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IQUA

CENTRAL KERRY

Field Guide No. 20

1996

Cumann Staidéar Ré Cheathartha na h-Éireann
Irish Association for Quaternary Studies

Ciarraí Láir
Central Kerry

á eagrú ag/edited by

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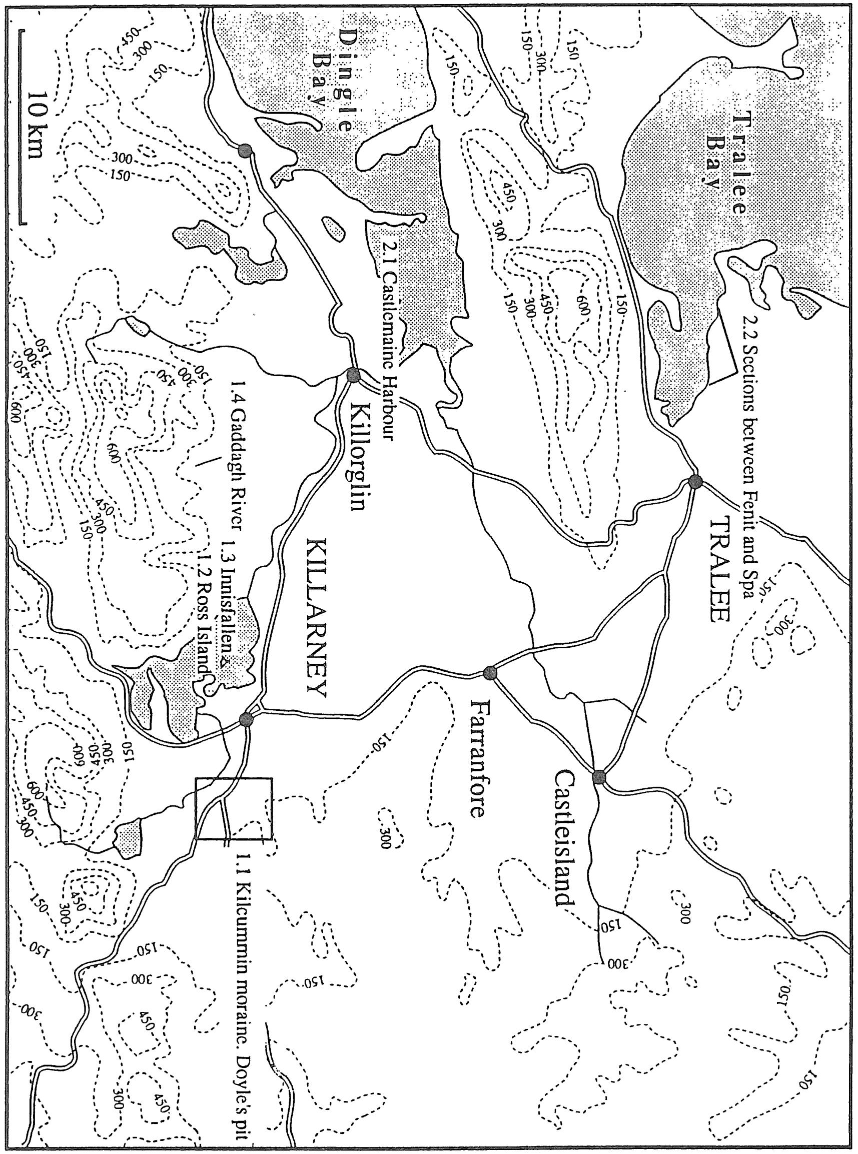


Figure 1. Sketch map of locations to be visited during the 1996 IQUA fieldmeeting. Sites are located on more accurate maps (where available) in the body of the guidebook.

PREFACE

This guide is intended to complement a weekend field meeting (Friday 4th October to Sunday 6th October, 1996) of the Irish Association for Quaternary Studies (IQUA).

Given the complexity of the Quaternary history of the region this Guide cannot be regarded as comprehensive. However, it is hoped that it will serve as an adequate field guide to the sites that will be visited and provide a useful guide to information on recent and, in several instances, still on-going research. Unfortunately, due to time constraints we cannot do justice to the Quaternary of the area and much of interest awaits the visitor.

Please note that some of the sites referred to in this guide are private property and permission should be sought before entering.

Material in this guide has been drawn from a number of sources which are attributed in the text.

The area that we will cover during this trip is on the Ordnance Survey of Ireland's 1:50,000 *Discovery Series* sheets 71 and 78 and some of the sites that we will visit are shown on Figures in this guide.

Outline of the Field Excursion: The localities are marked on Figure 1.

Saturday 5th October

1.1 Kilcummin moraine. Doyle's pit
1.2 Ross Island
1.3 Innisfallen
1.4 Gaddagh River Moraines

Sunday 6th October

2.1 Castlemaine Harbour
2.2 Sections between Fenit and Spa

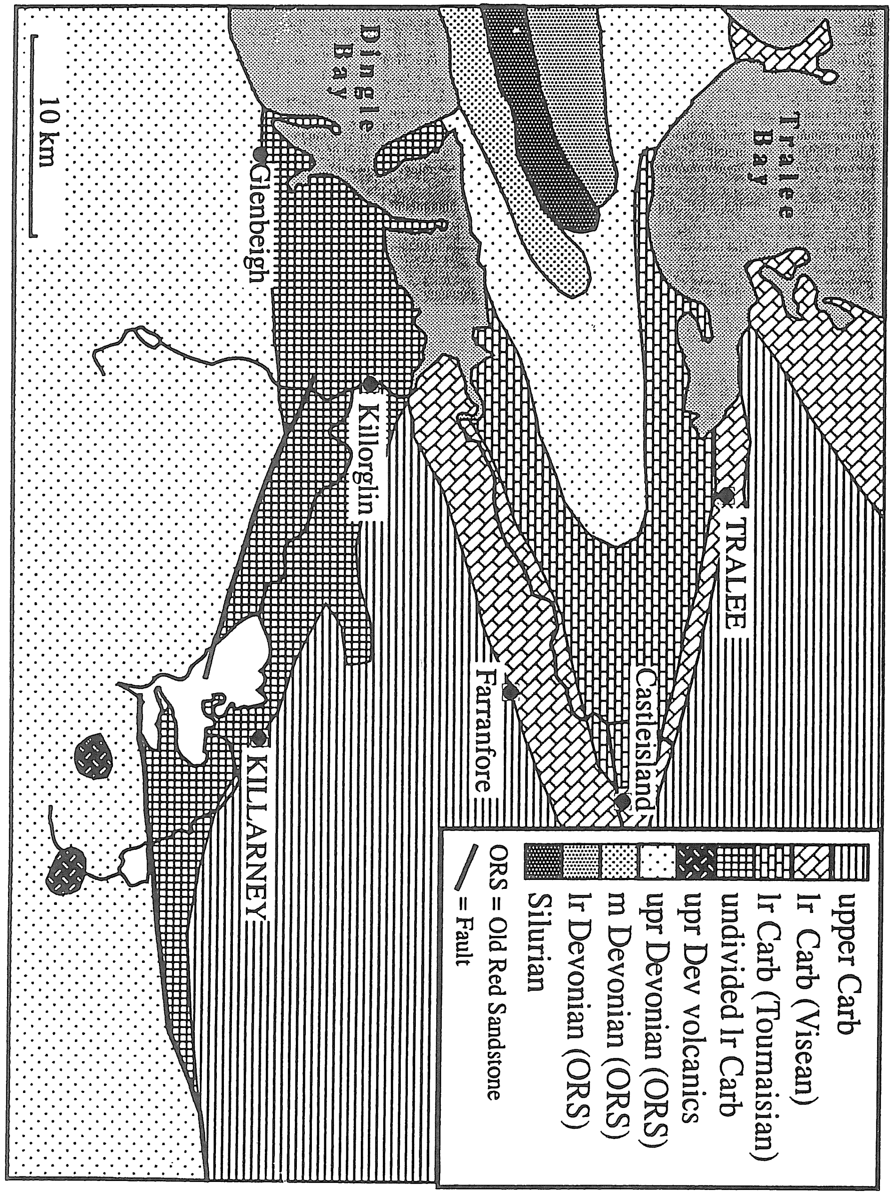


Figure 2: Pre-Quaternary geology of East Kerry.

