unique position, clustered about a point with 60% medium and fine sand, 30% fines, and only 10% gravel and coarse sand.

Also plotted on Fig. 98 is the field covered by 11 samples of outwash sand and gravel[2]; these samples have a much wider range of variation than either the Upper Boulder-clay or the Lower Boulder-clay, but by visual comparison on the diagram it could be said that the Upper Boulder-clay field has more in common with the field for sands and gravels, while the Lower Boulder-clay field has more in common with the field for calcareous till.

---

1. For example, at Druidston a calcareous till sample from near the top of the cliff yielded only 12.0% fines.

2. These samples are listed in Appendix X (D).

The sandy and gravelly nature of many of the till samples is further brought out when the curves for the inland tills (Figs. 90 - 93) are compared with the curves for the 11 sand and gravel samples (Fig. 99). These latter curves are characterised by several stages of convexity or else by shallow concavity. Similar curves are characteristic of most of the inland till samples, although the convexity is seldom as strong as in the exceptional samples for Scleddau and Ford. In general, it seems that the Upper and Lower Boulder-clays have closer affinities with the curves for sand and gravel than with those for calcareous till.

On the basis of the above evidence it may be suggested that the grain-size distributions of the Upper Boulder-clay and the Lower Boulder-clay are remarkably similar, although the Lower Boulder-clay samples display a slightly greater range of variation. While the coastal calcareous till samples yield cumulative curves rather similar to some of those for gleyed inland tills, they are characterised by very low percentages of gravel and coarse sand, and appear to be distinct from the inland samples analysed. Thus the inland tills are probably not decalcified Irish Sea tills; like the tills at Ogof Golchfa and Caerbwdy they are land facies of the Dewisland till which may contain a high proportion of outwash materials. Gleying is the sole process responsible for the apparent differences between the Lower Boulder-clays and the Upper Boulder-clays; lithologically the two drifts are seen to be one.

(C) <u>Other investigations in Dewisland.</u>

<u>Stone counts.</u> The map of divided circles for Western Dewisland (Map 4) reveals that the stone-content of the gleyed tills on the moorlands is no different from that of tills on adjacent areas of well-drained land.

The stone-content of all the till samples is more closely related to the underlying bedrock than to any other factor. This is well brought out in Figs. 100 and 101, where proportional circles indicate the percentage of certain rock-types at the 35 sampling-points.[1] On sedimentary bedrock up to 90% of sedimentary pebbles was recorded in the drift cover, whereas in the centre of western Dewisland the highest percentage recorded was 24% at Ffordd Caerfai and Treleddyd-fawr. Higher percentages (68% at Whitesands North and 44% at Trefeiddan) occur just to the south and east of the sedimentary outcrops, confirming the overall southward to south-eastward carriage of

1. Stone-counting details are given in Appendix IV.

drift by the Irish Sea ice-sheet. This direction of movement is again confirmed in Fig. 101, where the percentage of Ordovician intrusive pebbles in each locality is seen to be high (between 50% and 26% in the western part of the region) just to the south of the outcrops, with smaller percentages further south. Except for the anomalously high percentage of igneous pebbles at Caerfai, the greater part of Western Dewisland has few Ordovician igneous pebbles in the size-range counted.

Although a southward to south-eastward ice-movement is indicated, the percentage of indicator pebbles at localities southwards from the outcrops does not decrease steadily, so that it would be unwise to construct isopleth maps for the area. The spasmodic concentration of erratic indicators at various localities does not appear to have been controlled by topography; it appears, therefore, that some localised ice-streams within the ice-sheet may have picked up erratics and transported them more effectively than others. One may be justified in proposing that ice-movement was spasmodic and localised over Western Dewisland.

Another conclusion which may be drawn from the maps of erratic distribution is that the till over the whole area is essentially composed of local rock-types. As mentioned earlier in the thesis, the percentage of erratic pebbles encountered in the collection of field samples was seldom greater than 2%. It is difficult to explain this fact satisfactorily, although it has been proposed that the Irish Sea ice which over-rode Western Dewisland may have been relatively weak, at least in its basal layers; underlying head and beach deposits were not severely eroded.

However, it has also been proposed that the till deposited in the coastal sections was not "plastered", but let down in a dead-ice environment. In so far as the till cover is, in most localities, a vestige of the last phase of glaciation when the ice-stream must have lost much of its original strength, the local nature of the till need cause no speculation.

Preferred orientation analyses. From the orientation diagrams on Map 4, it will be seen that the surface layers of till in Western Dewisland are generally disturbed and, on the steeper slopes near the coast, often soliflucted.[1] The low strengths of diagrams for inland sites are noticeable; at Trefeiddan West, for example, there are only 24% of pebbles in the dominant 30° sector, while there are only

---

1. Data concerning sampling-sites are given in Appendix XI.

26% at Clegyr. At Treswni Moor the figure is 28%, and at Croes Philip 26%. The strong preferred orientation of the second sample at Emlych is unusual (with 46% in the dominant 30° sector), but it appears to have been influenced by a local slope on the undulating bedrock surface beneath (Plate 38).

The orientation diagrams for the coastal tills at Ogof Golchfa and Caerbwdy have been discussed earlier; of the other twelve plotted diagrams on Map 4, only the samples for Caerfai and Porthlysgi show anything like an "ideal" preferred orientation, (i.e. with pebble long-axes parallel with the direction of ice-movement and dipping up-glacier). All seven of the diagrams from inland sampling-localities appear to reflect disturbance since deposition or else deposition in a "chaotic" state, while the majority of the diagrams from coastal sites clearly show sludging during deposition or post-depositional solifluxion.

This investigation of preferred stone orientation reveals nothing of the direction of ice-movement, and indicates that in Western Dewisland the drift cover may initially have been devoid of a distinguishable fabric, or else may have been subjected to considerable post-glacial cryoturbation or solifluxion.

Conclusions.

The results of the quantitative investigations undertaken in Western Dewisland may be summed up as follows:

1. Roundness analyses on pebbles from the Upper and Lower Boulder-clays revealed very similar histograms, suggesting that there may be no lithological difference between the deposits.

2. The grain-size distribution of the sandy stony drifts and the gleyed moorland tills are so similar that any Upper Boulder-clay/Lower Boulder-clay subdivision seems unjustified.

3. The plastic calcareous Irish Sea tills of the coastal areas have a characteristic grain-size distribution which may be diagnostic.

4. The drift cover over the whole area is essentially local in character. Although stone-counts confirm the general southward to south-eastward transport of erratics, drift composition at most localities closely reflects the bedrock geology.

5. Stone-counts confirm earlier suggestions that, at least at the time of till deposition, ice-movement over Western Dewisland was relatively weak.

6. The network of preferred orientation diagrams constructed for the area does not reveal the direction of

ice-movement. Virtually every sample appears to have been influenced by depositional sludging or post-depositional solifluxion and cryoturbation.

PART IV

Chapter 9.

Drift Features in the Fishguard Area.

A. The Western Region

B. Fluvio-glacial deposits in the Eastern Region.

C. The Age of the Deposits

D. The significance of hummocky topography

E. Conclusions.

Chapter 9.

DRIFT FEATURES IN THE FISHGUARD AREA.

In Chapter 7 it was suggested on the basis of coastal exposures that there is no Upper Boulder-clay in North Pembrokeshire and no evidence in support of the South Wales End-moraine. In the Fishguard area (Fig. 102) lies much of the critical inland evidence concerning the End-moraine, and the hypothesis cannot be discussed satisfactorily until the field evidence from inland has been examined.

(A) The Western Region.

At the base of the Pen Caer Peninsula, between Abermawr in the west and Scleddau in the east and extending as far south as Mathry Road, is an area of undulating landscape which rises above 400 ft. only in isolated localities. It is an area where the landscape has been greatly modified by glaciation; thick deposits of till, sand, and gravel mask the pre-glacial topography, and in places river valleys are filled with drift. The landscape contrasts greatly with that of Western Dewisland.

There are no comprehensive sections in the area; one has to depend to a large extent upon Jehu's descriptions of sites, which were made when deep borings and railway construction were in progress. Some idea of the drift stratigraphy of the area may be gained from the following records by Jehu:

(a) Trebrython Farm.

5 ft. of earthy clay.

5 ft. of yellowish clay, with rock fragments.

10 ft. of a somewhat tough greyish-blue clay.

Slate rock.

(b) Cnwc Sandy railway cutting.

7 ft. of stiff yellowish-brown clay with fragments of slate-rock.

10 ft. of fine yellow sand with shell-fragments.

18 ft. of stiff dark-blue boulder-clay with shell-fragments.

5 ft. of gravel.

Rock.

From these sections and many other localities in the area (see Fig. 10) Jehu's belief in the tripartite drift succession was confirmed. At Cnwc Sandy, his example *par excellence*, he considered there was a definite thick Upper Boulder-clay separated by sands and gravels from Lower Boulder-clay.

1. *The drift-filled depressions*. As in Dewisland, there are several moorland areas in which "Lower Boulder-clay"

is exposed. Jehu mentioned exposures at Dyffryn, Drim, on Tre-groes Moor, and at Clyn Fach (St. Nicholas), while gleyed tills may also be found on Waun Ddu Moor, Rhos-y-Clegyrn, and on the other moorland areas of Pen Caer.

The surface deposits on these moorlands appear, from frequent augering, to be even more variable than the gleyed tills of Dewisland. On Tre-groes Moor, for example, there are red and yellow stony clays free of mottling, rich red gleyed sands, and mottled buff-blue clays. On Rhos-y-Clegyrn Moor there are mottled yellow clays and foxy-red gleyed sands, and on Clyn Bach Moor gleyed reddish gravel rests above darker clay. On Waun Ddu Moor several old clay-pits reveal tenaceous blue mottled clay, while a similar blue clay, mixed with patches of sand, is encountered half a mile to the west on Waun Fawr Moor. Spot samples from Rhos-y-Clegyrn and Waun Ddu Moors yielded cumulative grain-size curves with a marked break at the 0.5 mm - 0.25 mm grade (Fig. 92); both samples yielded rather high percentages of fines (29.5% at Waun Ddu and 41.4% at Rhos-y-Clegyrn) and both curves are similar to those for sticky clay tills from Dewisland. It may be suggested that the surface deposits on these moors are often true tills.

Yet in spite of the surface variations on the moors there is reason to suspect the presence of Irish Sea till at depth as in Dewisland. Indeed, Jehu's "stiff dark-blue boulder-clay with shell fragments" at Cnwc Sandy and Clyn Bach, and the tough clay at Trebrython, must surely be calcareous tills. The last-named locality is over 3 miles inland from the coast in the direction of estimated ice-movement, and there is every reason to assume that in the favourable localities of Tre-groes and Rhos-y-Clegyrn Moors, Irish Sea till must be present at depth.

2. The Sands and Gravels, and the Question of the "South Wales End-moraine". The most conspicuous superficial deposits in the area are the fluvio-glacial sands and gravels which mark much of the land surface. In Fig. 103 the drift deposits of the Manorowen area have been simplified and plotted from the 6" field map; the sand and gravel deposits are exceedingly complex, and it was not without good reason that Jehu said "It would be almost impossible to map them, as their occurrence is so irregular and patchy; they are apt to die out laterally in a sudden way, passing into clay or rubbly-drift". (P. 69). The gradations from one type of deposit to another are so subtle that the drift boundaries plotted are somewhat arbitrary and the drift categories employed are inevitably guilty of over-

simplification.

However, the map serves to illustrate the relationships of the main sand and gravel area (between Manorowen and Cnwc Sandy) with the surrounding deposits. In the centre of the area there are several small topographic features which owe their origin directly to fluvio-glacial deposition. South of Manorowen two broad ridges trend towards the north-east, separated by a series of associated hollows. One of these, close to the point at which the Cnwc Sandy road branches from the St. David's - Goodwick road, appears to be a closed depression. Between Cnwc Sandy and Clyn there are further depressions, one of which is almost closed.

Other mounds of sand and gravel are found to the west of the Manorowen area between Tre-llys-y-Coed and Tre-llys-y-Cnwc, and to the north of Garngilfach between Caer-lem and North Pole. On Rhos-y-Clegyrn Moor there are hummocks of sand and gravel standing above the gleyed surface of the moor (Fig. 104). South of Tre-llys-draw there are sandy hummocks with four closed depressions which look like kettles; however, it would be dangerous to interpret these as initial glacial features, for the farmer who owns the hummocky field says that these hollows have deepened appreciably within his lifetime as a result of sub-surface spring sapping and subsidence. On the hillside to the north-west of Glanthool there are sandy and gravelly hummocks.

It should be emphasised that from the point of view of scale, the fluvio-glacial features in this area do not bear comparison with those of some other glaciated areas in Britain. The ridges and hummocks are seldom more than 20-30 ft. high and the hollows seldom more than 10 ft. deep. The flanks of the features seldom slope at more than 20°.

The nature of the fluvio-glacial material in the area is variable, and is often difficult to discern due to lack of good exposures. Unfortunately the Manorowen sandpit (where Jehu recorded 12 ft. of sands, silts and shelly gravels) is now overgrown, and the old exposure obscured by sixty years of slumping; however, in Manorowen churchyard stony and gravelly till is seen, passing northwards into foxy-red sands and gravels with sub-angular erratics. In the overgrown sandpit on the roadside north of Clyn dark sandy and stony loam is seen to overlie foxy-red sand, while one hundred yards to the west at least four feet of fine reddish sand is found at the surface. On the roadside at Tre-llys-draw an exposure reveals coarse torrential outwash with large igneous boulders, but fine bedded sands occur at Cnwc Sandy (Jehu, 1904) and Tre-llys.

The observed variations in outwash texture are confirmed by mechanical analyses; from Fig. 99 it can be seen that some of the outwash deposits in the area consist predominantly of coarse sand and gravel, while other deposits consist largely of fine and medium sands. Of the samples analysed, only those at Jordanston Halt and Wolfscastle had more than 25% of fines, while at Tre-llys the fines percentage was as low as 1.5% and at Ford .9%. There appears to be little doubt, however, that most of the deposits recognized as outwash in the field have grain-size distributions very different from the associated tills.

The impression is gained from many localities within the area plotted on Fig. 103 that stony yellowish tills frequently overlie, or are interbedded with, the sands and gravels. This is a feature which is not encountered in Dewisland, and which must prompt some examination of the question of the Upper Boulder-clay. Indeed, as mentioned in Chapter 7, Griffiths (1940), and Mitchell (1962) appear to have accepted the presence of an Upper Boulder-clay in the Manorowen area.

Unfortunately I did not have time to carry out a detailed programme of fabric analysis in the area, but it is worth noting that the yellow till, where it does occur, is generally thin and sandy.[1] In addition, its distribution is essentially intermittent, and over the greater part of the sand and gravel area in Fig. 103 there is no surface till. If the till was deposited during a local Welsh glaciation, as envisaged by Mitchell, one would perhaps expect a more continuous till cover; furthermore, over-riding ice would surely have destroyed many of the sand and gravel mounds in the area. It is therefore possible that the till masses in the area are patches of ablation till laid down in a dead-ice environment at the same time as the sand and gravel masses. Such interdigitation of fluvio-glacial deposits and till is common in areas where ice-sheet and glacier wastage is observed today, as in East Greenland (Hartshorn, 1961), North-west Iceland (John and Sugden, 1962) and Alaska (Price, 1964).

The interpretation of the sands and gravels as dead-ice features is supported when their distribution is examined. They are scattered haphazardly over the whole landscape of Pen Caer and the Manorowen area (Fig. 102); in waterlogged depressions they are severely gleyed, while elsewhere they are banked on hillsides in a fresh state

---

1. The 7 ft. of yellowish-brown till above sand in the Cnwc Sandy railway cutting may be an exceptional thickness, although I found at least 4 ft. of stony yellow clay in the fields near Brwynant.

or mixed with soliflucted head and till. Around Manorowen Hill there is a mantle of stony and sandy till, while sands and gravels lie for the most part beneath 300 ft. O.D. in the valley of the Goodwick Brook.

A further clue to the relationship between topography and fluvio-glacial deposits is seen in the vicinity of Rhos-y-Clegyrn Moor (Fig. 104). Here the upstanding rock masses of Carn Llys and Moel-ddu are devoid of fluvio-glacial deposits and are flanked by a thick apron of head which extends down to an altitude of c. 360 ft. O.D.; at about this altitude the feather-edge of the head can be seen to overlie sandy tills and outwash deposits. On Rhos-y-Clegyrn Moor the till is severely gleyed, but careful field examination revealed that lithologically it is no different from the non-gleyed tills to the south of Clegyrn Farm. The sand and gravel hummocks on the moor undoubtedly overlie the gleyed till; the field interpretation of both deposits is supported by stone-counts (Fig. 105), although the stone-type histograms indicate that the fluvio-glacial deposits incorporate a greater range of stone-types. Thus the drifts in this area indicate the presence of gleyed tills with sand and gravel patches in the depressions, sandy tills on the surrounding slopes, and drift-free areas around the upstanding rock masses. Stratigraphically the sand and gravel hummocks and some of the head deposits are younger than the gleyed tills and the stony sandy tills which cover the greater part of the landscape. In this area there is no evidence of an Upper Boulder-clay; as in the coastal sections at Aber-mawr till deposition appears to have been followed by a phase of outwash deposition and restricted solifluxion.

Again, there is no evidence of an Upper Boulder-clay at Tre-llys, (less than a mile to the east of Aber-mawr), where a gravel-pit has been cut into thick outwash banked against the side of Tre-llys Hill. Well-bedded gravels, sands and silts lie directly above striated bedrock in the pit, and lenses of shelly outwash occur within 4 ft. of the ground surface (Plate 40A). Slump features are common in the lower part of the pit (Plate 40B), where contorted gravels are also seen beneath coarse torrential outwash. In places small patches of till are interbedded with the gravels, but nowhere in the pit is till seen above the fluvio-glacial deposits. From the structures in the pit a strong impression is gained that the deposits were laid down in temporary water-bodies impounded against masses of dead ice.

Thus throughout this western area there is no evidence which conclusively indicates that there was a separate ice-advance to deposit the Upper Boulder-clay. On the other hand there is much evidence to suggest that the till is spasmodically distributed and essentially a part of a complex suite of dead-ice deposits. At Tre-llys, Rhos-y-Clegyrn and elsewhere there is evidence of ice-stagnation in situ, with the carns and higher hills deglaciated at an early stage, and with strips of ice remaining longest in the moorland depressions and river-valleys. Hummocks of sand and gravel are generally best-developed in localities where ice was in contact with hillsides (as at Glanthool, Tre-llys and Caer-lem) or in the lowest available localities (as at Manorowen and Rhos-y-Clegyrn). This pattern of dead-ice deposition is by no means unusual, for the late persistence of ice bodies in the major drainage depressions during deglaciation has been established for example by Strøm (1956) and Holmsen (1963) in Central Norway, and by Flint (1929) in Central North America.

The evidence quoted above provides no support for Charlesworth's hypothesis of a retreating ice-margin in the vicinity. There are no linear features in the Manorowen area, and certainly none in the proposed position of the "South Wales End-moraine" (Fig. 102) a mile or two to the south. It has been suggested in Chapters 5 and 6 that there is no evidence in coastal sections for Glacial Lakes Nevern and Teifi, and it has emerged from this study that there is no evidence of Glacial Lake Manorowen, whose postulated margins are shown in Fig. 102. There are no shoreline traces or lacustrine or deltaic deposits which might indicate the presence of an extensive glacial lake in the area.

(B) Fluvio-glacial deposits in the Eastern Region.

The evidence analysed in the early part of this chapter has been unrelated to the Gwaun-Jordanston channel-system, which is the predominant landscape feature to the south of Fishguard (Fig. 102). This channel-system is analysed in Chapter 10, but at the moment it may be useful to interpret briefly the associated superficial deposits.

The deposits over the greater part of the region are stony and sandy remanié drifts related lithologically to those of Dewisland (Map 3) and the Manorowen area (Fig. 103). In some areas there are severely gleyed tills; at Rhos Isaf (Dinas) there is c. 15 ft. of calcareous till (Jehu, 1904); and in the upland areas there is a great deal of angular bedrock debris in the intermittent drift cover. Unfortunately considerations of space preclude any detailed examination of these deposits, although they have been mapped in the field. In this section only the fluvio-glacial deposits of the area are examined.

1. <u>Depositional evidence of wasting ice.</u> Hummocks of sand and gravel occur infrequently in association with the meltwater channels (Fig. 102). Above the Gwaun Channel, for example, there are few hummocks but extensive thin spreads of sand and gravel up to an altitude of c. 800 ft. O.D.; there are other extensive spreads alongside the Dinas-Newport road,[1] especially west of Pont Felin-wern-dew, and in the Afon Nevern basin in the vicinity of Temple Bar.

However, hummocky patches of fine foxy-red sand occur up to an altitude of 825 ft. O.D. near Brynhyfryd, above the Dinas Cliff, and in the small area examined in detail around the intake of the Gwaun Channel there are abundant fluvio-glacial deposits with a marked topographic expression. Mounds of fine sand and gravel are especially common around Caersalem Chapel and Constantinople. Further to the east there are hummocky sands and gravels in a hill top site at Pen Creigiau Cemmaes (where they were considered to be part of the South Wales End-moraine by Charlesworth), and an extensive area of sands and gravels at Bancywarren near Cardigan (Fig. 106). At the latter site some of the hummocks are over 100 ft. high, and on examination of their

---

1. A good exposure of sands and gravels interbedded with head may be seen in the sand-pit near Party-bach.

bedding-structures indicates that they are probably original depositional forms. In north-east Pembrokeshire near Monington, there are broad ridges of gravel, and in the same region work by K.J. Gregory and D.Q. Bowen has revealed the presence of eskers and other depositional features.

I have found no convincing evidence to the east of the Gwaun Valley in support of Charlesworth's Glacial lake hypothesis. Although observations are restricted to some extent by scarcity of good exposures, no clear deltaic bedding features have been seen to date in these deposits, so that they do not appear to have been laid down as lacustrine deltas. W.D. Evans (1964) noted varved clays in the area east of the Brynberian Gorge, but I found only stony clay tills in the locality; and while lacustrine deposits are assumed by Allen (1960) to be present in the Teifi valley, his evidence is not well documented concerning their extent. There are no shoreline traces in any of the areas investigated, and the sand and gravel masses do not coincide with postulated lake levels. It seems that the doubt cast upon the existence of Glacial Lakes Nevern and Teifi in Chapter 7 is reinforced considerably when evidence from inland is examined.

As in the Manorowen area, it appears most reasonable to interpret all these features as characteristic of ice-wastage *in situ*,[1] with fluvio-glacial sand and gravel laid down around masses of wasting ice.

2. Deposits within the channels. Sands and gravels are seldom discernible within the walls of the channels shown in Fig. 102. For the most part these channels are flat-floored, but infills of alluvium and (in the case of Esgyrn Bottom) thick peat generally make it difficult to decide whether the valleys hold fossil sandur deposits.

However, at several localities deposits have been discovered. On the floor of the Gwaun Channel there are terraces of coarse outwash, and sands and gravels are known to be at least 30 ft. deep (Joy, 1963).[2]

---

1. F.M. Synge (in Mitchell, 1962) suggests that the Bancywarren hummocks are the dissected remnants of an outwash plain. In view of their hill top site, like that of the Pen Creigiau Cemmaes gravels, this suggestion is difficult to accept.

2. A possible extension of the Gwaun Channel between Parc-y-Morfa and the coast is filled with outwash gravel. At the mouth of this channel, c. 80 ft. of stratified gravels are exposed in the cliffs at Pwll Betty.

At Scleddau patches of torrential outwash gravel with large boulders rest in bedrock hollows (Fig. 107), and an extensive fan of outwash has been found at the outlet of the Escalwen North Channel (Map 5). Within the walls of the Jordanston channel, at Jordanston Halt, 15-20 ft. of coarse torrential outwash is exposed in an abandoned railway cutting; the outwash, which is in places covered by a black shale head, appears to extend along both sides of the valley in isolated strips. Similar strips of sandy outwash may be discerned along the sides of the Panty-coch channel, the Maildy channel, and the Castle morris channel, which carries the Western Cleddau river (Map 5).

All these strips, which have since been dissected by post-glacial erosion, culminate in a great mass of outwash in the vicinity of Mathry Road where the Afon Cleddau and Western Cleddau rivers meet (Fig. 108). A large part of the area between Y Garn, Llangwarren, and Rhosdenny is covered with thick fluvio-glacial gravels, which are best exposed in the Mathry Road gravel-pit.

In this pit fine current-bedded sands and gravels are seen to be at least 35 feet thick; the lowest deposits exposed are gently-dipping sands, silts and fine gravels, overlain by up to 5 ft. of gravels with well-marked foreset bedding (Plate 41) and 5 ft. of structureless torrential outwash. In the flooded part of the pit large erratic boulders are encountered at a depth of 10-15 ft.; these boulders could be derived from a basal till, and there appear to be other patches of till on an inlier of bluish siliceous bedrock in the centre of the pit. The impression that the lower gravels in the pit contain moraine is apparently strengthened by the stone-counts analysed in Fig. 109. The silt and sand bands in the lower part of the pit dip at 1° to 3° towards the north-west, while the steeply-dipping foreset beds above dip in the same direction. The direction of stream-flow thus indicated is something of an anomaly, for it is directly in opposition to the present direction of flow of the Western Cleddau (Fig. 108). Perhaps this may be explained by proposing that the gravel-pit exposes but one flank of an extensive delta laid down in a temporary lake during deglaciation by a powerful Afon Cleddau. Certainly, the direction of bedding in the pit indicates that the Western Cleddau cannot have been the dominant stream at this time. Only careful levelling of the terrace remnants in this area of complex stream diversions can elucidate the late-glacial directions of stream-flow, and the possibility must be borne in mind that the major drainage route at this time may have been northwards and westwards via the Castle-Morris Channel and the Llanbed Gap to the sea at Aber-mawr (Map 5).

The history of events represented at Mathry Road is relatively simple. Following the deposition of till on the floor of the valley, the ice wasted in situ; this is indicated by the presence of hummocky dead-ice topography to the east of Mathry Road station. A pro-glacial lake was dammed in the vicinity of the Afon Cleddau - Western Cleddau confluence and outwash material was carried into this lake by powerful meltwater streams, of which the dominant member appears to have been the Afon Cleddau. The sequence of deposits in the Mathry Road gravel-pit indicates that a sandur plain advanced well into this lake before it was drained; and extensive sandur plains were built up in all the main valleys of the area as ice-wastage proceeded.

The evidence cited above suggests strongly that during ice-wastage in North Pembrokeshire some of the meltwater channels of the Gwaun-Jordanston system were used by sub-aerial braided streams which built up extensive sandur plains.[1] These streams appear to have originated in dead-

---

1. Further evidence of extensive sandurs may be seen at the northern end of Treffgarne Gorge, where terraces of outwash are preserved at Ford. South of the Gorge there are extensive outwash plains in the valley of the Western Cleddau at least as far south as Haverfordwest.

ice masses in the Manorowen area and perhaps in the vicinity of the deep channels to the east. These features are easily distinguished from the hummocky dead-ice topography of areas outside the channel margins.

(C) <u>The Age of the Deposits.</u>

The Dewisland Glaciation was probably responsible for the deposition of all the drifts described in the foregoing pages. This is indicated by the shallow depth of weathering at most localities, the negligible decalcification of the shelly gravels at Tre-llys, and the occasional presence of head layers above the fluvio-glacial deposits. The occurrence of the short periglacial phase after the Dewisland Glaciation is further attested by the presence of fossil ice-wedges at Mathry Road (Plate 42) which were possibly formed at the same time as the wedges at Aber-mawr South and Pen Dal-aderyn. As far as can be ascertained, the sequence of events related to the Dewisland Glaciation in this area was as follows:

5) Sandy loams deposited on surface.

4) Periglacial phase - ice-wedge cracking and solifluxion.

3) Valley sandurs - large-scale meltwater flow.

2) Deglaciation - wastage of dead-ice masses <u>in situ</u>.

1) Extensive Glaciation - ice-movement probably from the north and north-west (striations at Tre-llys, Aber-mawr, and Parrog). } Dewisland Glaciation.

(D) <u>The significance of hummocky topography</u>.

One of the major problems concerning the North Pembrokeshire drifts is the great contrast between the drift deposits of Dewisland and the Fishguard area; in Dewisland fluvio-glacial deposits appear to be virtually absent except for a few small hummocks, while near Fishguard there is a vast amount of outwash material, often with well-marked hummocky topography. It was partly because of this distinction that Charlesworth proposed a Newer Drift advance for the Fishguard area but not for Western Dewisland. Again, as Jehu noted in 1904, the drifts thicken appreciably from west to east.

It has been suggested in the foregoing pages that there was no Newer Drift advance; how then does one explain the distinction? The presence of the Gwaun-Jordanston system of channels is by no means the only factor responsible for the presence of thick fluvio-glacial deposits near Fishguard, for it has been shown that the deposits of Manorowen and Pen Caer are quite unrelated to these channels.

Perhaps the ice was somewhat thicker in the Fishguard area, where possible supplies from the Prescelly Mountains and Central Wales may have augmented Irish Sea ice; but against this idea there is the evidence of Irish Sea till on the coast and striations which indicate ice-movement from the north and north-west, suggesting that the Irish Sea ice of the Dewisland Glaciation was dominant throughout the whole of North Pembrokeshire and met little resistance from Welsh ice. In support of this, Griffiths (1940) has found traces of Irish Sea drift at Crymmych, at the head of the Afon Nevern valley, and at Pentre-cwrt, 16 miles inland in the Teifi Basin (Fig. 88).

It is likely, therefore, that the underlying surface topography has had an important effect on the characteristics of the drift cover; it can be no coincidence that the hummocky fluvio-glacial drifts are only found in Pembrokeshire where the pre-glacial relief was moderately or severely dissected, with upstanding carns and hills and deep pre-glacial valleys. Perhaps this strongly differentiated topography was responsible for severe crevassing of the ice-sheet, to be exploited during ice-wastage by melt-water streams. Perhaps in a dead-ice environment fluvio-glacial material was derived largely from hill slopes covered with moraine. And perhaps, as a result of the differentiated sub-glacial topography, shearing within the ice-sheet was responsible for the carriage of moraine within the ice-mass rather than at its base, with subsequent ice-wastage accompanied by the re-deposition of en-glacial material as outwash.

In each of these cases there would have been more effective fluvio-glacial deposition in the Fishguard area than on the flat erosion surface of Western Dewisland. However, until the mechanics of dead-ice deposition are understood more fully, it may be wise to accept Mr. Penny's warning (1964) that "the formation of 'hummocky topography' by glaciers is capricious" (P. 388) and to leave the problem sub judice.

(E) Conclusions.

1. From this brief study it appears that the dead-ice deposits are spasmodically-distributed. In no sense could they be claimed to represent an end-moraine, for the line proposed by Charlesworth coincides with singularly few fluvio-glacial hummocks; most of the hummocks occur to the north of the line, but some are found south of it. There is a lack of evidence for Glacial Lakes Nevern and Gwaun, and the "South Wales End-moraine", the corner-stone of the glacial lake hypothesis, does not exist.

2. The fluvio-glacial deposits in the Fishguard area may be categorized under the broad heading of hummocky dead-ice

topography and valley-sandurs.

3. The "Lower Boulder-clay" in the drift-filled depressions is a true till which is possibly underlain by calcareous Irish Sea till.

4. The yellow "Upper Boulder-clays" in the area are in part solifluxion deposits and in part masses of ablation till laid down at the time of ice-wastage.

5. All the drifts in the area may be related to the Dewisland Glaciation. There was no separate ice-advance to deposit the so-called "Upper Boulder-clay".

PART V.

SOME OBSERVATIONS ON THE MELTWATER CHANNELS OF NORTH PEMBROKESHIRE.

The next two chapters constitute something of a digression from the developing theme of drift distributions. However, no study of the glaciation of North Pembrokeshire could omit an analysis of the spectacular series of melt-water channels made famous by Professor Charlesworth in 1929, and in the following pages some attempt is made to re-assess their origins and age.

The emphasis of both chapters rests upon the analysis of morphological features, which provide much additional evidence of the course of glaciation in the county. The chapters are essentially complimentary; in the Gwaun-Jordanston area lies most of the evidence for the origin of the channels, while in Dewisland lies most of the evidence for their age.

Chapter 10.

The Gwaun-Jordanston System

of Channels

Chapter 10.

THE GWAUN - JORDANSTON SYSTEM OF CHANNELS.

