QUATERNARY GLACIATION AND CHANGES OF SEA LEVEL IN THE SOUTH OF IRELAND

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ABSTRACT

Synge, F. M. 1981 Quaternary glaciation and changes of sea level in the south of Ireland. *In:* A. J. van Loon (ed.): Quaternary geology: a farewell to A. J. Wiggers – Geol. Mijnbouw 60: 305-315.

In the south of Ireland the glacial succession consists of two major glacial episodes (Munsterian and Midlandian), considered to be Elsterian (or Saalian) and Weichselian respectively. These are separated from each other by two phases of high sea level along the south coast, at 12-13 m and 3-5 m above present mean sea level.

Foci of local glaciation were particularly prevalent in highland areas outside the limits of the Midlandian ice sheet.

INTRODUCTION

Just over a century ago evidence of the former presence of a Quaternary ice sheet was recognized in Ireland, in the vicinity of Dublin (CLOSE, 1867). Some quarter of a century later the division of the glacial drifts into a *Younger* and *Older* Series came to be accepted (WRIGHT, 1914). The limit of the Younger Series ('*Newer Drift*') was traced across the country as the southward termination of fresh glacial landforms such as kames, kettle-holes and eskers (CARVILL LEWIS, 1894; CHARLESWORTH, 1928). The general absence of fresh landforms on the surface of the *Older Drifts* that extended south of the Newer Drift limit (the South of Ireland End-moraine of Charlesworth) was particularly noted. A broadly morphostratigraphic correlation placed the Newer Drift in the Warthe of continental Europe, and the Older Drifts in the Elsterian and Saalian (WRIGHT, 1936).

In this paper the problem of the true stratigraphic positions of Newer and Older Drifts in the south of Ireland (i.e., south of a line Dublin – Galway) will be discussed, using the current terminology where appropriate. The younger phase of glacierization is now termed *Midlandian* because the axis of the ice sheet then lay across the Irish midlands, while the older ones are termed *Munsterian* from the name of the province where their surface drifts occur most widely (MITCHELL, 1976).

The generally accepted limit of the Midlandian ice sheet passes off the east coast of Ireland between Rosslare and Kilmore Quay (COLHOUN & MITCHELL, 1971; CULLETON, 1978-b). Thick accumulations of glacial drift extending across the floor of St. George's Channel indicate the continuation of the end-moraine into the limit of the English *Devensian* (Weichselian) along the coast of north Pembrokeshire in Wales (BOWEN, 1973; GARRARD, 1977). A detached independent ice cap about 8500 km^2 in extent occupied south-west Ireland, in the counties of Kerry and Cork, at that time. Also cirque glaciers occupied other highland areas in Kerry, in the Galtees, Knockmealdowns, Comeraghs, Slievenamon and Mount Leinster (Fig. 1).

Subdivisions of the glacial phases have been largely based on morphostratigraphic investigations in the Wicklow highlands. On two successive occasions an ice sheet advanced from the north to impinge against the highland margins, interleaved each time between two expansions of the local glaciers (FARRINGTON, 1934, 1949):

YOUNGER PHASES	Late-Glacial moraines (Cirque glaciers)
	Athdown-II moraines (Valley glaciers)
	Midland General Glaciation (Ice sheet from northwest)
	Athdown-I moraines (Valley glaciers)
OLDER PHASES	Brittas moraines (Swollen valley glaciers)
	Eastern General Glaciation (Ice sheet from northeast)
	Enniskerry local drift (Local ice cap)

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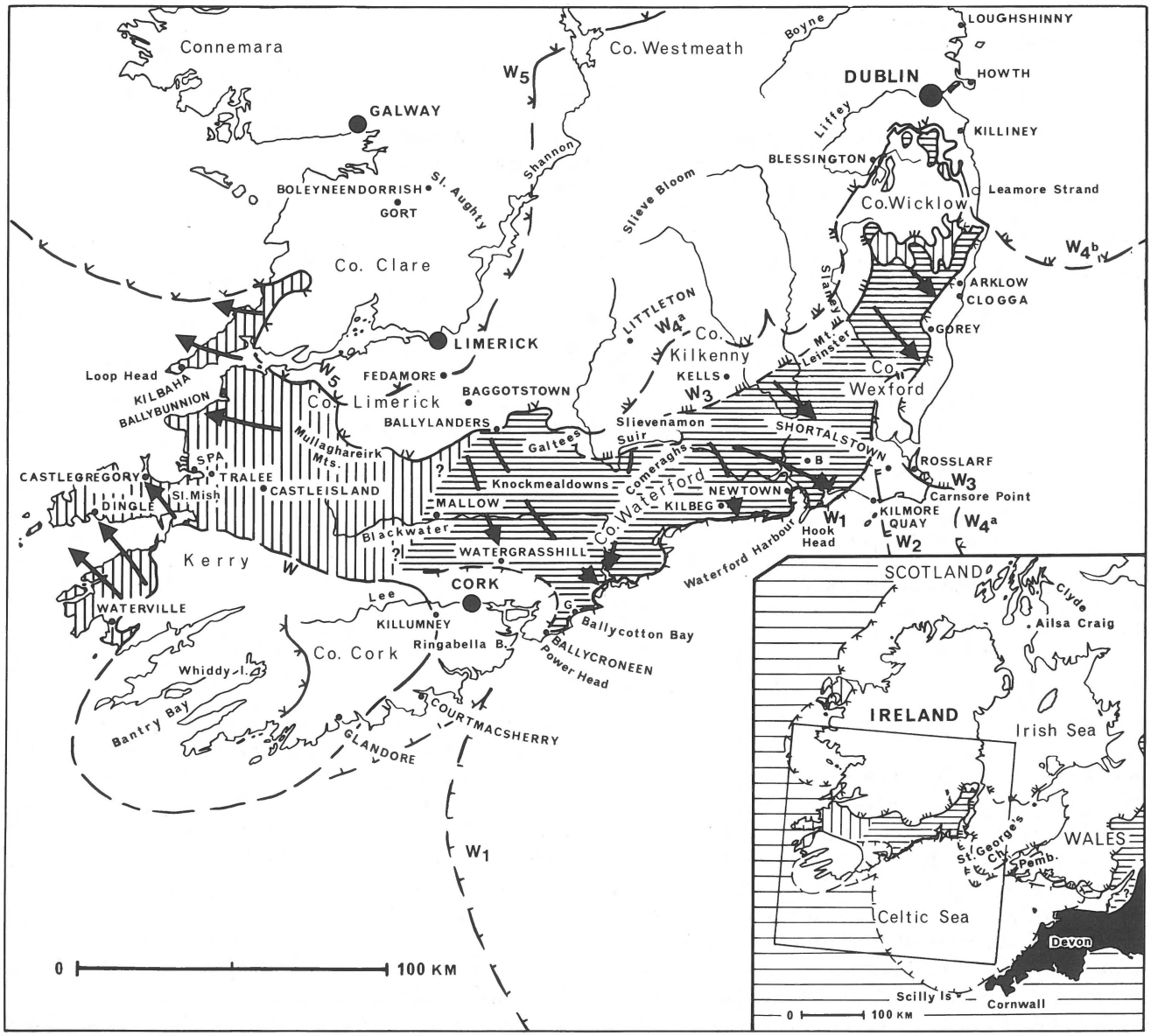

Fig. 1
Ice limits in the south of Ireland.
Areas covered by Midlandian (Weichselian) ice is unshaded (substages W_1-W_5 are named in Figure 3); Munsterian (? Elster) surface drifts are shown by horizontal shading. The extent of the problematical Connachtian drifts is indicated by vertical shading; these either constitute an intermediate glacial episode (? Saale) or they represent the later part of the Munsterian. Abbreviations: B = Ballykeerogemore; G = Garryvoe.