PRE-PLEISTOCENE GEOLOGY OF CENTRAL KERRY
(AF)

The exposed bedrock in east Kerry is composed of sedimentary rocks of Devonian and Carboniferous age together with some volcanic rocks of Devonian age. These are described in order of age below.

The area is underlain by Old Red Sandstone (ORS), a succession of conglomerates, sandstones and mudstones deposited in lakes and in the beds and floodplains of large rivers. These rivers were draining and eroding mountains in the northern and western parts of what is now Ireland in the late Devonian period, about 350 million years ago (Ma). The eroded sediment was transported south across a desert landscape to be deposited in a large fault-bounded trough called the Munster Basin. The commonly red colour of these rocks is due to the oxidising conditions under which the sediments were deposited, allowing iron oxide to coat the quartz grains that make up the bulk of the rock. In the green sandstones (also part of the ORS), the cement is of chlorite, a soft green mineral of the clay family. In the conglomerates pebbles of vein quartz (white) and jasper (red) may be seen. These are strong materials and survived the erosion and transport from their source without being broken down as much as the other sediments.

At the same time as the deposition of the sandstones, volcanic activity occurred in an area SE of Killarney. Rhyolite lava flows and accumulations of ash built up in three volcanic centres, eventually being covered with more ORS sediments. It is thought that these volcanic rocks may share a common magmatic source with the Leinster Granite.

At the start of the Carboniferous period, about 340 Ma, the sea level rose and a major marine transgression began. The terrestrial sediments of the ORS were covered by marine sediments as the sea flooded the land from the south. Initially, these were marginal marine sandstones and mudstones but, as the water became deeper, limestones began to form. In the Fenit area these limestones contain well preserved fossils such as crinoids, brachiopods and corals, all of which lived on the bottom of the warm shallow seas and which were preserved in the accumulating lime-rich sediments. The transgression eventually covered most of the present area of Ireland and the thick deposits of Carboniferous limestones that underlie large parts of Ireland were laid down.

Later during the Carboniferous period, land areas emerged from the sea due to large scale uplift of the seabed and/or a fall in sea level. Large rivers draining these land areas brought fine organic-rich material to the sea to form coastal swamps and deltas. These sediments formed the middle Carboniferous (Namurian) rocks of East Kerry. These are locally known as "pencil" due to their dark colour and friable nature. Because they are relatively resistant to erosion (as compared to the underlying limestone), the Namurian rocks form rounded hills. Rocks containing coal seams were probably deposited on top of the Namurian rocks of the area but were eroded off afterwards.

Late during the Carboniferous the Variscan (also known as the Hercynian) mountain-building phase occurred. The mountains of Cork and Kerry belong to this chain which extends east to Cornwall and Central Europe. The effects of the deformation that caused the mountains of the SW can be seen in folds and veins in the ORS and Carboniferous Limestones of the area. In the Killarney area a large fault of this age occurs. The steep north face of Torc Mountain coincides approximately with this fault which extends west at the base of the MacGillycuddy's Reeks. This fault marks the northern edge of intense Variscan deformation; at Killarney the limestones are badly deformed and do not contain well preserved fossils whereas further north around Fenit the limestones are relatively undeformed and contain numerous well preserved fossils.

There are no rocks younger than Carboniferous (other than glacial till) preserved in Kerry except for a very small deposit of Cretaceous chalk at Ballydeanlea on the road from Killarney to Farranfore. The chalk here has flint nodules similar to those in other Cretaceous chalk deposits in Antrim and at Dover but in Killarney is largely mixed with Namurian shale fragments. It is thought that this deposit resulted from slumping of Namurian and overlying chalk down a fault scarp during Cretaceous times. It is not now thought to be a product of karstic collapse.

The overall outcrop of the rocks described above is shown in Figure 2. In South Kerry there is little Carboniferous preserved because of the greater degree of uplift and erosion that occurred south of the large fault mentioned above. Folding is intense along the Iveragh and Beare Peninsulas and individual folds can be traced for many kilometres along strike.

In North Kerry, the uplands are also made of deformed rocks but here they are folded more gently. A good example is the Slieve Mish Anticline south of Tralee. This forms the root of the Dingle Peninsula and has ORS in the core of the fold, limestones around this core and Namurian shales on the outer edge (Figure 2). This outcrop pattern is due to the plunge of the fold to the east - this is clearly visible from large parts of Kerry where we can see the ORS rocks of the Slieve Mish Mountains dipping to the east under the Carboniferous limestones and shales.

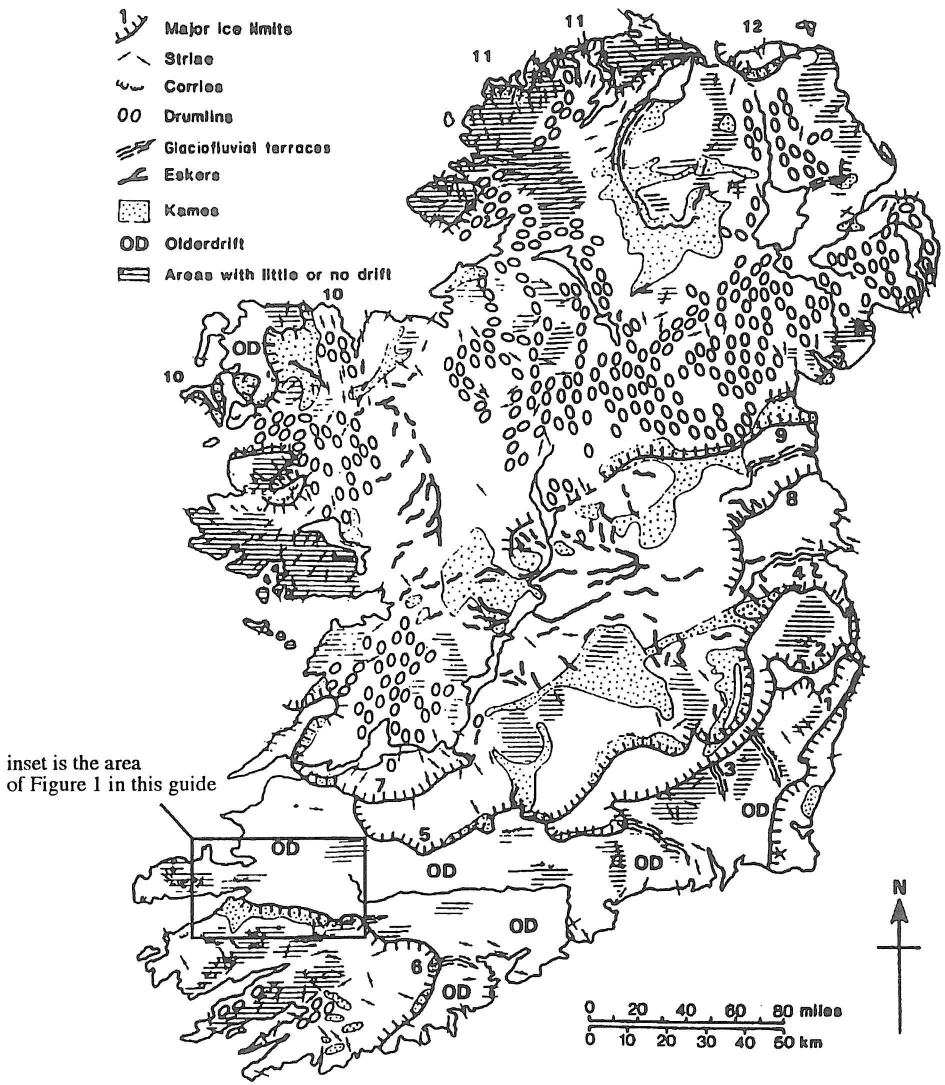


Figure 3. The Quaternary geology of Ireland
(from McCabe, 1987)

Regional Pleistocene Glaciation
(PC)

Figure 3 is a map of Ireland showing the general distribution of glacial landform elements within the country. This map (modified after McCabe, 1987) is the traditionally adopted model showing deposits predominantly formed during the last cold stage (Midlandian) but also including areas which have been considered as ice free during the Midlandian (i.e. those areas marked as "older drift"). The ice movement directions (based on numerous studies of till content and erratics) are depicted on Figure 4A and 4B and although the timing of these glacial events is the subject of some controversy this general pattern is one that must have predominated during major glacial episodes.