The Gwaun - Jordanston system of channels, on the north-western flanks of the Prescelly Mountains, has long been recognised as a legacy of glaciation. The present-day streams of the area flow for the most part in steep-sided and flat-floored rock channels which form an interconnected system. Most of these channels appear to have been cut through "pre-glacial" cols[1], and at the present day few of the channels are used for the whole of their length by one stream; watersheds occur on the flat floors of the valleys, as in the Cwmonnen and Nant-y-bugail channels and Esgyrn Bottom. The main watershed between streams flowing south to the Treffgarne Gorge and those flowing to the North Pembrokeshire coast descends abruptly from an altitude of 1096 ft. O.D. on Mynydd Cilciffeth to c. 390 ft. O.D. on the floor of Nant-y-Bugail channel in a distance of one mile (Map5).

The Pattern of Channels.

Map 5 shows the Gwaun-Jordanston channel-system and its relationship with the surrounding relief. The largest

---

1. "Pre-glacial" in this section means prior to the earliest glaciation of which there is evidence in the area.

channel is that of the Gwaun, which is over eight miles long and which passes between the hill masses of Carningli and Mynydd Prescelly to connect the drainage basins south of Newport and Fishguard Bays. The Gwaun channel (Plate 43) is joined on its northern flank only by the discordant Cwmonnen channel, which runs south-eastwards from the scalloped cliff overlooking the village of Dinas. On its south side the Gwaun joins the Criney channel, Esgyrn Bottom (Plate 2), and the Nant-y-bugail channel, all within the space of 1½ miles. The former two channels join to run into the Scleddau channel and are also connected by the Llanwern Channel. Further south the spectacular Nant-y-bugail channel (Fig.102), which in places is over 250 ft. deep, sweeps southwards and then westwards for over five miles before joining the Afon Cleddau valley at Newbridge.

In addition to these channels there is a small isolated system (the Escalwen channel-system) which originates on the hillside near Gelli and joins the Scleddau channel through three distributaries. Several of the small channels in this system are completely dry, although minute streams flow on the floors of the larger channels. Other channels isolated from the Gwaun-Jordanston group today, but similar in form, are the small channels south of Drim and the Cwm Dewi Channel (noted by Jehu) which all but isolates Dinas Island. In addition, slight "col" depressions sometimes connect channels, as in Llanstinan Parish between the Nant-y-bugail channel and the channels to the north, and between Scleddau and Jordanston. The only large stream in the area which does not flow in a deeply-cut valley is Goodwick Brook, which drains Waun Ddu and Rhos-y-clegyrn Moors. Some of the small tributary valleys which hang above the Gwaun and Nant-y-bugail channels also have shallow cross-sections.

Pre-Glacial Relief.

It is apparent from the dimensions and relationships of the channels in this area that they are not the products of sub-aerial fluvial erosion, and there is much evidence which indicates that glacial meltwater has probably been the major agent in their formation. A reconstruction of possible pre-glacial relief (Fig. 110) has been made from the O.S. 2½" and 1" sheets (SM 93 and 138 respectively). In most cases channel sides are cut into older valley-slopes and cols, so that pre-glacial relief has been reconstructed by the simple extension of truncated contour-lines. The drainage-pattern in Fig. 110 is a complex one, and several anomalies appear; for instance, there is evidence of an almost enclosed basin north of Escalwen, and there are several possible outlets for pre-glacial streams in the Newbridge - Jordanston - Castle Morris area. Thick drift in the pre-glacial valleys makes reconstruction of the topography almost impossible in these areas without deep borings, for there may have been "a complicated series of river-captures" prior to the first glaciation (Cox, 1930).

Some attempt at a reconstruction of pre-glacial events has been made by Burton (1952). His chronology of drainage evolution is based upon the adjustment of drainage to a regressive sea-level, falling spasmodically from 490 ft. O.D. to present sea-level, and he considers that glaciation occurred in the area while sea-level lay between 295 ft. O.D. and 240 ft. O.D. There is, however, no field evidence in support of this hypothesis. As early as 1904 Jehu had recognised that the main valleys of the area pre-dated the "Lower Boulder-clay" glaciation; many of these valleys are graded to below present sea-level, and could not have been cut if sea-level had fallen to only 240 ft. O.D. when glaciation occurred. Evidence from the estuaries of the Afon Nevern and Teifi (Chapters 5 and 6) has shown that the larger valleys of the area were probably graded to a sea-level lower than at present even before the earlier of the two glaciations traceable in Pembrokeshire;

furthermore, head beneath till in all the coastal valleys indicates that prolonged sub-aerial conditions prevailed prior to the Dewisland Glaciation. There is no evidence from the Irish Sea or elsewhere of a sea-level above 240 ft. O.D. during glaciation; on the contrary, field evidence from glaciated lands all round the North Atlantic indicates that sea-levels were as low as -390 ft. at the peak of the Last Glaciation[1], and possibly almost as low during earlier glaciations(see, for example, Farrington, 1945; Donn, Farrand, and Ewing, 1962; Fairbridge, 1962). Consequently Burton's field evidence, and his conclusions, seem unconvincing.

<u>The Origin of the Channels.</u>

(a) <u>Charlesworth's Hypothesis of Glacial Lakes.</u> While bearing in mind that complex river-captures may have contributed to the development of a drainage-pattern on the lines of that shown in Fig. 110, it appears that the channels have been cut, for the most part, across pre-existing cols. This fact was recognised by Charlesworth, and from it grew his hypothesis of the meltwater lakes of

1. Other high relative sea-levels during the Late Pleistocene have been suggested for other parts of Britain (e.g. by Anderson, 1939); they are possibly the result of isostatic depression.

North Pembrokeshire.

Charlesworth proposed that the Irish Sea ice of Newer Drift times advanced across the North Pembrokeshire Coast but terminated at the line of the "South Wales End-moraine" and impounded a series of pro-glacial lakes in the existing valleys of the area. Charlesworth's map (his Fig. XX) of the development of these lakes was complex in the extreme, but in Fig. 111 an attempt is made to elucidate the various stages which he envisaged. At the maximum stage of ice-extension, Lake Teifi (the largest lake in the series) overflowed westwards through the Pont-gareg channel at an altitude of 450 ft. O.D. into Lake Nevern. This lake had an initial surface altitude of 380 ft. O.D., and flowed over a pre-existing col at this altitude into the Gwaun Valley, which itself supported a lower lake. From the latter the earliest outlet was considered to have been the Nant-y-bugail channel. As the ice-front retreated and the level of Lake Gwaun fell, subsequent overflows used cols further north to cut the Escalwen channels, Esgyrn Bottom, and the Llanwern and Criney channels. Further falls in the level of Lake Gwaun led to the cutting of the Gwaun channel by meltwater. All the overflows were thought to grade into the Jordanston channel, which itself drained a small Lake Manorowen southwards into the Western Cleddau System. At this stage (Diagram B in Fig. 111) Lake Nevern was considered to have been drained by an ice-marginal stream along the Dinas cliff and into the Cwmonnen channel. A similar stream is considered to have drained Lake Moylgrove (at a higher altitude) during the subsequent stage. During the last stage (Stage II of Charlesworth) Lake Nevern was drained westwards through the Cwm Dewi channel. As a result of the changes induced by the overflows of the Last Glaciation, the drainage of the Gwaun-Jordanston area retained its new southward orientation, so explaining the apparent anomaly of streams originating less than a mile from the North Pembrokeshire coast, breaching the main watershed of the county through the Treffgarne Gorge, and reaching the sea at Milford Haven.

Several subsequent workers have supported Charlesworth's hypothesis of glacial lake overflows. In 1940 W.D. Evans proposed that much of the supply of water for Lake Nevern may have originated as snow-melt from the Prescelly Mountains. Griffiths (1940) accepted the existence of glacial lakes and overflows related to the maximum of the Irish Sea ice. However, in view of the existence of higher channels and gaps south of the Teifi he reasoned that the lakes which overspilled through these channels could not have been impounded by Newer Drift Irish Sea ice terminating on the North Pembrokeshire and Cardiganshire coast; he proposed, therefore, that the lakes must have been impounded by ice at a higher level, which must have been of "Older Drift" age. In 1946 M. Jones followed the lake hypothesis in his reconstruction of the Teifi drainage, although he realised that lake evolution and channel cutting may have been far more complex than Charlesworth envisaged. The hypothesis received widespread recognition as a result of its inclusion in the South Wales Regional Geology Handbook (Pringle and George, 1948). It has been re-stated by Charlesworth (1963 and personal communication, 1963) and in slightly altered form by O.T. Jones (1964 and personal communication, 1964), who cites as evidence for glacial lakes the current-bedded sands at Banc-y-warren and possible lake-marginal features near Pentrecwrt. Like Griffiths, he considers that the highest channels south of the Teifi are part of the overflow channel series and of the same age as those at lower altitudes. Erosion of most of the gorges in the Teifi valley is considered to have taken place after the draining of the glacial lake. W.D. Evans (1964) supports this idea, relating the cutting of gorges to periodic flood-waters flowing westwards and northwards from inland ice after the disappearance of the

Irish Sea ice.

(b) <u>The Inconsistencies of the Hypothesis.</u> The glacial lake hypothesis appears to contain several inconsistencies, as noted by Joy (1963) and Bowen (1964). In the first place, the highest outlet of Lake Teifi was considered to be the Pont-gareg channel at an altitude of 450 ft. O.D. However, other high col channels at Blaenffos (intake at 560 ft. O.D.) and Crymmych (intake at 720 ft. O.D.) are very similar in form to the Gwaun and Criney channels (Fig. 112). Both are cut through pre-glacial cols, and both appear to have been formed by a similar process. Their presence was apparently disregarded by Charlesworth, for with glacial lakes in mind their gradients indicate "over-spill" in the wrong direction, i.e. from west to east; but both channels certainly carried a far greater volume of meltwater than the Pont-gareg channel.

Lakes Nevern and Gwaun were considered to have had successively lower water-levels than Lake Teifi, and yet Lake Gwaun supposedly overflowed the pre-glacial Nant-y-bugail col; this would have been impossible, for the original col must have had an altitude of c. 650 ft. O.D. (Fig. 113). A similar problem is concerned with the outlet of Lake Nevern via the Gwaun Valley. Work from cross-profiles (Burton, 1952; Joy, 1963) has indicated that the watershed of the pre-glaacial Gwaun-Clydach area was at an altitude of c. 600 ft. O.D., so any lake which used the col as an outlet must have had a higher initial surface level. If Lake Nevern had a surface altitude of 600 ft. O.D., it would almost certainly have used the Lower Blaenffos col as an outlet (at 560 ft. O.D.). In Charlesworth's view the maximum surface level of Lake Nevern was c. 380 ft. O.D., which is lower than the present divide on the floor of the Nant-y-bugail channel.[1] If the lake levels postulated by Charlesworth are correct, Lake Nevern could never have had an outlet into the Gwaun channel, and the waters of Lake Gwaun could never have escaped via Nant-y-bugail channel. In the same way the pre-glacial Cwmorren col has been reconstructed at c. 375 ft. O.D.; if the surface of Lake Nevern fell to this altitude there seems no reason why it should not have continued to use the lower Gwaun Valley, where a meltwater route was already established.

From the reconstruction of pre-glacial relief (Fig. 110) it appears that the Esgyrn, Llanwern, and Criney

---

1. Burton (1952) recorded the altitude of the Nant-y-bugail divide as 300 ft. O.D. In fact the divide is shown on the O.S. 2½" map at c. 385 ft. O.D., about 10 feet higher than the Gwaun-Clydach divide.

cols may have been successively lower than one another, at altitudes of 320 ft., 310 ft., and 290 ft. O.D. But when the channels through these cols are considered further inconsistencies appear. Charlesworth's earliest Esgyrn Bottom channel appears to coincide with the courses of the Escalwen East and Panty Phillip channels; subsequent channels on his Fig. XX apparently coincide with Escalwen West channel, Esgyrn Bottom proper, and the Criney channel. (No mention is made of the Llanwern channel). The Escalwen channel-system originates in shallow lateral depressions at an altitude of 525 ft. O.D. on the hillside above Gelli; none of the channels in the system could have been used as an overflow route by a Gwaun Lake with a maximum surface altitude of under 380 ft. O.D., and since the channels are not cut into pre-glacial cols there could have been no overflow at this point even from a lake with a surface altitude above 525 ft. O.D.

The foregoing analysis of Charlesworth's hypothesis has done no more than suggest that his proposed sequence of events must be considered doubtful. The possibility remains that the channels in the system could have been cut by lake overflows at higher levels than envisaged by Charlesworth (Professor O.T. Jones, personal communication), or impounded in different localities and for less prolonged periods by a more irregular wasting ice-margin. There is no doubt that large pro-glacial lakes can form between ice and land during deglaciation. There has been a recent tendency to minimise the importance of pro-glacial lakes, but they are common in areas of present-day ice-wastage, although generally of limited extent and duration. A large lake, drained over deeply-cut rock spillways, is impounded by the Rypefjord Glacier in East Greenland, and Okko (1955) and Thorarinsson (1939) frequently mention such features in Iceland. Okko figures a magnificent rock spillway draining a marginal lake. Other lakes dammed by an ice-cap margin are the Conn, Bieler, and Generator Lakes around the Barnes ice-cap, Baffin (Ward, 1952).

Much of the evidence for Late-Pleistocene pro-glacial lakes is indisputable. Convincing evidence for ice-dammed lakes over 60 miles long and 45 miles wide has been presented by Ives (1960) for part of Labrador-Ungava; these lakes are considered to have been dammed against ice-free mountain slopes by wasting inland-ice in the lowlands, and they were apparently drained over sub-aerial spillways. Traces of other drained lakes have been found north of the Barnes ice-cap, Baffin (Ives, 1962), and in Britain there is good field evidence for pro-glacial lakes up to

1½ miles long during the deglaciation of the Cairngorms (Sugden, 1965) and for the extensive Edderacres Lake in Co. Durham (Smith, 1965). Also, the sub-aerial drainage of pro-glacial lakes was an important element in the theories of Mannerfelt, (1945); the process has been mentioned by Liestøl (1955), Gillberg (1956), and others in Scandinavia.

Thus there appears to be no reason why a sequence of events somewhat similar to that proposed by Charlesworth should not have occurred in the Gwaun-Jordanston area, if the field evidence so indicates.

(c) <u>A further problem.</u> Field and theoretical evidence, however, throws doubt upon the existence of any large pro-glacial lakes during deglaciation. In the last chapter it was pointed out that all the hummocks of sand and gravel in the Fishguard area are best interpreted as dead-ice features; there is no evidence for the South Wales End-moraine, for a retreating ice-front, or for the pro-glacial lakes. Joy (1963) has pointed out further problems concerning the mechanism by which glacial lakes cut down-wards through their spillways.

A reconstruction of the pre-glacial relief reveals that the humped bedrock divide on the floor of the Gwaun channel (at Llannerch) is in approximately the same position as the pre-glacial col; the small Gwaun and Clydach streams flow upon deep drift fills westward and eastward of this rock divide, indicating that it probably does not owe its existence to recent stream erosion. It is difficult to see how the position of the divide could be maintained under sub-aerial meltwater overflow, for a sequence of events as indicated in Fig. 114 would be expected to occur (after Peel, 1949). Furthermore, a glacial overflow channel must have a continuous gradient downwards from its intake point; such gradients are seldom present in the Gwaun-Jordanston system of channels.

Another interesting point is that the Gwaun channel maintains its gorge-like form for one mile to the east of the present divide (Plate 43). If, as would be expected, the divide at all times marked the maximum westward extension of Lake Nevern in this vicinity, there could be no mechanism for cutting a deep channel further east beneath the surface of the lake. The only possible mechanism could be a reversal of overflow from Lake Gwaun into Lake Nevern, as suggested for other areas by Kendall (1902); this is considered too unlikely an occurrence to be acceptable (Peel, 1956; Sissons, 1961).

"Humped" long profiles exist in most of the channels of the area, and in several cases it is demonstrable that these profiles are not the result of post-glacial drainage modification. The spectacular Nant-y-bugail channel flows upon a drift fill in places, but its humped long profile is too prominent a feature to have been achieved by recent headward erosion (Fig. 115). The humped profile of the Llanwern channel is cut in a rock floor, but seems to have resulted largely from the downcutting of Esgyrn Bottom and the truncation of an earlier Llanwern - Esgyrn long profile. The valley-bottom divides on Esgyrn Bottom and the floors of the Scleddau and Cwm Dewi channels are today on deep drift infills; it is not known at present how the positions of these divides are related to the rock floors of the channels. The humped long profile of the Cwmonnen channel does not owe its origin to recent headward erosion (Joy, 1963); in general, its floor falls towards the north-east (i.e. in a direction opposite to that of a possible overflow channel draining Lake Nevern.)

(d) The Alternative Hypothesis. Charlesworth's Lake hypothesis appears to be unproven in the Gwaun-Jordanston area, in view of the lack of supporting field evidence and its inherent inconsistencies. Sub-glacial and marginal meltwater drainage may therefore be largely responsible for the features investigated above. The exploitation of cols by sub-glacial meltwaters has been discussed in some detail by Sissons (1960), and "col channels" have been described by Mannerfelt (1945), by Derbyshire (1961) in the Cheviots, and by Gregory (1962) in Eskdale, Yorkshire; the resulting channels are similar in cross-section to those in Figs. 112 and 113, and are often characterized by humped long profiles (Sissons, 1960). Valleys like the Llanwern channel "hanging" above the floor of Esgyrn Bottom are noted by Soons (1960) in Kinrosshire, where glacial meltwater channels were associated with wasting ice. Perhaps the closest analogy can be drawn when the complete integrated pattern of channels in the Gwaun-Jordanston area is considered. The system displays most of the diagnostic characteristics of meltwater channels as noted by Derbyshire (1958), and looks remarkably similar to channel systems shown by Mannerfelt (1945) and by Hoppe (1950; 1957) for regions in Sweden where meltwater from downwasting ice has cut rock channels marginally and subglacially. Again, there are marked similarities with several integrated channel series[1] figured by Sissons (1961) from Scotland.

---

1. Derbyshire (1961) has proposed the term "sub-glacial channel systems" for such systems.

Several features in the area suggest that the greater part of the channel system may have been cut sub-glacially. The humped long-profiles of the channels bear witness to the capacity of sub-glacial meltwater for eroding bedrock powerfully when flowing uphill for short distances under hydrostatic pressure. (Sissons, 1961).

In the Gwaun channel there are several small arcuate channels which have been cut across rock spurs on the channel side. Two of these features, at Parc-y-dyffryn and Allt Pengegin Isaf, have been examined by Joy (1963), and she concludes that in each case a rock knoll standing above the valley-floor is backed by a small humped channel. At Allt Pengegin Isaf (Plate 44) there appear to be two such features associated with a steep chute descending the valley-side. At Cronllwyn a rock spur at the intake of Esgyrn Bottom has been crossed by another humped channel running NE - SW. Other shallow channels cross a low spur beneath the main wall of the Gwaun channel just east of Criney Bridge, and other erosional scallops occur on the valley side at Kilkiffeth Wood, Coed Pen-yr-allt-ddu, and around Garn.

Similar features occur elsewhere in the area. A spectacular arcuate channel occurs on the northern flank of the Blaenffos channel, and a dry channel is cut across a spur high on the southern valley-side near Castellan Farm. On the face of the Dinas Cliff three small arcuate channels have been cut across pre-glacial rock spurs. The largest and most spectacular of these, Cwm-mawr (Plate 45), has a humped long profile which is truncated at its western end. The Bryn-niwl channel is a less distinct feature, but at Castell a channel appears to have cut across a larger spur to isolate an upstanding rock knob on the platform surface below. On the cliff above Newcastle is a smaller rock knob which appears to be related in form to the Bryn-niwl channel.

Arcuate channels such as these cannot have been formed sub-aerially by water from lake overflows; neither does it seem that they can have been formed marginally[1] or as a result of downcutting supraglacial streams, as suggested by Sissons (1961) for other areas. The combination of humped long-profile and arcuate plan must surely mean that they formed sub-glacially.

Therefore, on the basis of the major characteristics of the Gwaun-Jordanston channel system, and from analogy with other related systeme, it appears most reasonable to

---

1. Charlesworth appears to have envisaged marginal drainage towards the Cwmonnen channel along the face of the Dinas Cliff.

propose that sub-glacial meltwaters were largely responsible for its formation.

Other meltwater features.

However, some of the smaller meltwater features in the area provide valuable clues to the course of glaciation and deglaciation in the Fishguard area. While the weight of evidence in the area suggests that the larger channels and arcuate features were cut sub-glacially, there is also abundant evidence of a downwasting ice-margin.

Marginal channels as described by Mannerfelt (1945) are rare in this area, as they are in some other glaciated upland areas of Britain (Derbyshire, 1961). However, a series of degraded terraces high on the flanks of Mynydd Carningli and on Foeldrygarn may be ice-marginal features. On the northern flank of Mynydd Carningli at an altitude of c. 925 ft. O.D. is an undulating depositional terrace c. 200 yards long; below this terrace blocky solifluxion features appear to be less well-developed than above. Lower terraces on the northern flank of the hill are of a less distinct character. On the south side of Carningli five main terraces above 800 ft. O.D. dip down at between 2° and 4° towards the Gwaun valley. All these terraces are covered with blocky scree. The lower two terraces are both over 20 yards wide, and one is over 200 yards long.

The variable directions of dip of these terraces suggest that they are not of structural origin; they appear to reflect the positions of a falling ice-margin, perhaps with marginal meltwater flowing south-westwards towards the Gwaun Valley. Other degraded marginal benches occur on the northern slopes of Mynydd Prescelly at Banc Llwydlos, beneath Foelfeddau, and beneath Mynydd-bach and Carnbica. Small marginal channels may be seen on the face of the Dinas Cliff, at an altitude of c. 390 ft. O.D. above Castell.

There is some evidence for sub-glacial chutes and sub-marginal channels in the area (Mannerfelt, 1945; Sissons, 1961). At Ty-canol several spur-end channels plunge steeply from intakes at c. 530 ft. O.D. north-westward towards Constantinople, and there are other notches in the hillside to the west. These features cannot have formed sub-aerially in their spur-end position, and today they are quite dry; it is possible that they may have originated as sub-glacial chutes. Many deep chutes fall steeply down the flanks of the Gwaun channel. Several of these may have been cut post-glacially by small streams descending the steep channel-side, but Cwm-du, Cwm Mawr, and Coed Sychpant are especially noticeable features which are unlikely to have formed post-glacially in view of the limited size of the streams which use them; they may have originated as sub-glacial chutes. If this was the case, then dead-ice may have filled the Gwaun channel at a late stage of deglaciation.

The Escalwen channel-system (Fig. 116) bears the characteristics of a marginal, sub-marginal, and sub-glacial drainage system (Joy, 1963). The slight depressions around Gelli are occasionally one-sided, and since they run along or obliquely to the contours they cannot have been cut by normal stream erosion. Near Pant-y-wrach these small channels plunge through two intakes into the Escalwen East channel, which runs obliquely down the end of the spur towards Escalwen (Plate 46). Small outlets leave this deep channel at altitudes of 380 ft. and 360 ft. O.D., and at the foot of the spur it bifurcates into the Panty Philip Channel and the Escalwen West channel. Meltwater flow appears to have been less continuous in the Escalwen North channel, for it is a shallow feature unlike the others in form. It is likely that the Escalwen features were formed in an environment of downwasting ice, with marginal meltwater (which cut the Gelli channels) passing through a short sub-marginal phase at Pant-y-wrach before achieving full sub-glacial erosion in the deeper channels of the system (Plate 47).

Similar channel-systems of composite origin are commonly described in the literature, e.g. by Sissons (1961) and Hoppe (1957).

The small channels around Drim (Fig. 103) also appear to have been cut by sub-glacial meltwaters at a relatively late stage in deglaciation, for they are not related to the main channel-system of the area. They are best explained by a sub-glacial diversion of meltwaters while downwasting ice filled the lower part of Goodwick Valley, and it appears that they must have been cut by meltwaters flowing northwards. The features at Escalwen and Drim, together with the possible low-level marginal features on the Dinas Cliff and the sub-glacial chutes of the Gwaun valley, may therefore be approximately contemporaneous, post-dating by a short while the integrated sub-glacial channel-system of the area.

The Age of the Meltwater Channels.

It was an essential part of Charlesworth's hypothesis that the Gwaun-Jordanston meltwater channels were formed during the Last Glaciation. This dating is apparently accepted today by O.T. Jones, W.D. Evans, K.J. Gregory, and D.Q. Bowen. The lone voice of dissention has been that of Griffiths (1940), who considered that the channels were cut during the Older Drift Glaciation.

In Chapter 7 it was tentatively suggested that the ice of the Dewisland Glaciation achieved little erosion and little deposition in Dewisland. It may therefore have been relatively thin and inactive, even at the time of its maximum extension. Within the limits of its ability it appears to have assaulted the coast of north and west Pembrokeshire and southern Cardiganshire from the north and north-west, leaving as witness striated bedrock slabs and calcareous Irish Sea till. As inferred by earlier workers, the surface of this ice-sheet must have sloped down towards the south-east.

In contrast the meltwater channels apparently suggest the presence of a powerful ice-mass which moved towards the south-west. It has already been suggested in Chapter 5 that the Porthmelgan meltwater channel pre-dates the Dewisland Glaciation; the same is apparently true of all the other steep-sided valleys studied in association with the coastal sections. Similarly, there is some depositional evidence concerning the age of the Gwaun-Jordanston channels. Overall, there appears to be little drift in the channel system, and to date no true till has been found; but at the Jordanston channel intake calcareous shelly till has been recorded by Jehu (1904), and thick drift on Rhos-y-clegyrn moor blocks the northern end of the Maildy channel.

Most significant, however, is the record of at least 15 ft. of shelly till at Rhos Isaf, Dinas (Jehu, 1904). This till lies on the floor of the major channel draining towards Cwmonnen; it is weathered to a depth of only 24", so there is little doubt that it is a representative of the Dewisland Glaciation. The channel must pre-date the deposition of the till, and unless this till was laid down completely by ablation the possibility must be considered that the Cwmonnen channel, and possibly the other channels of the system, date from the Early Glaciation.

This evidence is inconclusive, but it appears to be supported by the orientation of the channels (Map 5). Recent work in Scandinavia and elsewhere suggests that sub-glacial drainage is "directed" more accurately by the ice-gradient than by the sub-glacial topography; consequently, in areas where the ice-sheet summit does not coincide with the pre-glacial drainage-divide, ice-directed drainage breaches this divide in the early stages of deglaciation (Sollid, 1964). If, as is indicated by erratic transport and striations, the ice-gradient at the peak of the Dewisland Glaciation sloped down towards the south-east, one would also expect ice-directed sub-glacial drainage to follow an approximate south-eastward course. Only the Panty-coch, Jordanston, and Lower Gwaun (Fishguard) channels have a marked south to south-eastward component, and most of the channels appear initially to have carried meltwaters toward the south-west. If these channels were cut beneath active ice moving towards the south-east[1], then the Gwaun channel for the lower and middle parts of its course must have carried meltwater under hydrostatic pressure in the same direction, only for this meltwater to be forced, at times, to flow towards the north-west in Nant-y-bugain and Esgyrn channels. Alternatively the Gwaun channel must have carried water directly against the ice-gradient in order to supply the Nant-y-bugail, Esgyrn, and Criney intakes. Neither possibility is attractive, for although the role of topography in directing sub-glacial drainage has been stressed (Gjessing, 1960), it generally plays a less significant part than ice-gradient (Sollid, 1961, 1964; Trømberg, 1964).

A more reasonable explanation of the orientation of the channel-system is that it was controlled by an ice-gradient sloping down towards the west or south-west; beneath such a gradient it would be quite possible for most

---

1. Derbyshire (1961) considers that active ice has to be present at depth in order to control the lower level of sub-glacial meltwater erosion in ice-sheets; similarly channels cut across cols in the Cairngorm Mountains appear to have been directed by active ice (D.E. Sugden, personal communication).

of the channels to be cut and used contemporaneously. Such an ice-gradient would account for the presence of marginal channels dipping towards the south-west on the eastern spurs of the North Pembrokeshire upland masses (Carningli and Foeldrygarn), and also for the fact that the Escalwen East channel continues into the Panty Phillip channel, rather than crossing the low spur to the south. It would also explain the north-westward orientation of the sub-marginal channel on Ty-canol spur; the channel would probably not have followed this orientation if there had been an ice-gradient towards the south-east. The dating of the channel-system to the Early Glaciation appears, therefore, to provide reasonable answers to several questions.

Possible stages of channel development. It is possible that the dating of the channels as Early Glaciation features may be afforded some support when the stages of channel development have been elucidated. In view of the presence of sub-glacial and marginal features within the channel system, it can be said with some certainty that there have been at least two stages of channel development;: namely a stage when sub-glacial meltwaters were flowing at some depth beneath the ice-surface, and a stage when meltwaters may have been flowing along the margins of downwasting ice within the channels, or even subaerially upon the channel floors.

A third stage may be discerned in the evidence of "channels within channels"; these are particularly noticeable in the Llanychaer - Criney district, where old valley floors appear to hang above the present channel walls. The Cwmonnen Channel joins the Gwaun Channel discordantly, and it has been mentioned that the Llanwern Channel is truncated at its eastern end. The humped channels at Criney Bridge are truncated by steep valley-sides. Thus there was probably a second stage of subglacial erosion prior to the phase of marginal flow.

It is difficult to determine when these stages of erosion occurred, but it is quite possible that they did not all occur within the same glaciation. The later stages of incision may have occurred within the Dewisland Glaciation, with sub-glacial meltwaters using a pre-existing channel system dating from the Early Glaciation; indeed, it is possible that some of the channel sections which are orientated N.W. - S.E. could have formed entirely during the Dewisland Glaciation.

However, as with all the ideas put forward in the course of this chapter, this must be considered a tentative suggestion only. The dating of the channels to the Early Glaciation can only be finally determined if head or organic deposits are found in situ within the walls of the channels beneath till or outwash gravels of the Dewisland Glaciation.

Conclusions.

The major suggestions which may be made on the basis of this chapter are as follows:

1. The widely-accepted glacial lake hypothesis of Charlesworth contains many inconsistencies, and is not supported by evidence in the field.
2. There appears to be much in favour of a sub-glacial origin for the major channels of the integrated Gwaun-Jordanston system.
3. Some minor erosional features in the area appear to be related to the margins of a downwasting ice-mass; this supports the depositional evidence quoted in the last chapter.
4. There have probably been at least three phases of channel formation; the two earlier phases were sub-glacial, and the most recent probably marginal.
5. The anomalous orientation of the channels may indicate that the channels were cut initially during the Early Glaciation.

PART V

Chapter 11.

The Meltwater Channels

of Dewisland.

Chapter 11.

THE MELTWATER CHANNELS OF DEWISLAND.

The deep river-channels of Dewisland have generally been considered of sub-aerial origin, owing their incised forms to pre-glacial rejuvenation (Cox, 1930; Davies, 1939; Burton, 1952). However, there are indications that these valleys may have been cut by sub-glacial meltwater during the glaciations of the area.

The distribution of deep channels is shown in Fig. 117. For the most part they are concentrated on the south coast of Dewisland, although eight deeply-cut channels run northwards and north-westwards towards Cardigan Bay in the coastal stretch between Abereiddy and Pen Caer. The larger channels are Merry Vale, the Solfach and St. Elvis valleys, and the Abereiddy and Aber-mawr valleys. They are very similar to one another in form (although of variable depth), and an examination of cross-profiles shows that they have marked differences from the only shallow valleys of the area, at Whitesands[1] and Bathesland Water (Fig. 118); the larger channels are similar in form to the meltwater channels of the Gwaun-Jordanston System, and in some cases appear to be

1. As noted earlier, Green (1911) proposed that the Whitesands Valley was cut pre-glacially by the River Alan before it was diverted into Merry Vale.

incised into older valley-floors.

The smaller valleys of the peninsula, which are again steep-sided and flat-floored, are at Porthmelgan, Porthgain, Trevine, Aber-castle, Pwllstrodur, and Aber-bach on the north coast, and at Caerbwdy and Porth-y-Rhaw on the south coast. Between Solva and Newgale there are deeply-cut "cwms"[1] on the coast at Porthmynawydd, Cwm-bach and Cwm-mawr, and dry channels at St. Justinian, Carneddgwion, Pwll Crochan, and around Morfa. There are distinct one-sided benches at Carreg-yr-afr and Penclegyr on the north coast, and the cols between Carnllidi and Carn Treliwyd appear to have been deepened by water-action.

On the north coast Barry Island and Mynydd Morfa are almost isolated from the mainland by channels, as noted by Jehu in 1904; in each case it is possible to walk from coast to coast without moving off the floors of the drift-filled channels (Fig. 119).

The Origin of the Channels.

From a careful examination of O.S. 2½" maps, it appears unlikely that the valleys have been cut by simple pre-glacial rejuvenation. No two streams appear to have had the same base-level. The Solfach and Merry Vale channels ~~axx~~ fall to well below present sea-level, and at Caerbwdy the stream,

---

1. "Cwm" is here used in its Welsh sense as a steep valley-head (Stamp, 1961).

although entering the sea accordantly, drops steeply in the lower part of its course. The smaller streams in the cwms, and in small channels such as the Trevine channel, are left "hanging" above present sea-level, to which they descend through small waterfalls. It is difficult to explain away these discordant and variable characteristics as the result of various stages of rejuvenation. Nor, it seems, can variable cliff retreat be used as an explanation, for it has been suggested earlier that since the cutting of the mouths of the major valleys of the Teifi and Afon Nevern, cliff retreat has been negligible.