In this scheme (Figs. 2 and 3) a phase of weathering was noted between the deposition of the shelly Eastern General till and that of the Midland General till (FARRINGTON, 1944), later to be given interglacial status (Ipswichian/Eemian) by MITCHELL (1960). However, recent investigations in county Wicklow by the writer indicate that the Eastern General phase of glacierization corresponds to one of the Midland General phases, and is therefore younger than Munsterian.

The early extension of Irish Sea ice (Eastern General) almost as far as Cork Harbour to deposit the *Ballycroneen* till is generally considered to be Munsterian in age (MITCHELL, 1972), being penecontemporaneous with subsequent expansion of inland ice (*Ballyvoyle* till) across the present coastline. But recent work in Co. Wexford by the writer suggests that the relationship between inland and coastal ice may not have been so simple. There are indications that the coastal ice arrived considerably later, after the dissolution of the inland ice.

Interglacial deposits, termed Gortian, underlie Midlandian tills at a number of sites (viz. Boleyneendorrish, near Gort; Baggotstown, Co. Limerick; and near Kells, Co. Kilkenny). These were correlated on a palynological basis with the

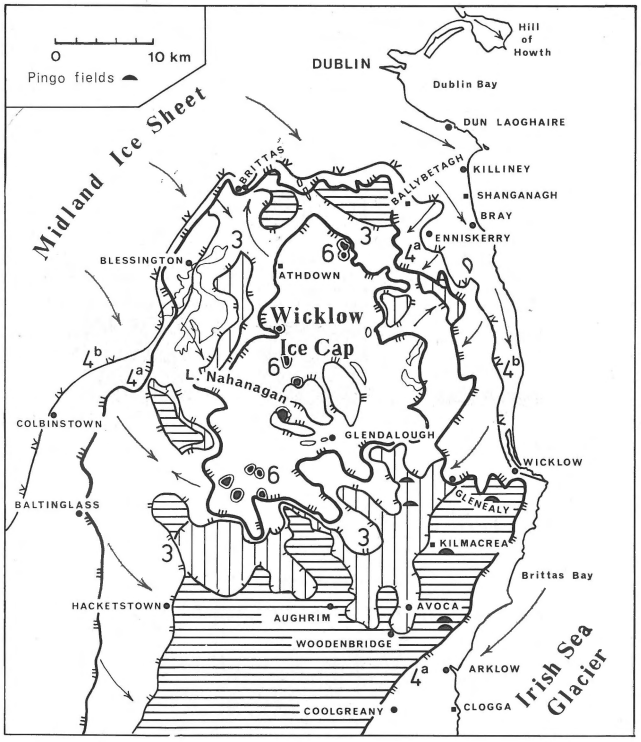

Fig. 2
Glacial substages in County Wicklow.
The shaded areas represent pre-Midlandian (pre-Weichsel) glaciations. There is, however, a possibility that the Aughrim substage (vertical shading) may represent the early part of the Weichsel, rather than a separate glaciation of Saale age. The Midland Ice limit in the west (3, Hacketstown substage) predates the Irish Sea glacial limit (4a, Glenealy substage). Both of these correspond with an expansion of the local glaciers (Brittas and Athdown substages). Subsequently an important readvance of Midland Ice surged southeast to Wicklow Head, across the area vacated by Irish Sea Ice. A late reappearance of cirque glaciers (6, Nahanagan substage) occurred during the Late Glacial (pollen zone III).

WARM/COLD STAGES		WSW Co's Galway, Clare, Limerick	SW Kerry, Co.Cork	SE Co's Dublin, Wicklow Wexford, Waterford
HOLOCENE (LITTLETONIAN)		SEA LEVEL BELOW THAT OF PRESENT		RAISED BEACHES N. OF WICKLOW
WEICHSELIAN (MIDLANDIAN)	W_6		NAHANAGAN CIRQUE SUBSTAGE	
	W_5	FEDAMORE SUBSTAGE	DRUMLIN (BANTRY) SUBSTAGE	? CIRQUE GLACIERS
	W_{4b}			COLBINSTOWN/ WICKLOW SUBSTAGE
	W_{4a}	BALLYLANDERS SUBSTAGE	KILLUMNEY SUBSTAGE	BLESSINGTON/ ATHDOWN/ GLENEALY SUBSTAGE
	W_3			HACKETSTOWN/ BRITTAS SUBSTAGE
	W_2			KILMORE QUAY S.
	W_1		GARRYVOE SUBST.	
			BALLYCRONEEN SUBSTAGE	
EEMIAN (GORTIAN)		INTERGLACIAL PLANT BEDS		
			COURTMACSHERRY BEACH 3-5M MSL	
? SAALIAN (CONNACHTIAN)		?	ICE FROM EAST IN N. CO. KERRY	?AUGHRIM SUBSTAGE
?HOLSTEINIAN			MARINE ROCK PLATFORM UP TO 11M MSL	
?ELSTERIAN (MUNSTERIAN)			ICE FROM NORTH IN E. CO. CORK	BANNOW/ CLOGGA TILLS

Fig. 3
Correlation table for the Quaternary succession in southern Ireland. Note that the Gortian beds may either directly underlie Midlandian (Weichsel) tills, or might be separated from them by another glacierization, the so-called Connachtian.

Holsteinian of western Europe (WATTS, 1959). However, this basis of correlation has now been questioned, as an objective treatment of the drift stratigraphy would now seem to place these beds firmly in the last interglacial (WARREN, 1979). The stratigraphy (fig. 4). is not so clear at certain sites beyond the glacial limit marked by the South of Ireland end-moraine. At the Kilbeg site, only 3 km from the Co. Waterford coast, the stratigraphy was established from a borehole (WATTS, 1959). But one might reasonably ask: is the 5 m bed of 'boulder-clay' that seals the interglacial sequence a till or a solifluction deposit? At Newtown, also in Co. Waterford, the organic beds occur near the base of a marine cliff where much slumping occurs at the present day (SYNGE, 1977). Even if the overlying till is *in situ* (MITCHELL, 1948) its identification with inland ice rather than with coastal ice is a matter of conjecture.

A marine beach consistently standing at 3-5 m above m.s.l[2], and termed the Courtmacsherry Beach (MITCHELL, 1962), occurs throughout the south coast of Ireland. Associated with Gortian beds at Spa in Co. Kerry and Newtown in Co. Waterford, this raised beach can be regarded as an isochronous unit and is, therefore, an excellent stratigraphic marker horizon (WRIGHT & MUFF, 1904; FARRINGTON, 1966; WARREN, 1979). Evidence of cool climatic conditions was considered to place this shoreline in a glacial phase (WRIGHT & MUFF, 1904; FARRINGTON, 1966; SYNGE, 1977), but widespread occurrence of a similar 3-5 m eustatic shoreline throughout the coast of south England and France with a temperate fauna indicates that it belongs to the last interglacial (BOWEN, 1973; WEST, 1968). Therefore the more extensive marine rock platform (STEPHENS, 1957) that extends up to a cliff notch at 12-20 m m.s.l. throughout the east coast of Co. Wicklow (Fig. 5) probably relates to the preceding interglacial, rather than the last interglacial as was formerly supposed (SYNGE, 1977).