Traditionally Irish glacial deposits have been subdivided on the assumption that there is evidence of two major cold stages within which ice advances and retreats can be recognised and subdivided using a number of lines of evidence. Figure 4 (4A and 4B) outlines this view showing supposed ice directions during the Munsterian and Midlandian cold stages. The problems inherent in this approach are reviewed in detail by McCabe (1987, pp262-264). It is increasingly clear that the existing subdivision of the Irish Quaternary cannot remain viable as many sites considered to be Munsterian in the older literature (summarised in Mitchell *et al*, 1973) have been reinterpreted and some have actually been dated and found to be far more recent than originally believed. A more likely scenario for the Late Midlandian (Glenavy Stadial) is that depicted on Figure 4C which shows extensive ice cover and includes evidence from a wide series of studies (e.g. Scourse, 1991, McCabe, 1996 and McCabe and O'Cofaigh, 1996). For the present a working framework for the subdivision of the Quaternary is outlined in Figure 5. However, a more acceptable and rigorous classification of Irish Quaternary stratigraphy is soon to be published as a *Quaternary Correlation Report* by the Geological Society of London. This will be an extensive update of the 1973 version of Mitchell *et al.* (1973).

The Irish Quaternary succession used in this guide is reproduced in Figure 5. The regional stratigraphy is not reproduced here as it requires serious reinterpretation.

Glaciation in the area covered by this guide

The earlier literature suggested that during the Munsterian the region was affected by ice of the *Greater Cork-Kerry Glaciation* (the "older drifts" on Figure 3 and see Figure 4A) whilst the Midlandian ice formed the ice dome of the *Lesser Cork-Kerry Glaciation* (which formed in the Early and Late Midlandian - Herries Davies and Stephens, 1978, Figure 6.2). The history of previous work in the region is summarised by Warren, 1977 (*in* Lewis, 1977 p. 37) and his account shows that there is considerable doubt regarding the glacial limits in the region.

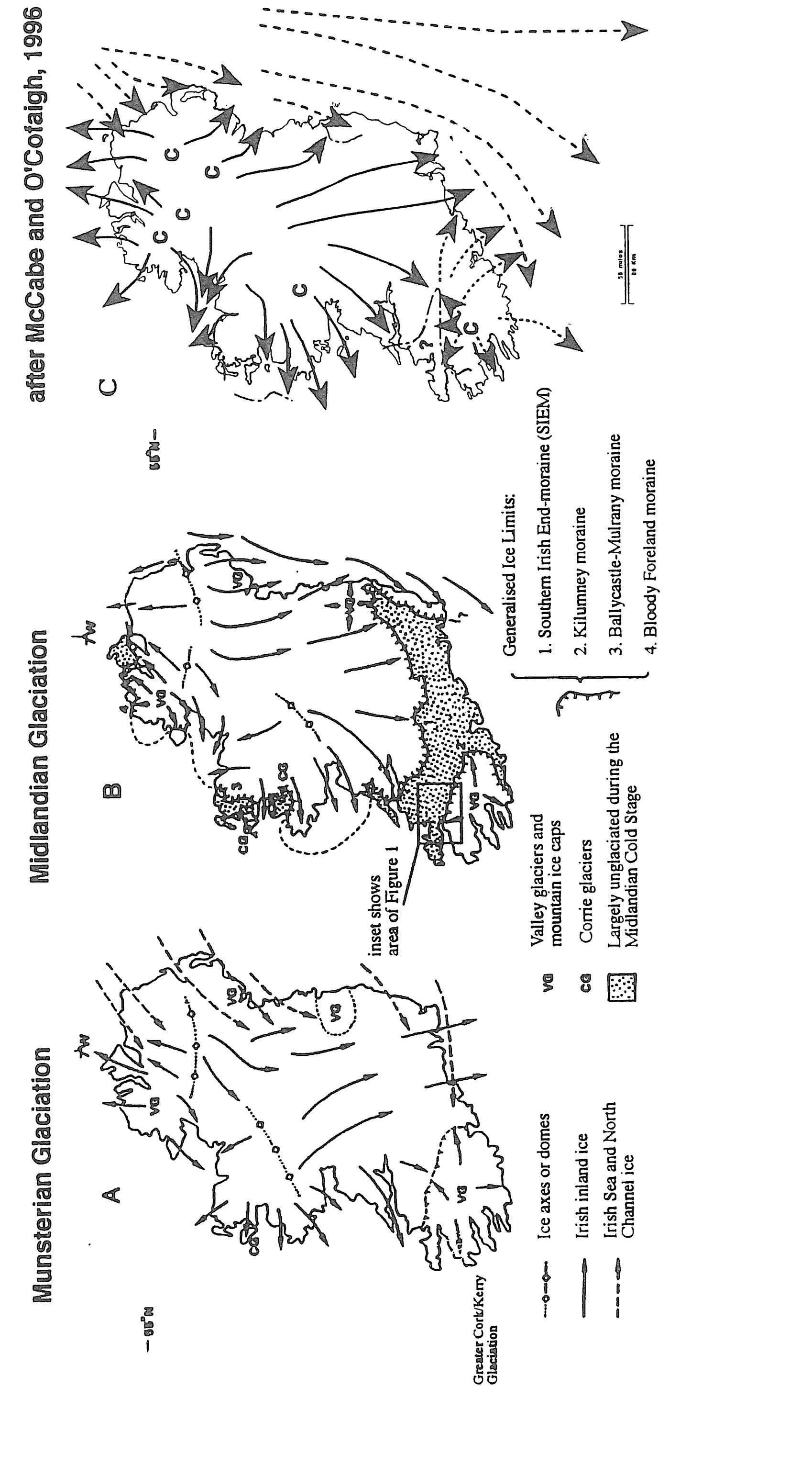


Figure 4. General directions of ice-sheet movement in Ireland

Figure 5. The subdivision of the Quaternary Period in Ireland
(after Mitchell *et al.* 1973, McCabe 1987 and Coxon, 1993)