Similarly, the long profiles of the streams provide no reliable indications of rejuvenation, for they flow upon drift floors in their lower (channel) sections, and on thick drift covers in wide, shallow valleys further upstream. The Solfach river (which would probably be called the example _par excellence_ of stream rejuvenation in Dewisland[1]) and the Caerbwdy stream are found upon examination to have strongly convex long-profiles which bear no evidence of knick-points. Although the possibility of rejuvenation

---

1. Burton (1952) has traced the pre-glacial development of the Solfach river, which he considered to have flowed to the sea at Caerbwdy at an early stage. He suggested that the deep channel section was cut by a vigorous consequent stream which beheaded the older stream.

cannot be ruled out on this basis (Sparks, 1960), there are other features which give the strong impression that the glaciations of Dewisland may have had considerable influence on the drainage-pattern as we see it today. Indeed, it would be unnatural if the meltwaters of the two glaciations of Pembrokeshire did not leave their imprint upon the landscape.

While the rejuvenation hypothesis is apparently hindered by a lack of favourable evidence, there is abundant evidence for large-scale meltwater erosion. The shallow channel at St. Justinian cuts across a small peninsula and has a humped long-profile; it bears no sign of ever having carried a sub-aerial stream. The same may be said of the dry channels at Pwll Crochan and around Morfa. The least tortuous explanation of these features is that they were cut by glacial meltwater; in the case of the St. Justinian channel there is good evidence in the humped long-profile that it may have been eroded sub-glacially.

The one-sided channels on the north coast are fresh in appearance, and that near Penclegyr has a hump near its western end. It is unlikely that they can be the remnants of ancient river-valleys which have had their seaward slopes removed by cliff retreat; as noted earlier, cliff retreat appears to have been negligible in this area since "pre-glacial" times, and in any case it is unlikely that pre-glacial or post-glacial streams would have flowed parallel to the contours and the coast-line. There is a strong likelihood that the features were cut marginally or sub-marginally by glacial meltwater flowing along the coast, possibly when stagnant or weakly-active ice filled the offshore coastal area, leaving the Penbiri-Carnllidi area ice-free.

The deep "cwms" of the south coast carry minute streams, and it is difficult to imagine that they have been formed entirely by headward spring-sapping. Porthmynawyd and Cwm-mawr valleys are sizeable features, the latter being 200 ft. deep and yet less than half a mile in length (Plate 48). Both Cwm-bach and Cwm-mawr have two intake points, one of which is completely dry. In view of the marked similarities of these "cwms" (and other smaller ones near Caerbwdy and Ogof Lle-sugn) to the deep sub-glacial chutes of the Gwaun Valley, a similar origin may be proposed. It is not certain, however, that they were cut by meltwater entering dead ice from streams on the deglaciated coastal platform; although there are slight traces of old melt-water courses inland from the "cwm" heads they do not appear to be extensive enough to have carried the large amounts of water needed for the cutting of the channels.

Therefore they may have been cut at the point where either the wasting ice-surface or a sub-glacial meltwater stream crossed the old coastal cliffs during deglaciation.

It has been suggested in Chapter 5 that Porthmelgan and Aber-mawr channels were cut by glacial meltwater, and field evidence indicates that the other large channels of the area may have been cut in a similar way. In the Solfach valley (Plate 49), there are deeply-cut intake points at Carn-y-fran and two spectacular chutes at Llain-gamma. Near Middle Mill there are dry scallops on the hillside above the channel, and a small rock knob lies on the valley floor at the point where the tributary stream from New England enters the channel. A deep chute at Trecadwgan is not graded properly to the floor of the channel; instead it appears to enter the valley at the same height as a series of rock steps on the eastern valley-side (Plate 49B). Using the same criteria as in the section on the Gwaun-Jordanston channels, it seems likely that the Solfach channel and its neighbour to the east of the Gribin were cut by sub-glacial meltwater. There have probably been at least four stages in the valley's development:

1. Normal river-valley, perhaps graded to a sea-level above present O.D.

2. Initial sub-glacial cutting of the channel. The floor of this stage is represented by the rock benches.
3. Further downcutting to present level (by later glacial meltwaters?)
4. Present-day modification of the channel by the Solfach river.

The first two of these stages are clearly illustrated in the cross-profile in Fig. 118, while the second two stages become apparent upon field examination of the valley.

Perhaps the most convincing evidence for the sub-glacial origin of these channels may be seen in Merry Vale at the point where the road from St. David's enters the channel. Here a massive rock knob constituting an old valley-spur supports a complex arcuate channel which has two outlets (Plate 50). The long profile of the channel is humped, and its intake and outlet points hang up to 25 ft. above the present valley floor. The channel has a maximum depth of c. 20 ft. From its characteristics this channel (and very probably Merry Vale itself) appears to have been cut by sub-glacial meltwater in several stages.[1]

---

1. Green (1911), having noted the steep-sided nature of Merry Vale channel, proposed that it was cut by glacial meltwaters over-flowing from an ice-dammed lake to the north of St. David's.

While the possibility must not be dismissed that some of the deep channels in the area owe their form to pre-glacial rejuvenation, there appears to be abundant evidence that the major channels have been used, and probably cut, by sub-glacial meltwaters.

Channel Orientation.

An interesting correlation between the Dewisland channels and those of the Gwaun-Jordanston system can be made when the distribution and orientation of the channels is considered in some detail. In the analysis of Porth-melgan channel it was noted that its orientation is difficult to reconcile with an ice-gradient falling towards the south-east (as was apparently the case during the Dewisland Glaciation), and similar problems arise with most of the other channels of Dewisland. From Fig. 117 it will be seen that the channels have a strong westerly component in their orientation; in general, the channels of the south coast appear to have carried meltwater towards the south-west, and those of the north coast towards the north-west. This divergent pattern is difficult to explain as the product of one glaciation, for beneath a large ice-sheet, ice-directed drainage should display a reasonably consistent orientation (Sollid, 1964).

It is probable that some of the features of the pattern are the result of geological and topographical control. For example, the Porthmelgan channel is cut along the outcrop of Arenig shales between the basic intrusions of Carnllidi and St. David's Head, while the Abereiddy channel is cut through Upper Ordovician shales and bounded by igneous masses. Of the streams flowing to the south coast, the middle section of the Solfach Valley between Rhosgranog Uchaf and Carn-y-fran is cut along a faulted zone, for the most part coinciding with the outcrop of Lower and Middle Cambrian rocks (Cox, 1930). Again, the deepest channel section of Merry Vale is possibly related to a fault system (Green, 1911), although recent field mapping suggests that its lower course is cut perpendicularly across all the zones of weakness in the area (R. Leake, personal communication). Also, the Trevine, Pwllstrodur, and Aber-bach channels may owe the strong westerly component in their orientation to the influence of geology and structure.

On the other hand the Caerbwdy channel appears to be unrelated to structural weaknesses, as does the lower section of the Solfach channel, which is cut apparently at random through a series of basic igneous intrusions (Cox, 1930). Similarly the two Porthgain channels and the Aber-castle and Aber-mawr channels have been cut almost perpendicularly across the strike of the Ordovician rocks of the area. It appears, therefore, that while the orientation of channels has been influenced by bedrock structure in many localities, some channels appear to owe their orientation to other factors.

The major influences upon channel orientation were probably the "pre-glacial" surface topography, and the slope of the ice-sheet surface. Of these, the latter factor is held to be the most important for deep channels cut by ice-directed drainage beneath active ice (Sollid, 1961). And yet the divergent pattern of channels in Dewisland remains an anomaly, which can perhaps be explained by resort to one of four tentative hypotheses:

(a) If the channel gradients and orientations accurately reflect the direction of meltwater flow beneath an ice-cap, then the surface contours of the ice-cap must have been approximately as shown in Fig. 117. However, the depth of the larger channels is comparable to those of the Gwaun - Jordanston system, and suggests the presence of a large ice-sheet which must have had its source well beyond the shores of Pembrokeshire; an ice-sheet "spur" over Pembrokeshire would be improbable under these conditions, even though such a feature was suggested by Carvill Lewis in 1903!

(b) If all the channels are contemporaneous, they were perhaps cut beneath an ice-sheet with a surface gradient falling approximately south-westwards. The orientation of the south coast channels suggests that they carried ice-directed meltwaters approximately towards the south-west, i.e. in the same direction as the major channels of the Gwaun - Jordanston system. Some evidence therefore appears to support the suggestion made in the last chapter that the ice-gradient during the Early Glaciation sloped down towards the south-west.

And yet when the north coast evidence is considered major difficulties are encountered, for the channels between Abereiddy and Aber-mawr run northwards, northwestwards, and westwards (Fig. 119). It is possible that these channels were cut by meltwater flowing uphill along pre-existing river-valleys from the low ground in Cardigan Bay onto the Dewisland platform surfaces. Prolonged uphill flow at least from present sea-level to c. 200 ft. O.D. is theoretically possible if the meltwater is subject to sufficient hydrostatic pressure. Many of the tunnel-valleys of Denmark must have been cut by meltwater flowing uphill from the Baltic Basin (Schou, 1949), and the process has been amply demonstrated from present-day glaciers (Okko, 1955; Thorarinsson, 1939).

However, if the channels around Mynydd Morfa and Barry Island were cut contemporaneously by water flowing uphill, then the southern ends of the channels in Fig. 119 must have been areas of convergence; if hydrostatic pressure had been maintained in this area, a great concentration of meltwater would have been expected to cut even deeper channels to the south. There are no traces of such channels to the south of the "island" systems, so it is possible that at an altitude of c. 150 ft. O.D. hydrostatic pressure dropped abruptly, perhaps as the streams emerged from the ice-front or flowed into less coherent ice.

(c) The channels may have been cut at several different stages of one glaciation, or during different glaciations. It is possible that the east-west channels of the pattern (notably the Abereiddy, Pwllstrodur, and Aber-bach channels) may have been cut beneath an ice-gradient falling towards the west, while the Aber-mawr and Porth-gain channels were cut at a different time beneath an ice-gradient falling towards the south. A difficulty in this interpretation is that none of the channels in the system are demonstrably of younger age than the others; if there have been two phases of cutting then some of the channel floors should be truncated, as has been noted at several localities in the Gwaun-Jordanston system. Perhaps future work will reveal that such truncations do exist beneath drift covers.

(d) The possibility must be considered that some of the channels which are devoid of the suggested diagnostic features of sub-glacial channels may be original sub-aerial valleys, or else old valleys which have been deepened sub-aerially by melt-waters flowing from dead-ice masses in Dewisland and the Fishguard area.

While there are undoubted difficulties in interpreting the channels of Dewisland as sub-glacial features, there are far greater difficulties to be overcome if they are accepted as sub-aerial valleys of rejuvenation. The channels on the north coast are very difficult to interpret, and until further work has been done on the characteristics of these channels, and the mechanics of sub-glacial meltwater erosion in particular, it will be as well at the moment to keep an open mind concerning their mode of formation. While the attempted explanations on the foregoing pages may appear tortuous in the extreme, they may at least serve some use as working hypotheses during future investigations.

The age of the Channels.

Finally, a brief examination may be made of the hypothesis that most of the channels of West Wales were cut during the Last Glaciation (Charlesworth, 1929; Bowen, 1964).

Fortunately, in Dewisland the meltwater channels are terminated by the present coast-line, so that there is ample opportunity to examine the drifts on the channel floors. In Part III of the thesis, head beneath till was described in the channels at Porth-melgan, Caerbwdy, Abermawr, and Cwm-mawr; there is also head beneath soliflucted till at Porthmynawyd and Trevine, and there is a good thickness of undisturbed till on the floor of the Abereiddy channel. As suggested earlier, there must have been a prolonged period of sub-aerial solifluxion between the cutting of the channels and the deposition of the till. At Druidston and Cwm-mawr there is some evidence that raised beach gravels lie on the rock floors of channels at their seaward ends; while this evidence needs confirmation it may indicate that some of the channels, at least, were cut prior to the Poppit Interglacial period of high sea-level.

The till in all the channels appears to have been deposited during the Dewisland Glaciation, while the raised beach gravels were deposited somewhat earlier. Thus there appears to be abundant evidence that the meltwater channels of Dewisland were cut, at the latest, during the Early Glaciation. If, as seems likely, the channels of the Gwaun-Jordanston system are no younger than those of Dewisland, then the views of Bowen and Gregory (1965) concerning the age of the channels must be open to doubt.

<u>Conclusions to Part V.</u>

1. The most important fact to emerge from the study of meltwater channels in North Pembrokeshire is that most of them appear to have been cut by sub-glacial meltwaters rather than by glacial lake overflows. In Dewisland and the Gwaun-Jordanston area several anomalous features have been encountered in association with the channels; these features are perhaps best explained by postulating several stages of channel formation.

2. While the evidence of channel orientation is not conclusive, it nevertheless suggests that most of the sub-glacial erosion was achieved beneath an ice-sheet sloping down towards the south-west. It has been indicated in the foregoing pages that no evidence has been found which conflicts with this idea on a regional scale, although as yet it is not supported by evidence of erratic indicators.

The small channel-systems at Barry Island, Mynydd Morfa and Drim are anomalous, and deserve much closer investigation than I have been able to undertake.

3. The channels appear to have been cut almost entirely during the Early Glaciation or glaciations. This is suggested by the presence of head deposits beneath till of the Dewisland Glaciation on the floors of some channels. The ice of the Dewisland glaciation, as suggested earlier in the thesis, appears to have moved onshore from the north and north-west, in a direction which does not satisfactorily explain the orientation of the meltwater channels. While the marginal benches on the north coast and smaller features such as the St. Justinian Channel may date from the Dewisland Glaciation, the meltwaters of this ice-sheet did little more than clean out accumulated head and till deposits from older channels.

PART VI.

THE PLEISTOCENE EVENTS OF PEMBROKESHIRE IN A WIDER CONTEXT.

Now that the various lines of evidence concerning the Pleistocene events of Pembrokeshire have been examined, Chapter 12 is devoted to a brief resumé of the discernible Pleistocene history.

In Chapter 13 some attempt is made to establish whether the drift stratigraphy and sequence of events suggested for North Pembrokeshire may with confidence be applied to other areas around the Irish Sea and Bristol Channel. The drift successions of certain areas, as far as they are known, are taken largely from the literature, and are correlated on purely stratigraphic principles. No reference is made to any scheme of absolute chronology, although an attempt is made to establish the relative ages of the drifts discussed.

Pleistocene sea-level movements in Western Britain have apparently received little attention from geomorphologists. Earlier in the thesis a scheme of sea-levels was proposed for Pembrokeshire; in Chapter 14 this scheme is considered in the context of evidence from elsewhere, and in the light of some recent views on the topic.

Chapter 12.

Glaciation and Deglaciation

Chapter 12.

GLACIATION AND DEGLACIATION.

In the foregoing chapters the major glacial drifts and topographic features of North Pembrokeshire have been examined; at this point, before attempting correlations with other areas around the Irish Sea, it will be worth summarising briefly the evidence presented for the sequence of glaciation and deglaciation in the area studied in detail.

The earliest event represented in the sections was a prolonged phase of warm interglacial or pre-glacial climate which rotted the bedrock at West Angle and possibly Druidston. Perhaps in part contemporaneously and in part later, there was a long period of sub-aerial valley erosion, in which the mature drainage basins of the Afon Nevern, the Teifi, and the Daucleddau were eroded. Sea-level at this time appears to have been relatively low, for the rock floors of all the large valleys are graded to a sea-level well below present O.D. The coastline at this period must have been some distance seaward of the present coast.

After this long phase sea-level appears to have risen to near its present level, perhaps during several large-scale oscillations. The lower parts of the old valleys were drowned, and the approximate outlines of the present coast were established. Cliffs were cut within the walls of the drowned river-valleys, and high cliffs established even in the resistant igneous rocks of the North Pembrokeshire coast. Again, this phase appears to have been prolonged. After an unknown length of time had elapsed, sea-level rose above present O.D. and perhaps oscillated through a range of at least 50 ft.; during stillstands platforms were cut at many altitudes between 3 and 50 ft. O.D.

The next event to occur was the Early Glaciation, for which records are unfortunately scanty. However, it does seem that it was a glaciation of some strength, for it entirely removed any pre-existing periglacial or beach deposits from coastal localities. During the wastage of the ice of the Early Glaciation all the major melt-water channels of North Pembrokeshire were cut, and the presence of channels in the Prescelly Mountains indicates that the ice may have been several thousand feet thick at the maximum. The orientation of the channels apparently indicates that during this glaciation the ice-gradient sloped from north-east towards south-west; Welsh ice may therefore have been dominant, with the effects of Irish Sea ice reduced to negligible proportions. At this time it is reasonable to suggest that sea-level was low.

The Poppit Interglacial, which followed the Early Glaciation, appears to have been prolonged, for in the coastal areas it removed completely any till which may have remained after the glaciation. There was a complex series of sea-level movements; at West Angle there are fine silts and clays which possibly record an early transgression, while storm-beach deposits and gravelly beaches accumulated at altitudes up to 30 ft. O.D. However, no single stillstand appears to have been prolonged, for no demonstrably fresh raised beach platforms were cut. In the early part of the interglacial there may have been at least one phase of solifluxion, and there was certainly solifluxion with the deterioration of climate which marked the approach of the Dewisland Glaciation.

During the early phase of the Dewisland glacial period there was no land-ice in the coastal areas of North Pembrokeshire. Sea-level appears to have been low, and under moderately severe periglacial climatic conditions steep slopes were mantled with thick head deposits. The head incorporated pre-existing beach deposits, river gravels, and till wherever these were available. At least one warmer phase interrupted the solifluxion process, and a weathering horizon developed at Aber-mawr; however, sea-level remained low, and it is possible that the offshore forest which was later destroyed by ice-action established itself far out in Aber-mawr Bay at this time. After this slight amelioration periglacial conditions returned, and solifluxion was rapid for a while. However, the climate became increasingly cold and arid, and head deposits assumed the characteristics of flaky gravels at Aber-mawr. At the peak of this period of maximum cold there may have been corrie-glaciation in the Prescelly Mountains and a sizeable ice-cap over Central Wales; local Welsh ice reached the coast as far west as New Quay, but there are no traces of this glaciation in the Teifi Estuary.

Again there was a climatic amelioration, but this time the climate did not become warm enough for weathering. Instead there was a renewed phase of solifluxion under a moderately cold and moist periglacial climatic regime. This phase was prolonged enough for the re-deposition of the local glacial deposits at New Quay, and caused the accumulation of blocky heads further west.

During Phase II of the Dewisland Glaciation Irish Sea ice over-rode the whole of Western Pembrokeshire and extended at least as far south as West Angle. The glaciation does not appear to have been a powerful one, however, for it achieved little destruction of existing deposits, and meltwaters achieved only limited erosion within the Gwaun-Jordanston channel-system. Irish Sea tills were deposited in coastal localities and perhaps in inland depressions, and local tills laid down where the ice moved off the land. Upon ice-wastage dead-ice masses remained longest in inland depressions and deep valleys, and large expanses of ice-contact outwash gravels were deposited in the Fishguard area. Considerable meltwater streams utilised the old meltwater channels of North Pembrokeshire, in some cases sweeping them clear of existing deposits and in other cases laying down extensive valley sandurs.

Following deglaciation there was renewed solifluxion for a while, leading to the accumulation of thin bedrock heads and rather thicker rubble-drifts where fluvio-glacial and glacial deposits were available. The periglacial climate during this phase appears to have been only moderately severe, and it was interrupted by at least one short phase of weathering. Towards the close of the periglacial phase wind-action may have been powerful, and sandy loams were deposited over most of the land-surface. Offshore forests became established and later drowned as the climate became warmer and sea-level rose to its present level.

The reliability of this sequence of events may be questioned, for it is based largely on what remains of the stratigraphic record; in spite of evidence for the weakness of the Dewisland Glaciation, it is not known just how much of the record was removed by ice. While bearing in mind that parts of this brief history of glaciation and deglaciation may have to be revised, it may serve as a useful basis for an examination of the stratigraphy of other drifts around the Irish Sea; it will be interesting to see how typical this tentative history is of a wider area.

PART VI

Chapter 13.

Correlations with other regions around the Irish Sea.

1. South-East Ireland
2. The Lleyn Peninsula
3. The Gower Peninsula
4. The North Coast of Cornwall and Devon.

Summary and Conclusions

Chapter 13.

CORRELATIONS WITH OTHER REGIONS AROUND THE IRISH SEA.

In this chapter brief correlations of the drift sequence in Pembrokeshire are made with related areas around St. George's Channel (Fig. 120). These areas are:

1. South-East Ireland.
2. Lleyn Peninsula.
3. Gower Peninsula.
4. The North coast of Cornwall and Devon.

It is emphasised that the correlations are based entirely on published literature, although I have been able to visit South-East Ireland, Gower and North Devon briefly. Where there is a major disagreement concerning the drift stratigraphy of an area, some discussion is undertaken; otherwise the conclusions of recent authors are accepted. No chronological correlations are made at this point, in view of the dangers involved. Neither is any discussion of interglacial sites undertaken, for such sites are seldom represented in coastal sections, and they are best mentioned in the final chapter, on Pleistocene chronology.

The task of correlating the drifts has been greatly simplified by the work of G.F. Mitchell, F.M. Synge, and N. Stephens, who have already correlated many of the sections around the Irish Sea; much of this chapter is based upon their conclusions.

1. SOUTH-EAST IRELAND.

(a) Rock Platform.

On the coast of South-East Ireland[1] the earliest feature closely associated with the Pleistocene drifts is the rock platform described by Wright and Muff (1904). Its altitude is generally between 14 and 25 ft. I.O.D.[2] although altitudes of 30 ft. I.O.D. are recorded. Platform remnants are generally highest on the headlands (.e.g. at Ardmore Point and Clogga Head) and lowest in bay-heads; there does not appear to be any appreciable tilt in the level of the platform. The platform may be up to 300 ft. in width (Stephens, 1957), but it is masked by overlying drifts along much of the coast of Eastern Ireland. Where it does outcrop it is seen as a well-planed surface developed across a variety of rock-types. The platform has been widely accepted as a marine-cut feature of great antiquity; it has been termed "pre-glacial" by Wright and Muff (1904), but Mitchell and other authors have considered it of interglacial age. It has been named the 'Courtmacsherry shore-platform' by Mitchell (1960), after one of the type-localities of Wright and Muff on the south coast of Ireland (Fig. 121).

---

1. For convenience, defined as the area on the Ordnance Survey of Ireland 1:250,000 sheet (2nd edition), No. 4. (Ireland-South-east).

2. Irish Ordnance Datum; this datum is c. 8 ft. below English O.D.

(b) Erratics.

Erratic pebbles derived from inland outcrops are found on the rock platform in places and incorporated in overlying deposits. The erratics are of limited size, and apparently include no Scottish rocks (Synge, 1961); in any case foreign erratics are not known from beach deposits west of Courtmacsherry (Mitchell, 1960). The erratics were considered to have been introduced by ice-floes by Wright and Muff, although Mitchell (1960) feels that they are the remnants of destroyed glacial deposits. He has termed the erratics the "Courtmacsherry erratics".

(c) Raised beach.

Resting upon the rock platform in many localities is a deposit of beach gravel. The pebbles on the beach are generally local, but in places erratics are incorporated. No shells have been found in the beach deposits (Synge and Stephens, 1960). In places beach sands are incorporated (Watts, 1959), and possible blown sands overlie the beach at Wood Village. At Howe's Strand in Courtmacsherry Bay sandrock and beach pebbles are seen upon a channelled rock platform, while at Garryvoe and Ballycotton Bay raised beach remnants are occasionally seen cemented to the platform (Fig. 122). Further good exposures of the raised beach may be seen at Wood Village (where it is cemented by iron and manganese oxides, as at Poppit), and at Kilmore Quay (where it is occasionally cryoturbated). It is possible that head lies beneath beach pebbles at Wood Village and Cahore Point; however, it is difficult to establish whether the deposits are in situ, so it may not be safe to assume that a periglacial phase intervened between the cutting of the platform and the deposition of the beach.

The intermittent distribution of the beach deposits is attributed by Mitchell (1960) to destruction by wave-action as sea-level fell following a transgression which submerged the beach. The beach is named by Mitchell the "Courtmacsherry Beach".

(d) Solifluxion Deposits.

Above the beach in many localities is a suite of head deposits up to 30 ft. thick (Synge, 1961). In places the head is interbedded with beach deposits (as at Howe's Strand), and it appears to have formed shortly after the deposition of the beach. The head is of variable composition, and interbedded flaky and blocky heads can be seen at Garryvoe, where some exposures of cryoturbated head can also be seen (Fig. 122). It is possible that a green clay-like deposit at Nemestown, Kilmore Quay, is a severely weathered and gleyed solifluxion deposit associated with the lower "main" head.

(e) Lowest (Enniskerry-Clogga) Till.

The oldest till deposit in South-East Ireland appears to be the Cloggs till (Fig. 123) which was deposited by an ice-sheet flowing towards the Irish Sea from the west (Farrington, 1954). This ice-sheet probably had its source in the Wicklow Hills and Leinster Mountains, for its drifts are only found between Dublin and Cahore Point (Synge, 1964b), and granites and schists from the mountain chain are the major erratic constituents (Martin, 1955). This till is thought to be the equivalent of the Enniskerry granite drift in the Wicklow Mountains described by Farrington in 1944.

According to Synge (1964b) the Clogga till is not seen to overlie interglacial beach gravels; on the contrary, he considers that beach deposits lie above the till, mentioning as evidence a bed of rounded pebbles with head above a thin Clogga till at Cahore Point, and a thin gravel horizon between Clogga till and overlying deposits at Seabank Point. Stratigraphically, therefore, the Clogga till should perhaps be placed beneath the raised beach gravels. However, the "Clogga till" at Cahore Point is not entirely convincing, and the gravel horizon at Seabank Point may be outwash;

for the moment it may be best to accept the suggestion of Farrington (1957) that the Enniskerry-Clogga Glaciation was but an early local phase of the succeeding Eastern General Glaciation.

(f) Eastern General Tills.

At Seabank Point, the Clogga till is clearly seen to underlie a calcareous and relatively stoneless chocolate-coloured Irish Sea till. This till is found as an extensive sheet along the east coast of Ireland south of Wicklow Head, and was named the "Eastern General Till" by Farrington (1944). Between Wicklow Head and Kilmore the till is found at the surface, but further north it is overlain by later drifts (Fig. 123). The calcareous till is again seen on the coast between Dungarvan and Power Head, and in Ballycotton Bay is an excellent section which shows that it is overlain by later glacial deposits. In the east of County Wexford the Irish Sea till gives rise to heavy gleyed surface soils with a typical "Macamore" profile (Gardiner and Ryan, 1964); gleying and decalcification of the till is seen to extend to a depth of c. 10 ft. in places. The till is termed the "Ballycroneen till" by Mitchell (1960).

(g) Sands and Gravels.

Synge (1964) has emphasised that the Eastern General till contains masses of shelly sands and gravels, and there are further outwash deposits above the till. At Garryvoe, the sands and gravels are related to the Eastern General till, and are overlain by a local till (Farrington, 1954). Similarly Cole and Hallissy (1914) have recorded the position of the "Wexford manurial gravels" as lying between a calcareous Irish Sea till and a stony loam; Mitchell (1962) considers this stony deposit to be another local till.

(h) Bannow-Brittas Local Tills.

The local tills which overlie Eastern General till and outwash gravels are the cause of some disagreement.

In the Leinster Mountains Farrington (1942; 1944) has recognised a local gravel deposit overlying Eastern General till and underlying a later till; the gravels are related to a "Brittas Mountain Glaciation" which is thought to have advanced as the Eastern General ice in the Irish Sea stagnated (Fig. 123). The gravels consist largely of granite pebbles and limestone and other erratics derived from older deposits of Eastern General till, and the best exposure is at Fassaroe, between Enniskerry and Bray where a large fluvio-glacial delta is seen at an altitude of 360 ft. O.D. (Farrington, 1957).

On the south coast of Ireland other local drifts are seen to overlie Eastern General till, as at Kilmore Quay and Garryvoe (Fig. 122). However, it is not certain whether these drifts represent a later glaciation or simply a western ice-stream from the Irish Lowlands which was contemporaneous with that of the Irish Sea. The ice which deposited the local till on the coast between Kilmore Quay and Dungarvan is related by Mitchell (1957) to a "Munster General Glaciation"; the ice of this glaciation is considered to have been most effective upon the decline of the Irish Sea ice, when it was able to over-ride Eastern General till deposits. Munster General ice extended to the south coast of Wexford at the time of the Brittas advance, while ice from an independent Cork-Kerry ice-cap in the west pushed eastwards at least as far as Youghal Bay (Farrington, 1954). This glaciation from the west was termed the "Garryvoe Mountain Glaciation" by Mitchell (1960).

An alternative interpretation of the sandy till of southern Ireland is given by Synge (1964b), who calls it the "Bannow till"; he considers that it is no younger than the Eastern General till, having been deposited by a contemporaneous inland ice-stream. He states that it is misleading to correlate the Bannow till with the Brittas till, for the latter was deposited some time later, and was restricted to the immediate vicinity of the Wicklow Hills.

Thus there appears to be some disagreement concerning the relationships of the southern Ireland drifts, although all authors agree that the whole suite of Eastern General till, sands and gravels and local till belong to the same glaciation. On the basis of the sections at Garryvoe and elsewhere the following stratigraphic succession seems reasonable:

Local till (Bannow-Brittas)	)	
Outwash sands and gravels	)	phases of Eastern
Eastern General Till	)	General Glaciation.
Enniskerry-Clogga Till)	)	

(i) Midland General Till.

The deposits of this glaciation are less extensive than those of the Eastern General Glaciation and are bounded by an end-moraine complex which passes from Tipperary to the northern end of the Wicklow Hills and thence offshore at Wicklow Head (Fig. 124). The ice is thought to have crossed the coast again from the Irish Sea to the north of Wexford

(Synge and Stephens, 1960). The glaciation is thought to have originated entirely within the shores of Ireland, although its ice-streams may have been influenced by Irish Sea ice to the east. The drifts of the Midland General Glaciation are generally sandy and stony, with a high proportion of limestone pebbles; the matrix is lighter in colour than that of the Eastern General till, and is devoid of shells, except where older Irish Sea drifts have been over-ridden (Farrington, 1949). The drifts usually display a hummocky topography and within the end-moraine lies a complex of drumlins, eskers and kames (Fig. 124).

Before this ice-sheet attained its maximum extension there may have been a long phase of solifluxion, for upper head and cryoturbation features are found above Eastern General till mainly to the south of the Midland General limit. Stone-polygons in Mayo and Cork are thought to date from this early period of the Midland General Glaciation. (Synge and Stephens, 1960).

As in the Eastern General Glaciation, a local mountain glaciation preceded the arrival of the general ice; this glaciation has been traced to the Leinster mountains by Farrington (1942; 1944), who has named it the "Athdown Mountain Glaciation". This glaciation had a final short period of expansion during the stagnation of the Midland General ice-sheet, and left moraines and outwash gravels in the main valleys of the mountains (Farrington, 1949). The complete sequence of deposits related to the Midland General Glaciation appears to be as follows:

Outwash gravels and sands.	Phases of Midland General Glaciation.
Athdown Mountain drift.	
Midland General till.	
Earlier Athdown Mountain drift.	
Upper Head.	

On parts of the east coast, where Brittas till does not occur, Midland General till is seen to be separated from the underlying Eastern General till by outwash sands and gravels. The Shankhill cliff, near Dublin, may be cited as an example. In other places, as at Bottle Quay, Sutton (Stephens and Synge, 1958), Midland General till lies directly upon the surface of the Eastern General till.

(j) Sandy loams.

Capping many drift-cliffs of south-east Ireland, and also found inland above fluvio-glacial deposits, is a deposit of dark sandy loam associated with head fragments and the recent soil horizon. In various localities it may represent windblown fines (as above the Ballyduff esker,

Table XIX. A Tentative Drift Stratigraphy for South-East Ireland (based upon Synge and Mitchell)

(k)	Sandy loams	Solifluxion earth (Mitchell)	
(j)	Outwash sands and gravels		
(i)	Athdown Mountain drift Midland General till Early Athdown Mountain drift Upper Head	Tipperary-Athdown Moraines(Mitchell)	
(h)	Bannow-Brittas Local Tills	Garryvoe Mt. Glac. Munster General Glac.	Mitchell
(g)	Sands and Gravels.	Wexford Outwash Gravel (Mitchell)	
(f)	Eastern General and Bannow tills	Ballycroneen Till Munster General Glac.	(Mitchell)
	(Raised beach ?)	(Synge)	
(e)	Enniskerry - Clogga till		
(d)	Lower Head		
(c)	Blown Sands Raised Beach	Courtmacsherry Beach (Mitchell)	
(b)	Erratics	Courtmacsherry Erratics (Mitchell)	
(a)	Rock platform	Courtmacsherry Shore-platform (Mitchell)	

Tullamore), hillwash, or weathered drift. It is described in detail by Stephens and Synge (1958) from Sutton.