EARLIER GLACIERIZATION

Throughout southeast Ireland, in the counties of Wicklow and Wexford, thick ice once covered even the highest ground, flowing uniformly towards the southeast according to the distribution of glacial striae, roches moutonnées and erratic carriage. In the vicinity of Arklow this glacial episode is represented by the Clogga till, which lies below the level of the

[2] The measured height of the Courtmacsherry Beach of 6-8 m was incorrectly ascribed to mean sea level (m.s.l.) instead of Irish Ordnance Datum in Synge (1977). Irish O.D. is 2.554 m *below* m.s.l.

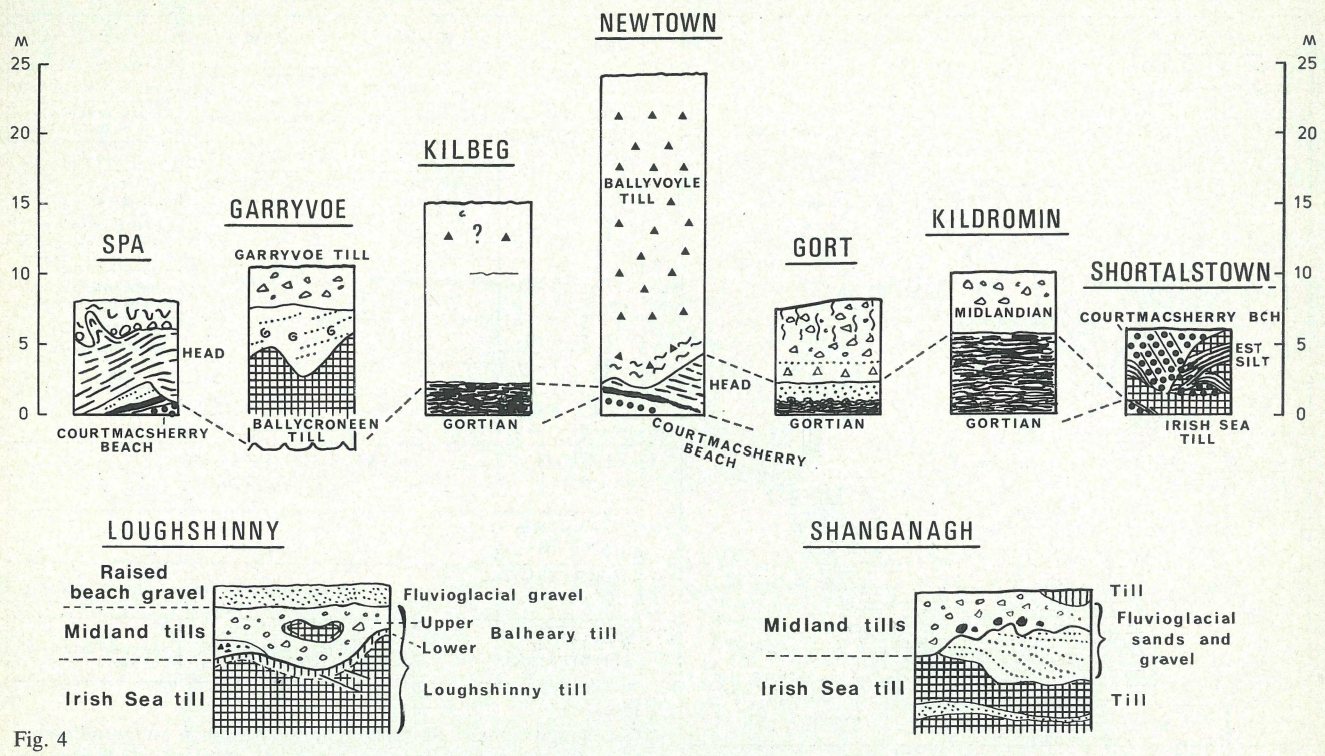

Fig. 4
Stratigraphy of the glacial drifts.
The Midlandian (Weichsel) is represented by, either till *in situ* (at Garryvoe, Gort, Kildromin and Shortalstown), 'head' deposits (at Spa), or as slumped tills (Kilbeg and Newtown). The interglacial Gortian beds overlie the Courtmacsherry Beach at Spa and Newtown. At Shortalstown the interglacial plant remains occur in estuarine (est.) silt.
In the vicinity of Dublin, at Loughshinny and Shanganagh two interpretations of the sequence are shown. On the left the deposits have been subdivided into two phases of the Midlandian – the earlier and lower related to Irish Sea ice from the northeast, and the upper, younger drift derived from Midland ice flowing from the northwest. On the right the entire sequence is considered as primary deposition from Irish Sea ice alone. The writer favours the interpretation shown on the left.

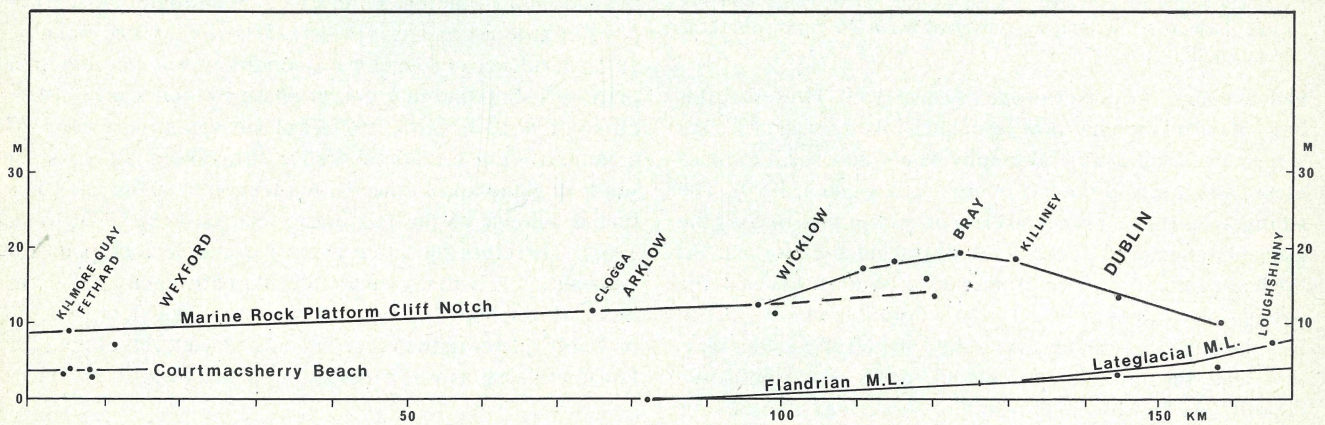

Fig. 5
Shoreline diagram of raised beaches between Dublin and Waterford Harbour.
Four series of raised beaches have been identified. The oldest is represented by a cliff notch, generally at 9-11 m m.s.l., at the back of a distinctive marine rock platform. Between Wicklow and Killiney this feature has been tectonically uplifted. The next, or Courtmacsherry Beach, at 3-5 m m.s.l. probably represents the last interglacial (Eemian). The third series only appears north of Killiney, rising isostatically; this is the equivalent of the Drumlin substage (W_5). Finally the fourth series, only found north of Wicklow, represents the Flandrian beaches at about 5000 years B.P. These are isostatically uplifted to the north and downwarped to the south.