Series	Stage	Age	Substage	Comments
Holocene	Littletonian	10,000	Nahanagan Stadial	Named after glacier activity at Lough Nahanagan in the Wicklow Mountains (Colhoun and Synge 1980). Extensive glaciation has not been recognised in Ireland but many periglacial features and the evidence of small glaciers are found (Coxon 1988, Gray and Coxon 1991, Wilson 1990a andb and Walker *et al.* 1994).
		Late-glacial 11,000	Woodgrange Interstadial	This complex interstadial (with an early phase of climate amelioration and containing at least one period of erosion and climate deterioration) is recorded in many biogenic sequences from Irish Late-glacial sites (Watts 1977; 1985, Cwynar and Watts 1989, Walker *et al.* 1994).
Pleistocene	Midlandian: Late	13,000; 17,000	Drumlin Event	A distinct event (within the Drumlin Readvance Moraine of Synge 1969) producing drumlins. Evidence from north Mayo dates this event to around 17ka (McCabe, Haynes *et al.* 1986) and the period is discussed in detail by McCabe (1985; 1987; 1993).
		Glenavy Stadial	Main Event	The maximum ice advance of the last glaciation peaking by 20–24ka. Sequences of till and organic sediments from Aghnadarragh (McCabe, Coope *et al.* 1987) allow this phase of glaciation to be put into context within the framework of the Midlandian cold stage.
	Midlandian: Middle	*c.* 25,000	Derryvree Cold Phase	Organic silts found between two tills at Derryvree (Colhoun *et al.* 1972) show a treeless, muskeg environment. The mammal remains from Castlepook Cave (Mitchell 1976; 1981; Stuart and van Wijngaarden-Bakker 1985) date from this period (34–35ka). Recent dates for mammal faunas from caves range from 32ka-20ka (Woodman and Monaghan 1993) indicating the possibility of ice free areas in Cork during the Glenavy Stadial.
	Midlandian: Early	*c.* 40,000	Hollymount Cold Phase	Organic muds found at Hollymount (McCabe, Mitchell *et al.* 1978), Aghnadarragh (McCabe, Coope *et al.* 1987) and Greenagho (Dardis *et al.* 1985). Fossils suggest cold, open, treeless environments. Possibly a continental climate with high seasonality.
		> 48,000	Aghnadarragh Interstadial	Pollen and beetle evidence from Aghnadarragh (McCabe, Coope *et al.* 1987) suggests cool temperate conditions with woodland, similar to that of Fennoscandia today. Dated to >48ka and tentatively correlated to the Chelford Interstadial (McCabe 1987).
			Fermanagh Stadial	Till pre-dating organic beds at Derryvree, Hollymount (McCabe, Mitchell *et al.* 1978) and Aghnadarragh (McCabe, Coope *et al.* 1987) are believed to have covered most of Ulster. Evidence (from the presence of certain tree taxa in the subsequent interstadial) suggests that the glaciation may have been short-lived (Gennard 1986; McCabe 1987).
		c. 115,000	Kilfenora Interstadial	UTD dates place cool temperate organic deposits at Fenit in Co.Kerry early within the Midlandian Glaciation (118,000 years BP -Heijnis 1992, Heijnis *et al.* 1993). The biogenic sediments represent cool conditions during Oxygen Isotope Stage 5a or (more likely) 5c.
	Last Interglacial	*c.* 120,000		The discovery of a reworked ball of organic sediment within the sands and gravels of the Screen Hills moraine (500m north of Blackwater Harbour within the Screen Member of Thomas and Summers 1983) gives hope of finding deposits of last interglacial age, as here for the first time in Ireland a *Carpinus* -rich pollen assemblage has been recorded (McCabe and Coxon 1993). This material may represent Oxygen Isotope Stage 5e, a warm temperate stage, but the evidence to date is far from conclusive.
	Munsterian	*c.* 132,000		Widespread glacigenic sediments in the southern part of Ireland (Munster) have long been regarded as belonging to an 'old' glaciation on the grounds that they show distinct assemblages of erratics, striae and glacial limits as well as exhibiting subdued relief, deep weathering profiles and a lack of 'fresh' glacial landforms (Mitchell *et al.* 1973; Synge 1968; Finch and Synge 1966; McCabe 1985; 1987). The lack of (any) stratigraphic control has meant that although the Munsterian deposits exhibit certain unique characteristics the relative age of the cold stage is unknown. A distinct possibility is that some 'Munsterian' deposits are in fact Midlandian (including Early Midlandian) in age, but this theory awaits further verification (McCabe 1987; O'Cofaigh 1993; McCabe and O'Cofaigh 1996)
	Gortian	estimated minimum age *c.* 302,000; rapid termination	Gn IV; Gn IIIb; Gn IIIa; Gn II; Gn I; Pre-Gn I-g	Eleven sites have been described from around Ireland that record part of a characteristic temperate stage deposit with a biostratigraphically identifiable record. The Gortian is represented by a unique record of vegetational succession and by a number of fossil assemblages that represent stages which have been described in a number of ways (e.g. by Mitchell 1981; Watts 1985; Coxon 1993). Particularly noticeable aspects of the Gortian are its sudden truncation (Coxon *et al.* 1994) and biogeographically interesting flora (Coxon and Waldren, 1995). Opinion is divided as to the age of the Gortian (Watts 1985, Coxon 1993). Biostratigraphically it resembles the Hoxnian of Britain and the Holsteinian of Europe. Amino-acid racemisation results on marine Gortian sediments from Cork Harbour (Scourse *et al.* 1992; SHELF, in prep.) confirm this suggestion and the interglacial may represent Oxygen Isotope Stage 9 or 11 (see Coxon 1993). The dates on this chart are tentative and based on Bowen, Richmond *et al.* 1986.
	Pre-Gortian	estimated maximum age *c.* 428,000		Prior to the Gortian are sediments of late-glacial aspect, suggesting the temperate stage was preceded by a cool/cold stage. This stage is not represented by long or datable sequences, and the age is unknown.
	Ballyline	age unknown possibly > 428,000		A deposit of laminated, lacustrine, clay over 25 metres thick was discovered in 1979 by the Geological Survey of Ireland filling a solution feature in Carboniferous Limestone below glacial sediments near Ballyline, Co. Kilkenny (Coxon and Flegg 1985). From the evidence available the pollen assemblages can be seen to be typical of Middle Pleistocene sequences in Europe, but a firm correlation to a particular stage is not possible.
Pliocene	Pollnahallia (Pliocene-Pleistocene boundary?)	*c.* 2.3Ma		A complex network of gorges and caves in Carboniferous Limestone at Pollnahallia, Co.Galway, contains lignite deposits —now covered by superficial material including wind-blown silica-rich sands (Tertiary weathering residues) and glacigenic deposits. Palynological results (Coxon and Flegg 1987; Coxon and Coxon in press) suggest that the lignite infilling the base of the limestone gorge is Pliocene or Early Pleistocene in age. Since the original study a further continuous core through the lignite has been taken.

Whatever the precise timing of glaciation was in the area around central Kerry, the widespread erosional and depositonal forms suggest that large glaciers have emanated from ice masses that formed to the south of the MacGillycuddy's Reeks in the Kenmare River area and pushed northwards and northwestwards breaching the Reeks in two places (see below) and also circumventing their western flanks.

The region we are dealing with here includes the impressive features of the Kilcummin and Gearha Moraines (Warren, 1977 and 1979) and as such it straddles the boundary of a major ice advance out from the southern ice dome of the last cold stage (Figure 6). A lack of dating control of Irish Quaternary deposits places any proposed stratigraphy in doubt but it is most likely that these moraines represent a period of considerable importance during the maximum of the Midlandian Glaciation (Glenavy Stadial -see Figure 5).

The ice dome centered to the south of the MacGillycuddy's Reeks (e.g. see Wright, 1927, Lewis 1967, Warren, 1977 *in* Lewis, 1977 pp 38-40 and Warren, 1979) has left behind some very impressive scenery. With regard to the area we are visiting the ice dome spread northwards breaking through the MacGillycuddy's Reeks themselves at two points (Warren, 1977); Alohart (V850 850) and Ballagh (V855 850) which are c. 2.5km and 1.5km west of the Gap of Dunloe respectively (Figure 6). Far larger outlet glaciers moved north through the mountains *via* the Gap of Dunloe and the valley of the Gearhameen River leaving the spectacular glacially eroded scenery of the Upper Lake area and terminating in the piedmont moraines around the Killorglin lowlands (Lewis, 1967). Ice also moved through numerous passes to the west and WSW which can be picked out on the OS 1:50,000 map (*Discovery Series* Sheet 78) with the help of Figure 6.

The extent of this ice advance, the shape of the piedmont lobe, the associated glacial lakes formed by ice proximal meltwater (e.g. at Glen Gaddagh) and the meltwater spillways (e.g. Barry's Glyn) are all depicted on Figure 6 and are discussed in detail by Warren (1977 amd 1979). The prominent end moraines appear to represent ..."an important and prolonged period of glacial equilibrium" (Warren, 1977) but Warren (*ibid.*) goes on to note that there is evidence of earlier glaciation beyond the moraine limits and that "There is very little difference between the glacial tills that occur inside and those that occur outside the Kilcummin Stage moraine..."

The geomorphological evidence for Nahanagan Stadial glaciers has yet to be dated but they almost certainly existed, along with extensive snow banks, in the uplands of the MacGillycuddy's Reeks. Numerous corrie moraines and protalus ramparts can be found in the mountains of SW Ireland and there is little doubt that some of these features must date to the Late-glacial. It is just a matter of time before we can assess the nature and extent of Nahanagan Stadial ice cover in the SW of Ireland. It is even possible, as noted by Warren (1979), that some of the smaller periglacial features date to the Little Ice Age. This latter time period and the Late-glacial both warrant much research in the mountain areas that we shall see on this visit.