Thus it may be seen that the Pleistocene stratigraphy of the coast of South-East Ireland is complex and by no means adequately disciphered. Drift correlations are difficult even within this coastal area, for there may be some difference in drift stratigraphy between upland and coastal areas and areas to the north and south of the Midland General end-moraine. However, correlations have been attempted by Mitchell (1960) and by Synge (1963), and it is largely upon these tables that the tentative reconstruction in Table XIX is based.

2. THE LLEYN PENINSULA.

(a) Rock platform.

The ancient rock platform of the Lleyn Peninsula was mentioned by Jehu (1909) and Matley (1936), and was examined in detail by Whittow (1960). On the western coast of the Peninsula between Nevin and Bardsey Island a rock platform occurs at an altitude of c. 20 - 25 ft. O.D. In many localities it is cut across steeply-dipping and contorted strata, but its width is masked in most cases by a thick drift cover. In places old sea-stacks are preserved on the platform, as at Ynys Gwylan and Aberdaron, and Porth Dinlleyn (Whittow, 1960). As in south-east Ireland, the platform rises in altitude on the headlands. The platform is called "the Pre-drift raised beach platform" by Whittow, and was probably cut at a time of interglacial or pre-glacial high sea-level.

(b) Raised Beach.

Jehu (1909) suggested that there are raised beach deposits in Porth Oer, although Whittow (1960) found no trace of these deposits. Synge (1964a) has described "ferruginous, bedded sands and gravels resting on rounded beach material" above a possible rock platform at Penrhyn Bodeilas, and on the north side of Porth Oer sandrock ~~at~~ and local beach gravels again occur on a rock platform (Fig. 125). Synge considers that these deposits underlie head or glacial drifts, so they appear to be the stratigraphic equivalents of the raised beach gravels of south-east Ireland.

(c) Head deposits.

At several sections in Lleyn lower head deposits have been described by Synge (1964a). At Penrhyn Bodeilas and Porth Oer heads of angular stones overlie raised beach deposits and underlie Irish Sea till; at the former locality angular granite boulders are set in a matrix of laminated clay. Other exposures of blocky head beneath Irish Sea till occur at Porth Simdde and Llech Lydan. The thickest lower head deposit described by Synge is at Porth Neigwl, where it is up to 25 ft. thick. At its base the head is made up of angular blocks, while above are fine-bedded materials; a similar succession of head deposits has been noted at Aber-mawr and at Garryvoe in Southern Ireland. Synge does not record the presence of erratics in this head; however, it must represent a prolonged periglacial phase later than the formation of the raised beach and prior to the deposition of the Irish Sea till.

(d) Soliflucted till.

At two localities Synge has described a ~~strong~~ stony non-calcareous till which appears to have been soliflucted. In each case the deposit appears to underlie Irish Sea till. At Llech Lydan the drift is rather sandy, and has clear bedding downslope; at Porth Neigwl is a till-like deposit of striated stones in a matrix of non-calcareous clay. Downslope bedding is visible, and individual stones have a preferred orientation downslope. Both deposits appear to represent old tills which have been soliflucted sub-aerially prior to the deposition of the Irish Sea till, and their characteristics invite correlation with the Lower Rubble-drift at New Quay West. Synge is inclined to interpret these deposits as the representatives of an early local glaciation of unknown extent.

(e) Gravelly Drift.

At Porth Oer and Penrhyn Bodeilas a variable deposit of gravelly drift lies beneath the Irish Sea till; at the former locality gravelly drift, with a matrix of purple clay, and bedded silts and gravels are seen, while at the latter locality there appear to be horizontal beds of sand and gravel beneath the calcareous till.

The relationship of these patches of drift to the overlying till is not certain, and Synge does not commit himself on the question of whether they are glacial outwash or interglacial deposits. From his correlation, it seems that he considers the patches to be related to an early Welsh Glaciation. Whatever their origin, they may correlate with the sandy-gravelly lenses beneath Irish Sea till at Poppit West (see Chapter 6).

(f) Calcareous Irish Sea till.

As in south-east Ireland, this till appears to be the most common deposit in the coastal sections. It is seen at Dinas Dinlleu, near Clynnog Fawr, and at Trevor and Llech Lydan beneath thick overlying drifts. At Penrhyn Bodeilas and Porth Oer the till is represented at the top of coastal sections, and it is exposed elsewhere on the south-west coast of Lleyn beneath a variety of outwash and head deposits (Synge, 1964a). The till is generally highly-calcareous, relatively stoneless, and purple in colour. It contains shell fragments, and at Porth Simdde contains interbedded sands and gravels. At Porth Colmon a calcareous till exposure is described where the upper section is a stony facies with local stones, the middle section is a band of gravel, and the lower section is a less stony purple till; these changes of facies may be similar to those seen at Druidston and New Quay.

The till, the "Lower Boulder-clay" of Jehu (1904), is thought to have been deposited by an Irish Sea ice-sheet which moved along the Lleyn Peninsula towards the south-west (Synge, 1964a). This interpretation is supported by striations, although Smith and George (1948) and Charlesworth (1957) have shown ice-movement towards the south and south-east.

The ice may have coalesced with Welsh ice on the south coast of the Peninsula (Fig. 125) for at Porth Neigwl the calcareous till appears to pass laterally into a stony local till. A similar local till is seen at Criccieth. Synge (1964a) considers that the maximum extension of the Welsh ice occurred prior to the main Irish Sea Glaciation.

(g) Later Welsh Till.

At Llech Lydan a gravelly drift with local stones overlies the Irish Sea till. Synge has related this drift to a late readvance of local Welsh ice which was less extensive than the earlier advance. The evidence for this hypothesis appears rather scanty, however, and Matley (1936) has mentioned evidence of erratic indicators and east-west striations for a late movement of Welsh ice as far west as St. Tudwal's Peninsula, implying a rather extensive glaciation. In this he differed from Jehu (1909), who had proposed that a sporadic "Upper Boulder-clay" was deposited by an ice-sheet which "followed the same course as that which produced the Lower Boulder-clay". (P. 52).

Whether or not the "Upper Boulder-clay" glaciation was of limited or widespread extent, all three authors appear to consider that it followed the main Irish Sea glaciation after but a short interval of time, without the intervention of an interglacial.

(h) Sands and Gravels.

On most of the coastal sections described by Synge, sands and gravels appear above the Irish Sea till. At Trwyn-y-Tal 16 - 20 ft. of laminated clays and silts are interbedded with sands and gravels, and rest upon coarse gravel with striated stones. Near Porth Nefyn silts and sands with shell fragments rest upon a related Irish Sea till, and at Porth Neigwl varved clay and shelly gravels rest upon the till. At Llanbedrog 50 ft. of sands, gravels, and laminated silts are seen, and extensive terraces of outwash occur inland at Traian and in the St. Tudwal's Peninsula-Pwllheli district (Matley, 1936). Laminated sands are also exposed at Llanengan, near the eastern side of Porth Neigwl. From his study of the outwash deposits of southern Lleyn, Matley proposed that they were laid down in a meltwater lake whose surface fell from 250 ft. O.D.; the major stillstand of the surface level was thought to be at 50 ft. O.D., at which altitude extensive terraces are preserved. The sands and gravels are capped by other glacial drifts in places, and from this fact emerged Jehu's (1909) interpretation of the outwash as "intermediate sands and gravels".

(i) Upper till and head.

Unlike the earlier authors, Synge has proposed that there is a major ice-limit in the Clynnog Fawr - Brynkir district (Fig. 125). This limit is thought to mark the southernmost extension of an Irish Sea ice-sheet separated in time from the earlier ice-sheet by a full interglacial. Sands and gravels, silt and slightly calcareous gravelly till at Clynnog Fawr are assigned to the late glaciation, as is a gravelly till with outwash at Dinas Dinlleu. To the south of the limit the equivalents of this late till are upper head deposits, as at Porth Neigwl, Porth Nefyn and near Trevor. The corries on Yr Eifl and scree deposits around some of the other carns of the area are also attributed to this pro-glacial phase of periglacial action.

The limit itself (which was noted as a major glacial limit by Carvill Lewis in 1903) is marked by a line of sand and gravel hummocks and other outwash features; other mounds are found to the north, but there are none to the south, where the drift cover appears denuded and the landscape is featureless except for meltwater channels and carn masses (Synge, 1964a). Against this favourable evidence it may be argued that apparently undisturbed outwash gravels occur well to the south of the limit, while at the type-locality of Clynnog Fawr, within the limit, silts and gravels are frost-heaved to a depth of seven feet; the possibility must be considered that the deposits south of the Brynkir-Clynnog Fawr moraine are no older than those to the north.

(j) Post-Glacial raised beach.

Although Synge has remarked upon the absence of a post-glacial raised beach in North Wales, such a beach was described four years earlier by Whittow (1960) from Porth Neigwl. A cemented beach conglomerate with local and erratic pebbles and marine and terrestrial mollusca was discovered c. 3 ft. A.H.W.M., and was thought to have "formed as a beach at the foot of a boulder-clay cliff in post-glacial times" (p. 37). If this deposit is the correlative of the post-glacial beach in Ireland, then it follows that it must have been deposited during a post-glacial marine transgression.

As in south-east Ireland, the precise stratigraphy of the coastal sections is open to some doubt; however in

Table XX. A Tentative Drift Stratigraphy for Lleyn

(based largely upon Synge)

(j)	Post-glacial raised beach		
(i)	Upper Till and head		
(h)	Sands and gravels		
(g)	Later Welsh till	Upper Boulder-clay (Jehu)	
(f)	Calcareous Irish Sea till	Main Irish Sea till	Lower Boulder-clay (Jehu)
		Early local till	
(e)	Gravelly drift		
(d)	Soliflucted till		
(c)	Lower Head	Fine flaky head	
		Coarse head	
(b)	Sandrock		
	Raised beach		
(a)	Rock platform	Pre-drift raised beach platform (Whittow)	

Table XX an attempt is made to summarise the stratigraphy as recorded by Synge (1964a), with slight emendations from the other workers mentioned above.

3. THE GOWER PENINSULA.

(a) "Patella" Beach Platform.

Tiddeman (1900) and George (1932) recorded rock platforms at many localities on the south coast of Gower. Generally, the platform remnants occur at altitudes of 20 - 25 ft. O.D.; they are well-planed across Carboniferous limestone and are often backed by high cliffs (Plate 51). Frequently they are covered with superficial deposits. In places the platform remnants are indistinguishable from the platform of the present beach, although some platform remnants (as in Three Cliffs Bay and Shirecombe) are somewhat above 25 ft. O.D. Baden-Powell (1927, 1928) considered that there were at least two ancient beaches in Gower, and in 1965 Bowen records no less than six shoreline traces at altitudes of 55 ft., 44 ft., 33 ft., 22 ft., 16 ft., and 5 ft. O.D. Bowen's lower shorelines are considered to have been cut during the last glacial period in the Gower; if he is correct, the Patella beach platform of George is a composite feature cut in several stages.

(b) Erratics.

George considered that the cutting of the rock platform and the deposition of the overlying Patella Beach occurred during a cold phase of high sea-level, for he considered that erratics in the beach must have been rafted onto the platform by ice-floes. Although Tiddeman (1900) recorded no erratics on the platform, George (1932) recorded up to 40% of erratic material in some of the beach deposits; among the erratics were Old Red Sandstone pebbles and abundant Coal Measures sandstones, quartz grits, conglomerates, Cretaceous flints and igneous rocks. He considered that ice must have been present to the north in order to account for these deposits, but did not propose that the ice actually over-rode Gower. Bowen (1965) considers that the erratics are derived from glacial deposits which were in the area prior to the cutting of the rock platform, while Mitchell (1960) has suggested that the erratics were introduced into the area during a glaciation which post-dated the cutting of the beach platform.

(c) Patella Beach.

The raised beach was described by Tiddeman as "a mass of well-rounded pebbles of limestone". It has many facies. In Caswell Bay a well-cemented shelly beach with rounded and angular pebbles in a sandy matrix is seen up to 30 ft. O.D. (Plate 52); on some headlands and higher platform remnants the beach takes the appearance of a storm-beach (George, 1932); and often the beach is a fine cemented shingle (Bowen, 1965). Thirteen species of marine mollusca have been recorded from the beach, although *Patella* spp. and *Littorina* spp. are most frequently found. Chatwin (in George, 1932) considered that the species have a range so wide that they could not be used for deductions concerning the climatic conditions under which the beach was deposited.

The *Neritoides* beach, which George considered to be separated from the *Patella* beach by a head deposit, is thought to be best preserved in the vicinity of Minchin Hole. Here the two beach deposits are separated by an "ossiferous breccia" which is indicative of a rather warm climatic phase "of not inconsiderable dimensions" (George, 1932, P. 300). The *Neritoides* beach was thought to have been deposited during a ~~subsidence~~ submergence immediately following the breccia phase.

There may be some reason for separating the *Neritoides* beach stratigraphically from the *Patella* beach, but Bowen (1965) has expressed doubts about George's interpretation and has interpreted the *Neritoides* sand as an aeolian deposit. Since both supposed beach deposits fall within the broad span of a "raised beach period" it may be safest for the time being to assume that they are both of approximately similar age. However, the possibility must be borne in mind that head deposition was associated in some way with the beach, for possible head fragments are found beneath beach pebbles at some localities in south-east Ireland and North Devon; George's assertion that there are two beaches which pre-date the Gower till must be borne in mind.

(d) Blown Sands.

As recognized by Tiddeman (1900), the beach is overlain by foxy-red deposits of blown sand which are firmly cemented. This sand is seen, for example, in Caswell Bay, Minchin Hole, and in localities between Heatherslade and Hunts Bay. The sand is up to 12 ft. thick, and contains a warm fauna of land mollusca which caused George (1932) to associate it closely with the *Neritoides* beach. The upper part of the sand deposit is interbedded with a cemented head of limestone blocks, and is sometimes directly overlain by till. At Heatherslade there is some evidence of frost-heaving in the sand (Bowen, 1965) and like the raised beach it sometimes contains erratic pebbles.

Ball (1960) has described a relic soil near Worm's Head in the same stratigraphic position as the blown sands. He describes it as a "bright red sandy clay loam" (P. 497) which is similar to terra rossa and related limestone soils from warmer areas. The loam, which is up to 18" thick, is thought to be an interglacial deposit indicative of a climate rather similar to that of today, but with warmer summers. Other exposures of this red loam are mentioned by Bowen (1965).

(e) Lower Head.

George (1933) recorded a head of angular limestone fragments from many localities overlying raised beach gravels and sandy loams. Occasionally this head is cemented, and Bowen (1965) has shown that it is occasionally made up of soliflucted raised beach pebbles, as at Ogof Golchfa in Dewisland. Other facies of the head consist of angular limestone blocks with derived erratics and soliflucted foxy-red sands. George (1933) did not always distinguish clearly between the head and overlying glacial deposits, and considered that, in view of the intercalation of drift and head in places, both deposits should be assigned to the glacial stage. On the other hand Bowen (1965) has assigned the head to a short periglacial stage prior to glaciation.

There is some doubt about the importance of the lower head in the Gower. Ball (1960) records thick lower head beneath till near Worm's Head, and no head above the till; similarly George records head beneath till, but not above, at Rothers Sker and Hunts Bay, while Wirtz (1953) mentions lower head beneath till, but no upper head, at Port Eynon. At the east side of Caswell Bay 4 - 6 ft. of lower head of limestone fragments is overlain by sandy till. Elsewhere, head is intercalated with till or, as at Rhossili, found both above and below till. Bowen (1965) considers that an upper head, above the local till, is the more significant periglacial deposit, but gives little evidence in support of this claim. For the moment it may be best to accept the suggestion of the officers of the Geological Survey (1907) that the lower "head" is the periglacial deposit of most widespread occurrence.

(f) Gravelly Till.

The till in the Gower Peninsula is a sandy and gravelly deposit containing Welsh erratics from the north and typical "Irish Sea" erratics. George (1933) has shown that the till is by no means a uniform deposit; at Hunts Bay alone he describes three facies of glacial drift. "Glacial breccias" consisting of angular limestone fragments with abundant erratics are contrasted with limestone-free glacial gravels and roughly-stratified loams with lenses of erratic pebbles. A glacial gravel with many erratics is described from Eastern Slade, and also from Kilboidy, Rhossili and elsewhere. Bowen (1965) has re-examined many of the exposures in the Gower, and has concluded that much of the till is soliflucted. As examples he cites the till at Rhossili, Eastern Slade, Brandy Cove and Snaple Point, and it seems that the till at these exposures may correlate with the soliflucted gravelly till with head flakes at West Dale Bay (Groom, 1956).

Strahan (1907) and George (1933) considered that the glacial drift was derived from two contemporaneous ice-streams, one of which moved southwards and south-westwards from a northernly source, and the other which moved eastwards along the Bristol Channel. Griffiths (1939) discerned two tills at Langland Bay and proposed that Irish Sea ice impinged upon the Gower coast, but Bowen (1965) prefers to assign all the drift in Gower to a Welsh Glaciation which in places incorporated older Irish Sea erratics.

Concerning the environment at the time of drift deposition, George considered that the ice was thin and patchy and glaciation intermittent; on the other hand Bowen considers that the glaciation (his "Main Welsh Glaciation") was a product of powerful Welsh ice.

(g) Upper head.

As mentioned above, the head above the glacial deposits is considered by Bowen to be the "Main Head"; above this he

Table XXI. A suggested stratigraphy for the Drift Deposits of Gower (after George and Bowen)

(h)	Sandy loam - hillwashes			
(g)	Upper Head	Upper Head	Head	Bowen
			Clays	
		Main Head	Head	
			Soliflucted till	
(f)	Gravelly till			
(e)	Lower Head (Five facies - Bowen)			
(d)	Blown sands - Interglacial soil (Ball)			
(c)	*Patella* Beach	*Neritoides* Beach		George
		Head		
		Patella Beach		
(b)	Erratics			
(a)	*Patella* Beach platform	Late Monastirian		Bowen
		Main Monastirian		

places a further, "Upper" head which is separated by a sandy clay. This clay is thought to represent a short climatic amelioration in periglacial conditions, but since it may not be widespread stratigraphically, it is perhaps best to group the soliflucted tills, the uncemented upper head, and the clays together at this point.

(h) Sandy loam.

George noted the occurrence of an upper loam up to 10 ft. thick above head and glacial deposits. It sometimes grades down into glacial deposits, indicating that there was no great interval between the deposition of the two layers. George was not inclined to propose a wind-blown origin for the loam, and it is presumably the "hill-wash" of Bowen.

As in south-east Ireland and the Lleyn Peninsula, there are differences of opinion concerning the precise stratigraphy of the Gower drifts. However, an attempt is made in Table XXI to reach a compromise between the opinions of George and Bowen.

4. THE NORTH COAST OF CORNWALL AND DEVON.

St. Erth-Hele-Ellerslie deposits.

In 1960 Mitchell suggested that some deposits of the South-West Peninsula are of Lower Pleistocene age, pre-dating the cutting of the raised beach platform. At St. Erth there are beds which contain a rich marine fauna (Kendall and Bell, 1886; Reid, 1890); they lie at an altitude of c. 100 ft. O.D. and were thought by Mitchell (1960) to represent a sea-level at c. 200 ft. O.D. At Hele, near Barnstaple, and at Ellerslie there are gravels at 185 ft. O.D. and 125 ft. O.D. respectively, which apparently represent aggradation to a high sea-level (Mitchell, 1960). These deposits are correlated with gravels at c. 150 ft. in the Scilly Isles, which are thought to have been deposited by river aggradation at a time when the islands were perhaps joined to the mainland.

In spite of the conclusions of earlier workers (e.g. Barrow, 1906) concerning the great age of these deposits, the recent discovery by Dr. Mitchell of Irish Sea till in the Scilly Isles[1] confirms a suggestion by Hinch (1918) that the Irish Sea Glacier at one time extended at least

1. Dr. Mitchell exhibited his findings at the annual field meeting of the Quaternary Field Study Group at Durham, April, 1965.

as far south as latitude 50° N; the possibility must be borne in mind that the glacier may have attained altitudes well above 200 ft. O.D. along the north coast of the peninsula, and that the gravel deposits mentioned above could be related in some way to the Pleistocene glaciations. Indeed, Stephens (1964) has related the Hele and Ellerslie deposits to the wasting phase of the ice which laid down the till at nearby Fremington. Perhaps a re-examination of the St. Erth beds will indicate that at least in the upper layers, the ancient fauna is derived, like the Crag fauna of the outwash gravels at Wexford (McMillan, 1964).

(a) Rock Platform.

Many workers have recorded rock platforms on the north coast of Devon and Cornwall. Green (1943) records a platform 5 - 10 ft. A.H.W.M. near New Quay and a higher platform c. 30 ft. A.H.W.M. on Pentire Point East. Pengelly (1867) recorded a rock platform around Barnstaple, and Arkell (1943) recorded one at 15 - 20 ft. O.D. in the Camel Estuary. Stephens (1964) has noted the presence of platforms as high as 45 ft. O.D. at Middleborough and Pencil Rock (Plate 53). The notch at the back of the platform at Middleborough is at 50 ft. O.D., while at Pencil Rock beach deposits are found up to 60 ft. O.D. The platform has been termed the "Fremington shore-platform" by Mitchell (1960), after the extensive platform beneath raised beach gravels and clay at that locality. It may be misleading, however, to assume that all the rock platforms in this area are contemporaneous. Stephens[1] considers that there may be two rock platforms at Pencil Rock, and as Messrs. Kennard and Kirkaldy (in discussion on Green, 1943) warned, the platforms span such a height range that they may be of very different ages.[2]

(b) Erratics.

The erratics which occur on the rock platform at Trebetherick Point and elsewhere were attributed by Arkell (1943) and earlier workers to rafting by ice-floes at the close of a glacial phase. Taylor (1956) has recorded many erratic boulders upon the platforms near Croyde and Saunton (Plate 54) while the best-known erratic in the South-west Peninsula is possibly the 50-ton block of garnetiferous microline gneiss at Porthleven (Flett and Hill, 1912; Mitchell, 1960). Dewey (1910) has noted that several of

---

1. In discussion at I.G.C. Symposium 57a at Exeter, 1964.

2. In South Cornwall, South Devon, and Brittany "there are two raised platforms, quite distinctly ten feet apart and separated by a prominent notch". (A.R. Orme, personal communication, 1965).

the boulders near Saunton are best matched with certain West Scottish rocks. Stephens (1964) argues that the erratics are restricted to a narrow coastal zone below 30 ft. O.D., and were probably rafted by ice-floes; Mitchell, on the other hand, considers that the erratics (which he terms the "Porthleven erratics") are derived from destroyed glacial deposits.

(c) The raised beach series.

At many localities along this coast raised beach shingle with erratics and sandrock are seen to rest upon the rock platform. The raised beach often contains fragments of *Mytilus* and *Patella*. In Bloody Basin (Saunton), c. 6 ft. of beach pebbles are seen interbedded with sandrock layers, while at Pencil Rock the beach deposits appear to be separated from the Sandrock by a blocky head. This head is occasionally seen to underlie beach deposits (Stephens, 1964).

At Trebetherick Point there is an absence of shells in the raised beach; to the north of the point the beach pebbles have the characteristics of a storm-beach, while south of the point the beach deposits are fine bedded sands and gravels (Arkell, 1943). Mitchell (1960) figures thick raised beach deposits at Fremington beneath later till, and Stephens (1964) records that the beach is disturbed to a depth of 8 ft. by cryoturbation.

The sandrock deposits at Trebetherick and Saunton (Plate 55), which attain a thickness of c. 40 ft. in places, were considered by Arkell to be concreted wind-blown sands, although the interbedding of the lower layers with raised beach may indicate that there is a lower facies of beach sand.

(d) Main Head.

A thick blocky head overlies the sandrock and raised beach platform in many localities. It consists of angular blocks of all sizes set in a sandy matrix; it generally displays good pseudo-bedding, although in places there are signs of frost-disturbance. At Saunton Down and Baggy Point the head has sludged into an "apron" around the higher ground inland, and its even upper surface appears to represent a marine erosion surface (Arber, 1960). However, Stephens (1961) has argued that there is no evidence of marine planation in North Devon since the deposition of the main head. The Main Head at Trebetherick appears not to have been deposited until the sandrock surface had been eroded and weathered, although at Saunton the lower part of the main head is clearly interbedded with the sandrock. Arkell recorded "some fairly large pebbles of quartz and other rocks as in the Boulder Gravel" (P. 145) in the Main Head at Trebetherick; it is not certain whether this statement implies the presence of erratics, as in the lower heads at Aber-mawr. Stephens has recorded no erratic pebbles from the main head in North Devon, although Carboniferous limestone fragments are recorded from its surface.

(e) Irish Sea Till.

Maw (1864) recognized a calcareous shelly Irish Sea till at Fremington and North Devon. The till overlies a variable thickness of stoneless lake clays and in 1964 another stony layer was found beneath the lacustrine deposits, suggesting that the whole expanse of c. 25 ft. of clay is part of a glacial suite. The Fremington till was said by Dewey (1948) to be at least 78 ft. thick, and is weathered to a depth of 6 - 10 ft. (Plate 56).

On the north shore of Croyde Bay, at Middleborough, Stephens (1964) has recorded decalcified till which is lithologically almost identical with that at Fremington. Dewey (1913) has described a weathered clay with striated erratics in the cliff sections west of Fremington Quay, and erratics have been found at Crock Point at 150 - 200 ft. O.D. and in Braunton Great Field. Marginal drainage channels have been described between Lynton and Hartland Quay by Stephens, who considers that at one time Irish Sea ice attained an altitude of c. 600 ft. on the coast.

Further south, Dr. Mitchell's discovery of Irish Sea till in the Scilly Isles must lead to a reconsideration of Barrow's (1906) record of striated erratics at altitudes of over 100 ft. O.D. on the islands, which were accepted by Arkell as being indicative of a huge packing of ice-floes with erratics. In view of this evidence it may well be that Arkell's problematical "boulder-gravel" of erratics and the "pebbly clay with erratics" at Trebetherick may be glacial deposits; his interpretation of the bed was largely condition by the assumption that North Cornwall was not glaciated, and he himself realised that the "50-foot sea-level" which he invoked to explain its stratification was founded upon little real evidence. Furthermore, the bed lies in exactly the same stratigraphic position as the till of North Devon, i.e. above raised beach and sandrock, and beneath later hill wash and solifluxion debris.

It would probably not be too radical to suggest that there may have been two glaciations of North Devon and Cornwall, and that the "Fremington" glaciation may be represented intermittently in the drift stratigraphy of the whole coast between Lynton and the Scilly Isles.

(f) Outwash Deposits.

A sand layer recorded by Stephens (1964) from above the Middleborough till may be outwash related to the till, and it has been noted above that the Hele-Ellerslie gravels and the Trebetherick boulder-bed may be outwash deposits.

(g) Upper Head. At Fremington the till is overlain by up to 5 ft. of blocky head and solifluxion earth, and an upper head separated from the main head by sandy layers is also described from Middleborough and elsewhere by Stephens (1964). The upper head at Middleborough is disturbed by fossil ice-wedges to a depth of c. 3 ft. At Trebetherick the upper head is seldom over 1 ft. thick, and consists largely of material soliflucted from the underlying boulder gravel (Arkell, 1943). The head deposits on the floors of some of the coastal marginal channels of North Devon may correlate with the upper head.

(h) Blown Sands, hill wash etc.

Above the upper head at many localities on the North coast of Devon and Cornwall is a suite of variable deposits. At Saunton and Trebetherick there are thick "Holocene" blown sands (Arkell, 1943), while elsewhere there are sandy hill washes associated with the modern soil horizon.

In spite of the doubtful stratigraphic position of the gravel deposits at St. Erth, Hele-Ellerslie, and

Table XXII. A Tentative Drift Stratigraphy for North Devon and Cornwall (after Stephens and Mitchell)

(h)	Blow sands and hillwash		
(g)	Upper Head		
(f)	Outwash	Hele-Ellerslie sand and gravel Trebetherick boulder-gravel (Arkell)?	
(e)	Irish Sea till	Fremington boulder-clay (Mitchell)	
(d)	Main head		
(c)	Raised beach series	Sandrock Beach pebbles Old head ?	Fremington Beach (Mitchell)
(b)	Erratics	Porthleven erratics (Mitchell)	
(a)	Rock platform	Fremington shore-platform (Mitchell)	

TABLE XXI A CORRELA' OF DRIFT IGRAPHY AROUND THE IRISH SEA.

S.E. IRELAND	LLEYN	PEMBROKESHIRE	GOWER	N. DEVON AND CORNWALL
(k) Sandy loam	(j) Post-gl raised beaches	Sandy loam	(h) Sandy loam	(i) Blown sands etc.
(j) Outwash S+G	Sands and gravels	Upper head - Rubble-drift	(g) Upper Head {Upper / Main}	(h) Upper Head
i {Athdown Mt. Dr. / Mid. Gen. till / Early Athdown Mt. drift / Upper head}	(i) Upper Till and head			
{(h) Sands and G. / (g) Bannow-Brittas till} (f) E. Gen and Bannow tills (e) Enniskerry-Clogga till	{(h) S + G / (g) Later Welsh till} (f) Irish Sea till (Early local till?)	S + G Local tills Irish Sea till	(f) Gravelly till	g {Hele-Ellerslie S+G? / Trebetherick B.G.?} (f) Fremington till
(e) Lower head	(e) Lower Head	Main Head {Coarse / Fine / Coarse}	(e) Lower Head	(e) Main Head
(c) Blown sands Raised beach	(b) Sandrock Raised beach	Blown sand Raised beach	(d) Sand -Int. soil (c) R. beach	(d) Sandrock and raised B.
(b) Erratics		Erratics	Erratics (b)	(b) Erratics
(a) Rock Platform	(a) R. plat.	Rock plat.	Rock plat (a)	(a) R. plat.

Trebetherick Point, the overall drift stratigraphy appears to be closely related to that of glaciated areas around the Irish Sea. A tentative summary of the stratigraphy is made in Table XXII, after Mitchell (1960), and Stephens (1961; 1964).

Summary and Conclusions.

The stratigraphic successions suggested for each of the four regions are compared in Table XXIII.

There is a very close agreement in the lower half of the table. In all regions rock platforms are overlain by erratics and raised beach pebbles, and in many localities blown sands, which are sometimes cemented, are associated with the raised beach. This sequence suggests that each region experienced at least one long phase of platform-cutting prior to an Early Glaciation. The arguments used by George (1932), Arkell (1943), Stephens (1964) and others to explain the presence of the erratics in the raised beach by ice-rafting are unconvincing, for much modern work has shown that if conditions were cold enough for ice-rafting were to occur in the Bristol Channel, sea-level would certainly be much lower than at present (Fairbridge, 1962). It appears most reasonable to follow the suggestion of Mitchell (1960) that the erratics are derived from the destroyed glacial deposits of an Early Glaciation.

The strength of the Early Glaciation is attested by the size of the sub-glacial channels cut in Pembrokeshire during its wastage, and it is possible that it left thick till deposits over a wide area. No coherent till dating from this glaciation appears to have been found, and it may be reasonable to assume that the succeeding interglacial stage, during which the raised beach was deposited, was prolonged enough to destroy all but the more resistant erratics. Further evidence in favour of the correlation of all these beach deposits is the intermittent association of head fragments, and the fact that pebbles are often solidly cemented with calcite or severely stained with iron and manganese oxides. If, as Ball suggests, the red loam above the beach at Worm's Head is an inter-glacial soil, then the severe staining of the beach and the thick accumulation of blown sands, as at Bloody Basin, may have taken place at this time.

The Lower ("Main") Head in each region is a thick deposit which sometimes reveals a gradation from blocky head at the base to finer head above. The tentative conclusions reached in Pembrokeshire concerning a periglacial climate of increasing severity at this time may therefore be applicable to the other regions around the Irish Sea. The status of the lower head in Gower is open to question, but Bowen (1965) agrees that it represents a periglacial phase prior to glaciation, as appears to have been the case elsewhere. In Eastern Ireland and the Lleyn Peninsula, as at New Quay, the stratigraphic counterpart of the thick lower head appears to be a dual deposit of bedrock head and soliflucted till.