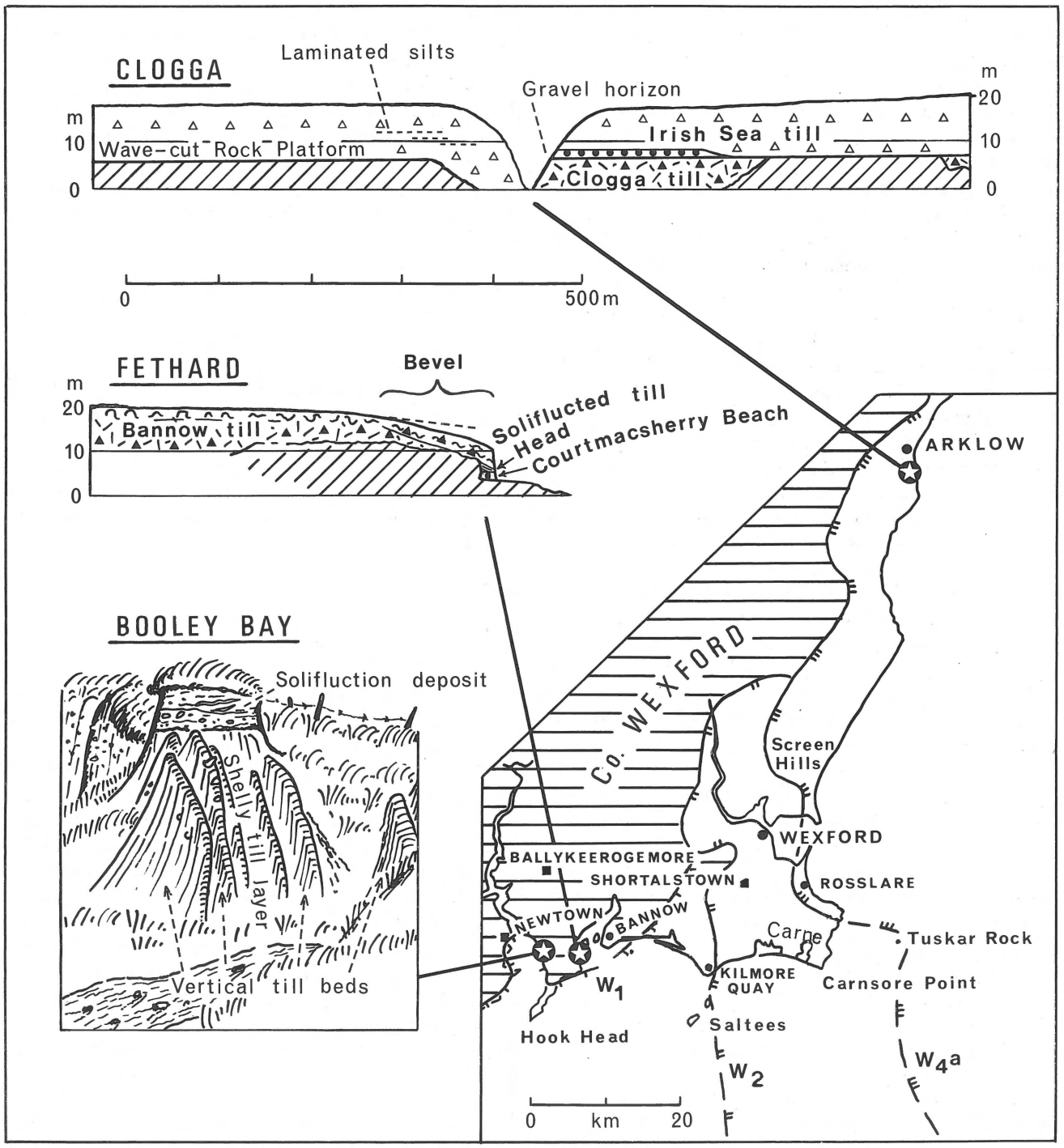

Fig. 6
Key coastal sections in south east Ireland.
At Clogga levelling has confirmed the extension of the Wave-cut Rock Platform across Munsterian till. An overlying gravel horizon derived in part from this till has been interpreted as a beach gravel, although Huddart (1981) regards it as fluvioglacial in origin on account of poor sorting and abrasion; this is not conclusive as beach deposits can be very variable.
At Fethard the till, capping the interglacial beach, is seen to be a solifluction deposit. This periglacial activity has resulted in the 'bevelling' of the cliff top to form a seaward sloping drift apron. At Booley Bay stony till beds interspersed with layers of shelly marine till have been pushed against the rocky coastline and deformed into a vertical position by sea ice.

Clogga rock platform (SYNGE, 1977) and predates glacierization by Irish Sea ice (FARRINGTON, 1954) that deposited the overlying shelly till (Fig. 6).

Further south, in Co. Wexford, the equivalent Munsterian till to that at Clogga –the Bannow till– has been represented as overlying the 3-5 m (Courtmacsherry) beach (MITCHELL, 1962). But a closer examination at these sites suggests that the till-like deposit that overlies the head which seals the beach is a product of solifluction (SYNGE, 1977). In many localities the capping 'till' shows slump and flow structures directed downslope, and lacks the original compact structure of a true lodgement till. Furthermore, in these localities the top of the present cliff has a seaward slope or 'bevel': a feature produced by soilcreep and/or periglacial weathering during, or after, marine cliffing (i.e., at Fethard, Fig. 6). The evolution of the coastal succession in the counties of Wicklow and Wexford is explained in figure 7.

The apparent, almost complete, absence of glacial striae on the Courtmacsherry beach platform throughout the south coast between Garryvoe and Kilmore Quay may be significant. WRIGHT & MUFF (1904) have only recorded one such locality (viz., beneath shelly till adjoining Dungarvan Harbour, Co. Waterford) between those points. This contrasts with the situation west of Garryvoe; in the vicinity of Cork Harbour, for example, glacial action has removed part of the raised beach at Ringabella Bay, for till can be seen resting on the waterworn surface of the rock platform associated with striae trending east-southeast. Likewise on the east coast subsequent glacierization by an Irish Sea glacier has almost entirely removed the beach and deposited a shelly till upon an ice-polished striated surface.

The coastal ice that laid down the marine tills on the south coast, for the most part, would have appeared to be weak in erosive power, as in most places it merely truncated the head that seals the raised beach. In some localities the marine till passes upwards into a local stony till attributed to inland ice from the north (WRIGHT & MUFF, 1904). But this Ballyvoyle till (WATTS, 1959) may, in part at least, represent a local facies of the coastal ice, derived from the local rock and pre-existing drift. Further investigation is required to demonstrate whether this is so, or not.

If the Munsterian drifts represent the *only* glacial event to cover entirely the southeast of Ireland, they are likely to represent the largest expansion of the North European ice sheet, either Elsterian or Saalian in age. If they are Elsterian, some evidence of a more limited Saalian would be expected. There is a possibility, as yet unproven, that such a glacial limit could lie buried in east Ireland beneath the younger Midlandian (Weichselian) drifts. Perhaps the eastern terminus of the fan of erratic boulders of Galway granite in the Slieve Bloom mountains may represent this *Connachtian* glacial limit (SYNGE, 1979)?

In north Kerry there is a possibility that this drift sheet appears as a surface deposit outside the Midlandian limit. Striae indicate a glacial movement trending towards west-northwest across the Loop Head peninsula (FINCH & SYNGE, 1966), a direction quite different from that of the Munsterian which carried boulders of Galway granite south to Watergrasshill near Cork city (Fig. 1). The surface till of north Kerry must be considered pre-Midlandian in age, because it has been observed beneath the Courtmacsherry beach near Ballybunnion (unpublished observation by Mitchell in 1977; WARREN, 1981). A zone of dissected gravel mounds athwart the Blackwater valley in the vicinity of Mallow may mark its eastern limit. Some denuded eskers and meltwater channels belonging to this phase of glacierization have been observed between Tralee and the Shannon estuary.