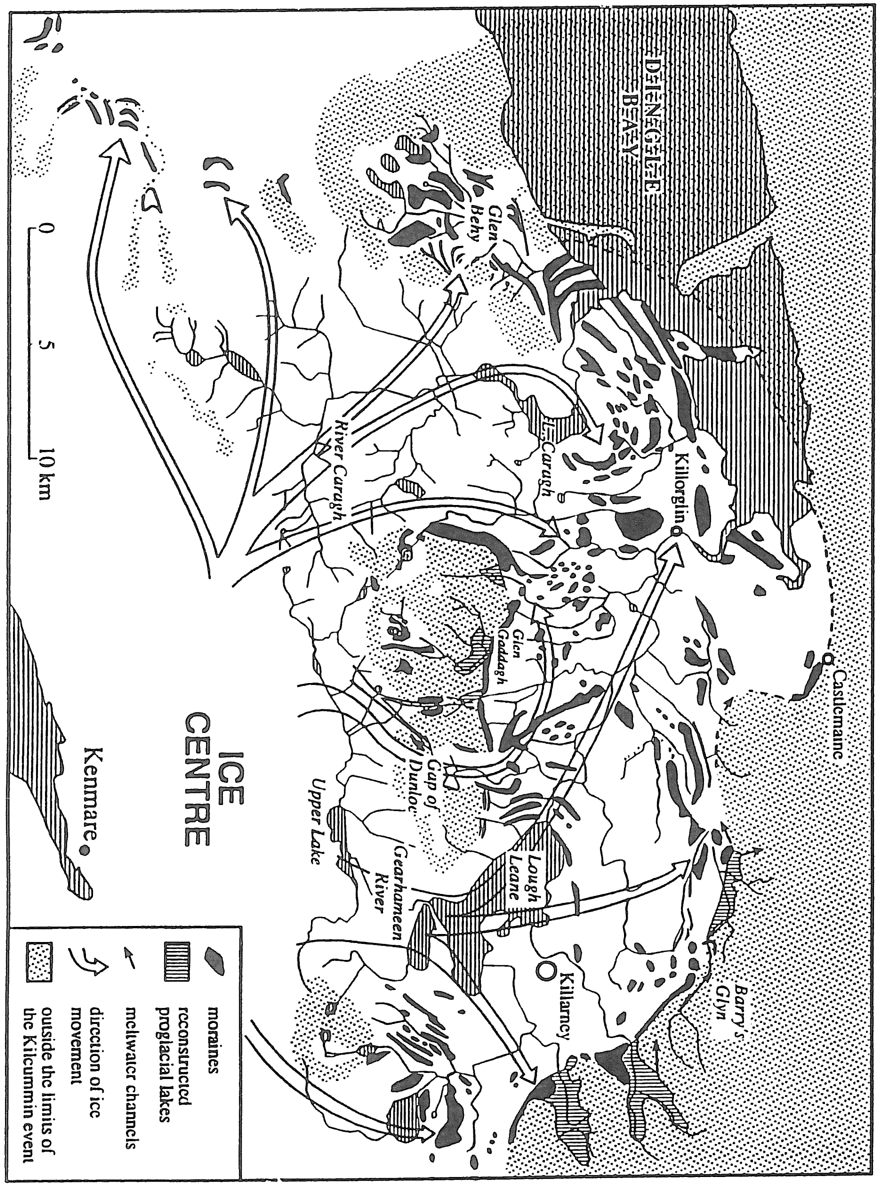


Figure 6. Ice limits associated with the Glenavy Stadial ice cap. After Warren, 1977.

SITE 1.1: THE KILCUMMIN MORAINE, DOYLE'S PIT (MP)

ASPECTS OF TERRACE MORPHOLOGY AND COMPOSITION EAST OF KILLARNEY

Introduction

The area of Killarney town and eastwards for c.3 miles is notable for a series of distinct gravel terraces and drainage channels, which were formed during the unsteady retreat of the ice-front southwards. Lakes at c.500 ft and successively lower elevations were trapped between the ice and the Namurian uplands (max. 815 ft) to the north-east. Meltwater dumped sediment into these lakes, forming deltas, some of which developed extensive, partly subaerial, topset terraces. The lakes drained to the sea through a series of overflow channels in Namurian bedrock to the north-west and around the northern margin of the ice. In a few places the highest-level lakes extended several miles eastward up earlier river valleys (Figure 6), where only veneers of fine sediments were deposited, plus small deltas derived directly from the uplands.

The terraces were mapped by W. B. Wright (1927 and 6-inch maps) as part of his more extensive study of the glacial geology of the Killarney-Glenbeigh-Kenmare area. Further details of the northern outlet channels, high level terraces in the Reeks and other aspects of glaciation have been recorded by Warren (1977, 1978, 1979), who also reviewed previous work more fully. My own work has centred mainly on the active pits in the map-area of Figure 7, and has provided (unpublished) information on many exposures that no longer exist.

Only one terrace/pit will be visited during this fieldtrip, Doyle's pit in T1, where a variety of features can be examined. Some of the other terraces can be seen from the road up from Killarney, and from the entrance to Doyle's pit (SE corner of the terrace). The field diagrams that follow were prepared in April this year. It is unlikely that all these faces will have survived for this October field meeting, but the diagrams illustrate what is or was present, and some of the recorded features will be repeated elsewhere in the pits.

The term "terrace" is used here to refer both to the top surface and the underlying sediments. It should be noted, however, that the foundation material of a terrace and its surface beds may have been deposited in completely different environments. (This is an important point when prospecting for commercial deposits!)

The Terraces

The eastern part of the terraced area is shown in Figures 7 & 8 with Wright's (1927) terrace numbers (N.B. on his 6-inch sheets the sequence of numbers is

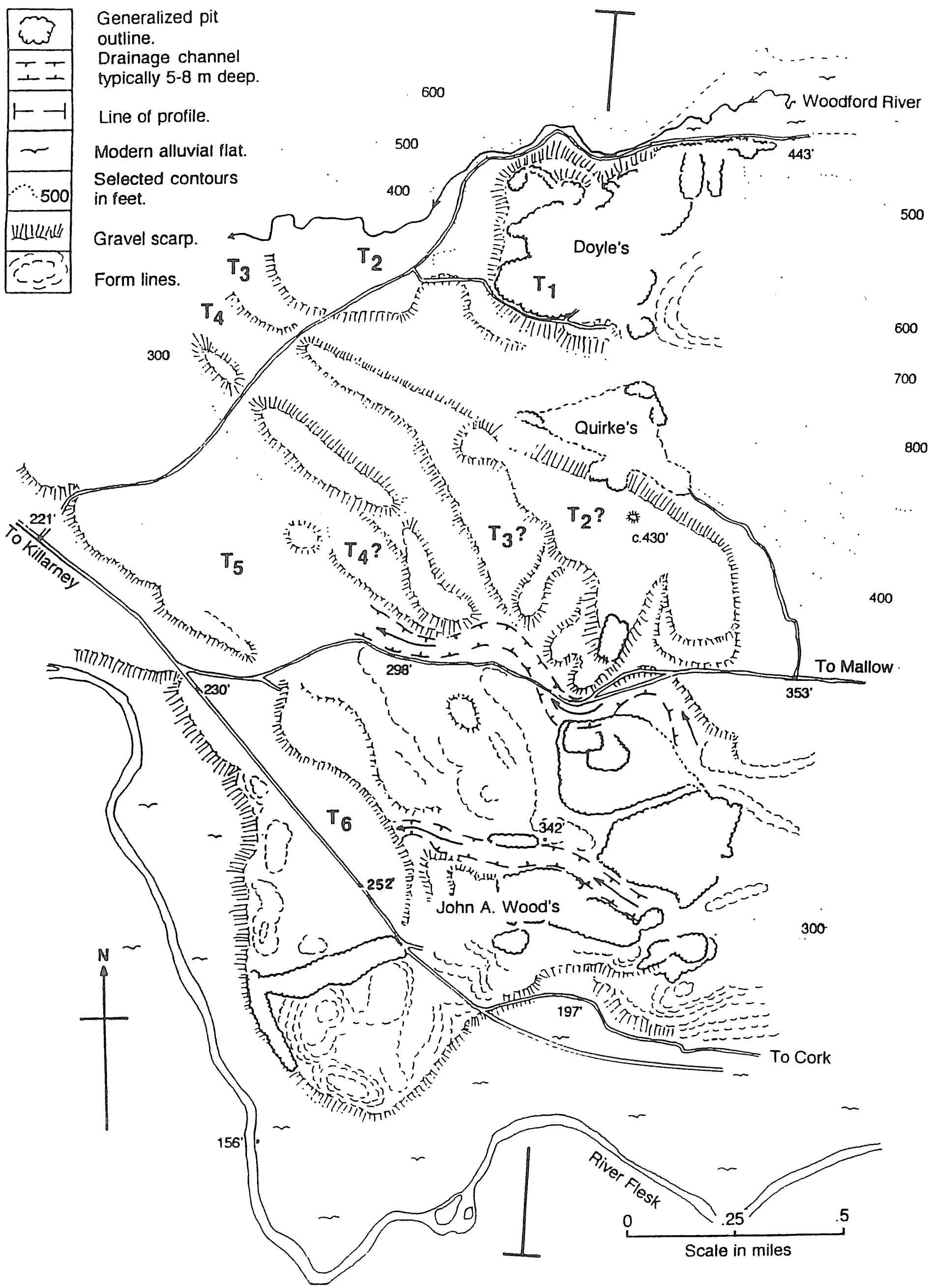


Figure 7: Geomorphology of the area c.3 miles east of Killarney located on Figure 1, showing the outline of the main gravel terraces, drainage channels, modern river flats, bedrock hills and miscellanaeous mounds (of till and proximal gravel). Spot heights and contours are in feet. Northern part of map after Wright (1927), southern part MP unpublished.
Note: North side of gorge north of Doyle's pit is of bedrock.

reversed). At their eastern end the terraces become less distinct and a number of intermediate levels are apparent on the ground, hence Wright's uncertain identifications (Figure 7). The irregularities are partly due to a sediment facies change southwards into probable sub-glacial tills, which extend upwards above the terraces. Severer erosion of earlier terraces at this proximal end is another likely cause.