The soliflucted till invites some speculation. There appears to be no trace of it in Pembrokeshire, Gower, or Devon and Cornwall. Furthermore, in Ireland it does not appear to be present in coastal sections to the south of Cahore Point. It can be no coincidence that the three regions in which the soliflucted till does occur lie within the sphere of influence of upland areas. In Ireland Dr. Farrington has demonstrated the role of the high Leinster Chain (with many peaks over 2000 ft. O.D.) in the initiation of the Enniskerry, Brittas, and Athdown Mountain Glaciations, and there is good reason to assume that these glaciations were matched in the mountains of Central Wales and Snowdonia. It would not be unreasonable to propose that the coasts of Pembrokeshire, Gower and Devon and Cornwall were too far removed from the major centres of accumulation at this time to experience full-glacial conditions.

The local tills at New Quay, Llech Lydan, Porth Neigwl, and Seabank Point are severely soliflucted, and apparently indicate that after their deposition there was a prolonged period of solifluxion prior to the arrival of the Irish Sea ice. Synge (1964b) places a full interglacial between the local glaciation and the Eastern General Glaciation, but this interpretation is based upon doubtful evidence of a high sea-level at Cahore Point; several of the participants on the I.G.C. Field Study Tour which visited the site in 1964 expressed doubt about the presence of a till beneath the pebbly gravel, and wondered whether the gravel itself might be outwash. Until more decisive evidence is available, it may be best to assume that the local Clogga glaciation was separated from the Irish Sea Glaciation by a periglacial phase, with all three episodes falling within the time-span of one major glacial stage. Indeed, this hypothesis appears to be supported by the fact that no weathering horizon intervenes between the two tills at New Quay or in Lleyn. Furthermore, the head deposits at Aber-mawr reveal a three-fold subdivision of blocky head/flaky head/blocky head beneath the Irish Sea till. This sequence has already been interpreted tentatively as indicating two moderately cold periglacial phases separated by a phase of extreme cold; it is tempting to correlate the phase of extreme cold with the local glaciation at New Quay, only thirty-five miles away. If this correlation is correct, then the blocky head at Aber-mawr may have accumulated under less severe conditions while the freshly-deposited till at New Quay was being soliflucted.

Above the lower head and soliflucted till, the Irish Sea till appears to be a good datum for correlation. In North Pembrokeshire and North Devon, Irish Sea ice carrying sea-floor drift impinged upon the coast; in both cases calcareous till directly overlies the lower head, and is itself overlain by sands and gravels and upper head or rubble-drift. The gravelly till in Gower lies in the same stratigraphic position, but correlates more closely on lithological grounds with the stony non-calcareous tills at Ogof Golchfa at Caerbwdy on the south coast of Dewisland. In both Gower and South Dewisland the till is a "land facies", although in the former case it appears to have been deposited largely by Welsh ice.

Synge (1963), Stephens (1964) and Mitchell (1960; 1962) have had no hesitation in correlating the calcareous Irish Sea tills of Pembrokeshire, Lleyn, Gower and Devon with the Eastern General till of Ireland. It seems entirely reasonable from a stratigraphic standpoint, to propose that they were all deposited at the time of the Dewisland Glaciation. Thus the full correlation up to the peak of the Dewisland/Eastern General glacial stage may be as follows:

S.E. Ireland & Lleyn	New Quay	N. Pembs.
Irish Sea till	Irish Sea till	Irish Sea till
Solifluxion	Solifluxion	Blocky head.
Local Glaciation	Local Glaciation	Fine head
Solifluxion	Solifluxion	Blocky head
Sandrock		Blown sand
Raised Beach	Raised beach ?	Raised beach

It is realised that the evidence for this correlation is by no means conclusive. However, some light may be thrown upon its reliability as a working hypothesis when the stratigraphy of the Lower Heads of Devon, Gower and Southern Ireland are examined in more detail, and when Mr. and Mrs. E. Watson complete their studies of the important sections on the east coast of Cardigan Bay.

Above the Irish Sea till, it is again possible to examine Pembrokeshire, Gower, and North Devon on the one hand, and South-East Ireland and Lleyn on the other.

(a) In the southern group of regions outwash deposits of limited thickness overlie the Irish Sea till in places; elsewhere the gravelly local facies of the till itself appears to have been deposited under conditions ice-wastage. In association with the outwash, or lying directly upon the till deposits, is generally an upper head or rubble-drift. The upper head is generally of limited thickness, although the till itself is often soliflucted.

(b) In the northern regions, and at New Quay, the deposits above the Irish Sea till are more complex. On the south coast of Ireland some drift-cliffs are capped by Bannow-Brittas local tills, and further north tills of a local mountain glaciation are associated with the Midland General till (Farrington, 1949). In Lleyn there is good evidence for a "Welsh readvance" at least as far west at St. Tudwal's Peninsula, and Synge (1964a) has suggested that the equivalent of the Midland General ice-limit is to be found in the Clynnog Fawr-Brynkir area. At New Quay, although there seems to be no coherent local till above the Irish Sea till, there is undoubtedly a great deal of local outwash material, perhaps suggesting that a local ice-mass was not far off during deglaciation.

As noted earlier in the thesis, Jehu (1904; 1909) has not been the only person to equate the upper rubble-drift of North Pembrokeshire with the uppermost deposits in Lleyn; Synge (1963) has described the upper rubble-drift at Aber-mawr as a local till, and Mitchell (1962) has assumed that the rubble-drift at Manorowen correlates with the Ogof Golchfa till. The deposits at all three localities are thought by these authors to correlate with the Brittas till. It has been suggested after fabric analysis that the upper rubble-drift in North Pembrokeshire is but a solifluxion deposit, while a similar origin was proposed for some of the Bannow-Brittas tills of South-East Ireland by participants of the I.G.C. Field Study Tour in 1964. The possibility must be borne in mind that some of the so-called upper tills of South-East Ireland and Lleyn may be solifluxion deposits.

In spite of this, however, there appears to be much convincing evidence that in the northern coastal areas of St. George's Channel there may have been glacial fluctuations which are not recorded in either North Pembrokeshire, Gower, or North Devon and Cornwall. South of the Midland General - Clynnog Fawr limit, periglacial conditions prevailed during the Midland General and its associated glaciations, so that head, rubble-drifts and soliflucted till are the only drifts which formed after the stagnation of the Irish Sea ice.

Whether or not the Midland General drift represents a completely fresh glaciation, there is a great deal of stratigraphic evidence to suggest a synchroneity of events around the southern Irish Sea Basin between the deposition of the raised beach and the Dewisland Glaciation. It appears that a chronology for North Pembrokeshire will also be a chronology for the greater part of the drift succession in South-East Ireland and Lleyn, and probably for the whole succession in Gower and the north coast of Devon and Cornwall.

PART VI

Chapter 14.

Some observations on relative movements of land and sea.

1. The drowned valleys of West Wales and the age of the coastline.
2. The marine-cut platforms and raised beaches.
3. The "Post-Older Drift" Platform.

Chapter 14.

SOME OBSERVATIONS ON RELATIVE MOVEMENTS OF LAND AND SEA.

> "...it is probable that Middle and Upper Pleistocene times were characterized by complex eustatic oscillations ranging from 150 feet above to at least 150 feet below sea-level. ... Considerable evidence ..... suggests that the 25 foot strandline was cut principally during the Hoxnian (Holstein) Interglacial or possibly earlier, on a coast which had been blocked out initially during local preglacial times."
>
> A.R. Orme, in Brunsden *et al*, 1964.

A great body of recent literature has indicated that there is a close relationship between glaciation and sea-level movements; in view of this fact it will be worthwhile at this point to make some comment upon the wider significance of the sea-level movements suggested for Pembrokeshire. The sea-level movements discernible from the coastal sections and the major topographic features of the area are as follows:

Events.	Sea-level movements.
10) Present coastal erosion	Sea-level at O.D.
9) Submerged forest	-60 ft. O.D. ?
8) Periglacial phase	Low; rising
7) Dewisland Glaciation	Very low
6) Long periglacial phase	Low - falling.

Events.	Sea-level movements.
5) Raised beaches - **Poppit Interglacial.**	Fluctuating - High; O.D. to c. 30 ft. O.D. ?
4) **Early Glaciation**	Very low ?
3) Some raised beach platforms ? Establishment of approx. present coastline.	Fluctuating - up to 50 ft. O.D. ? Sea approx. at O.D. ?
2) Buried channels	Very low; at least - 200 ft. O.D.; fluctuating ?
1) Old coast-line - to seaward ?	Lower than at present ?

These movements can be accommodated with ease in the liberal scheme quoted at the head of this chapter, but the table contains several features which contradict recent viewpoints.

Many of the views expressed in the recent literature appear to have their roots in the work of Professor Zeuner (1959). He considered that there was a spasmodic fall of sea-level throughout the Pleistocene, interrupted only by glacio-eustatic oscillations which were characterised by low sea-levels during glaciations and high sea-levels during interglacial stages. In Britain the 600-ft. stage was assigned to the Calabrian, the 300-ft. stage to the Sicilian, and the 200-ft. stage to the Milazzian.[1]

1. For an explanation of these terms see Zeuner (1959, P. 301)

The lower stages are summarised below from tables on Pp. 307 and 368 of Zeuner (1959):

Stage.	Sea-level.	Thames events.
Tyrrhenian	+32m.	Great Interglacial
Penultimate Glaciation	-200m. (?)	(Taplow Bench)
Main Monastirian	+18m.	Last Interglacial
Late Monastirian	+7.5m.	
Last Glaciation (1)	-100m.	(First buried channel)
Epi-Monastirian	+3m.	First Interstadial
Last Glaciation (2)	-70m.	(Second buried channel)
Last Glaciation (2/3)	-10m.	(Ponders End Aggradation)
Last Glaciation (3)	-30 m.	(Third buried channel)

From the above it will be seen that low sea-levels (i.e. more than a few metres below O.D.) are thought to have occurred only during the Penultimate Glaciation and various stages of the Last Glaciation. Fairbridge (1962) has further elaborated these views, and from the evidence of shorelines in many stable parts of the world he has suggested glacio-eustatic oscillations and an overall sea-level fall during the Pleistocene as shown in Fig. 8.

Notwithstanding the severe criticisms which Professor Zeuner's book received[1], two authors (B.W. Burton and D.Q.

1. "Ce livre eût été un bon livre, mais en 1940. Il ne tient aucun compte de tout ce qui a été découvert au cours des vingt dernières années. Or, c'est pendant ce temps que nous avons le plus appris sur le Quaternaire......" Review of "The Pleistocene Period" in Rev. Géomorph. Dyn. XI, P. 30 (1960).

Bowen) have carried out detailed analyses of the low-level erosion surfaces of South Wales within the scheme of Zeuner. In 1952 Burton proposed that in Pembrokeshire there was an intimate relationship between glaciation and marine platform-cutting, and suggested that the latter part of Pleistocene glacial times was contemporaneous with the 295-ft. and 240-ft. marine stages. Bowen (1965), in a study of Central South Wales, reconstructs 29 Pleistocene shorelines beneath 720 ft. O.D., all of which he relates to transgressions and regressions in interglacial and glacial stages. Like Zeuner, he considers that in general the highest shorelines are the oldest features and the lowest shorelines the youngest, indicating that each transgression attained a lesser altitude than its immediate predecessor. Thus both Burton and Bowen consider the low-level erosion surfaces to be essentially recent features related directly or indirectly to the Pleistocene glaciations; neither author talks of low interglacial or pre-glacial sea-levels which might have influenced the course of landscape evolution.

On the other hand Orme (1962; 1964 a, b) has suggested that the strandlines of Southern Britain are not necessarily all related to the Last Interglacial (Monastirian); he suggests that the coastline may have been established prior to both the Last Glaciation and the Penultimate Glaciation of Zeuner, and it follows that the Lower and Middle Pleistocene may have experienced prolonged stages of low sea-level.

This latter viewpoint differs greatly from that of Zeuner and Fairbridge; however, it is supported fully by the field evidence in South Devon and South-East Ireland, and the evidence in Part III of this thesis affords further support from Pembrokeshire.

1. The Drowned Valleys of West Wales and the age of the Coastline.

The drowned valleys of Western Britain have long been the cause of morphological speculation. With the Bristol Channel or the Severn Estuary as the examples par excellence (North, 1929), drowned channels occur in Southern and Eastern Ireland, in North and South Wales and in the South-West Peninsula in abundance. Almost every major river has beneath its estuary a rock channel graded to a sea-level well below that of the present day.

In 1938 Wills proposed that the buried channel of the Severn was not excavated till after the Little Welsh Glaciation (Kidson, 1964), and as indicated in the last table Zeuner considered that the Thames channels were cut in three phases during the Last Glaciation.

Both these datings, when taken alongside the work of Wooldridge (1950), appear to have had much influence on contemporary thought concerning buried channels. For example, Kidson (1964) proposes that the Tawe channel was cut after the Last Glaciation, while Hawkins (1962) has suggested that the buried channel of the Bristol Avon was eroded during the first or second phase of the Last Glaciation. In 1960 Orme proposed that the over-deepening of the drowned estuaries of South Devon occurred after the 24 ft. strandline had been cut and "followed a withdrawal of the sea during Late Glacial times" (P. 128). He dated the strandline to a late stage of the Last Interglacial, implying that the buried channels were not cut until the Last Glaciation. Closer to Pembrokeshire, Allen (1960) has dated the cutting of the deep Teifi channel to an early stage of the Last Glaciation, while Bowen (1965) gives a similar age to the Loughor and Tawe channels.

The publications of the London I.G.C. (1964) provide a pointer to contemporary thought on the age of the buried channels. In "The British Isles", Linton (Chapter 7, P. 113) talks of "a spasmodically-falling, eustatically-controlled base-level" during the Tertiary, and Sissons (Chapter 8) suggests that this overall sea-level regression was continued during the Pleistocene period, although admitting that some of the drowned valleys may have been excavated prior to "the last major eustatic lowering of ocean level". On a more local scale, in "Field Studies in the British Isles", Peel (Chapter 5) states that the buried channels of the Bristol Channel area were cut during "the final low-water phase" of the Pleistocene, and Gresswell (Chapter 17) suggests that the drowned estuaries of Cardigan Bay were cut during "the more recent cold period" or the "early and late stages of each interglacial". Thus in a considerable body of recent literature there appear to be few references to low sea-levels during the Tertiary and Quaternary eras. Those low sea-levels which are accepted are related to either full-glacial conditions or to the waxing and waning phases of glacial stages.

However, there is some evidence for ancient low sea-levels which were apparently not related to local glaciations. For many years it has been accepted that such "rias" as Plymouth Sound and Cork Harbour were formed by the flooding of the lower parts of mature river-systems; these could not have been cut either by glacial meltwaters or by increased river-flow in a short periglacial phase at the commencement or end of a glaciation.

This impression is amply confirmed when field evidence from within the drowned estuaries is examined. In South-

East Ireland Wright and Muff (1904) noted that raised beach platforms are found within the estuaries of the larger river-valleys. Similarly Arkell (1943) recorded the presence of rock platforms in the Camel Estuary, Carrick Roads and Falmouth Harbour, while Orme (1960) has shown that they occur in the mouths of the Dart and Kingsbridge Estuaries, Wembury Bay, and Plymouth Sound. Other ancient marine-cut platforms are known within the estuary of the deep Severn Channel (Donovan, 1962). Clearly, all these estuaries must have been drowned prior to the cutting of the raised beach platforms.

In Pembrokeshire and Cardiganshire there is more evidence for the age and origins of the drowned valleys. The magnificant natural harbour of Milford Haven has long been recognized as a ria, as distinct from a glaciated trough or meltwater channel (see discussion in Codrington, 1898). This is supported by its graded long-profile, its gentle cross-profile, and the accordant nature of its drowned tributary valleys (Plate 57); overall, it has the appearance of a mature valley-system graded to a sea-level at least 100 ft. lower than at present[1], and drowned by a

1. At Burton, ten miles from the mouth of Milford Haven a rock floor at -79 ft. N.D. has been proved (Soil Mechanics, 1958). It is likely that more recent investigations near the mouth of the Haven in association with the construction of oil tanker terminals have revealed even deeper rock floors.

subsequent relative rise in sea-level (Burton, 1952; Davies, 1939). The valley may well have been deepened and modified in places by the action of meltwater during both the Early and Dewisland Glaciations,for recent borings have revealed steep bedrock slopes in places, overlain by thicknesses of fluvio-glacial sands and gravels (Soil Mechanics, 1958). However, there is no indication that either glaciation has substantially altered the coastal configuration of the Haven. Like Cork Harbour and Plymouth Sound, and like the Teifi and Afon Nevern estuaries, Milford Haven appears to have been drowned before the establishment of the coast and before the cutting of the rock platforms and the deposition of raised beaches (See Chapter 6).

While it would be misleading to assume that all the buried channels of Britain, or indeed of West Wales, have formed in a similar way, it is worth noting that Charlesworth (1957), in summarising much of the evidence of buried river-valleys in the British Isles, stated "Since they preceded the infraglacial beach, as shown in South Ireland and in South Wales, subaerial rivers probably eroded then during a protracted period when the land was somewhat higher...." (P. 1254). Again, O.T. Jones (1942) and North (1929) were in no doubt concerning the probable pre-glacial age of the drowned estuaries of the Bristol Channel region.

From the evidence presented above it is reasonable to support Charlesworth's suggestion that the drowned valleys are of essentially sub-aerial origin. They were cut in a prolonged period prior to the Poppit Interglacial, and probably prior to the Early Glaciation. Bowen's assertion that the valleys were cut <u>after</u> the <u>Patella</u> beach platform and immediately prior to the Main Welsh Glaciation of Gower, does not appear to be supported by the field evidence.

There are further differences of opinion concerning the age of the coastline of Western Britain.

O.T. Jones (1930) has suggested that the Bristol Channel basin is an ancient feature which has been in existence since the time of Miocene earth-movements, while Mitchell (1960) has stated that prior to the "Lowestoft Glaciation" the Irish Sea "was essentially the sea we know today" (P. 315). Support for this assertion has come from Orme (1962) who suggests that "the present coastline was largely blocked out by erosion during "pre-glacial" (Cromerian) times and subsequently trimmed during later interglacials". (P. 282). Again, in 1964 Orme repeated that the coastline of South Devon had approximately its present configuration in "local preglacial times".

In contrast D.Q. Bowen (1965) has denied Mitchell's assertion, and appears to consider the coastline of Gower as a product of the *Patella* beach interglacial. This dating derives from Zeuner's suggestion that sea-levels prior to the Last Interglacial were above that of the present day (see Chapter I), so that earlier coastal zones are preserved well above present sea-level.

As George (1932) noted in Gower, the present-day coastline appears to have been established before the cutting of the *Patella* beach platform, for platform remnants are found in many minute inlets and even on the exposed isolated rocks of Worm's Head. The glaciation of Gower modified the coastline hardly at all, and post-glacial changes have been negligible. In Pembrokeshire the preservation of raised beach platforms even on exposed headlands (as at Pen Dal-aderyn) supports these observations, and attests to the great age of the coast.

The relationships of meltwater channels and coastline, as indicated in Chapter 11, provide valuable clues concerning the relative ages of features. It has been suggested that the channels of Dewisland were cut in the Early Glaciation, and while none of them are graded to a specific sea-level they do display a certain degree of accordance with the present coastal configuration; their mouths generally coincide with bays or inlets in the coast, and they are often incised into older river-valleys. In addition, the Aber-mawr channel appears to have been cut later than the rock platform on Pen Deudraeth, so that in this vicinity even the details of coastal configuration may be older than the Early Glaciation. The broad outlines of the coast, and in places the details of configuration, appear to have been established before the Early Glaciation.

However, the apparent truncation of some of the meltwater channels by marine erosion (as at Cwm-mawr and Trevine), and the presence of marine cliffs within the walls of the channels at Caerbwdy, Porth-y-Rhaw, Solva (Plate 58), Porth-clais, Aber-mawr, and elsewhere suggests that there has been at least some marine erosion on the coastline since the cutting of the meltwater channels.

On the basis of this evidence it may tentatively be suggested that the coastline attained approximately its present form before the Early Glaciation, and was further trimmed in the Poppit Interglacial.

2. <u>The Marine-cut platforms and raised beaches.</u>

The precise dating of the raised beach platforms of the Irish Sea is again the source of disagreement. Most commonly the beaches have been dated simply by stating that they are older than the drifts which rest upon them. For example, since the work of Charlesworth (1929) it has been widely accepted that "Older Drift" rests upon the rock platform in Pembrokeshire; the platform must, therefore, be pre-Older Drift in age (see George, 1932; Wright, 1937; Arkell, 1943). There have been many complex arguments concerning the age of this Older Drift, but Zeuner (1959) has dated the raised beach platform as Monastirian (Last Interglacial) on the basis of its altitude; according to his scheme, all the drift deposits above the platform must therefore date from the Last Glaciation.

In Chapter 7 it was suggested that the rock platforms around the coast are not necessarily the same age as the beach deposits resting upon them. Among many others, George (1932), Wright (1937), Zeuner (1959) and Bowen (1965) have tended to assume that the platforms are not notably older than the raised beaches, i.e. they were cut in the same interglacial stage. In favour of this idea must be cited the noticeable "freshness" of the rock platforms in many localities (Arkell, 1943). However, as Orme (1962) has noted, "a shore-zone shaped during an earlier still-stand may be trimmed anew and its original deposits replaced by or incorporated within fresh beach debris during subsequent stillstands near the same level". (P. 281). The deposits resting upon a platform must post-date the cutting of the platform by an unknown amount.

However, there is some evidence for the age of the platforms. It was argued in Chapter 5 (A) that erratics resting upon a platform are not likely to have been introduced until after the cutting of the platform. In Pembrokeshire, Gower, and South-East Ireland this argument is not entirely convincing in view of the limited size of the erratics, which could conceivably have been soliflucted or carried by storm-waves from pre-existing glacial deposits onto a fresh rock platform, as implied by Bowen; however, the huge erratic at Freshwater Gut (Plate 54) and other large erratics on the rock platforms of the South-West Peninsula can hardly have been moved by storm-waves or soliflucted from the old cliff-line, and they appear to have been carried into place by ice of the Early Glaciation after the platforms were cut (Mitchell, 1960).

In support of this hypothesis may be quoted the head deposits beneath and intermingled with some raised beaches in South-East Ireland and North Devon, which have caused Farrington and Stephens (1964) to insert a period of solifluxion between the cutting of the platform and the deposition of the beaches. Again, it is tentatively suggested from Pen Deudraeth in North Pembrokeshire that an ancient coastal rock platform pre-dates a meltwater channel of the Early Glaciation. Thus there appear to be several lines of evidence suggesting that the rock platforms may be ancient features which pre-date two major glaciations.

There is a strong temptation to group all the coastal rock platforms of Western Britain into one early interglacial. However, in Gower the platforms occur at altitudes between present sea-level and 55 ft. O.D., and Bowen has discerned six independent platform series; in Eastern Ireland platform remnants are found at all heights between 33 ft. and 13 ft. I.O.D. In the South-West Peninsula Green (1943) has recorded platforms from 15 ft. O.D. to 75 ft. O.D., and Stephens (1964) notes beach remnants up to 60 ft. O.D. at Pencil Rock. While part of this range of variation can be accounted for by differential tidal ranges (Steers, in Green, 1943), and part by the fact that platform remnants rise in altitude from bayheads to headlands (Martin, 1955; Stephens, 1957) a vertical difference in altitude of at least 65 ft. between the highest and lowest platforms must surely indicate several phases of platform-cutting during several stillstands.

Table XXIV. Rock platform remnants on the North Pembrokeshire coast, and to the south.

	Locality	Approximate altitude above M.S.L.	Authority	Site	Beach Deposits
1.	Gwbert	14 - 16 ft		Estuary	-
2.	Poppit	3 - 11		"	+
3.	Parrog	5 - 26		"	+
4.	Newport Sands	11		"	-
5.	Pen Deudraeth	18 - 27		Headland	-
6.	Trwynhwrrdyn	14 - 17		Promontory	-
7.	Whitesands South	8 - 10		Bayhead	+
8.	Porthcadno	39 - 44		Outer coast	-
9.	Pen Dal-aderyn	34 - 37		Headland	-
10.	Ogof Henllys	15 - 35		Outer coast	-
11.	Ogof Lle-sugn	25		" "	-
12.	Ogof Golchfa	15 - 35		" "	+
13.	West Angle	19	Dixon	Estuary	+
14.	Milford Haven	6 - 10	Dixon	"	+
15.	Freshwater West	6 - 26	Dixon	Bayhead	+
16.	Manorbier	25 - 30	Dixon	"	+
17.	Caldey Island	19 - 27	Leach	Island	+
18.	Grassholm Island	40 - 50	Dixon	Island	

N.B. Altitudes are approximate only. Measured to M.S.L. by Abney Level. Not surveyed accurately.

In Pembrokeshire there is a similar range of platform altitudes, as shown in Table XXIV. The highest platform remnant is at c. 44 ft. O.D. at Porthcadno, and the lowest at Poppit, at c. 3 ft. O.D. There are no major differences in the altitudes of the remnants in coastal areas from Cardigan Bay to the Bristol Channel, although the higher platforms (above 25 ft. O.D.) are generally located on exposed coasts and the lower platforms (below 10 ft. O.D.) are located in bayheads or river estuaries. The platform at 40 - 50 ft. O.D. on Grassholm Island (about 20 miles to the south-west of Ramsey Sound) is found, understandably, in the most exposed locality. In no one coastal locality is a "staircase" of beach platforms observed, although in places (as in the Afon Nevern estuary) individual platform remnants are found over a height range of over 20 ft.

The high platform remnants in Pembrokeshire (at Pen Dal-aderyn, Porthcadno, and Ogof Golchfa) appear to be more degraded than those at lower altitudes, and they may be somewhat older; however, the rapid weathering on these platforms may be a function of exposure rather than age, so it would be unwise to base any conclusions on this criterion. What can be said is that even the lowest platforms support the typical Pembrokeshire drift succession; the whole suite of platform remnants may therefore pre-date the Early Glaciation. The platforms may have been cut interglacially or pre-glacially by a series of marine stillstands at different levels.

The Neritoides beach of George (1932) was considered to have formed some time after the Patella beach, and Charlesworth (1957) places a full glacial stage between them. On the other hand Bowen (1965) has denied that there was any lapse between the deposition of the two beaches. No evidence has been found in North Pembrokeshire to suggest that any of the raised beach deposits are much younger than any of the others.

The post-glacial Heatherslade beach of the Gower (George, 1932) may correlate with the post-glacial raised beach of Lleyn (Whittow, 1960) and the post-glacial beach of Eastern Ireland (Stephens, 1957). Again, no beach remnants which can be correlated with these beaches have been found in North Pembrokeshire, although the status of certain cemented beach fragments at West Angle Bay deserves closer investigation.

3. The "Post-Older Drift Platform".

For many years there has been speculation concerning a high sea-level after the "Older Drift" glaciation of Gower and elsewhere. In 1932 George remarked upon a gently-sloping terrace cut across variable drift deposits between Oxwich Point and Eastern Slade, and in Overton Mere and

Rhossili Bay in Gower; the terrace generally slopes shorewards from c. 50 ft. O.D., but at Oxwich Point it is below this level and in Rhossili Bay it is higher. R.O. Jones (1931) has noted a 50 foot terrace feature in the Tawe valley and has related it to the Gower terrace. Again, Arkell (1943) has related his "Trebetherick boulder-gravel" to the 50 foot sea-level at which the Gower terrace, the Portland raised beach, and other features, were thought to have formed. In 1936 Matley proposed that a "50 foot terrace" of sand, gravel and laminated silts, in southern Lleyn, may have been formed in a marine embayment partly dammed by ice.

More recently Davies (1959) has described gently-sloping surfaces developed on till in South-East Ireland; these surfaces extend up to 100-130 ft. O.D. and are terminated at 50 - 80 ft. O.D. by the present-day cliff-line. Arber (1960) has suggested that there are two surfaces in North Devon which are cut across head deposits; the higher surface, at 150 - 100 ft. O.D., is named the "Hele Surface", while the lower surface, at c. 50 ft. O.D., is named the "Croyde Surface". Both surfaces are thought by Arber to have been cut by high sea-levels in an interglacial stage.

In West Wales there also appears to be some evidence for post-glacial coastal platforms. At Aberayron there is an extensive drift terrace with its upper edge at c. 100 ft. O.D., and a similar feature may be seen beneath an ancient cliff-line at New Quay West. At Druidston the sharp break of slope between the old valley-side and the drift-fill deserves mention, and on the north shore of Milford Haven, at Mullock Bridge, there is an extensive gravel terrace which falls seawards at $\frac{1}{2}^{o}$ - 1^{o} from 100 ft. to c. 60 ft. O.D.

The theory that these features in Western Britain owe their origin to marine erosion under a high-level inter-glacial or post-glacial sea has received heavy criticism. In 1961 Stephens stated that the low-level "surfaces" of North Devon do not owe their origin to marine erosion, but simply to the processes of solifluxion; and in 1965 Bowen came to the same conclusion concerning the "post-Older Drift" platforms of Gower. Like Stephens, he found no trace of wave-trimming and no deposits which could be assigned a marine origin, and decided that the terraces were formed by the solifluxion of head and other deposits from the base of high cliffs of the coast or else from coastal valleys. These findings for the Gower are supported by M. Bridges (personal communication, 1965). Similarly, there appear to be no marine deposits on the drift terraces at New Quay or Druidston.

However, the lack of marine deposits in a coastal area does not necessarily preclude the presence of a high relative sea-level. Stephens (1963) has described late-glacial shorelines in North-East Ireland which have no associated beach deposits, and in Kjove Land, East Greenland, marine features at an altitude of 440 ft. are no more than slight gravel terraces or washing-limits (Sugden and John, 1965). In the East Greenland Fjords and in the South Shetland Islands the present-day shore is seldom marked by "marine" deposits.

There appears to be no good reason why marine-cut features should not be found on the drift cover of the coasts of Western Britain. It has been suggested that the ice of the Dewisland/Eastern General Glaciation may have extended as far south as the Scilly Isles; if this was the case the ice in St. George's channel would probably have been several thousand feet thick, and may have achieved considerable isostatic depression of the land-surface. In spite of the world-wide eustatic lowering of sea-level at such a time (Farrington, 1945; Fairbridge, 1961), isostatic depression of the surface of the Irish Sea Basin could have been greater. Upon deglaciation, as in other glaciated lands, there could have been a marine transgression of 50-100 ft.

The conjectural zero isobase of Stephens (1963) in the Irish Sea area passes from Dublin to the southern Lake District. However, the pattern of isostatic deformation of the coastal areas is by no means fully discipherea,[1] and the possibility should be borne in mind that there could have been a high relative sea-level in Wales at the close of the Dewisland/Eastern General Glaciation. At the moment, the cases for and against are unproven.

Summary.

In this chapter it is suggested that there is much evidence around the shores of St. George's Channel and the Bristol Channel in support of the scheme of sea-level movements proposed for Pembrokeshire. The present coastlines of the area were probably established after a prolonged period of sub-aerial denudation with a sea-level much lower than at present. The submerged channels of Pembrokeshire, and perhaps elsewhere, were submerged before the Early Glaciation.. The coastlines and the raised beach platforms probably pre-date two glaciations, while

1. For example, D.B. Smith has discovered a drift terrace at 98 ft. O.D. near Hartlepools; it supports patches of shelly gravel, and although it is well to the south of the 50 ft. isobase of Movius (1942), it may prove to be a marine-cut feature.

the raised beach deposits may date from the Poppit Interglacial.

In many respects this scheme of events differs from that of Zeuner and Bowen.

PART VII.

THE GLACIAL CHRONOLOGY OF WEST WALES.

In this final part of the thesis an absolute chronology is reconstructed for the late stages of the Pleistocene period in West Wales. Faunal analyses are made of derived shells in till and outwash, and the clues thus obtained to the relative and absolute ages of the drifts are followed up with C14 dating of organic materials. After an examination of the Late Pleistocene chronology of Northern Europe, an attempt is made to date the main Pleistocene events which have occurred in Pembrokeshire.

Much has been said in the foregoing pages concerning the stratigraphic relationships of the Dewisland till; this till appears to correlate with the Eastern General till of Ireland and the Irish Sea tills of Lleyn, North Devon, and possibly even the Scilly Isles. However, there is great disagreement concerning the age of the Dewisland/Eastern General Glaciation; Mitchell, Synge and Stephens consider it to be the equivalent of the Continental Riss/Saale, while Bowen and Penny follow Zeuner in considering it the equivalent of the Continental Würm/Weichsel.

On a relative scale, the Dewisland till appears to be fresh. Whatever its age, it must be older than the Midland

General - Clynnog Fawr tills, and younger than the New Quay till and the Main Heads of the Irish Sea. Older still than the Main Heads are the Poppit Interglacial and the Early Glaciation. In Chapter 15 it is submitted that there is reliable evidence for placing the Dewisland Glaciation within the last 38,000 years, and in the Conclusion some of the implications of this dating are mentioned.