From the above discussion the stratigraphy of the 'Older Drifts' may be represented as follows:

(5) Gortian interglacial beds	} *Interglacial*
(4) Courtmacsherry Beach (3-5 m m.s.l.)	} *Interglacial*
(3) *Connachtian* (N.Kerry till)	*? Saalian*
(2) Clogga marine rock platform (cliff notch 12-20 m m.s.l.)	*Interglacial*
(1) *Munsterian* (Bannow/Clogga tills)	*? Elsterian*

As yet no fauna has been definitely associated with the marine horizons; weathering processes appear to have removed all shelly material.

LAST (EEMIAN) INTERGLACIAL

The palynological basis on which the Gortian sites have been placed in the penultimate interglacial has been seriously questioned (WARREN, 1979); comparisons between the taxa of the Histon Road, Cambridge Ipswichian site and those of Gort, show as much differences as similarities (WALKER, 1953; JESSEN ET AL., 1959). Gortian pollen diagrams start with a *Salix/Betula* association and with the slightly later expansion of *Juniperus* and *Hippophae* along with a decline of the herb pollen. There follows a rapid expansion of *Pinus, Taxus, Alnus* and *Rhododendron* with smaller amounts of *Quercus, Hedera, Corylus, Fraxinus, Ilex, Abies, Picea* and *Buxus*. Towards the top of the succession, based on the Kilbeg site, and above a local unconformity, *Pinus* falls off markedly, while *Quercus* persists for a time in small amounts after the extinction of all other arboreal pollen. There is a reappearance and expansion of *Juniperus* at the top of the succession along with a rapid increase of herbs (MITCHELL, 1976).

South of the South of Ireland End-moraine only two sites (Kilbeg and Newtown in Co. Waterford) show Gortian beds beneath till. At Kilbeg the top of the interglacial peat bed lies about 14 m below ground level beneath about 8 m of lacustrine sediments capped by 5 m of 'boulder clay' covered by a peaty soil (WATTS, 1959); the basin lies within an amphitheatre about 400 m in diameter and formed by outcrops of local rock. The actual 'site lies at the north end of a mound of drift' (MITCHELL, 1948). In such a situation might not the 'boulder clay' be regarded as a solifluction deposit derived from the mound of drift? Further, the Kilbeg peat is one of the few

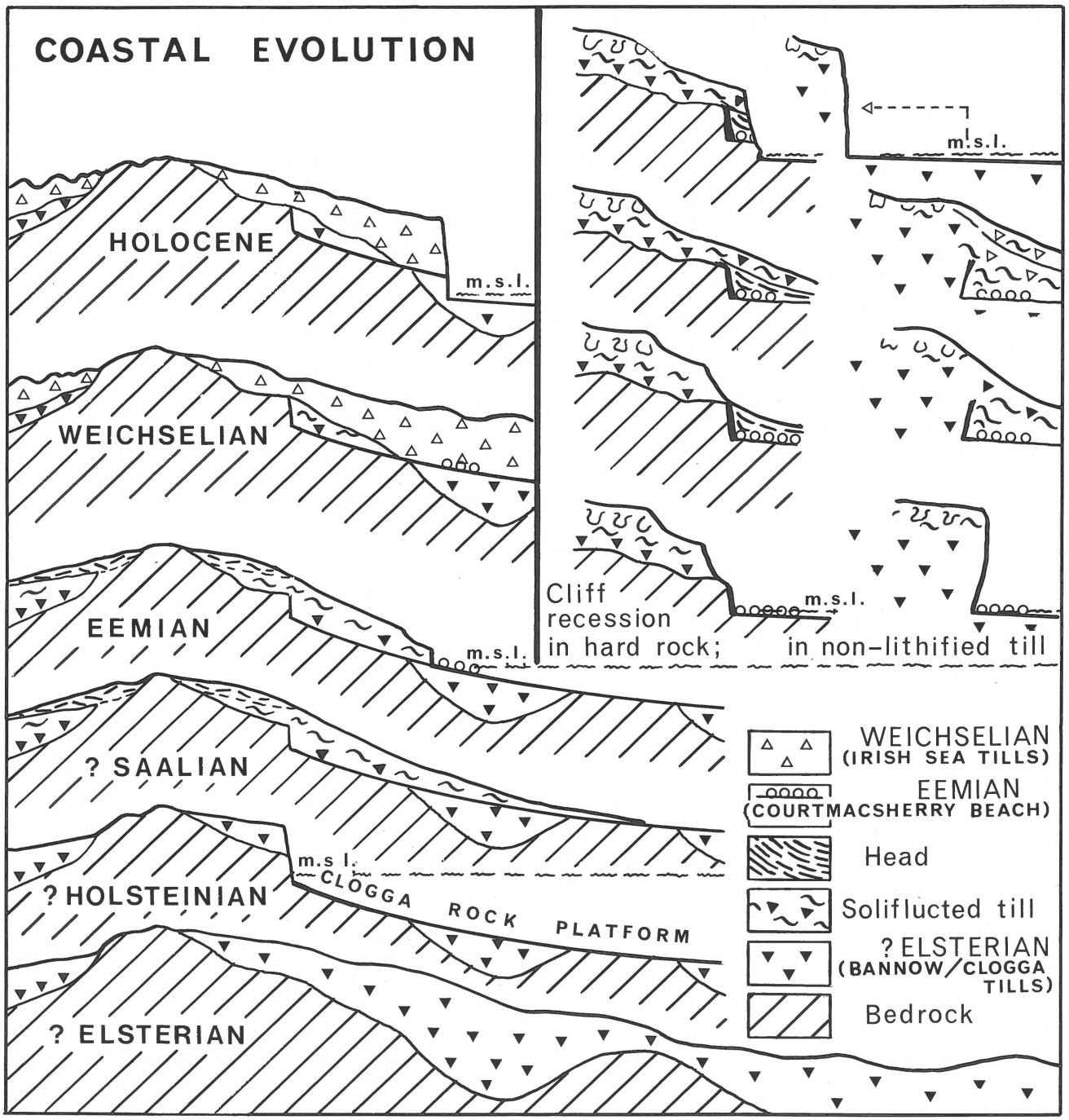

Fig. 7
Coastal evolution during the Late Quaternary in Southeast Ireland.
The succession on the left represents events along the east coast of counties Wicklow and Wexford, from the time of the deposition of the older glacial tills (? Elsterian) up to the present day. Note that the main phase of marine erosion by rising sea level is represented by the Clogga rock platform. The younger Courtmacsherry platform is merely a small notch cut in the older surface. In the inset, coastal development in hard rock and non-lithified till since that interglacial, is indicated for the south coast of Co. Wexford outside the Weichselian limit.

Gortian organic beds not seriously truncated by glacial erosion. On these grounds I would argue that there is a possibility that no ice sheet passed over the site since the peat bed was formed.

At Newtown, beside Waterford Harbour, till was observed in a marine cliff overlying a compressed peat containing pollen indicative of a Gortian flora dominated by open pinewood. These beds appear to overlie a cemented beach deposit (WATTS, 1959; MITCHELL, 1948, 1962). Later re-examination of the site (SYNGE, 1977) suggested that the (Bally-

voyle) till, deposited by ice from the northwest, may have slumped as a landslip from the back of the cliff. Although slumps commonly occur along this part of the cliff and obscure the succession, they do not give adequate grounds for invalidating the sequence worked out by Mitchell and Watts (viz. solifluction earth/upper (Ballyvoyle) till/band of upper head/lower (Newtown) till/silt sequence containing the Gortian peat bed/lower head/cemented (Courtmacsherry) beach). The recent discovery that a shelly marine till bed has been thrust against the cliffs on the opposite shore at Booley Bay (Fig. 6) suggests a third possibility, namely that the rather isolated and unique mass of till at Newtown is part of the lateral moraine of an early Weichselian ice lobe that moved north into Waterford Harbour under pressure from shelf ice filling the Celtic Sea. The (? northwards) carriage of streaks of organic matter and even a large lens of compressed peat up into the upper till might support this idea.