Even the flattest of terraces (e.g. T6) slope gently away from their proximal ends (see spot heights in Fig. 7), a result of sub-aerial aggradation on the delta top. Some of the terraces have been cut by distinct drainage channels, two of which are shown in the southern half of the map (Fig. 7). These were incised by subaerial streams following a drop in lake level. The southern one has been left 'hanging' where it enters T6 ; the outer end was truncated during development of the lower terrace. The broad valley containing Quirke's pit is a larger-scale erosional feature, in its final form post-dating T3. Whether sediments on the floor of this valley are remnants of higher terraces, or were deposited on the valley floor after erosion, has not been established.

Doyle's Pit --- Terrace T1

Most of the top surface and foundation material of this terrace have by now been removed in Doyle's pit (Fig. 7). The terrace surface lies slightly above 500 ft. On its eastern side it merges with the rising ground of the Namurian uplands, and bedrock is visible locally in the south-eastern part of the pit complex, underlying thin gravels. Bedrock is also exposed along the road beside Woodford River and in the bottom of the gorge (Figure 9B). Its position beneath the rest of the pit is unknown. The lowest levels of the pit are in sub-horizontal fine sands and silts (delta bottomsets) that are unlikely to be further exploited.

Earlier faces in the pit showed large-scale foreset gravels and sands, dipping approximately north, as shown diagrammatically in Figure 3B. The height of these foresets was some 25-30 m, nearly the full depth of the pit. Remnants are now visible in the south face. The delta appears to have prograded northwards in a straightforward manner across earlier bottomsets, the top of which rises progressively across the pit; sub-horizontal sands dominate the succession in the northern part (Figure 3B). Smaller-scale foreset gravels are still being exploited in small northern sub-pits. Topset beds were well developed across the top of the deposit and showed large-scale cryoturbation lobes and vertically aligned boulders. Similar features still survive around the pit margin. Some faces in east-central part of the pit show diamicts 1-3 m thick at a high elevation.

Details of an active sub-pit in the north-western corner of the terrace (Doyle's "NW pit"; Figure 7 & 9A) were recorded in April (1996). Field diagrams of the faces and entrance cut (Figures 10-12) are accompanied by notes and discussion in the captions; only a summary of the main features will be given here.

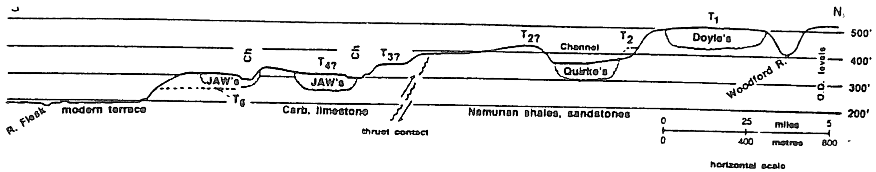


Figure 8: North-south profile (located in Figure 7) across terraces between the Woodford and Flesk rivers. The line of profile lies east of most of the clearly developed terraces, hence the uncertain identifications. The profile in the vicinity of John A. Wood's pit is partly controlled by glacial tills.
Ch = channel; T_1, etc. = terraces.

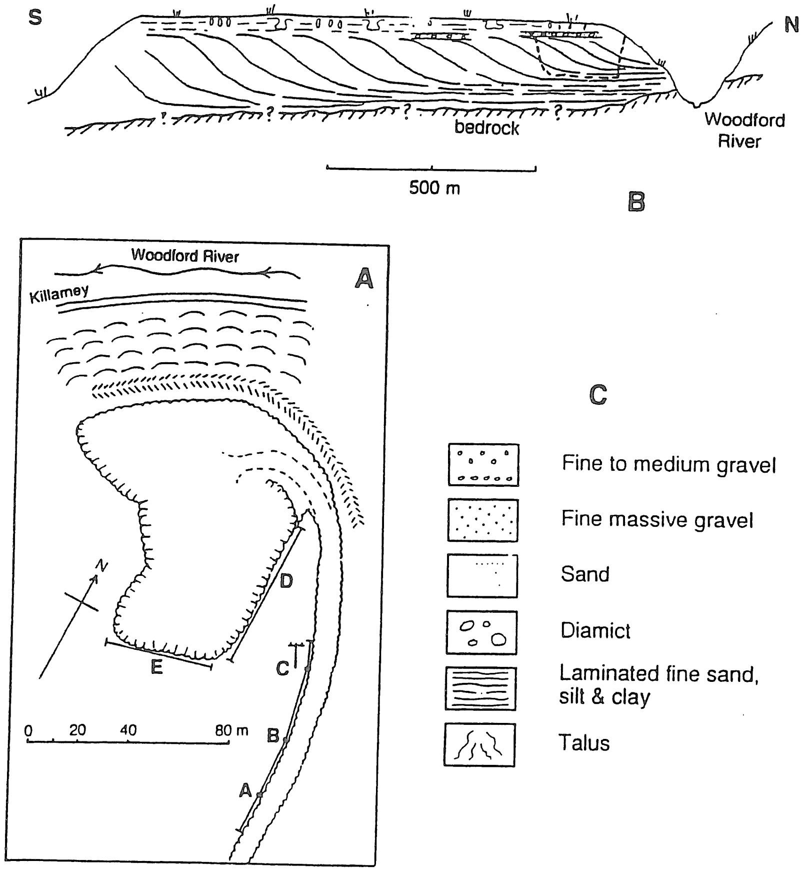


Figure 9:
A. Sketch map of Doyle's 'NW' pit (date 7.4.96), showing location of cross-sections in Figures 10-12. Note telegraph pole at C.
B. Diagrammatic cross-section through terrace T_1, showing position of Doyle's 'NW' pit. Most of the terrace consists of large-scale delta foresets, prograding N or NW, but the highest deposits are mainly topsets with cryoturbation features. At least one diamict bed, 2-3m thick is present.
C. Key to Figures 10-13.

Typical foresets and bottomsets are illustrated in figures 10 & 12. Fine gravel foresets less than 12m thick dip northwards and pass down dip into sands, merging gradationally into bottomsets. A small channel with back-set beds is visible near the centre of the east face of the pit (Figure 10). Most of the bottomset features, including the dipping beds, angular unconformity and convolute beds, can be matched elsewhere in the pit complex.

Less typical features are the overfold and low-angle thrusts in the foresets exposed in the east face of the pit (Figure 10), which indicate that ice-push was from the south. Folding at 4 in Figure 10 may be directly linked to the thrusts, the style of deformation varying with the material affected.

A complex diamict unit truncates the top of the foresets, including the overturned beds. The unit consists mainly of matrix-supported boulders in pebbly sand and subordinate clayey silt. The unit also includes discontinuous wavy laminated beds <50cm thick, containing few pebbles. At the top of the unit boulders and cobbles are locally vertically aligned, due to cryoturbation.

The diamict unit is interpreted as a melt-out till, consisting partly of debris flows and partly of proximal gravelly outwash. It was deposited just beneath, or close to the front of, retreating ice that had lifted off the underlying sediments.

Deformation in the foresets is believed to predate deposition of the diamict unit, because:
i) sets of small-scale crossbeds (2 and 3 in Figure 10) overlying the foresets but predating the diamict are undeformed, and but its composition suggests that it is a melt-out till and was not directly associated with deformation of the foresets.
ii) the diamict unit is interpreted as a melt-out till, not a deformation till.