Chapter 15.

The Evidence for a Recent Glaciation

A. Faunal analysis of derived marine mollusca in glacial deposits

B. Radio-carbon dating of glacial deposits.

Chapter 15.

THE EVIDENCE FOR A RECENT GLACIATION.

(A) FAUNAL ANALYSIS OF DERIVED MARINE MOLLUSCA IN GLACIAL DEPOSITS.

Shells from Outwash Gravels.

Shell fragments were collected from glacial outwash gravels at two important localities in the hope that some idea could be gained of their relative ages. One of these localities (Tre-llys) is in the area of hummocky gravels supposed by Charlesworth (1929) to be part of the South Wales End-moraine; the other (Mullock Bridge) is well to the south of this limit, in the area of so-called Older Drift (Griffiths, 1939). If the shelly gravels at Mullock Bridge and Tre-llys are the representatives of the Older Drift and Newer Drift glaciation respectively, then they may be expected to display some faunal differences, as have been recognized between the Corton Beds and March Gravels of East Anglia (Baden-Powell, 1955).

(a) Mullock Bridge.

At Mullock Bridge, just north of the mouth of Milford Haven, a large gravel-pit has been cut into a terrace of fluvio-glacial outwash material, which has a maximum surface altitude of 100 ft. O.D. In the sides of the pit at least 25 ft. of current-bedded basal sands are visible; these sands appear to have been deposited deltaically, in the sea or in a pro-glacial lake. The sands are overlain by, and interbedded with, fine shelly gravels, which are in turn overlain by coarse torrential outwash. In parts of the gravel-pit unleached shelly gravels are seen within 3 ft. of the terrace surface. The northern part of the terrace surface has a patchy covering of stony and gravelly till, beneath which the shelly gravels are severely contorted. Shell fragments were collected from shelly gravel layers throughout the pit, but care was taken that none were taken from the decalcified and weathered horizons close to the terrace surface.

Buccinum undatum L.	Astarte sulcata (da Costa)
Littorina littoralis (L)	Cardium edule L.
Littorina littorea (L)	Chlamys islandica (Müller)
Lora nobilis (Müller)	Arctica islandica (L)
Nassarius spp.	Macoma balthica (L)
Nucella lapillus	Mytilus edulis L.
Ocenebra erinacea (L)	Ostrea edulis L.
Patella vulgata L.	Pecten maximus L.
Trivia monacha (da Costa)	Venus verrucosa L.
Trophonopsis clathratus (L)	
Trophon truncatus (Ström)	
Turritella communis Risso	

(b) Tre-llys.

The shell fragments in this sample were collected from the contorted shelly gravels at an altitude of 200 ft. O.D. in Tre-llys gravel pit[1] (See Chapter 9). The species recorded are as follows:

Buccinum undatum L.	Aloidis gibba (Olivi)
Littorina spp.	Anomia sp.
Littorina Neritoides	Arctica islandica (L)
Nucella lapillus (L)	Astarte elliptica (Brown)
Sipho jeffreysianus (Fischer)	Astarte montagui (Dillwyn)
Trophonopsis clathratus (L)	? Astarte sulcata (da Costa)
Trophon truncatus (Ström)	Cardium edule L.
Turritella communis Risso	Glycymeris glycymeris (L)
	Macoma balthica (L)
	Mya arenaria L.?
Dentalium sp.	Mytilus edulis L.
	Nuculana sp.
	Pecten maximus L.
	Venus verrucosa L.

Examination of the mollusca from these two localities reveals that most of the species represented are common in

---

1. Some of these gravels are seen in Plate 40A.

Pembrokeshire waters today; there are no extinct species in either collection. The most abundant species at Mullock Bridge appeared to be Mytilus edulis and Turritella communis, followed by Littorina littorea and Nucella lapillus, each of which prefer a temperate environment similar to that of today (Barrett and Yonge, 1964). On the other hand cold indicators (not found in the area today) such as Trophonopsis clathratus, Trophon truncatus, Lora nobilis, and Chlamys islandica are represented, giving the collection a rather northern aspect. It is unlikely that the Mullock Bridge collection represents a single fauna, however, for the slightly warmer species Ocenebra erinacea would not have grown alongside the Arctic species mentioned above; furthermore Littorina littorea (which cannot live where there is much sea-ice) is found in the gravels alongside Trophonopsis clathratus, which thrives in such an environment.

The list of mollusca for Tre-llys is almost identical to that for Mullock Bridge. Again, most of the species in the gravel are found in the area today. However, at Tre-llys there appear to be few fragments of Mytilus, but many of Astarte spp and Venus spp, which may mean that the bulk of the shells were derived from a rather colder environment. Northern species such as Astarte elliptica and <u>Astarte montagui</u> are represented with the Trophons, and the cold genera of <u>Sipho</u> and <u>Nuculana</u> have been found at Tre-llys but not at Mullock Bridge. On the other hand the cold indicator <u>Chlamys islandica</u> was found at Mullock Bridge but not at Tre-llys. It seems that the gravels at both localities contain a similar mixture of species representing temperate and rather cold climatic conditions.

The mixing of faunas in Pleistocene deposits in Britain has been considered in some detail by Baden-Powell (1955). He has proposed that prior to the Last Glaciation a steeper temperature gradient existed around the British Isles, allowing "warm" and "cold" mollusca to live in close proximity.[1] There is, however, no clear independent evidence to support this idea (Manley, 1951, 1953), and it seems unlikely that the North Atlantic Drift could have altered its course greatly during Pleistocene Interglacial stages without some major tectonic or climatic upheaval, neither of which is recorded (Flint, 1957). Even at the peak of the Last Glaciation (when the greatest interference with climate in the North Atlantic might have been expected), surface isotherms to the west of Britain are thought to have followed approximately their present course (Klute, 1951)

---

1. This hypothesis has received recent support from Boulton and Worsley (1965) in an unpublished study of the marine mollusc species found in outwash sands in Cheshire.

although it has been suggested by Fairbridge (1964) that the climatic belts of the Northern Hemisphere may have migrated southwards by 2,000 - 3,000 km. Furthermore, analysis of deep-sea cores (Emiliani, 1955),and interglacial pollens (West, 1955; Zagwijn, 1961) do not indicate that past interglacial atmospheric circulations were very different from that of today. Dr. H.H. Lamb (personal communication, 1965) has said, concerning the squeezing together of isotherms in interglacials, "I am quite sure that the opposite is true of the interglacials, when there must have been a much smaller overall temperature gradient from equator to pole than either now or in the ice ages....Generally speaking, much less is known about the interglacials and warm epochs of geological time than about the ice ages or our present climate, but at least it is sure that there was a smaller difference of temperature between low and high latitudes."

Evidence from present-day Arctic waters indicates that there is a sensitive response on the part of marine mollusc communities to changes in water-temperature, depth, and salinity. For example, Portlandia artica is an accurate indicator of peculiar ecological conditions often associated with the proximity of glacier ice in East Greenland (Jensen, 1905; Thorson, 1933); it is found in raised beach zones A and D, which coincided with the late-glacial extension of the inland-ice and the Zone III readvance respectively (Sugden and John, 1965), and again at the present day in Scoresby Sund, indicating a recent climatic deterioration. Coversely <u>Mytilus edulis</u> thrives best in the littoral zones of temperate seas, and is not found today in those parts of East Greenland inhabited by <u>Portlandia.</u> In Spitzbergen Feyling-Hanssen and Olsson (1959) have shown by C14 dating that raised beach shell-communities accurately reflect climatic conditions; for example, beaches formed under Arctic conditions between c. 12,000 and 10,300 B.P. contain no "temperate" species[1], while such species had arrived in large numbers by the time the "Post-glacial Temperate" raised beaches (10,300 - 9,400 B.P.) were being formed. This evidence suggests that the immigration and emigration of marine mollusc communities in response to the movement of an ice-front can be a rapid process, while there is little evidence that a prolonged "mixing" of communities occurs. Even if the Mullock Bridge and Tre-llys mollusca were in undoubted marine deposits, which they are not, there appears to be no reason why they should be considered the constituents

1. For example, <u>Mytilus edulis</u>, <u>Littorina saxatilis</u> and <u>Buccinum undatum</u>.

of one community, and thus of the same age (Dr. G.Y. Craig, personal communication).

Two possibilities remain concerning the provenance of the shell assemblages:

(A) that only some of the shells represented were native to the coastal waters of Pembrokeshire, with the cold-water species transported from further north, and

(B) that all the shells lived in the vicinity, but at different times and depths as climatic conditions deteriorated prior to glaciation. It is possible that a sequence of events occurred as illustrated in Fig. 33. Whatever the mechanism by which the faunas were mixed, it appears most reasonable to assume that the mollusc species represented at Mullock Bridge and Tre-llys may have lived in widely separated localities and may span an age range of several thousands of years.

In Table XXV the species recorded for Mullock Bridge are compared with those found in the Dale area at the present day (Bassindale and Barrett, 1957), with the Manorowen outwash deposits (Jehu, 1904), and with the Wexford outwash gravels (McMillan, 1964). The mollusca at Manorowen were considered by Jehu to represent a range of climates similar to that postulated for the other Pembrokeshire gravel pits. In addition to some of the species recorded in the table, he found the following at Manorowen:[1]

Lora rufa (Mont.)	Astarte borealis, Gray
Lora turricula (Mont.)	Arca lactea. L.
Natica clausa, Brod. & Sow.?	Cardium islandicum, Chem. ?
Puncturella noachina, L.	Mya truncata, L.
Sipho gracilis (da Costa)	Nuculana pernula (Müll)
	Spisula solida (L)
	Venus casina, L.
	Tapes decussatus, L. ?
	Modiolus modiolus (L) ?

There are no peculiarities about the Manorowen mollusca, and it seems that Glycymeris glycymeris, Astarte sulcata, Artica islandica, and the "cold" species Trophonopsis clathratus were the most common species, alongside Turritella communis and Buccinum undatum. The common species from Pembrokeshire outwash are also recorded by Williams (1927) from shelly outwash gravels in Cardiganshire, and by George (1933) from glacial deposits at Rhossili Bay, Gower.

When the Pembrokeshire outwash mollusca[2] are compared

---

1. The species collected by Jehu were identified by Mr. Henry Woods.

2. A complete list of the derived marine mollusca found to date in glacial deposits in Pembrokeshire is given in Appendix XII.

Table XXV. A Comparison of the Mullock Bridge shell assemblage with assemblages elsewhere.

Mullock Bridge Species (to date)	Present-day mollusca at Dale (Bassindale and Barrett)	Manorowen species (Jehu)	Wexford (McMillan)
Patella vulgata	x	-	x
Littorina littoralis	x	-	x
Littorina littorea	x	-	x
Nucella lapillus	x	-	x
Ocenebra erinacea	x	x	x
Nassarius spp.	x	x	x
Buccinum undatum	x	x	x
Lora nobilis	-	-	x
Trophonopsis clathratus	-	x	x
T. truncatus	-	-	x
Turritella communis	x	x	x
Trivia monacha	x	-	x
Mytilus edulis	x	x	x
Pecten maximus	x	-	x
Ostrea edulis	x	-	x
Chlamys islandica	-	-	x
Astarte sulcata	x	x	x
Cardium edule	x	-	x
Arctica islandica	x	x	x
Venus verrucosa	-	-	x
Macoma balthica	x	x	x

x = Recorded at a locality

\- = Not recorded

with those from other localities around the Irish Sea, a marked similarity is observed. Most of the recognized abundant species of British glacial deposits are represented (Neaverson, 1955), indicating that the presence of cold species in Pembrokeshire is not at all unusual. The fauna of the Shaw Cross outwash sands in Cheshire is apparently very similar to that of the Pembrokeshire outwash (Boulton and Worsley, 1965). Furthermore, an examination of Table XXV reveals that there are great similarities between the Pembrokeshire mollusca and those of the Wexford gravels, which are also considered to be glacially-derived (Mitchell, 1962). Only one of the species which I have found in Pembrokeshire outwash (namely Littorina neritoides) has not been recorded for Wexford; conversely some late Pleistocene and Crag shells found in Wexford have not yet been discovered in Pembrokeshire (McMillan, 1964). In Wexford Sipho spp. and Trophon spp. appear to be more abundant than in Pembrokeshire, although they are well represented at Tre-llys. Taken as a whole, the Wexford mollusca appear to have a more marked northern aspect, and the Mullock Bridge mollusca a more marked temperate aspect, than those of Tre-llys. Bearing in mind the dangers of attempting climatic and ecological comparisons on the basis of preserved mollusc valves in glacial outwash (see Chapter 4 a.), it may be tentatively suggested that the Mullock Bridge molluscsa are of of slightly more temperate origin than other Irish Sea outwash mollusca found to date, with increasingly cold faunas represented through Tre-llys to Wexford. This appears a reasonable theory, for in an interglacial or interstadial stage in the Irish Sea and Western Britain there should be a northwards decrease in temparate marine forms at any time. This is shown by the present-day restriction of certain warm-water species to the south and southwestern shores of Britain (Barrett and Yonge, 1964), while Baden-Powell (1955) has noted that during the Last Interglacial warm species were lacking in the Monastirian Clyde Beds, while warm forms were common in equivalent beds further south.

There may be some danger in correlating the Wexford Gravels, which contain Crag mollusca, with the Pembrokeshire and Cardiganshire Gravels, which do not. Baden-Powell (1955) has correlated the Wexford fauna with the Tyrrhenian stage, while superficial examination seems to indicate that the Pembrokeshire fauna correlates more closely with the Portland raised beach and the Kelsey Hill beds and March Gravels, considered to be of Monastirian age. If this faunal dating is correct, then the Wexford gravels could conceivably have been deposited during an earlier glaciation than that responsible for the deposition of the Pembrokeshire outwash. However, all the field evidence suggests that the Wexford fauna is derived (Mitchell, 1962), and the Crag species at Wexford may have been dredged by the advancing ice from fossiliferous deposits in the Clyde area (McMillan 1964). The Crag species therefore may have been re-deposited like the Jurassic fossils in the March gravels (Baden-Powell, 1934) and some well-preserved corals found at Tre-llys. There seems to be no faunal, morphological, or stratigraphic reason for assuming that the Wexford gravels are any older than those of West Wales (Mrs. N.F. McMillan, personal communication, 1965). Mitchell (1960) has already correlated the Wexford outwash gravels with those of Cardigan; it seems, therefore, that they may also correlate with those of Pembrokeshire.

Regarding the age of these outwash deposits, Mitchell (1960) has related them to the retreat of the Fremington (supposedly Riss/Saale) Irish Sea Ice-sheet. If this is correct, then the shells dredged up by this ice-sheet must indeed be of Tyrrhenian age, as suggested by Baden-Powell for Wexford. Other evidence, however, appears to contradict this dating. In derived material, the presence of extinct Crag species can be of no significance unless they are proved to be contemporaneous with "modern" species, and Crag species may yet be found in Pembrokeshire outwash. Whether or not Crag species are found, there appear to be firmer grounds for regarding the Pembrokeshire faunas as the correlatives of the March and Kelsey Hill gravels, which may also be glacial outwash (for an alternative view see Baden-Powell, 1934). All the Turritella fragments found at Mullock Bridge and Tre-llys to date have been identified as Turritella communis[1]; it therefore seems likely that they are of Late Pleistocene age (Baden-Powell, 1955). Indeed, the presence of many present-day Pembrokeshire species in the gravels invites some speculation that the faunas may have lived no earlier than the Last Interglacial. This speculation is supported by the negligible amount of decalcification in shelly gravels (at both Mullock Bridge and Tre-llys shelly gravels are found in permeable deposits within four feet of the ground surface).

Derived Shells from calcareous till.

In view of the apparent recent age of the shelly out-

1. The older forms, T. tricarinata (Brocchi and T. Pliorecens Monterosato have not been found in Wexford or Pembrokeshire; T. pliorecens may be expected in deposits dating from earlier glaciations.

wash gravels of Pembrokeshire and Cardiganshire, I have attempted some identification of marine mollusc fragments from Irish Sea till in order to assess the age relationship of this till with the gravels. Shell fragments were collected from Irish Sea till of the Dewisland Glaciation at Druidston and Aber-mawr. Most of the fragments were badly comminuted and smoothed, so that identification was often difficult; also, their rarity in the massive, compact till made the collection of large samples impossible.

(a) Druidston.

Shell fragments were collected from the face of the drift cliff or picked up from the drift surface where fragments had been washed from the till by rainwater. Some modern mollusca are found near the base of the cliff within the influence of storm-waves, and some valves have been carried up the cliff-face by sea-birds. However, these intruders were easily recognized, and the list below is believed to contain only derived species.

Buccinum undatum L.	Arctica sp.
Nucella lapillus (L)	Astarte borealis, Gray
Trophonopsis clathratus (L)	Astarte montagui (Dillwyn)
Trophon truncatus (Ström)	Cardium edule L.

Turritella communis Risso	Glycymeris glycymeris (L)
	Macoma sp.
Dentalium sp.	Macoma ballthica (L)
	Mya spp.
	Nuculana sp.
	Ostrea sp.
	Pecten maximus L. ?
	Venus spp.

Several of these species have been recorded for Druidston by Cantrill (1916), and his list also includes Astarte sulcata (da Costa) and Mytilus edulis (L). His list confirms the presence of Trophons in the till.

(b) Aber-mawr and other localities.

Shell fragments found in the Aber-mawr till represent the following species: Astarte montagui, Astarte sulcata, Dentalium sp., Pecten sp., and Mya arenaria. Williams (1927) has also recorded Astarte elliptica and Arctica islandica from calcareous Irish Sea till on the south Cardiganshire coast. Some of these species are mentioned by Jehu (1904) for various "Lower Boulder-clay" localities, but in addition he found Mytilus sp. in the Cardigan clay-pit, and Cardium islandicum Chem.?, Modiolus modiolus (L)?, and *Venus casina* L. in the Manorowen railway-cutting.[1]

Stratigraphic evidence has shown that the calcareous till at all these localities is dateable to the Dewisland Glaciation, so all the species recorded from the till may be examined together. All of these species are common in the outwash deposits, which have a similar mixture of Trophons alongside warmer species such as *Mytilus edulis*. The strong impression is gained that the same fauna is represented in both till and glacial outwash in West Wales, and there is good reason to suppose that both deposits are legacies of the Dewisland Glaciatiob.

Conclusions.

From the examination of the derived marine mollusca of the Pembrokeshire outwash gravels and Irish Sea till, the following suggestions may be made:

(A) The presence in the glacial deposits of species which might be found in coastal waters today indicates that temperate waters and possibly interglacial conditions extended into the Irish Sea at some time preceding the glaciation which dredged up the shells.

---

1. Jehu also found shells from inland Irish Sea till localities at Dinas and St. Nicholas. I have found *Astarte sulcata*, *Patella vulgata*, and *Patella intermedia* Jeffreys on the surface alongside the drainage reservoir on Treleddyd-fawr Moor; it is likely that these shells have been caried by sea-birds which frequent the reservoir.

(B) From faunal evidence it seems that the outwash and till may have been deposited during the same glaciation. Earlier stratigraphic evidence has suggested that this glaciation was the Dewisland Glaciation.

(C) The available faunal evidence suggests that the shell fragments in the deposits are probably no older than the Last Interglacial period, and may date from the early part of the Last Glaciation. The Dewisland Glaciation which dredged up these shells may therefore have occurred during the Würm.

(D) The faunal differences between the Mollusc collections from Mullock Bridge and Tre-llys are negligible, indicating that the glacial gravels of the so-called South Wales End-moraine are probably no younger than those much further south in Pembrokeshire.

(E) Faunal evidence affords no support for the theory that both Older Drift and Newer Drift deposits are to be found in Pembrokeshire.

Chapter 15.

(B) RADIO-CARBON DATING OF GLACIAL DEPOSITS.

Four organic samples from glacial deposits in Pembrokeshire have been dated by the radio-carbon method and confirms the impressions gained from stratigraphic studies and faunal analysis that the Dewisland Glaciation was the last glaciation of West Wales.

1. Samples from fluvio-glacial outwash.

Mullock Bridge. A sample of c. 400 gms. of marine mollusc fragments was collected from the gravel-pit described briefly in the earlier part of this chapter. In view of the prolonged search necessary to obtain a sample of 400 gms. of shells, every well-preserved fragment encountered was collected, regardless of species. The shells were collected from gravelly horizons throughout the pit, and were kept in a polythene bag; the sample was not allowed to come into contact with other organic materials prior to C^{14} dating. A C^{14} age determination on this sample by the National Physical Laboratory yielded the result

$$37{,}960 \begin{smallmatrix} +1700 \\ -1400 \end{smallmatrix} \text{ years B.P. (N.P.L. 80)}$$ [1]

---

1. A copy of N.P.L. Report No. C 66 (27th August, 1964) on this age determination is included in Appendix XIII.

Tre-llys. From the shelly gravels in Tre-llys Pit, near Aber-mawr, a sample of just over 300 gms. was collected. Only solid well-preserved fragments were collected, although the fragments were generally more finely comminuted and more friable than those at Mullock Bridge. Again the sample was carefully handled and kept in a polythene bag until dating could be undertaken. The sample was dated by the C^{14} method at the National Physical Laboratory as

$$37{,}310 \begin{smallmatrix} + 1515 \\ - 1275 \end{smallmatrix} \text{ years B.P. (N.P.L. - 97)}$$ [1]

It is thought that both age determinations are entirely reliable. Shells were not collected from leached and weathered layers in either pit, and the state of preservation of most fragments was good; few shells were badly pitted by the action of percolating groundwaters. P.H. values were taken in both pits at varying depths to investigate the possibility that percolating ground-waters may have contaminated the shelly gravels. At Tre-llys samples from the gravels above the shelly bands yielded P.H. values of 4.6 and 6.0, indicating that groundwaters are probably not alkaline and that "new" calcium carbonate has probably

1. A copy of Report C. 73 (14th April, 1965) is included in Appendix XIII.

not affected the shell fragments. Readings at Mullock Bridge from above the shelly gravels in various parts of the pit yielded values of 6.6, 6.4, 6.4, 6.4, and 6.6. In contrast the shelly gravels yielded values of 8.4 and 8.1. Again there seems to be little likelihood that there are contaminated ground-waters in the pit.

Laboratory pre-treatment included the rejection of apparently weathered shell fragments and the removal by leaching of the outer third of the shells in each test sample. The middle and inner thirds of each sample were dated separately, with almost identical results, apparently confirming that there has been negligible contamination.

The implications of the mixture of cold and temperate species in each sample have been discussed earlier in this chapter, and it must be borne in mind that both dates are <u>mean</u> dates obtained from samples incorporating mollusca which may vary greatly in age and provenance. It is possible that many shells older than c. 38,000 years B.P. are mixed with shells which lived after that date.

Since both samples were taken from glacial outwash deposits which are intimately associated with patches of non-calcareous till, it is clear that the shell fragments must have been dredged up from their living-positions on the floor of the Irish Sea, or from pre-existing beach deposits, by a major glaciation. The very presence of shells in the outwash at Mullock Bridge means that the ice must have moved from the north or north-west; this is also attested by the presence of erratics from the St. David's district in the Mullock Bridge pit. There can be little doubt that the ice-sheet responsible for the deposition of the gravels at Mullock Bridge and Trellys was a true Irish Sea ice-sheet. This ice-sheet must have over-ridden Western Pembrokeshire within the last 38,000 years, and if many of the shells in the samples are younger than 38,000 years B.P., it follows that the last glaciation of the area must have occurred even more recently.

This dating contradicts several previously-published opinions concerning the age relationship of drifts and the Irish Sea. As noted in Chapter 2, Mitchell (1960) and Synge (1964) have suggested that the Midland General - Clynnog Fawr moraine is the end-moraine of the Last Glaciation in the Irish Sea; alternatively Charlesworth (1929; 1957) has placed the Last Glaciation limit at the South Wales End-moraine, while Wirtz (1953) has also suggested a limit in the Teifi Basin. Recently Bowen (1965) has suggested that the last major glaciation of West Wales occurred before 50,000 years B.P. On the other hand the dates from Mullock Bridge and Tre-llys indicate that the last major Irish Sea glaciation occurred more recently than has previously been supposed, and extended at least as far south as the shores of Milford Haven. It follows that neither the Midland General - Clynnog Fawr moraine nor the South Wales End-moraine can be identified as true end-moraines, unless they represent minor re-advances or retreat stages during the last overall phase of deglaciation.

It is gratifying that this C^{14} evidence confirms the stratigraphic evidence against the existence of the South Wales End-moraine, and supports the conclusions based upon faunal analysis that the hummocky gravels in the Fishguard area are no younger than gravels with no hummocky topographic expression eighteen miles further south. Similarly, the dates confirm the field impression that the shelly gravels at Tre-llys and Mullock Bridge are recent deposits, for at the former locality shelly gravels are found within 4 ft. of the ground-surface, and at the latter within 3 ft. of the surface. If the gravels were not the representatives of the last glaciation of Pembrokeshire, decalcification would surely have proceeded to a greater depth.

The Tre-llys and Mullock Bridge dates indicate that there has been a recent glaciation in West Wales; however, they do not confirm that this recent glaciation was the Dewisland Glaciation, for at neither of the field localities in question was Irish Sea till or local till seen beneath the gravels. The stratigraphic evidence presented earlier in the thesis has suggested strongly that the Dewisland Glaciation was the last glaciation of Pembrokeshire; again, in the earlier part of this chapter it was argued that from the point of view of the derived faunas the Irish Sea till of West Wales is no older than the outwash gravels. However, it could still be argued that the Dewisland Glaciation occurred much earlier than the glaciation represented by the shelly gravels, and was perhaps separated from it by a full interglacial stage. Again, it could be argued that the so-called "Upper Boulder-clay" of North Pembrokeshire is the moraine of a later glaciation.

In order to resolve these problems collections of organic material from two exposures of Irish Sea till were submitted for C^{14} dating.

2. <u>Samples from Irish Sea till.</u>

<u>Druidston.</u> (See P.248 for stratigraphy). Shell fragments are difficult to collect in bulk from the Irish Sea till exposures of Pembrokeshire as a result of the scarcity of fragments and the small size of exposures. However, at Druidston the whole face of the exposure is accessible, and

after a prolonged search c. 110 gms. of shell fragments were collected from the till face. The fragments were generally found lying on the till surface as a result of the erosive action of rain-wash. Generally, these fragments were small and severely abraded by ice-action, and very few complete values were included in the test sample. The sample was submitted to Isotopes, Inc., of New Jersey, U.S.A., who reported on the age determination as

$>$ 36,300 years B.P. (I - 1687)

Aber-mawr. (See P.122 for stratigraphy). A sample of wood fragments was collected from the Irish Sea till at Aber-mawr North, where the till is accessible at storm-beach level. All the wood fragments were dug out of the till face with a knife or pick, and none were collected from the base of the drift-cliff[1] or from weathered horizons in the till. It is not considered that any of the wood fragments could have been intruded into the till face by wave-action; again, it is not possible that any of the fragments could be pieces of post-glacial root systems. Most of the fragments collected were less than

---

1. Fragments of wood and peat from the post-glacial submerged forest at Aber-mawr are occasionally thrown to the top of the storm-beach by waves. These fragments could be confused with the ancient wood fragments from the till.

2" long, and most were severely abraded by ice-action. Many fragments retained their brown colouring, and pieces of bark were often discernible; however, other pieces appeared to be very ancient, and bore affinities to lignite. Unfortunately the wood structure of most of the fragments was not discernible without the complex procedure of embedding in resin and cutting thin sections; however, one fragment was identifiable as Pinus. After careful drying and packaging in a polythene bag, the lignite fragments were rejected and a sample of c. 75 gms. was submitted to the National Physical Laboratory for dating, who have given the interim date: approximately

40,000 years B.P. (N.P.L. - 98)[1]

The date for the Druidston shell sample is a minimum date, and is of limited value only. It indicates that the mean age of the shells in the sample is greater than 36,300 years B.P.; it is still possible that some shells in the sample may be younger than 36,300 years B.P., and it is also possible that the actual mean age of the sampled shells

---

1. The report on this date has not yet been received, but the final age determination is not expected to differ greatly from the 40,000 years B.P. quoted above.

is similar to that for Mullock Bridge and Tre-llys.[1] There is no reason to assume that the sample was contaminated; laboratory pre-treatment included the breaking up of shell fragments and the removal of 15% of the weight by leaching before the sample was hydrolyzed. The outer parts of the shell (i.e. those most likely to be contaminated) were not used for the age determination.

The Aber-mawr date indicates that pine-trees were probably alive at some locality north of Aber-mawr in the period 45,000 - 35,000 years B.P. There is no reason to assume that this sample was contaminated, for wood is a good material for C^{14} dating (see Chapter 4 (b)), and the wood fragments embedded in the Irish Sea till were quite free of modern rootlets. As in the shell samples, it is possible that the date is a mean date, for even the "fresh" wood fragments varied in state of preservation.

The date of the Aber-mawr sample leaves no doubt that the Irish Sea till of Pembrokeshire is the same age as the shelly gravels at Tre-llys and Mullock Bridge. It seems that the Dewisland Glaciation was indeed responsible

---

1. The equipment at Isotopes Inc. can determine ages back to 35,000 - 40,000 years B.P. only, so that a sample 38,000 years old would be marginal. In the case of the Druidston sample the count rate was indistinguishable from the background count (J. Tucek, Isotopes Inc: personal communication, 1965).

for the deposition of all the coherent glacial drifts in Pembrokeshire, and it is thus established as the last glaciation of West Wales.

Before attempting to reconstruct a tentative chronology for the Pleistocene events in Pembrokeshire, it will be worthwhile to look to other areas for correlation. For the moment, little will be gained by analysing current ideas on the events of the last glacial stage in Britain, since absolute chronology is hampered here by a paucity of C^{14} dates prior to 10,000 B.P. (West, 1963). In Northern Europe, on the other hand, there are many C^{14} dates for the span of the Würm/Weichsel glacial stage, and on the basis of floral and faunal studies and these absolute dates are apparently reliable chronology has been constructed.

3. The Events of the Würm/Weichsel Stage in Northern Europe.

Many authorities now appear to accept that the Last Interglacial (Eemian) ended in Northern Europe c. 70,000 years ago (see, for example, Andersen et al, 1960; Gross, 1958 and 1964; Zagwijn, 1961). At the close of the interglacial sea-level was falling after the Eemian transgression, and the mean July temperature in Denmark was c. 15° C (Fig. 126). In the Netherlands the warm temperature forest was deteriorating to a cool temperate forest (Andersen et al, 1960).

During the early glacial phase of the Würm/Weichsel[1] stage the climate fluctuated between subarctic and cool-temperate, with possible interstadials at c. 64,000 years B.P. (the Amersfoort Interstadial) and c. 59,000 B.P. (the Brorup Interstadial). At about 53,000 years B.P. the climate deteriorated sharply, after which Arctic tundra conditions persisted in North-west Europe until 32,000 years B.P., according to Zagwijn (1961). Van der Hammen (1952) has named this phase the Pleniglacial A, which was characterised by cold wet conditions and rapid solifluxion and cryoturbation (Fig.127). There are few C^{14} dates for this phase, but in the Netherlands Dryas floral remains and peat and gyttja indicate that some vegetal growth was possible. Following a short interstadial (the Paudorf Interstadial) at about 29,000 years B.P. there occurred Pleniglacial phase B, during which the climate was one of severe cold and aridity with vegetal growth apparently impossible (Andersen et al, 1960); this phase lasted from about 25,000 years B.P. till c. 12,000 years B.P. The Late-glacial phase, which followed, was one of oscillating

---

1. Hereafter simply called the Würm, for convenience, in the sense used by Gross (1958; 1964).

climate around 10,000 years B.P., and short interstadials have been named the Bølling and Allerød Interstadials.

In North Germany there is a large degree of agreement with this chronology, and several workers have suggested a correlation between the "Early-glacial" period of the Netherlands and an Early Würm period during which boreal to sub-arctic conditions persisted. Again, there is widespread agreement that the Early Würm climate was never as severe as that of the Main Würm (the Hauptwürm of Gross, 1958), when the glacial maximum occurred (Fig.128). Woldstedt (1958) has said that the Early Würm ice of the Fennoscandian ice-sheet never extended as far south as it did in the period 16,000 - 18,000 B.P. and Gross has suggested that the Early Würm ice may have remained within the bounds of Scandinavia. Thus the Pleniglacial phase B of the Netherlands correlates with the maximum ice-advance of the Würm; between 25,000 B.P. and 17,000 B.P. the cold was probably more severe than at any other stage of the Würm (Graul, 1962).