At Spa, on the shores of Tralee Bay in north Kerry, similar Gortian peat beds overlie the Courtmacsherry Beach (MITCHELL, 1970). No *in situ* till appears to overlie the site (WARREN, 1981). My own observations agree with this description: at one point I have recorded 3 m of fairly fine textured lower head beneath 2 m of coarser upper head, strongly cryoturbated. The base of the upper deposit is composed of sandstone blocks, some of which are striated, and are regarded as the soliflucted remnant of a till. These are unlikely to represent the outer limit of a local glacier supposed to have carried these blocks east from the highlands of the Dingle peninsula near Castlegregory, as has been maintained (LEWIS, 1974). More likely these boulders represent the north margin of a boulder fan streaming west-northwest from the east end of the Slieve Mish during the Connachtian glacierization (Fig. 1).

Only at Shortalstown in Co. Wexford has a deposit been found with some Eemian affinities. Disturbed marine interglacial deposits contain pollen with a striking resemblance of Zone *e* of the Eemian (JESSEN & MILTHERS, 1928). No Gortian deposit shows the amount of *Ulmus* (up to 7%) present at this site; this difference 'makes its allocation to the Last Interglacial reasonably positive' (COLHOUN & MITCHELL, 1971). The pollen range probably represents the climax phase of an interglacial, and is consistent with a Gortian assemblage (WARREN, 1979). The deposit appears to have been disturbed by the advance of Irish Sea ice to the Rosslare moraine (W_4a), or to one slightly older.

LAST (WEICHSELIAN) GLACIERIZATION

Studies in southeast Ireland suggest a tripartite subdivision of the Weichselian glacial substages into an early, middle and late phase. During the earliest phase (W_1) the Irish Sea glacier expanded westwards from St. George's Channel to fill the Celtic Sea with a great lobe of floating shelf ice that reached the Devon coast and the Scilly Isles (Fig. 1). Sea level probably had not yet dropped significantly from its high stand during the preceding interglacial, as is suggested by the presence of a basal marine silt (Knocknasilloge beds) in east Co. Wexford (HUDDART, 1981). With weak erosive capacity this glacier advanced across southeast Co. Wexford, depositing a layer of till on top of the Courtmacsherry Beach at Kilmore Quay to extend some 6 km further west (CULLETON, 1978-b). This movement removed the raised beach gravels from low-lying Hook Head and striated the underlying limestone bedrock, and pushed vertical beds of till against the coastal cliffs of Waterford Harbour (Fig. 6).

Named the *Ballycroneen* advance from the locality where the westernmost deposit of marine tills was emplaced, this mass of ice may have temporarily dammed all major valleys opening on to the coast. Indeed high-level deltaic deposits in the Blackwater valley may have formed at this time as outwash was being delivered from the inland ice.

Historically the Ballycroneen till has been regarded as belonging to the older (Munsterian) glacierization because it was thought to have represented an earlier movement of Irish Sea ice that merged with inland ice across south Co. Wexford. More recent work has shown that what formerly was regarded as Irish Sea till does, in fact, belong to one of the tills of the Bannow formation deposited by inland ice (CULLETON, 1977, 1978-a). There is no evidence of contact between coastal and inland ice. The latter belonged to a much earlier event. At this time inland ice extended east across Cork Harbour and probably extended to a limit at Garryvoe shortly after the coastal ice had started to wane (FARRINGTON, 1954).

During the next main oscillation of the Irish Sea glacier the icefront readvanced almost to Kilmore Quay (W_2). By this time the shelf ice had dispersed and sea level was probably low, because the ice was now strongly erosive and removed all traces of the Courtmacsherry Beach. This glacial limit is also emphasized as the western terminus of large granite erratics from the Carne outcrop. The terminal moraine is indicated by St. Patrick's Bridge, a drift ridge extending out beneath the sea to the Saltee islands.

At the time of the Kilmore Quay substage marginal drainage and outwash travelling along the Slaney valley were deflected southwest into Bannow Bay, cutting across the intervening rock ridge by the Mulmontry gorge overflow channel (COLHOUN & MITCHELL, 1971). Continuity of the uppermost outwash terrace in the Slaney valley upstream from the ice margin as far as Bunclody shows that the inland ice (Hacketstown substage) did not extend across the granitic highlands of Wicklow during the Weichselian.

During the Late Weichselian (W_4a) the Irish Sea glacier terminated north of Wexford Harbour in a great kettle moraine (Screen Hills or Curracloe moraine), the lateral of which can be traced north past Gorey and Glenealy to Curtlestown (near Enniskerry). This 'line' appears to mark the termination of severe periglacial climatic conditions as both pingos and severe cryoturbation structures have not been found within this glacial limit (MITCHELL, 1973; SYNGE, 1973; WARREN, 1981). In the vicinity of Enniskerry this glacial limit