Overturning and thrusting of the foresets, and the removal of the uppermost gravels, are therefore interpreted as the direct action of overlying ice, which subsequently deposited the diamict as it melted back. A re-advance of the ice across the delta top seems to be implied by these features. Diamicts seen elsewhere in the pit complex may belong to the same episode, but correlation is very uncertain.

Further deltaic deposition followed ice retreat, but only after a period of quiet-water sedimentation, during which laminated clays and silts buried part of the diamict. These sediments are best exposed in the west face of the entrance cut to the pit. Laminated silts and clays (12 on Figure 12) were deposited in a shallow depression on the surface of the diamict, and indicate a substantial interval of quiet-water sedimentation. This was perhaps due to continued cold conditions, and limiated sediment transport after the retreat of the ice from the immediate vicinity. Contemporaneous erosion around the edige of this local depression is suggested by an unconformity (7 on Figure 12). Thin sands in the uppermost part of the laminated unit, and isolated clay bands in the lower part of the overlying beds reflect the gradual encroachment of coarser sediments, as deltaic bottomset deposition was resumed here.

Most of the overlying succession consists of nearly horizontal silt and fine to medium sand. Ripple lamination and the foreset dips in the scattered coarse sand/fine gravel dune-like bodies indicate current directions generally towards the north-west, with some deviation between west and north. This is similar to the earlier progradation direction of the large-scale delta foresets that formed the main part of the terrace succession (Figure 9B). Clay and silt bands <10cm thick reflect occasional periods of quiet-water deposition, probably within limited areas, as the main currents switched elsewhere.

Bottomset beds are not everywhere flat, with dips of up to 20° in places. Dips may be related to the slope of the underlying surface, although in some places in the pit high dips are associated with channel infills and larger-scale dune-like structures in the bottomsets. The association between slumping and relatively steep dips is apparent in several places in the pit (for example, 5 on Figure 12), Slumping takes the form of both convolute beds and low-angle thrusts.

An atypical feature within the sedimentary sequence is the collapse structure seen in the south face of the pit (Figure 11), interpreted as resulting from the melting of an ice block that had been buried by the foreset gravels. Melting took place during diamict deposition, as this unit thickens substantially into the collapse structure and has basal lobes penetrating the underlying gravel (8 on Figure 11). The top of the diamict forms a broad bowl, which was filled with interlaminated lacustrine clay, silt and fine sand which have been barely affected by subsidence (see 12 on Figure 12). Thinning of beds towards the edge of the bowl may have been either a response to continued subsidence or the normal pattern for very fine suspended sediment settling in a depression. A substantial period of low-energy conditions following retreat of the ice is implied for this locality, and probably a corresponding depositional hiatus in the adjacent more elevated area.

Ice-Melt Structure in Quirke's Pit, Terrace T2?

A better exposed ice-melt structure is illustrated in Figure 13. Although from a lower terrace, it is included here for comparison, as some features are different. In both cases diamict overlies the gravels in which the inferred ice block was buried. In both cases the diamict is overlain by a laminated unit, although at Quirke's clay bands are rare. In contrast to Doyle's example, in Quirke's the laminated beds are involved in the main melting phase --- indeed melting may not have begun there until well into, or after, deposition of the laminated beds. Melting certainly continued well after that, while overlying fine gravels were accumulating in the subsiding hollow. Of further interest near this locality is a round marshy depression, probably a kettle hole, in the field immediately south of this face, providing a complementary surface view of an ice-melt structure.

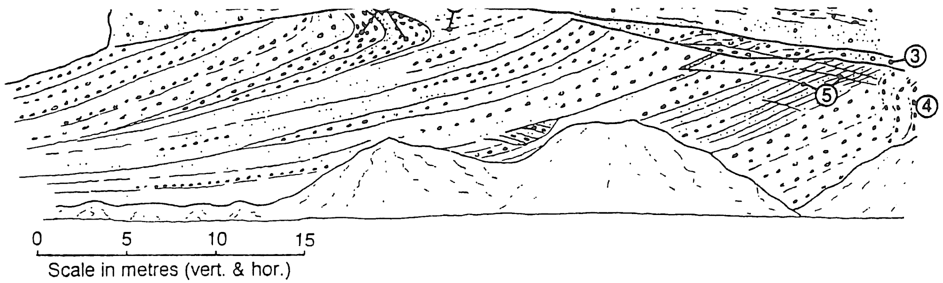


Figure 10: East face of Doyle's 'NW' Pit (5.4.96). Location of pit shown in Figures 9A and 9B. The top surface has been stripped.

Notes:

1. Overfolded gravel beds; axis approximately ENE. Fold does not involve beds to the right.
2. Poorly exposed, inaccessible area of very fine gravel and sand with nearly horizontal lamination. This sediment post-dates fold to left, and appears to be filling a depression behind it; it may be contemporaneous with 3.
3. Broad lens, partly diamict, partly bedded very fine gravel in small-scale foresets. The lens truncates underlying large foresets.
4. Deformed, locally vertical beds of fine gravel, the up-dip end of foresets. Deformation may be linked with thrusts to left, which appear to terminate at this gravel.
5. Low-angle thrusts in a zone >2m thick. Thrust planes dip 5-10° to SW. Displacements of <20cm. One thrust visible for >6m, cutting gravel beds.

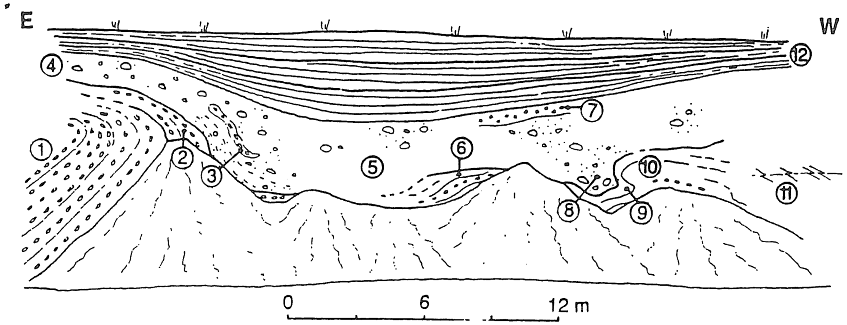


Figure 11: South face of Doyle's "NW" pit (6.4.96), located in Figure 9. The top of this face has been stripped.

Notes:

1. Foreset gravel beds, overturned near top (see 4 in Figure 10).
2. Gravel beds dipping 75-80° to WSW. It is unclear whether these are overturned beds, part of 1; or gravels streaked-out along the margin of the collapse structure to the right.
3. Distorted lens of very fine gravel with scattered small cobbles, parallel to 2.
4. Diamict unit, extending from E face (Figure 10); locally bedded
5. Face largely obscured; probably diamict.
6. Folded fine gravel and sand; probably part of main foreset succession.
7. Poorly sorted fine gravel c.50 cm thick on top of diamict; lateral relationships obscure
8. Lobe of diamict c.1m across, 1.5m deep.
9. Contorted thin beds of sand, grit (granule gravel) and very fine gravel, locally overfolded.
10. Beds of coarse sand and gravel, partly in irregular pockets; part of main foreset succession.
11. Diagrammatic representation of thrusts in the W face immediately adjacent to 10. These thrusts are located near the top of foreset beds and correspond to those at a higher elevation in the E face (5 in Figure 10). Thrusts dip at 0-10° to S, with northward displacements at <40cm.
12. Finely laminated clay, silt and fine sand <4m thick, beds thinning towards margin of depression. Similar (same?) unit accessible in entrance cut (Figure 12).

Sediments associated with the ice-melt structures

The two ice-melt structures illustrated here (Figures 11 & 13) both involve diamict and laminated beds above the gravels in which the ice blocks were buried. This suggests that there might be a genetic link between the sediment types, although more examples would be needed to confirm the association. A climatic link between diamict (ice re-advance) and laminated beds seems plausible: fine sediment accumulated on its own either because little debris was being released from the ice, or because coarser material in the readvancing delta (outwash) took some time to prograde to these locations. However, previous burial of ice blocks in delta foresets suggests rapid sedimentation and rather warmer conditions, and any link with the overlying diamict is more obscure. As noted above, the melting histories at the two localities are different, so the climatic sequences may also have differed.