However, there is some disagreement concerning the Middle Würm, which is the critical period for the interpretation of the Pembrokeshire C^{14} dates. After Zeuner (1954) Gross (1956 and 1958) has suggested that a Göttweiger

Interstadial occurred between 44,000 B.P. and 29,000 B.P., during which the climate varied from sub-arctic to fully temperate. On the other hand Zagwijn (1961) has said "it appears that the data from the Netherlands do not indicate any really important improvement in climate between 42,000 and 32,000 years B.P." (P. 37). The climatic curves given by Andersen et al (1960) similarly show no amelioration at this time (Fig.126) and Wright (1961) has suggested that much of the evidence on which the Göttweiger Interstadial is based is open to criticism. De Vries (1958) has wondered whether the Göttweiger is really the equivalent of the Brorup, while Büdel (1953), after Penck, has considered the Göttweiger to be in reality the Last Interglacial. In 1964 Frenzel undertook pollen analyses in the Fellbrunner soil complex at the type locality of the Göttweiger Interstadial, and proposed that the soil complex is in fact much older, dating back to the Eemian Interglacial and the Amersfoort and Brorup interstadials. Consequently Gross (1964) has retracted the term "Göttweiger", but still insists that there was a Middle Würm period of fluctuating boreal and sub-arctic climates between 50,000 B.P. and 30,000 B.P. (Fig.128).

Thus while there is considerable doubt about the events of the Middle Würm, there does seem to be agreement on the climatic fluctuations of the greater part of the Würm, as follows:

Zone III (Younger Dryas)	c. 10,000 B.P.	Cold.
Allerød Interstadial	c. 11,000-12,300 B.P.	Warmer.
Main Würm glacial maximum (Pleniglacial B)	c. 17,000-25,000 B.P.	Glacial
Paudorf Interstadial	c. 29,000 B.P.	(Warmer)
Middle Würm (Pleniglacial A)	c. 30,000-50,000 B.P. (Fluctuating interstadial climate - Gross. Cold and moist - Andersen *et al.*)	
Early Würm (Early Glacial)	c. 50,000 B.P.-70,000 B.P. (Cold - Boreal to Subarctic)	
including Brorup Interstadial	c. 59,000 B.P.	
Amersfoort Interstadial	c. 64,000 B.P.	
Eemian Interglacial	c. 70,000 B.P. - ?	(Warm)

(after Gross, 1958; 1964; Andersen *et al* 1960; Zagwijn, 1961, Graul, 1962; Flint, 1957).

4. A Tentative Chronology for West Wales.

While part of the European sequence listed above may subsequently be proved unreliable, it may serve as a useful basis for the dating of events in West Wales during the Würm.

It is apparent that all three of the reliable C^{14} dates for Pembrokeshire fall within the span of the Middle Würm.[1] Furthermore, they apparently support Gross's contention that boreal conditions persisted for part of this period, for the boreal shell species and wood fragments which have been dated indicate that the climate in Western Britain during the Middle Würm must occasionally have been as warm as during Holocene pollen zones V and VI. Unfortunately, from the Pembrokeshire dates no indication can yet be gained of the length of time covered by this interstadial in the Irish Sea area; this question may be resolved when C^{14} dating can be undertaken on single mollusc and tree species which are likely to have lived only during a specific climatic phase. Perhaps "cold" species will be most reliable for fixing the end of the interstadial by C^{14} dating.

Tentatively it may be suggested that the Dewisland Glaciation was the equivalent in time of the European Main Würm Glaciation (John, 1965). Against this dating it may be argued that the C^{14} dates for Pembrokeshire are clustered about 37,000 - 40,000 years B.P., apparently indicating that the Dewisland Glaciation may have occurred very shortly

---

1. Copies of the N.P.L. Reports for Mullock Bridge and Trellys samples are included in Appendix XIII.

after 37,000 years B.P. This may subsequently prove to be the case, but at the moment it may be wiser to assume that there was approximate synchroneity with other glaciated lands, and that the last glaciation reached its peak after 28,000 B.P.[1] This is supported by recent C^{14} dates for North-east Scotland by Fitzpatrick (1965) and for Cheshire by Boulton and Worsley (1965). At Tiendland, near Elgin, a soil horizon occurs beneath till; the upper layers of this soil have been dated to 28,140 $^{+480}_{-450}$ years B.P., and the evidence is taken by Fitzpatrick to indicate that non-glacial conditions persisted in North-east Scotland during the Würm until after that date. Marine molluscs from outwash gravels at Sandiway, Cheshire, have been dated at 28,000 $^{+1800}_{-1500}$ years B.P., and apparently indicate that the only major glaciation of the Würm in the Irish Sea occurred after that date. On the basis of the C^{14} dates available at the moment, it seems unlikely that the Dewisland Glaciation occurred between 38,000 and 28,000 years B.P.

If the Dewisland Glaciation is correlated with the European Main Würm, it is necessary to make some suggestion concerning the periglacial phase during which the rubble-

---

1. In North America the Classical Wisconsin Glaciation lasted from c. 28,000 B.P. until c. 12,000 B.P., although there were less extensive glacial stages between 44,000 and 34,000 B.P. and between 62,000 and 50,000 B.P. (see De Vries and Dreimanis, 1960; Flint and Brandtner, 1961).

drifts of Aber-mawr, Druidston and elsewhere were soli-flucted. Kerney (1963) has shown that in South-East England periglacial conditions were suitable during Zone III for the solifluxion of 3 m. of chalk sludge. It is quite possible that the rubble-drifts and upper heads of Pembrokeshire could have formed at this time under a moist oceanic periglacial climate. The slight weathering horizons in the post-glacial heads at Pen Dal-aderyn may tentatively be correlated with the Allerød and Bølling interstadials.

At the base of the Pembrokeshire drift succession it appears reasonable to propose that the Poppit Interglacial was the equivalent of the Eemian Interglacial, during which sea-level may have risen to at least 30 ft. O.D. It is probable that the clue to the age of this interglacial will be found in the organic silts at West Angle, and pollen analysis and C^{14} dating of the site is urgently required. According to the European chronology the interglacial should be dated at greater than 70,000, but it is by no means beyond the realms of possibility that the West Angle transgression and the Poppit Interglacial may prove to be the equivalent in time of the "Middle Würm Interstadial".

The main solifluxion phase in Pembrokeshire occurred after the Poppit Interglacial and before the Dewisland

Glaciation. It therefore appears entirely logical to correlate it with the Early Würm of Gross and perhaps with part of Van der Hammen's Pleniglacial A (Fig.127). The climatic fluctuations recorded by the lower heads at Aber-mawr are in accord with fluctuations recorded for the Netherlands at this time, and it is possible that the weathering horizon at Aber-mawr may correlate with either the Brorup or Amersfoort Interstadials. However, if this correlation is correct, why are there no traces of the Middle Würm Interstadial in the Pembrokeshire sections, when one would espect possible weathering-horizons <u>above</u> the lower heads at Aber-mawr? Did the interstadial occur such a short time before the Dewisland Glaciation that its weathering horizons were not deeply buried by head, and so were consequently removed by ice-action? This seems a plausible hypothesis, but it would be unwise to press correlations too far at this stage, and it may be best to state simply that the fluctuating periglacial climates of the Main Solifluxion phase in West Wales possibly occurred prior to the Middle Würm Interstadial.

Two more tentative correlations may be made at this point. The New Quay Glaciation and the fine flaky head at Aber-mawr apparently correlate with one another and may mark the culmination of a cold period; the maximum was

TABLE XXVI. A TENTATIVE LATE PLEISTOCENE CHRONOLOGY FOR WEST WALES.

Thousands of years B.P.	North Europe	C14 dates	Pembrokeshire terminology	Events in West Wales
5	Holocene			Weathering, soil development etc.
10	Zone III		Solifluxion	Upper head
	Allerød			Weathering?
15				
20	Main Würm Glaciation		Dewisland Glaciation	Irish Sea Glaciation from N.W.
25			Middle Würm (Inter-stadial?)	Boreal / arctic climates? Sea-level low? Weathering?
~28	Paudorf			
30	Middle Würm (Pleni-glacial A)			
35–45		Aber-mawr; Mullock Bridge; Tre-llys; Druidston (?)		
50	Early Würm		Main Solifluxion Phase	
55				New Quay Glac.
				Main head, with at least one phase of weathering?
60	Brorup			
65	Amersfoort			
70	Eemian Interglacial		Poppit Interglacial	Raised beach. Sea-level at least 30 ft. O.D.
80	Riss ?		Early Glaciation ?	Large glaciation from N.E.?

followed by a slight climatic amelioration and more moist periglacial conditions. It is tempting to suggest that the maximum cold recorded in West Wales was the peak of a Early Würm periglacial phase, and that the amelioration marked the onset of the Middle Würm Interstadial.

Again, it has been argued that the Early Glaciation of West Wales was more powerful than the Dewisland Glaciation, and had far-reaching effects upon the Pembrokeshire landscape. In Northern Europe, the Riss/Saale Glaciation was more extensive than the Würm (Woldstedt, 1958), and although it covered a shorter time-span it appears to have been more severe (Fairbridge, 1962). It seems logical to correlate the Early Glaciation with the Continental Riss.

On the basis of the arguments presented above, a tentative sequence of events for West Wales is suggested in Table XXVI. It may well be that some of these correlations may be proved unreliable, and indeed, there already appear to be several inherent contradictions which can only be resolved by careful palaeobotanical and C^{14} analysis of all available sites. However, the correlations seem reasonable in the light of the evidence available at present, and perhaps this tentative sequence of events may find some use as a working hypothesis during future investigations of the Pleistocene chronology of West Wales.

Conclusion

Some Possible Implications

Stratigraphic implications

1. From the stratigraphic studies which make up the bulk of this thesis, it is suggested that there is no tripartite drift subdivision in West Wales. It is possible that in other areas, too, the whole suite of drift deposits may date from a single glaciation; it may often be found that the sands and gravels do not lie between two tills related to separate readvances.

2. The South Wales End-moraine does not represent a Newer Drift readvance. This may indicate that in other areas, too, the southern limits of fresh drift features may not represent true glacial limits. The significance of hummocky topography needs to be reassessed, and it seems that some areas of Britain south of the so-called Newer Drift limit may have been glaciated during the Last Glaciation.

3. The Upper Boulder-clay in Pembrokeshire is in fact a solifluxion deposit which does not represent a local glaciation. It is possible that detailed examination of some of the local tills elsewhere in Western Britain will reveal that they are also solifluxion deposits.

4. The till deposits of Pembrokeshire, including the plastic Irish Sea till, were deposited for the most part by dumping in a dead-ice environment. This fact may provide some warning against the easy acceptance of networks of till fabric diagrams unless it can be proved that the preferred orientation of pebbles does represent the direction of regional ice-movement, rather than a local sludging direction.

5. In West Wales there is convincing evidence for only two glaciations. No evidence appears to have come to light which indicates that there was a glaciation earlier in the Pleistocene than the Early Glaciation, unless the Early Glaciation was itself composite in time.

6. The techniques used in this study have been simple, but much has been learned about drift characteristics which could not have been discerned from field observation alone. Perhaps the techniques employed may find some use in future studies of complex coastal drift sections.

Morphological Implications

1. Sea-level movements in West Wales have been complex, and are difficult to equate with the scheme of a high regressive Pleistocene sea. Perhaps evidence from elsewhere in the British Isles will be forthcoming to indicate

that there were prolonged periods of interglacial or pre-glacial low sea-level prior to the Early Glaciation. Also, perhaps more evidence will be found to suggest that the cutting of the coastal rock platforms and the deposition of the raised beaches of Western Britain were separated by a full glacial stage.

2. The evidence from Pembrokeshire supports the growing body of opinion against extensive pro-glacial lakes and overflow channels in Britain during the Pleistocene. As is now suggested for many other areas of Britain, the main meltwater channels of Pembrokeshire were cut sub-glacially.

It is often thought that the meltwater channels of Britain date from the Last Glaciation. There is convincing evidence from Pembrokeshire that they may be older, and perhaps the discovery of head or interglacial deposits beneath tills of the Last Glaciation on the floors of channels elsewhere may similarly indicate that many are ancient features, in spite of their apparently fresh appearance.

The implications of the dating of the Dewisland Glaciation

In the last chapter no attempt was made to discuss previous suggestions concerning the absolute age of the last major glaciation of Western Britain; indeed, without a personal knowledge of the sites on which these datings are based, it would be unwise to attempt a detailed discussion. However, as a conclusion to this thesis it may be relevant to summarise the datings which differ from that in the foregoing pages.

Radio-carbon dates comparable to those for Pembrokeshire have been obtained from Fladbury (38,000 ± 700 years B.P.) and Upton Warren (41,900 ± 800 years B.P.) in the Midlands by Coope, Shotton, and Strachan (1961). A further important date is that for Chelford (57,000 years B.P.) obtained by Simpson and West (1958). From interpretations of the floral and faunal associations at these sites, and their relationships with the Severn terraces and the Midland tills, Coope, Shotton and Strachan arrive at the conclusion that the Main Irish Sea Glaciation of the Midlands occurred prior to 42,000 years B.P. This is supported by Bowen (1965) for the Main Welsh Glaciation of South Wales, and by Godwin (1960), who has stated "... the strongest advance of the British ice during the last glaciation occurred between 57,000 and 42,000 years ago" (P. 291). Other authors (e.g. Peake, 1961; Embleton, 1964; Boulton and Worsley, 1965) have proposed a much more restricted Main Würm advance in the Midlands, possibly coinciding with Wills' Welsh Readvance.

In Ireland no C14 dates have yet been obtained for the Würm glacial stage, but as noted earlier, Synge, Stephens, and Mitchell have separated the Eastern General and Midland General glacial phasesby a full interglacial; the Eastern General Glaciation is dated as Riss, and the Midland General as Würm. Interglacial beds beneath Eastern General till or its equivalents at Gort, Kilbeg, Newtown, and Baggotstown have been interpreted by Watts (1959; 1964) and by Jessen <u>et al</u> (1959) as Mindel-Riss in age, while a plant bed above Irish Sea till at Ardcavan has been dated as Riss-Würm on the basis of pollen analysis (Mitchell, 1948). However, in spite of this work it may be significant that no interglacial beds have been found between Eastern General and Midland General tills (Farrington, 1957).

The Dewisland till of Pembrokeshire, dated as younger than 38,000 years B.P., is almost certainly the stratigraphic equivalent of the Eastern General till of Ireland and the Fremington till of Devon; probably it is also the equivalent of the Irish Sea till of the Scilly Isles and the

Main Irish Sea till of the Midlands (Wills, 1937). There appears no option but to propose that all the tills of the Main Irish Sea Glaciation are less than 38,000 years old. This dating may be open to many objections and will undoubtedly receive criticism, but from the literature there seems to be little evidence to contradict it. Indeed, the case for an extensive Main Würm Glaciation has already been argued forcibly by Penny (1964), and while it would be pointless to repeat Mr. Penny's arguments, it may be recalled that Wills was moved to admit in 1937 "There is no conclusive evidence in the Midlands that the cold conditions of the Welsh Readvance were anything but a climatic oscillation in the general amelioration that caused the gradual melting of the Irish Sea Glacier" (P. 94). Again, in Ireland Dr. Farrington (1957) has noted that the officers of the Geological Survey of Ireland saw no reason for separating the two major glaciations by an interglacial stage. In other words, the Eastern General and Midland General tills, and the tills of the Main Irish Sea Glaciation and the Welsh Readvance in the Midlands, may all be of Main Würm age. It is to be hoped that this suggestion may find confirmation in other detailed stratigraphic work and in C14 dating of other organic deposits from the Midlands, Wales and Ireland.

In 1964 Mr. Penny wrote "absolute dates, whatever part of the geological column they refer to,are good servants but bad masters...... their usefulness depends not only on their inherent accuracy, but also on their being correctly related, by basic field mapping and other stratigraphical studies, to the sequence of events in the area. It is hoped that this thesis has shown that the C14 dates for Pembrokeshire are good servants, for they confirm the impressions gained from a detailed stratigraphic study of a small area. The extent to which the Pembrokeshire chronology is relevant for the rest of Western Britain must remain a matter for conjecture, but perhaps this work may have shown that the Pembrokeshire drifts hold several valuable cluesto the Late Pleistocene chronology of Britain.

REFERENCES

Alimen, M.H. 1958 "Premiers résultats de l'étude morphométrique de Cailloutis sahariens" Rev. Géomorph. Dyn. 9, p.162.

Allen, A. 1960 "Seismic refraction investigations of the preglacial valley of the River Teifi near Cardigan". Geol. Mag. 97 (4) p.276.

Andersen, S.T. et al 1960 "Climatic change and radiocarbon dating in the Weichselian Glacial of Denmark and the Netherlands." Geol. en Mijnb. 39, p.38.

Anderson, R.C. 1955 "Pebble lithology of the Marseilles till sheet in north-eastern Illinois". J. Geol. 63, p.228.

Anderson, W. 1939 "Possible late-glacial sea-levels at 190 and 140 ft. O.D. in the British Isles". Geol. Mag. 76, p.317.

Andersson, J.G. 1906 "Solifluction, a component of sub-aerial denudation". J.Geol. 14,p.91.

Andrews, J.T. 1963 "The Cross-valley moraines of North-Central Baffin Island: a quantitative analysis". Geog. Bull. 20, p.82.

Annersten, L. 1964 "Interaction between surface cover and permafrost". 20th I.G.C. Abstracts of Papers, London, p.134.

Arber, M.A. 1960 "Pleistocene Sea-levels in North Devon". Proc. Geol. Ass. Lond. 71, p. 169.

Arkell, W.J. 1943 "The Pleistocene Deposits at Trebetherick Point, North Cornwall: their interpretation and correlation". Proc. Geol. Ass. Lond. 54,p.141.

——— 1946 "Three Oxfordshire palaeoliths and their significance for Pleistocene correlation". Proc. Prehist. Soc. 11, p.29.

Ault, W.U. 1964 "Radiocarbon dating service". Isotopes Inc. Services in Research. (unpub.).

Baden-Powell, D.F.W. 1927 "The Climatic Equivalence of the Raised Beach Mollusca". Geol. Mag. 64, p.432.

——— 1928 "On the Climatic Equivalent of raised beach mollusca". Rep. Comm. Pliocene and Pleistocene Terraces. I.G.U. 2 (12) p.107.

——— 1934 "On the marine gravels at March, Cambridgeshire". Geol. Mag. 71, p.193.

——— 1955 "The correlation of the Pliocene and Pleistocene marine beds of Britain and the Mediterranean". Proc. Geol. Ass. Lond. 66 (4) p.271.

Ball, D.F. 1960 "Relic-soil on limestone in South Wales". Nature, 187 (4736) p. 497.

Barrow, G. 1906 "The Geology of the Isles of Scilly" Mem. geol. Surv.

Bassindale, R. and Barrett, J.H. 1957 "The Dale Fort marine fauna" Proc. Bristol Nat. Soc. 29 (3) p.227.

Barrett, J.H. and Yonge, C.M. 1964 "Pocket Guide to the Sea-shore". London, Collins.

Blake, W. Jr. 1961 "Radiocarbon dating of raised beaches in Nordaustlandet, Spitsbergen". in G.O. Raasch (ed.) Geology of the Arctic, Toronto, 1, p.133.

——— 1964 "The Glacial History of Bathurst Island". 20th I.G.C. Abstracts of Papers, p.79.

Bonney, T.G. 1903 "Ice-work" (2nd Ed.) London, Kegan Paul, Trench, Trüber and Co.

Boswell, P.G.H. 1916 "The Petrology of the North Sea Drift and Upper Glacial Brickearths in East Anglia". Proc. Geol. Ass. Lond. , 27, p.79.

Boulton, G.S. and Worsley, P. 1965 "The Late Weichselian Glaciation in the Cheshire-Shropshire Basin" Nature, in press.

Bowen, D.Q. 1964 In discussion after Jones, O.T. "The glacial and post-glacial history of the lower Teifi valley". Proc. Geol. Soc. Lond. 1617 (1963-4) 30th October 1964, p.98.

———— 1965 "Contributions to the geomorphology of Central South Wales". Univ. of London Ph.D. Thesis (Unpub.)

———— and Gregory, K.J. 1965 "A glacial drainage system near Fishguard, Pembrokeshire". Proc. Geol. Ass. Lond. (in press).

Boyd, L.A.(ed.) 1935 "The Fjord Region of East Greenland". American Geog. Soc. Spec. Pub. 18.

Boyé, M. 1960 "Morphométrie des galets de quartz en Guyane Francaise" Rev. Géomorph. Dyn. 11(1) p.13.

Broecker, W.S. et al. 1960 "Evidence for an abrupt change in climate close to 11,000 years ago". Amer. J. Science, 258, p.429.

Brown, E.H. 1960 "The Relief and Drainage of Wales", Cardiff, University of Wales Press.

Brunsden, D. 1963 "The Denudation Chronology of the River Dart". Trans. I.B.G. 32, p.49.

Bryan, K. 1946 "Cryopedology - the study of frozen ground and intensive forest-action with suggestions on nomenclature". Amer. J. Science, 244, p.622.

Büdel, J. 1959 "Periodische und episodische Solifluktion im Rahmen der klimatischen Solifluktionstypen". _Erdkunde_, 13, p.297.

——— 1960 "Climatic types of solifluction - comparison of the present solifluction on Spitsbergen and that of the Pleistocene in Central Europe." _I.G.C. Norden, Abstracts of Papers_, p. 42.

Bull, A.J. 1942 "Pleistocene Chronology". _Proc. Geol. Ass. London_. 53, p.1.

Burton, B.W. 1952 "A contribution to the geomorphology of Pembrokeshire". University of London M.Sc. Thesis (unpub.)

Cailleux, A. 1945 "Distinction des galets marius et fluviatiles". _Bull. Soc. Géol. France_, 5 (15), p.375.

——— 1947 "L'indice d'émoussée: definition et première application". _C.R.Somm. Géol. France_.

——— 1955 "L'indice d'emoussee des grains de sable et gres." _Rev. Géomorph.Dyn_. p.78.

——— 1962 "Cartes de morphologie périglaciaire quaternaire en Europe". _Biul. Peryglac_. 11, p.129.

Callow, W.J. 1962 "Notes for guidance in the selection of material for radiocarbon measurement". National Physical Laboratory (duplicated sheet - unpublished).

——— _et al_. 1963 "National Physical Laboratory Radiocarbon Measurements I." _Radiocarbon_ 5, p.34.

Cantrill, T.C. _et al_. 1916 "The Geology of the South Wales Coalfield", Part XII, "The Country around Milford". p.154. Geol. Surv.

Carruthers, R.G. 1939 "On northern glacial drifts: some peculiarities and their significance." Quart. J. geol. Soc. Lond. 95 (3) p. 299.

——— 1947 "The secret of the glacial drifts". Proc. Yorks. Geol. Soc. 27 (2) p. 43.

Charlesworth, J.K. 1929 "The South Wales End-moraine" Quart. J. geol. Soc. Lond. 85 (3) p. 335.

——— 1957 "The Quaternary Era" Vol.2. London.

——— 1963 "Some observations on the Irish Pleistocene", Proc. Roy. Irish Acad. (B) 62, p.295.

Codrington, T. 1898 "On some submerged rock-valleys in South Wales, Devon and Cornwall". Quart. J. geol. Soc. Lond. 54, p.251.

Cole, G.A.J. and Hallissy, T. 1914 "The Wexford gravels and their bearing on interglacial Geology". Geol. Mag. 6 (1) p.498.

Coope, G.R. et al. 1961 "A late-Pleistocene fauna and flora from Upton Warren, Worcestershire." Phil. Trans. Roy. Soc. B. 244, p.379.

Cox, A.H. 1915 "The Geology of the district between Abereiddy and Aber-castle". Quart. J. geol. Soc. Lond. 71, p.273.

——— et al. 1930a "The Geology of the St. David's District, Pembrokeshire." Proc. Geol. Ass. Lond. 41, p.241.

——— et al. 1930b "The St. David's District --Report." Proc. Geol. Ass. Lond. 41, p.412.

——— 1930c "Preliminary note on the Geological Structure of Pen Caer and Strumble Head, Pembrokeshire." Proc. Geol. Ass. Lond. 41, p.274.

——— and Thomas, H.H. 1924 "The Volcanic series of Trefgarn, Roch, and Amblestone" Quart. J. geol. Soc. Lond., 80, p.520.

Cox, E.P. 1927 "A method of assigning numerical and percentage values to the degree of roundness." J. Palaeontol. 1, p.179.

Craig, G.Y. 1964 "An ecological approach to the study of fossil marine invertebrates" in Nairn, A.E.M. (ed.). "Problems in Palaeoclimatology" p.583.

Czeppe, Z. 1964 "Exfoliation in a periglacial climate". Geog. Palonica. 2,p.5.

Czudek, T. 1964 "Periglacial slope development in the area of the Bohemian massif in Northern Moravia". Biul.Peryglac. 14, p.169.

Davies, G.L. 1959 "Platforms developed in the boulder-clay of the coastal margins of counties Wicklow and Wexford." Irish Geog. 4, p.107.

Davies, M.F. 1939 "The Land of Britain" Pt.32, Pembrokeshire. Rep. Land Utilisation Survey, London.

Davis, W.M. 1909 "Glacial erosion in North Wales" Quart. J. geol. Soc. Lond. 65, p.281.

Derbyshire,E. 1958 "The identification and classification of glacial drainage channels from aerial photographs." Geogr. Annlr. 40, p.188.

——— 1961 "Subglacial col gullies and the deglaciation of the North-east Cheviots". Trans. I.B.G. 29,p.31.

Dewey, H. 1910 "Notes on some igneous rocks from North Devon." Proc. Geol. Ass. Lond. 21, p.429.

——— 1913 "The raised beach of North Devon". *Geol. Mag.* 10, p.154.

——— 1918 "On the origin of some landforms in Caernarvonshire". *Geol. Mag.* 55, p.145.

——— 1948 "South-West England". Brit. Reg. Geol.

Dines, H.G. *et al*. 1940 "The mapping of head deposits". *Geol. Mag*. 77(3) p.198.

Dixon, E.E.L. 1906 "Summary of progress for 1905". Mem. Geol. Survey, p.70.

——— 1907 "Summary of progress for 1906". Mem. Gol. Survey. p.63.

——— 1921 "The Geology of the South Wales Coalfield". Pt.XIII. The Country around Pembroke and Tenby, p.189. Geol. Surv.

Donn, W.L. *et al*. 1962 "Pleistocene ice volumes and sea-level lowering". *J.Geol*. 70(2) p.206.

Donovan,D.T. 1962 "Sea-levels of the last glaciation" *Bull. Geol. Soc. Amer*. 73, p.1297.

Donovan, D.T. *et al.* 1961 "Geology of the floor of the Bristol Channel" *Nature*, 189 (4758) p.51.

Driscoll, E.M. 1958 "The Denudation Chronology of the Vale of Glamorgan" *Trans.I.B.G*. 25, p.45.

Dylik, J. 1960 "Rhythmically-stratified slope waste deposits" *Biul. Peryglac*. 8, p.31.

——— 1964a "The essentials of the meaning of the term 'periglacial' ". *Bull. Soc. Sciences et des Lettres de Lodz*. 15, 2, p.1.

——— 1964b In discussion on head deposits,I.G.C. Symposium 57a, Exeter, 1964. (unpublished)

Elsden, J.V. 1905 "The igneous rocks occurring between St. David's Head and Strumble Head." Quart. J. geol. Soc. Lond. 61, p.579.

Embleton, C. 1964a "The planation surfaces of Arfon and adjacent parts of Anglesey: a re-examination of their age and origin". Trans. I.B.G. 35, p.17.

——— 1964b "The deglaciation of Arfon and Southern Anglesey, and the Origin of the Menai Straits". Proc. Geol. Ass. Lond. 75 (4) p.407.

Emiliani, C. 1955 "Pleistocene temperatures" J. Geol. 63, p.538.

Evans, W.D. 1940 "The Geology of the Prescelly Hills and adjoining areas in North Pembrokeshire and Carmarthenshire." University of London Ph.D. Thesis (unpub.).

——— 1945 "The Geology of thePrescelly Hills, North Pembrokeshire". Quart.J.geol. Soc. Lond. 101, p.89.

——— 1964 In discussion after Jones, O.T. "The glacial and post-glacial history of the Lower Teifi valley." Proc.Geol.Soc.Lond. 1617 (1963-4) 30th October, 1964. p.99.

Ewing, M. and Donn, W.l. 1961 "Pleistocene Climate changes" in Raasch, G.O. (ed.) "Geology of the Arctic", Toronto. p.931.

Fairbridge, R.W. 1961 "Eustatic changes in sea-level" in Ahrens, L.H. et al. (ed.) "Physics and Chemistry of the Earth" Pergamon, Vol. 4, p.99.

——— 1962 "World sea-level and climatic changes" Quaternaria, 6, p.111.

——— 1964 "African ice-age aridity" in Nairn, A.E.M. (ed.) "Problems in Palaeo-olimatology", London. p.356.

Farrington, A. 1939 "Glacial geology of South-east Ireland". Proc. Geol. Ass. Lond. 50 (3) p.337.

——— 1942 "The Granite drift near Brittas". Proc. Roy. Irish Acad. (B) 47, p.279.

——— 1944 "The Glacial Drifts of the district around Enniskerry, Co. Wicklow" Proc. Roy. Irish Acad. (B) 50, p. 133.

——— 1945 "The level of the ocean in glacial and late-glacial times" Proc. Roy. Irish Acad. (B) 50 p.237.

——— 1949 "The glacial drifts of the Leinster Mountains". Journ. Glac. 1, p.220.

——— 1954 "A note on the correlation of the Kerry-Cork Glaciations with those of the rest of Ireland". Irish Geog. 3, p.47.

——— 1957 "The Ice-age in the Dublin District". Journ. Inst. of Chem. of Ireland. 5, p.23.

——— and Stephens, N. 1964 "The Pleistocene Geomorphology of Ireland" in Steers, J.A. (ed.) "Field Studies in the British Isles", London.

Fergusson, G.J. 1955 "Radiocarbon dating system". Nucleonics 13 (1), p.18.

Feyling-Hanssen, R.W. and Olsson, I. 1959 "Five radio-carbon datings of Post-glacial shorelines in Central Spitsbergen." Norsk Geog. Tidss. 17 (1-4) p.122.

FitzPatrick, E.A. 1965 "An interglacial soil at Tiendland, Morayshire" (letter) Nature, August 7 (In press).

Flett, J.S. and Hill, J.B. 1912 "Geology of the Lizard and Meneage" Mem. Geol. Surv.

Flint, R.F. 1929 "The Stagnation and dissipation of the Last Ice sheet" Geog. Rev. 19, p.256.

——— 1957 "Glacial and Pleistocene Geology" New York, Wiley.

——— and Brandtner, F. 1961 "Climatic changes since the last Interglacial" Amer. J. Science 259 (5), p.321.

——— and Deevey, E.S. 1951 "Radiocarbon dating of Late Pleistocene events". Amer.J.Science 249, p.257.

Fraser, J.K. 1959 "Freeze-thaw frequencies and mechanical weathering in Canada" Arctic 12, p.40.

Frenzel, B. 1964 "Zur Pollenanalyse von Lössen" Eisz. und Geg. 15, p.5.

Funnell, B.M. 1961 "The Palaeogene and Early Pleistocene of Norfolk". Trans. Norfolk Norw. Nat. Soc. 19, p.340.

Galloway, R.W. 1956a "Études morphométriques de galets dans le Lyngsdal" Rev.Géomorph. Dyn. 7, p.53.

——— 1956b "The structure of moraines in Lyngsdalen, North Norway." Journ. Glac. 2, p.730.

——— 1958 "Periglacial Phenomena in Scotland" University of Edinburgh Ph.D.Thesis (unpub.)

Gardiner, M.J. and Ryan, P. 1964 "Soils of County Wexford" National Soil Survey of Ireland, Bulletin No. 1., Dublin.

Geikie, J. 1894 "The Great Ice-Age", London, Stamford.

George, T.N. 1932 "The Quaternary Beaches of Gower" Proc. Geol. Ass. Lond. 43, p.291.

——— 1933 "The Glacial Deposits of Gower" Geol. Mag. 70, p.208.

——— 1938 "Shoreline evolution in the Swansea district". Proc. Swansea Sci. and Field Nat. Soc. 2, p.23.

——— 1942 "The changing sea-level in South Wales" in Discussion on Bull, "Pleistocene chronology", Proc. Geol. Ass. Lond. 53, p.21.

Gillberg, G. 1956 Föreningens i Stockh. Förh. 78, p.357.

Gjessing, J. 1960 "Isavsmeltingstidens drenering, dens forløp og formdannende virkning i Nordre Atuedalen med sammenlignende studier fra Nordre Gudbrandsdalen." Ad Novas, 3.

Godard, A. 1961 "L'efficacité de l'erosion glaciaire en écosse du nord." Rev. Géomorph. Dyn. 12 (1), p.32.

Godwin, H. 1960 "Radiocarbon dating and Quaternary history in Britain". Proc. Roy. Soc. B, 153, p.287

——— 1962 (letter) Nature 195 (4845) p.984.