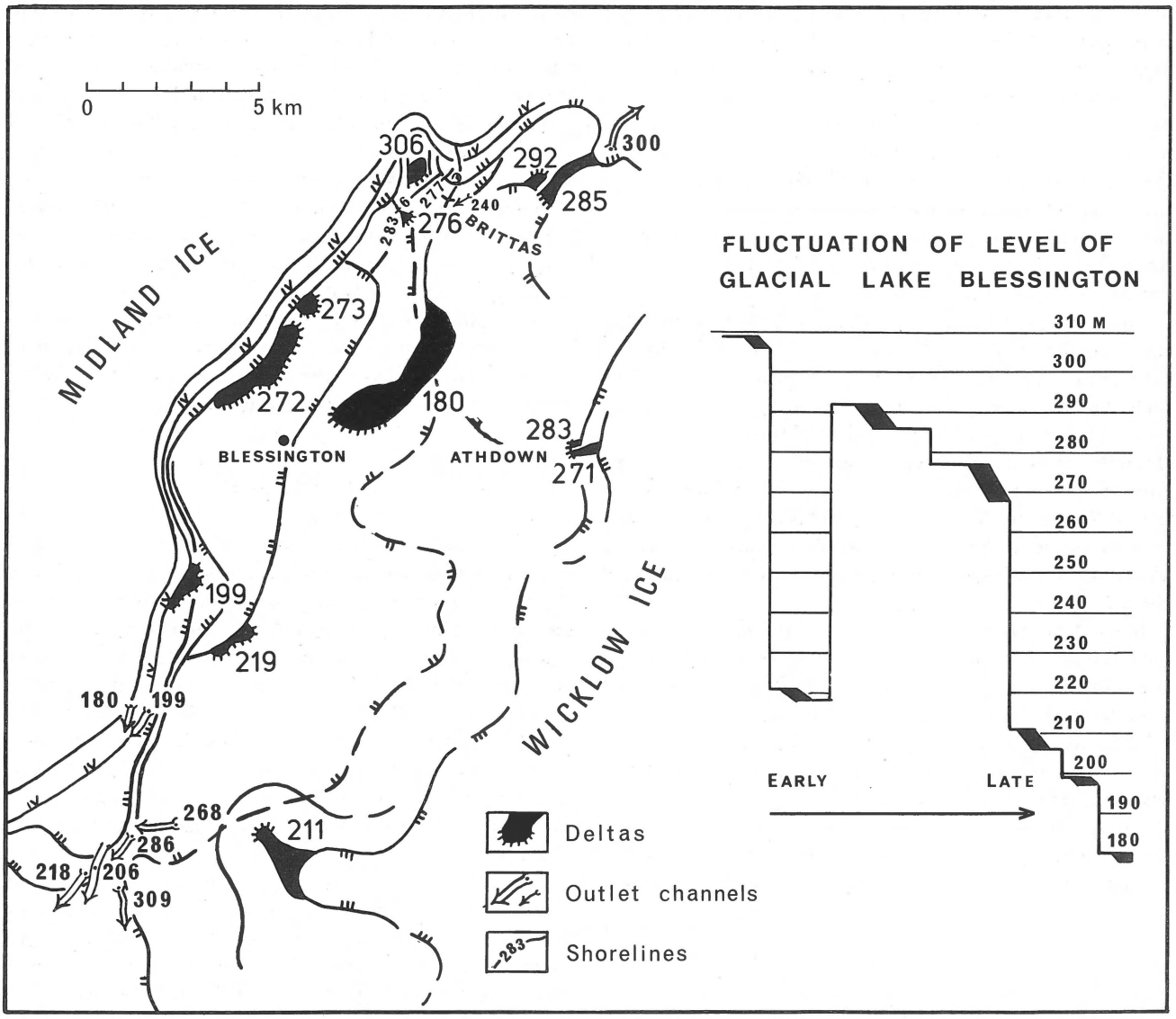

Fig. 8
Correlation of glacial phases by means of glacial lake levels.
Midland ice first advanced to its maximum impounding Glacial Lake Blessington at 306 –9 m; the level then dropped to 219 m as the icefront retreated. Subsequently a readvance again raised the level; to 286 m on this occasion. At the same time the local Wicklow glaciers advanced to the west. During deglaciation the level of the lake fell to successively lower and lower levels as the ice uncovered lower outlets. Phases of active downcutting at the different outlets are shown on the graph by thick lines.

represents the outer edge of Farrington's Eastern General advance, in the older chronology. Remapping now shows that this phase postdates that of the Hacketstown substage in the Blessington area, so that it cannot any longer be considered pre-Weichselian.

In Co. Wicklow correlation of moraines and drift limits is possible by means of interconnecting outwash systems such as ice-marginal deltas, glacial-lake shorelines, and the intakes of lake outlets. By the precise levelling of such features the interrelation of different glacial advances can be arranged chronologically. Thus in west Co. Wicklow the Athdown-I local glacial phase corresponds with the position of the inland-ice margin at the 283 –5 m level lake because deltas formed at both glacier margins at that level (Fig. 8). During the following oscillation of the inland-ice margin (W_4b) the lake level stood at 271 –3 m, although the next advance of the local glaciers (Athdown-II substage) did not occur until the lake level had dropped to 211 m. In a similar manner it can be shown that the earlier or maximum expansion of the inland-ice during the Hacketstown substage (SYNGE, 1973) postdates the greatest expansion of independent local glaciers (Aughrim substage).

The Wicklow substage (W_4b), also associated with the largest deltas in the Blessington area, represents a consider-

able readvance of the icefront, for it surged forward from the northwest foothills of the Wicklow highlands to Wicklow Head, a distance of 50 km, across terrain that had earlier been occupied by Irish Sea ice. According to HOARE (1977) this glacial advance across the coast north of Bray could not be associated with till deposition even though it is well documented (LAMPLUGH ET AL., 1903); all tills in the cliff section originated from the Irish Sea. It is apparent, however, that the upper unit of tills is composed of material eroded out of the lower series by the passage of the readvancing ice from the northwest (SYNGE, 1977).

The last important readvance of the icefront is often called the 'Drumlin Readvance' because it is associated with the widespread deposition of till in the form of drumlins. This phase followed a period of almost continuous ice-retreat when most of the great eskers of the midlands were deposited. The 'Drumlin' substage has been recognized across the midlands from Westmeath to the Shannon estuary; in Co. Limerick this glacial limit coincides with the Fedamore moraine. Further west this same ice limit has become the maximum westward extension of Midlandian, owing to the westward migration of the ice shed.

In southwest Ireland the 'Drumlin' substage has been recognized in west Co. Cork (FARRINGTON, 1936), delimiting a considerably smaller ice cap than that of the previous one, close to Cork city (FARRINGTON, 1959).

After the disappearance of the ice sheet renewed glacial activity reappeared in most highland cirques. At Lough Nahanagan in Co. Wicklow lenses of organic silt caught up in the outer moraines of a cirque glacier show a late-glacial *Juniperus-Empetrum* vegetation assemblage. These gave a ^{14}C age of 11,600 ± 260 and 11,500 ± 550 years B.P. (COLHOUN & SYNGE, 1980).

POSTGLACIAL EVENTS

Once the waning ice sheet was uncovering the Dublin area the rising waters of the sea started encroaching across the present coastline as this was one of the more heavily isostatically downwarped areas. The highest marine levels were reached by the time the icefront had receded to the line of the Boyne. With further deglaciation isostatic uplift outstripped the rate of sea-level rise. Further south, outside the zone of isostatic downwarping by the former ice load, sea level rose steadily from its low glacial level without being interrupted by a regression phase. Off Whiddy island, in Bantry Bay, lacustrine deposits containing Preboreal herbaceous pollen were found at −60 m m.s.l. (STILLMAN, 1968).

During this postglacial period a changing pattern of vegetational evolution took place, and is faithfully recorded in Littleton Bog. Both fauna and flora repopulated the land by immigration over some land-bridge from Britain. Such a land-bridge would be expected in the southern part of the Irish Sea basin, between the isostatically depressed north part of the basin and the waters of the ocean to the southwest. This land connection probably did not last long judging by the considerable elements of fauna and flora which populated the whole of Britain but were barred entry into Ireland.

The remarkable spread and development of the Giant Irish Deer (*Megaloceros giganteus*) is attributable to a very early use of the land-bridge route because this animal had already died out by about 10,800 years B.P. (MITCHELL, 1976). Great numbers of bones from these animals were found at Ballybetagh, a type site for the Irish Late Glacial, about 14 km south of the centre of Dublin.

The continued rise of the sea during the Holocene culminated in the Dublin area at c. 4 m by about 5,000 years B.P. Further south the peak of the transgression was later: shortly after 4,000 years B.P. in Ballycotton Bay (MITCHELL, 1977).

CONCLUSION

In this account of the Quaternary succession of the south of Ireland evidence has been presented to suggest some fairly radical changes to that usually adopted. The most radical of these are, (1) the suggestion that the Gortian interglacial is the equivalent of the continental Eemian; (2) that the Older Drifts are divisible into two separate glacierizations, an extensive Munsterian (? Elsterian) phase, and a more limited (? Saalian) phase; (3) that the 3-5 m Courtmacsherry Beach is Eemian and postdates a partially warped 9-20 m Clogga shoreline that is Holsteinian in age; and (4) that an early expansion of shelf ice, Weichselian in age, spread into the Celtic Sea.

The suggestion of a last interglacial age for the Gortian deposits and their correlation with the 3-5 m Courtmacsherry Beach is acceptable to a number of geologists. But the concept of three major phases of glacierization (instead of two), and that of a widespread advance of ice into the Celtic Sea during the early part of the Weichselian are viewed with some scepticism.

On sounder basis rests the subdivision of the Weichselian glacial phases into seven significant substages. The late- and postglacial sea-level changes are also well documented: a late-glacial transgression and regression in the most heavily isostatically affected area (in the vicinity of Dublin), and a postglacial rise culminating at about 5,000 years B.P., followed by a regression.

The Quaternary succession is most soundly based in those areas that have been remapped by Quaternary geologists, viz. the Dublin area, and counties of Wicklow, Limerick, Carlow and Kerry, and the area around Cork Harbour. Also fairly complete coverage of the Quaternary geology of counties Wexford and Clare has been achieved by the National Soil Survey. Knowledge of the intervening areas is sparse. Until more mapping is completed many aspects of the Irish Quaternary sequence will remain speculative.

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REFERENCES

Bowen, D. Q. 1973 The Pleistocene Succession of the Irish Sea – Proc. Geol. Assoc. 84: 249-272.

Carvill Lewis, H. 1894 Papers and notes on the glacial geology of Great Britain and Ireland – Longman, Green & Co. (London): 649 pp.

Charlesworth, J. K. 1928 The glacial retreat from central and southern Ireland – Q. J. Geol. Soc. Lond. 84: 293-344.

Close, M. H. 1867 Notes on the general glaciation of Ireland – J. R. Geol. Soc. Ir. 1: 207-242.

Colhoun, E. A. & G. F. Mitchell 1971 Interglacial marine formation and lateglacial freshwater formation in Shortalstown townland, Co. Wexford – Proc. R. Ir. Acad. 71B: 211-245.

Colhoun, A. E. & F. M. Synge 1980 The cirque moraines of Lough Nahanagan, County Wicklow, Ireland – Proc. R. Ir. Acad. 80B: 25-45.

Culleton, E. B. 1977 The origin and composition of soil parent materials in south Wexford – Ir. J. Agric. Res. 16: 171-185.

—— 1978-a Characterisation of glacial deposits in south Wexford – Proc. R. Ir. Acad. 78B: 293-308.

—— 1978-b Limits and directions of ice movements in south county Wexford – J. Earth Sci. R. Dubl. Soc. 1: 33-39.

Farrington, A. 1934 The glaciation of the Wicklow Mountains – Proc. R. Ir. Acad. 42B: 173-209.

—— 1936 The glaciation of the Bantry Bay district – Sci. Proc. R. Dubl. Soc. N.S. 21: 345-361.

—— 1944 The glacial drifts of the district around Enniskerry, Co. Wicklow – Proc. R. Ir. Acad. 50B: 133-157.

—— 1949 The glacial drifts of the Leinster Mountains – J. Glaciol. 1: 220-225.

—— 1954 A note on the correlation of the Kerry-Cork glaciations with those of the rest of Ireland – Ir. Geogr. 3: 47-53.

—— 1959 The Lee Basin. Part I: Glaciation – Proc. R. Ir. Acad. 60B: 135-166.

—— 1966 The early-glacial raised beach in County Cork – Sci. Proc. R. Dubl. Soc. A 2: 197-219.

Finch, T. F. & F. M. Synge 1966 The drifts and soils of west Clare and the adjoining parts of counties Kerry and Limerick – Ir. Geogr. 5: 161-172.

Garrard, R. A. 1977 The sediments of the South Irish Sea and Nymphe Bank area of the Celtic Sea. In: C. Kidson & M. J. Tooley (eds.): Quaternary history of the Irish Sea – Geol. J. spec. issue 7: 69-92.

Hoare, P. G. 1977 The glacial stratigraphy in Shanganagh and adjoining townlands, south-east county Dublin – Proc. R. Ir. Acad. 77B: 295-305.

Huddart, D. 1981 Pleistocene foraminifera from south-east Ireland – some problems of interpretation – Quaternary Newsletter 33: 28-41.

Jessen, K., S. Th. Andersen & A. Farrington 1959 The interglacial deposit near Gort, Co. Galway, Ireland – Proc. R. Ir. Acad. 60B: 1-77.

Jessen, K. & V. Milthers 1928 Inter-glacial fresh-water deposits in Jutland and North-West Germany – Danm. Geol. Unders. 2: 1-379.

Lamplugh, G. W., J. R. Kilroe, A. McHenry, H. J. Seymour & W. B. Wright 1903 The geology of the country around Dublin – Mem. geol. Surv. Ireland (Explanation to accompany Sheet 112).

Lewis, C. A. 1974 The glaciations of the Dingle peninsula, county Kerry – Sci. Proc. R. Dubl. Soc. A5: 207-235.

Mitchell, G. F. 1948 Two inter-glacial deposits in south-east Ireland – Proc. R. Ir. Acad. 52B: 1-14.

—— 1960 The Pleistocene history of the Irish Sea – Adv. Sci. Lond. 17: 313-325.

—— 1962 Summer field meeting in Wales and Ireland – Proc. Geol. Ass. 73: 197-213.

—— 1970 The Quaternary deposits between Fenit and Spa on the north shore of Tralee Bay, Co. Kerry – Proc. R. Ir. Acad. 70B: 141-162.

—— 1972 The Pleistocene history of the Irish Sea: second approximation – Sci. Proc. R. Dubl. Soc. 4A: 181-199.

—— 1973 Fossil pingos in Camaross Townland, Co. Wexford – Proc. R. Ir. Acad. 73B: 269-282.

—— 1976 The Irish Landscape – Collins (Glasgow): 277 pp.

—— 1977 Raised beaches and sea-levels. In: F. W. Shotton (ed.): British Quaternary studies, recent advances 13: 169-186.

Stephens, N. 1957 Some observations on the 'Interglacial' Platform and Early Post-glacial Raised Beach on the East Coast of Ireland – Proc. R. Ir. Acad. 58B: 129-149.

Stillman, C. J. 1968 The Post Glacial change in sea level in Southwestern Ireland: new evidence from fresh-water deposits on the floor of Bantry Bay – Sci. Proc. R. Dubl. Soc. 3A: 125-127.

Synge, F. M. 1973 The glaciation of south Wicklow and the adjoining parts of the neighbouring counties – Ir. Geogr. 6: 561-569.

—— 1977 The coasts of Leinster. In: C. Kidson & M. J. Tooley (eds.): Quaternary history of the Irish Sea – Geol. J. spec. issue 7: 199-222.

—— 1979 Quaternary glaciation in Ireland. In: Prospecting in areas of glaciated terrain 1979 – Inst. Mining Metall.: 1-7.

Walker, D. 1953 The Interglacial deposits at Histon Road, Cambridge – Q. J. geol. Soc. Lond. 108: 273-282.

Warren, W. P. 1979 The stratigraphic position and age of the Gortian interglacial deposits – Bull. Geol. Surv. Irel. 2: 315-332.

—— 1981 Features indicative of prolonged and severe periglacial activity in Ireland, with particular reference to the South-West – Biul. peryglacj. 28: 241-248.

Watts, W. A. 1959 Interglacial deposits at Kilbeg and Newtown, Co. Waterford – Proc. R. Ir. Acad. 60B: 79-134.

West. R. G. 1968 Pleistocene geology and biology – Longmans (London): 377 pp.

Wright, W. B. 1914 The Quaternary Ice Age – London.

—— 1936 The Quaternary Ice Age (Second ed.) – London.

Wright, W. B. & H. B. Muff 1904 The pre-glacial raised beach of the south coast of Ireland – Sci. Proc. R. Dubl. Soc. N.S. 10: 250-324.