———, Suggate, R.P. and Willis, E.H. 1958 "Radiocarbon dating of the Eustatic Rise in Ocean Level." Nature 181, (1518).

——— and Willis, E.H. 1959 "Radiocarbon dating of the Late-Glacial Period in Britain" Proc. Roy. Soc. B 150, p.199.

Godwin-Austen, R.A.C. 1851 "On the superficial accumulations of the coasts of the English Channel and the changes they indicate" Quart. J. geol. Soc. Lond. 7, p.118.

Goskar, K.L. and Trueman, A.E. 1934 "The coastal plateaux of South Wales" Geol. Mag. 71, p.468.

Graul, H. 1962 "Die Niederterrassenfelder im Umkreis von Basel." Eisz. und Geg. 13, p.181.

Green, J.F.N. 1911a "The Geology of the District around St. David's, Pembrokeshire." Proc. Geol. Ass. Lond, 22, p.121.

——— 1911b "Excursion to the St.David's District, South Wales." Proc. Geol. Ass. Lond. 22, p.215.

——— 1943 "The Age of the raised beaches of south Britain". Proc. Geol. Ass. Lond. 54, p.129.

Greenly, E. 1919 "The Geology of Anglesey". Mem. Geol. Surv.

Gregory, H.E. 1915 "A note on the shape of pebbles". Amer. J. Science 39, p.300.

Gregory, K.J. 1962 "The Deglaciation of Eastern Eskdale, Yorkshire." Proc. Yorks. Geol. Soc. 33(4) p.363.

Gregory, S. 1963 "Statistical Methods and the Geographer", London.

Griffiths, J.C. 1939 "The Mineralogy of the glacial deposits of the region between the Rivers Neath and Towy, South Wales" Proc. Geol. Ass. Lond 50(4) p.433.

——— 1940 "The glacial deposits west of the Taff, South Wales" University of London Ph. D. Thesis. (unpub.).

Groom, G.E. 1956 "The development of the Dale Valley" Rep. Field Studies Council 1955-56. p. 34.

Gross, H. 1956 "Das Göttweiger Interstadial, ein zweiter Leithorizont der letzten Vereisung". Eisz. und Geg. 7, p.87.

——— 1958 "Die bischeigen Ergebnisse von C^{14} Messungen und paläontologischen Untersuchungen für die Gliederung und Chronologie des Jungpleistozäns in Mitteleuropa und in den Nachbargebeiten". Eisz. und Geg. 9.

——— 1964 "Das Mittelwürm in Mitteleuropa und angrenzenden Gebeiten" Eisz. und Geg. 15, p187.

Hammen, Van der 1952 "Dating and Correlation of periglacial deposits in Middle and Western Europe." Geol. en Mijnb. 14, p.328.

——— and Maarleveld, G.C. 1952 "Genesis and dating of the periglacial deposits at the eastern fringe of the Veluve". Geol. en. Mijnb. 14, p.47.

Haring, A. et al. 1958 "Radiocarbon dating up to 70,000 years by isotopic enrichment." Science, 128, p.472.

Harris, S.E. 1943 "Friction cracks and the direction of glacier movement." J. Geol. 51, p.244.

Harrison, P.W. 1957a "New techniques for 3-dimensional Fabric analysis of till and englacial debris containing particles from 3 to 40 mm. in size". Journ. Geol. 65, p.98.

——— 1957b "A clay-till fabric: its character and origin". Journ. Geol. 65, p.275.

Hartshorn, J.H. 1961 "Evidence for local glacier stagnation in East Greenland." U.S. Geol. Survey Res. Paper 227.

Hawkins, A.B. 1962 "The buried channel of the Bristol Avon" Geol. Mag. 99, p.369.

Hicks, H. 1884 "On the Pre-Cambrian rocks of Pembrokeshire, with especial reference to the St. David's district." Quart. J. geol. Soc. Lond. 40, p.545.

——— 1885 in Bonney, T.G., "On the so-called Diorite of Little Knott (Cumberland), with further remarks on the occurrence of Picrite in Wales." Quart. J. geol. Soc. Lond. 41, p.518.

——— 1891 "Glacial action in Pembrokeshire" Geol. Mag. p.500.

Hinch, J.de W. 1918 "The Development and Decay of the Irish Sea glacier". Irish Nat. 27, p.53.

Holmes, C.D. 1941 "Till fabric" Bull. Geol. Soc. Amer. 52, p.1299.

——— 1952 "Drift dispersion in west-central New York" Bull. Geol. Soc. Amer. 63, p.993.

——— 1960 "Evolution of till-stone shapes, Central New York". Bull. Geol. Soc. Amer. 71, p.1645.

Holmsen, G. 1963 "Glacial deposits in South-East Norway." Amer. J. Science 261(9), p.880.

Hoppe, G. 1950 "Några exempel på glacifluvial fran det inre Norrbotten". Geogr. Annlr. 32, p.37.

——— 1951 "Drumlins i Nordöstra Norrbotten" Geogr. Annlr. 33, p.157.

——— 1952 "Hummocky moraine regions, with special reference to the interior of Norrbotten." Geogr. Annlr. 34, p.1.

——— 1953 "Några iakttagelser vid Isländska jöklar Sommaren 1952". Ymer, 4,p.241.

——— 1957 "Problems of glacial morphology and the ice-age." Geogr. Annlr. 39, p.1.

——— 1963 "Subglacial sedimentation, with examples from Northern Sweden." Geogr. Annlr. 45, p.41.

Horberg, L. and Potter, P.E. 1955 "Stratigraphic and sedimentologic aspects of the Lemont drift of North-East Illinois." Illinois St. Geol. Surv. Rep. of Investig. 185.

Hoskins, A.K. 1963 "Block terraces in the Neny Fjord area, Marguerite Bay, Graham Land." Brit. Ant. Surv. Bull. 1, p.45.

Howard, F.T. and Small, E.W. 1896 "Geological notes on Skomer Island." Cardiff Nat. Soc. Trans. 28.

Hughes, T. McKenny, 1885 "Notes on the Geology of the Vale of Clwyd." Proc. Chester Soc. of Nat. Sci. and Lit. 3, p.5.

——— 1887 "On the drifts of the Vale of Clwyd." Quart. J. geol. Soc. Lond. 43, p.73.

Ives, J.D. 1960 "Glaciation and deglaciation of the Helluva Lake area, Central Labrador - Ungava." Geog. Bull. 15, p.46.

Jahn, A. 1960 "Quantitative analysis of some of the periglacial processes." I.G.U. Norden, Abstracts of Papers, p.134.

——— 1964 "Experimental attempts to explain periglacial soil structure." 20th I.G.C. London (unpub).

Jehu, T.J. 1904 "The Glacial Deposits of Northern Pembrokeshire." Trans. Roy. Soc. Edin. 41 (1) p.53.

——— 1909 "The Glacial Deposits of Western Caernarvonshire." Trans. Roy. Soc. Edin. 47, p.17.

Jensen, Ad. 1905 "On the mollusca of East Greenland - Part I." Meddr. Grønland. 29, p.288.

John, B.S. 1964 "A description and explanation of glacial till in 1603 - George Owen (1552-1613)." Early Discoverers, No. XXI. Journ. Glac. 5(39) p.369.

——— 1965 "A possible Main Würm Glaciation in West Pembrokeshire" Nature, August 7 (in press).

——— and Sugden, D.E. 1962 "The Morphology of Kaldalon, a recently deglaciated valley in Iceland." Geogr. Annlr. 44(3-4), p.347.

Johnson, F. 1955 "Reflections upon the significance of radiocarbon dates", in Libby, W.F. "Radiocarbon Dating", p.141.

Jones, M. 1946 "The Development of the Teifi Drainage System" University of Wales M.Sc.Thesis (unpub.).

Jones, O.T. 1911 "The Physical Features and geology of Central Wales." Aberystwyth and Dist. Nat. Union of Teachers Souvenir, p.25.

———— 1912 "The Geology of Central Wales". Quart. J. geol. Soc. Lond, 68, p.339.

———— 1930 "Some episodes in the geological history of the Bristol Channel region." Rep. Brit. Assoc. 1930.

———— 1942 "The Buried channel of the Tawe valley near Yuystawe, Glamorgan." Quart. J. geol. Soc. Lond. 98, p.61.

———— 1951 "The Drainage Systems of Wales." Quart. J. geol. Soc. Lond. 107, p.201.

———— 1965 "The Glacial and post-glacial history of the lower Teifi valley." Quart. J. geol. Soc. Lond. (in press?)

Jones, R.O. 1931 "Notes on a 'terrace' in the boulder-clay in the Swansea Valley". Proc. Swansea Sci. and Field Nat. Soc., 1, p. 145.

Jope, M. 1960 in Stephens, N. and Collins, A.E.P. "The Quaternary Deposits at Ringneill Quay and Ardmillan, Co. Down" Proc. Roy. Irish Acad. 61(c) p.65.

Joy, J. 1963 "Glacial Drainage Features in North Pembrokeshire." University of Southampton, undergraduate dissertation (unpub.)

Karlstrom, T.N.V. 1952 "Improved equipment and techniques for orientation studies of large particles in sediments." J. Geol., 60, p.489.

Keeping, W. 1882 "The Glacial Geology of Central Wales." Geol. Mag. 19, p.251.

Kendall, P.F. 1902 "A system of Glacier Lakes in the Cleveland Hills" Quart. J. geol. Soc. Lond. 58, p.471.

Kerney, M.P. 1963 "Late-glacial deposits on the Chalk South-East England." Phil. Trans. Roy. Soc. B. 246, p.203.

Kidson, C. 1962 "The Denudation Chronology of the River Exe." Trans. I.B.G. 31, p.43.

——— 1964 "The Physiographic Evolution of the Severn Estuary" 4th Int. Harbour Conference, Antwerp.

King, W.B.R. 1955 "The Pleistocene Epoch in England." Quart. J. geol. Soc. Lond. 111, p.187.

Klute, F. 1951 "Das Klima Europas während das Maximums der Weichsel-Würm Eiszeit und die Anderungen bis zur Jetztzeit." Erdkunde, 5, p.273.

Krumbein, W.C. 1936 "The use of quartile measures in describing and comparing sediments." Amer. J.Science. 37, p.98.

——— 1939 "Preferred orientation of pebbles in sedimentary deposits". J.Geol. 47, p.673.

——— 1941 "Measurement and geological significance of shape and roundness of sedimentary particles." Journ. Sed. Petrol. 11, p.64.

——— and Pettijohn, F.J. 1938 "Manual of Sedimentary Petrography". New York.

Kuenen, P. 1958 "Some experiments on fluviatile rounding" Kon. Nederl. Ak. Wet. Proc. B. 61, p.47.

Kulp, J.L. 1961 "Geologic time-scale" Science, 133, p. 1105.

——— 1963 "Present status of Geochronometry". Isotopes Inc., Nov. 1963, Vol.1, No.1.

Lamar, J.E. 1927 "Geology and Economic resources of the St. Peter sandstone of Illinois." Ill. Geol. Surv. Bull. 53, p.148.

Lamplugh, G.W. 1906 "British drifts and the Interglacial problem" Rep. Brit. Assoc. p.13.

Leach, A.L. 1911 "On the relation of the glacial drift to the raised beach near Porth Clais, St. David's" Geol. Mag. 8, p.462.

——— 1933 "The Geology and Scenery of Tenby and the South Pembrokeshire coast." Proc. Geol. Ass. Lond. 44, p.187.

——— 1934 "The Geology and Archaeology of the Isle of Caldey" Proc. Geol. Ass. Lond. 45, p.189.

Leopold, L.B., Wolman, M.G. and Miller, J.P. 1964 "Fluvial processes in Geomorphology" San Francisco.

Lewis, Carvill 1903 in Bonney, "The Glacial Geology of Great Britain and Ireland." pp. 42 and 83.

Libby, W.F. 1955 "Radiocarbon Dating." 2nd Ed. Chicago.

——— 1961 "Radiocarbon Dating" Science, 133, p. 621.

Liestøl, O. 1955 "Glacier-dammed lakes in Norway" Norsk. Geog. Tidss. 15, p.122.

Linton, D.L; 1955 "The Problem of Tors" Geog. Journ. 121, p.470.

——— 1964 "Aspects of the Pleistocene history of North Mayo" Irish Geog. 5, p.42.

Lundquist, G. 1932 "Jordlagren" in Magnusson, N.H. and Lundquist, "Kartbladet nya Kopparberget" Sv. Geol. Under. (Aa) 175, p.46.

——— 1933 "Jordlagren" in Magnusson, N.H. and Lundquist, "Kartbladet Grängesberg" Sv. Geol. Under. (Aa) 177, p.65.

——— 1948 "Blockens orientering i olika jordarter". Sv. Geol. Under. (C) 497, p.1.

——— 1949 "The orientation of the block material in certain species of flow earth." Geogr. Annlr. 31, p.335.

MacClintock, P. 1959 "A till fabric rack" Journ. Geol. 67, p.709.

MacDonald, Hope 1961 "Some erratics from the Teifi estuary, Western Cardiganshire." Geol. Mag. 98, p.81.

Madsen, V. et al. 1928 "Summary of the geology of Denmark". Danm. Geol. Under. 5(4).

Magerud, J. 1963 "Isavsmeltningen i og omkring midtre Gudbrandsdal" Norges Geol. Under. 223, p.223.

Manley, G. 1951 "Range of variation of the British climate" Geog. Journ. 117, p.43.

——— 1953 "Climatic Variation" Quart. J. Roy. Met. Soc. 79, p.185.

Mannerfelt, C.M. 1945 "Nagra glacialmorphologiska formelement." Geogr. Annlr. 27,p.1.

Martin, S. 1955 "Raised beaches and their relation to glacial drifts on the east coast of Ireland" Irish Geog. 1(2), p.87.

Matisto, A. 1961 "On the relation between the stones of the eskers and the local bedrock in the area North-west of Tampere, South-West Finland." Comm. Geol. de Fin. Bull. 193.

Matley, C.A. 1936 "A 50-foot coastal terrace and other late-glacial phenomena in the Lleyn Peninsula." Proc. Geol. Ass. Lond. 47, p.221.

Maw, G. 1864 "On a supposed deposit of boulder-clay in North Devon" Quart. J. geol. Soc. Lond. 20, p.445.

McCann, S.B. 1964 "Raised beaches of North-east Islay and Western Jura, Argyll." Trans.I.B.G. 35, p.1.

McFarlane, P.B. 1955 "Survey of two drowned river valleys in Devon". Geol. Mag. 92, p.419.

McMillan, N.F. 1964 "The Mollusca of the Wexford Gravels (Pleistocene), South-East Ireland" Proc. Roy. Irish Acad. B, 63, No.15.

McQuillan, H. 1958 "The Geology and Structure of St. Bride's Bay, Pembrokeshire" University of Nottingham, Ph.D. Thesis (unpub.)

Miller, A.A. 1937 "The 600-foot platform in Carmarthenshire and Pembrokeshire". Geog. Journ. 90, p.148.

Milthers, V. 1909 "Scandinavian indicator-boulders in the Quaternary deposits: extension and distribution". Danm. Geol. Under. 2 (23).

Mitchell, G.F. 1948 "Two interglacial deposits in South-East Ireland". Proc. Roy. Irish Acad. (B) 52 (1), p.1.

——— 1957 "The Pleistocene Epoch", in Meenan, J, and Webb, D.A. (eds.) "A View of Ireland", Dublin.

——— 1960 "The Pleistocene History of the Irish Sea" Adv. Science, 68, p.313.

——— 1962 "Summer Field Meeting in Wales and Ireland" Proc. Geol. Ass. Lond. 73, p.197.

Movius, H.L. 1942 "The Irish Stone Age" Cambridge.

Murchison, R. 1839 "The Silurian System" London.

Myers, J. 1950 "Note on the age of the rocks on the East side of Newport Bay, Pembrokeshire." Geol. Mag. 87, p.

Neaverson, E. 1955 "Stratigraphical Palaeontology", Oxford.

Nicholas, T.C. 1933 "The Age of the Ford Beds of Pembrokeshire" Geol. Mag. 70, p.383.

Norris, G. 1962 "Some glacial deposits and their relation to the Hippopotamus-bearing beds at Barrington, Cambridgeshire." Geol. Mag., 99(2) p.97.

North, F.J. 1929 "The Evolution of the Bristol Channel", Cardiff.

Ockelmann, 1958 "The Zoology of East Greenland - marine Lammelibranchiata". Meddr. Grønland, 122 (4).

Oeschger, H. 1963 "Low-level counting methods" Radioactive Dating, p.13. Int. Atomic Energy Agency, Vienna.

Okko, V. 1955 "Glacial Drift in Iceland". Bull. Comm. Geol. Fin. 170, p.1.

Olson, E.A. and Broecker, W.S. 1958 "Sample contamination and reliability of Radiocarbon dates." Trans. N.Y. Acad. Sci. 20, p.593.

Olsson, I and Blake, W.(Jr.) 1961 "Problems of radiocarbon dating of raised beaches, based on experience in Spitsbergen". Norsk. Geog. Tidss. 18 (1-2) p.1.

Orme, A.R. 1960 "The Raised Beaches and Strandlines of South Devon". Field Studies, 1(3)p.109.

——— 1962 "Abandoned and composite sea-cliffs in Britain and Ireland". Irish Geog. 4(4) p.279.

——— 1964a "Planation surfaces in the Drum Hills, County Waterford, and their wider implications." Irish Geog. 5(1), p.48.

———— 1964b "The South Hams and Southern Dartmoor." in Brunsden et al "Denudation chronology of parts of South-western England" Field Studies 2(1) p.115.

Owen, G. 1599 "Treatise on clay marl" (unpub.)

Owen, G. 1603 "The Description of Penbrokshire.", in Owen, H. (ed.), 1892, Cymmrodorion Record Series (1), London.

Paterson, T.T. 1940 "The effects of frost action and solifluxion around Baffin Bay and in the Cambridge District." Quart. J. geol. Soc. Lond. 96, p.99.

Peake, D.S. 1961 "Glacial changes in the Alyn River system and their significance in the Glaciology of the North Welsh Border." Quart. J. geol. Soc. Lond. 117,p.335.

Pecsi, M. 1964 "Chronological problems of the patterned soils of Hungary" Biul. Peryglac. 14, p.279.

Peel, R.F. 1949 "A study of two Northumbrian spill-ways". Trans. I.B.G. 15, p.73.

Peltier, L.C. 1950 "The Geographic cycle in periglacial regions" Ann. Ass. Amer. Geog. 40, p.214.

Pengelly, W. 1867 "The raised beaches in Barnstaple Bay, North Devon". Trans. Devon Ass. 2, p.43.

Penny, L.F. 1964 "A review of the Last Glaciation in Great Britain". Proc. Yorks. Geol. Soc. 34(4) p.387.

Pentland, A. 1927 "A method of measuring the angularity of sands". Roy. Soc. Canada, Proc. and Trans. (3), 21, p.93.

Pettijohn, J. 1949 "Sedimentary Rocks", New York.

Pewé, T.L. 1964 "Palaeoclimatic significance of fossil ice-wedges". (unpub.).

Plumley, W.J. 1948 "Black Hill terraces. A study in sedimentary transport". Journ. Geol. 56, p.526.

Portmann, J.P. 1960 "The rocks embedded in glaciers". Geog. Helv. 15(1), p.1.

Prestwich, J. 1892 "The raised beaches and 'head' or rubble-drift of the South of England". Quart. J. geol. Soc. Lond. 48, p.263.

Price, R.J. 1964 "Land-forms produced by the wastage of the Casement Glacier, South-East Alaska." Rep. 9, Inst. of Polar Studies (Ohio St. Univ.)

Pringle, J. and George, T.N. 1948 "South Wales" British Regional Geol.

Ramsay, A.C. 1846 "On the denudation chronology of South Wales". Mem. Geol. Surv. 1, p. 297.

Rapp, A. 1960 "Talus slopes and mountain walls at Templefjorden, Spitsbergen." Norsk Polarinst. Skrifter, 119.

Reed, Cowper, 1895 "The Geology of the Country around Fishguard, Pembrokeshire". Quart. J. geol. Soc. Lond. 51, p.149.

Reichelt, G. 1961 "On the field study of the shape and degree of roundness of gravel particles" Pet. Geog. Mitt. 105, p.15.

Reid, Clement, 1890 "Pliocene deposits of Great Britain" Mem. Geol.Surv.

Richter, K. 1936 "Gefügestudien im Engebrae, Fondalsbrae, und ihren Vorlandsedimenten" Zeitsch. f. Gletsch. 24, p.22.

Rudberg, S. 1958 "Some observations concerning mass movement on slopes in Sweden" Geol. Fören. Stock. Förh. 53.

——— 1962 "A report on some field observations concerning periglacial geomorphology and mass movement on slopes in Sweden" Biul. Peryglac. 11, p.311.

Sawicki, L. 1912 "Die Einebnungsflächen in Wales and Devon" C.R. des Seances Soc. Sc. de Varsovie (V) 2, p.123.

Schou, A. 1949 "Atlas of Denmark" Vol.I. Copenhagen.

Simpson, I.M. 1960 "Stone-counts in the Pleistocene of the Manchester area". Proc. Yorks. Geol. Soc. 32, p.379.

Sissons, J.B. 1960 "Some aspects of glacial drainage channels in Britain" (Part I) Scot. Geog. Mag. 76 (3) p.131. (Part II) Scot. Geog. Mag. 77 (1), p. 15.

——— 1964 "The Glacial Period" Ch.8 in Watson, J.W. and Sissons, "The British Isles", London.

Smith, B. and George, T.N. 1948 "North Wales". Brit. Reg. Geol.

Soil Mechanics Ltd. 1958 "Site investigation for proposed River Dau Cleddau Barrage". Rep. No. 2665/1.

Sollid, J.L. 1961 "Terrengformes danna under nedsmeltinga" Hovedfags. Oslo Univ. (Utrykt).

——— 1964 "Isavsmeltingsforløpet langs hovedvasskillet mellom Hjerkinn og Kvikneskogen" Norsk Geog. Tidss. 19, p.51.

Soons, J.M. 1960 "Glacial retreat stages in Kinross-shire." Scot. Geog. Mag. 76, p.46.

Spärck, R. 1933 "Contributions to the Animal ecology of the Franz Josef Fjord and adjacent East Greenland waters I-II" Meddr. Grønland. 100(1).

Sparks, B.W. 1960 "Geomorphology" London.

————	1961	"The ecological interpretation of Quaternary non-marine mollusca" Proc. Linn. Soc. Lond. 172, p.71.
Stamp, L.D. (ed.)	1961	"A Glossary of Geographical Terms". London.
Starkel, L.	1960	"Periglacial covers in the Beskid Wyspowy". Biul. Peryglac. 8, p.155.
Steers, J.A.	1946	"The coastline of England and Wales" C.U.P.
———— (ed.)	1964	"Field Studies in the British Isles". London.
Stephens, N.	1957	"Some observations on the 'inter-glacial' platform and the early post-glacial raised beach on the east coast of Ireland. Proc. Roy. Irish Acad. B 58(6) p.129.
————	1961	"Pleistocene events in North Devon" Proc. Geol. Ass. Lond. 72(4) p.469.
————	1963	"Late-glacial sea-levels in North-east Ireland" Irish Geog. 4, p.345.
————	1964	"Some Pleistocene deposits in North Devon" (unpub.)
———— and Synge, F.M.	1958	"A Quaternary succession at Sutton, County Dublin". Proc. Roy. Irish Acad. B. 59(2), p.19.
Stevens, L.A.	1959	"The Interglacial of the Nar Valley, Norfolk." Quart. J. geol. Soc. Lond. 115, p.291.
Strahan, A.	1907	"The Geology of the South Wales Coal-field" Part IX, "West Gowes and the Country around Pembrey". Geol. Surv.
———— et al.	1914	"The Geology of the South Wales Coal-field" Part XI "The Country around Haverfordwest". Geol. Surv.

Strøm, K. 1956 "The Disappearance of the last Ice-sheet from Central Norway". Journ. Glac. 2, p.747.

Stuart, A. 1924 "Petrology of Dune Sands of South Wales" Proc. Geol. Ass. Lond. 35, p. 316.

Sugden, D.E. 1965 "Aspects of the Glaciation of the Cairngorm Mountains" University of Oxford, D. Phil. Thesis (unpub.)

——— and John, B.S. 1965 "The Raised marine Features of Kjove Lane, East Greenland". Geog. Journ. 131, p.235.

Symonds, W.S. 1872 "Records of the Rocks" London.

Synge, F.M. 1961 "Drifts in West Wales". Welsh Soils Disc. Group. Rep.2, Aberystwyth (unpub.)

——— 1963 "A correlation between the drifts of South-East Ireland and those of Wales". Irish Geog. 4(5) p.360.

——— 1964a "The Glacial succession in West Caernarvonshire" Proc. Geol. Ass. Lond. 75(4), p.431.

——— 1964b "Some problems concerned with the glacial succession in South-East Ireland" Irish Geog. 5, p.73.

——— and Stephens, N. 1960 "The Quaternary Period in Ireland - an assessment, 1960". Irish Geog. 4, p.121.

Taylor, C.W. 1956 "Erratics of the Saunton and Fremington areas". Rep. Devon Ass. Adv. Sci. 88, p.52.

Te Punga, M.T. 1957 "Periglaciation in Southern England" in "Geomorphological and Geophysical Studies presented to Professor Hol". Amsterdam.

Tester, A.C. 1931 "The measurement of the shape of rock particles". Journ. Sed. Petrol. 1, p.3.

Thomas, G.E. and Thomas, T.M. 1956 "Volcanic rocks of the area between Fishguard and Strumble Head, Pembrokeshire." Quart. J. geol. Soc. Lond. 122.

Thomas, H.H. and Jones, O.T. 1912 "The Pre-Cambrian and Cambrian rocks of Brawdy, Hayscastle, and Brimaston" Quart. J. geol. Soc. Lond. 67.

Thorarinsson, S. 1939 "Ice-dammed lakes of Iceland". Geogr. Annls. 21, p.216.

Thorson, G. 1933 "Investigations on shallow-water animal communities in the Franz Josef Fjord (East Greenland) and adjacent waters." Meddr. Grønland. 100 (2).

Tiddeman, R.H. 1900 "On the age of the raised beach of Southern Britain as seen in Gower". Geol. Mag. 7, p.441.

Tricart, J. 1956 "Étude expérimentale du problème de la gelivation" Biul. Peryglac. 4.

——— 1959 "L'étude comparée de la composition des alluvions fluviatiles et de la nature théologique (sic) du bassin moyen d'analyse des systèmes d'érosion". Rev. Géomorph. Dyn. 10 (1-2) p.2.

——— and Schaeffer, R. 1950 "L'indice d'émoussée des galets, moyen d'étude des systems d'érosion." Rev. Géomorph. Dyn. 1.

Trømborg, D. 1964 "Isavsmeltningen i omradet rundt nordenden av Femunden" Norsk Geog. Tidss. 19 (5-6) p.229.

Trowbridge, A.C. and Mortimore, M.E. 1925 "Correlation of oil sands by sedimentary analysis" Econ. Geol. 20, p.409.

Visher, S.S. 1945 "Climatic maps of geologic interest" Bull. Geol. Soc. Amer. 56, p.713.

Vries, Hl. de 1958 "Radiocarbon dates for Upper Eem and Würm-interstadial samples". Eisz. und Geg. 9, p.10.

——— and Barendsen, G.W. 1953 "A new technique for radiocarbon dating by a proportional counter filled with carbon dioxide." Physica, 19, p.987.

——— and Dreimanis, A. 1960 "Finite radiocarbon dates of the Port Talbot Interstadial deposits in South Ontario". Science, 131, p.1738.

Wadell, H. 1932 "Volume, shape and roundness of rock particles" Journ. Geol. 40(5) p.443.

——— 1936 "Volume, shape and shape position of rock fragments in openwork gravel" Geogr. Annlr. 18, p.74.

Ward, W.H. 1952 "The Glaciological studies of the Baffin Island Expedition, 1950, Part II". Journ.Glaciol. 2(11), p.22.

Watson, E. 1964 "Stone orientation at Morfa Bychan" (unpub.)

Watson, J.W. and Sissons, J.B. (eds.) 1964 "The British Isles" London.

Watts, W.A. 1959 "The interglacial deposits at Kilbeg and Newtown, County Waterford". Proc. Roy. Irish Acad. B, 60, p.79.

Wentworth, C.K. 1919 "A laboratory and field study of cobble abrasion". Journ. Geol. 27, p.507.

——— 1922a "A method for measuring and plotting the shapes of pebbles." U.S.Geol.Surv. Bull. 70c, p.91.

——— 1922b "The shapes of beach pebbles" U.S. Geol.Surv. Prof. Paper. 131-C, p.75.

——— 1922c "A scale of grade and class terms for clastic sediments" Journ. Geol. 30, p.377.

——— 1927 "The accuracy of mechanical analysis" Amer. Journ. Science, 13, p.399.

West, R.G. 1955 "The Glaciations and Interglacials of EastAnglia; a summary and discussion of recent research". Quaternaria 2, p.45.

——— 1963 "Problems of the British Quaternary" Proc. Geol. Ass. Lond. 74 (2), p.147.

——— and Donner, J.J. 1956 "The Glaciations of East Anglia and the East Midlands: a differentiation based on stone orientation measurements of the tills" Quart. J.geol. Soc. Lond. 112, p.69.

Whittow, J.B. 1960 "Some comments on the raised beach platform of South-west Caernarvonshire". Proc. Geol. Ass. Lond. 71, p.31.

Williams,K.E. 1927 "The Glacial drifts of Western Cardiganshire". Geol. Mag., 64, p.205.

Williams, P.J. 1960 "The Distribution of certain frozen-ground phenomena in relation to climate" I.G.C. Norden, Abstracts of Papers, p.313.

Williams, T.G. 1934 "The Pre-Cambrian and Lower Palaeozoic rocks of the eastern end of the St David's Pre-Cambrian area, Pembrokeshire" Quart. J. geol. Soc. Lond. 90, p.32.

Wills, L.J. 1937 "The Pleistocene History of the West Midlands" Rep. Brit. Assoc. 71, p.71

——— 1938 "The Pleistocene Development of the Severn from Bridgnorth to the sea". Quart. J. geol. Soc. Lond. 94,p.161.

Wiman,S. 1963 "A preliminary study of experimental frost weathering". Geogr. Annlr. 45 (2-3) p.113.

Winckworth, R. 1932–34 "The British Marine Mollusca". Journ. Conch. 19, p.211, p.334. 20, p. 9, p.51.

Wirtz, D. 1953 "Zur Stratigraphie des Pleistozäns im Westen der Britischen Inseln". Neues Jb. Geol. 96, p.267.

Woldstedt, P. 1958 "Das Eiszeitalter." Stuttgart.

Wood, A. 1959 "The erosional history of the cliffs around Aberystwyth." Liv. Manch. Geol. Journ. 2(2) p.271.

Wood, S.V. 1882 "The Pliocene Period in England." Quart. J. geol. Soc. Lond. 94, p.667.

Wooldridge, S.W. 1950 "The Upland Plains of Britain". Adv. Science. 7, p.162.

Wright, H.E. 1957 "Stone orientation in Wadena drumlin-field, Minnesota" Geogr. Annlr. 39, p.19.

———— 1961 "Late Pleistocene Climate of Europe: a review". Bull. Geol. Soc. Amer. 72, p.933.

Wright, W.B. 1914 "The Quaternary Ice-Age" (1st Ed.) (2nd Ed. 1937). London.

———— and Muff, H.B. 1904. "The Pre-glacial raised beach of the south coast of Ireland". Proc. Roy. Dub.Soc. 10, p.250.

Zagwijn, W.H. 1961 "Vegetation, Climate, and Radiocarbon datings in the Late Pleistocene of the Netherlands." Meded. Geol. Sticht. 14, p.15.

Zeuner, F.E. 1954 "Riss or Würm?" Eisz. und Geg. 4-5, p.98.

———— 1959 "The Pleistocene Period" London.

ADDENDA

Büdel, J. 1953 "Die "periglazial"- morphologische Wirkungen des Eiszeitklimas auf der ganzen Erde" Erdkunde 7, P. 249

Jessen, K., Andersen, S.T. and Farrington, A. 1959 "The interglacial deposit near Gort, Co. Galway, Ireland". Proc. Roy. Irish Acad. B , 60, P.1.

Kendall, P.F. and Bell, R.G. 1886 "On the Pliocene beds of St. Erth", Quart. J. geol. Soc. Lond. 42, P.201

Simpson, I.M. and West, R.G. 1958 "On the stratigraphy and Palaeobotany of a Late-Pleistocene organic deposit at Chelford, Cheshire" New Phytol. 57, P. 239

Watts, W.A. 1964 'Interglacial deposits at Baggotstown, near Bruff, Co. Limerick' Proc. Roy. Irish Acad. B, 63, P. 167