Other Terraces

The character of the other main terraces in the map-area of figure 1 is much less clear, because the large pits have been developed on the margins (due largely to housing). The pits operated by John A. Wood and Quirke's, and the small abandoned one just north of the Mallow road (Figure 7), all show terrace foundations that are more complicated than in Doyle's. Specifically, none show delta foresets on the same large scale as in Doyle's; successions are made up of much thinner units of sand and gravel, with foreset dips in various directions; and sub-glacial facies are present in the southern parts of John A. Wood's pits. However, to some extent the differences reflect the proximity of the contemporary ice front; the more distal, unexposed parts of terraces T5 and T6, for example, might more closely resemble the facies in Doyle's.

Quirke's pit is mainly in the valley floor, and some of the sediments in the centre may post-date valley erosion. The current northern face, which extends well above the valley floor, shows no dominant current direction in a varied, and locally very disturbed (glaciotectonized?) succession of sands, gravels and interlaminated clay & silt. These beds might be erosional remnants of terrace T2. The ice-melt structure in the southern face (Figure 13) lies above the general level of the pit, and is the only good exposure in this slope. The hillside above the eastern extremity of Quirke's is veneered with gravel to an altitude of at least 500 ft. This may be a remnant of terrace T1.

John A. Wood's pits extend from the River Flesk to the Mallow road (Figure 7). They have been developed in a range of sedimentary facies and different local terrace levels, which do not clearly correspond to those further west. Sub-glacial and ice-proximal boulder gravels and diamicts are exposed in the pit west of the Cork road (Figure 7) and glaciotectonic structures were formerly visible south of the main plant. North-eastwards the facies changes to deltaic and includes topsets with ice-wedge casts. A problem in interpreting sedimentation events in this extensive complex of pits is the lack of time markers, so only generalized or very local facies relationships can be established.

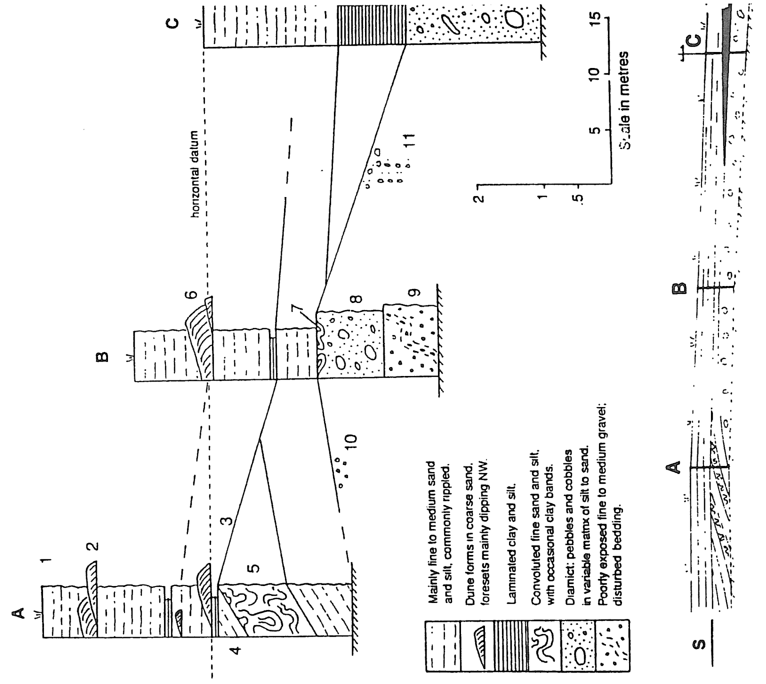


Figure 12: Beds exposed in west face of entrance cut to Doyle's "NW" pit, showing the upward extension of the succession in the pit. See Figure 9 for location. Lower, true-scale cross-section shows general arrangement of units and location of columnar sections above. black is laminated unit (12). Telegraph pole identifies location C. Line beneath 'N-S' is horizontal datum. 'Diamict' shows stratigraphic details at representative points.

Notes:

1 At least 3m of beds, including gravel, overlie this horizon up to the top of the terrace.
2 Dune forms located c.12m further south along this face.
3 10cm marker bed: 3cm of clay, overlain by silt. Beneath the dune it is missing, apparently eroded off. It reappears c.4m to the north.
4 >3m of beds, dipping SE at 20°, are present beneath the unconformity. They include other, thinner, convolute silts.
5 Highly convolute silt to medium sand with occasional clay laminae; bed is truncated at unconformity.
6 Lens of fine gravel (pebbles <2cm) and grit <40cm thick.
7 10cm bed of convoluted interlaminated clay and silt with sharply truncated top.
8. Diamict of unsorted pebbles, cobbles and occasional boulders in variable matrix of sand and clayey silt. Clasts locally dip WSW at 20-30°.
9 Poorly exposed fine to medium gravel, commonly disturbed.
10. Isolated exposure of unsorted cobble gravel in fine gravel matrix, with interbedded diamict
11. Poor exposure of vertical bands of gravel (cobbles <20cm long) and silt; overlain by horizontally interbedded diamict and gravel.
12. Lower part of unit consists of laminated clay: 2-3mm yellow bands spaced at c.1cm apart, separated by yellow-grey to blue-grey, very finely parallel-laminated clay. Upper part of unit consists of interlaminated clay and silt, with yellow clay bands 4-8mm apart; lamination here is more distinct but less uniform than below. Top 5-10cm locally convoluted, and includes interlaminated sand. Top contact is sharp and truncates convolutions; contact has a broad dish shape, possibly due to compaction. Overlying fine to medium sand includes some isolated clay bands in lower part.

The number of local erosion surfaces in the succession is noteworthy. These include the relatively large-scale angular unconformity at the southern end, and the truncated folds at 7 and at the top at 12. Less obvious is the erosion of the clay/silt marker (3) beneath the dune of coarse sand; the stronger current transporting this sand apparently scoured out the bottom to a depth of 10-20cm for a distance of c.4m.

Sands above the diamict in the entrance cut have similar characteristics to bottomsets elsewhere in Doyle's pit, and further gravels were deposited up-section (note 1). Although these sands are likewise interpreted as bottomsets, it is unlikely that large-scale foresets were developed at this stage in the construction of the terrace, since these beds lie within a few metres of the final surface. Few faces now survive showing the nature of the highest beds, which were, in any case, strongly cryoturbated.

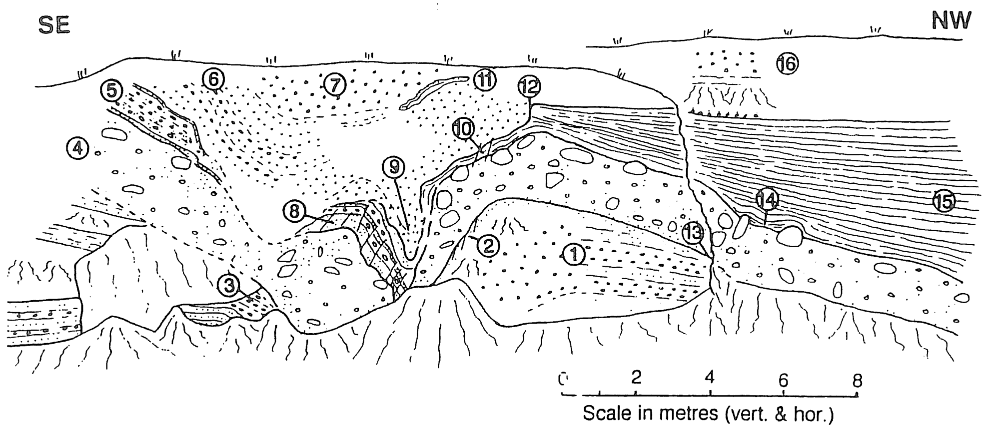


Figure 13: Ice-melt collapse structure (filled kettle hole) beneath terrace T_2, in old face immediately SW of plant area in Quirke's pit (Figure 7). Top surface stripped, except at NW end, which is set back several metres from the main face above the laminated beds.

Notes:

1. Interbedded fine to medium gravel beds <70cm thick, and grits <40cm. Dip WNW at 10-15°. Bedding dies out to left and gravel becomes massive.
2. Sand >30cm thick, cut by nearly vertical faults, 10-15cm apart, trending NE. Throw obscure, presumably to SE. This sand extends NW below the diamict to beyond 13.
3. Sand and sandy very fine gravel, mainly sub-horizontal; close to the diamict it dips parallel to contact.
4. Diamict with boulders <60cm across, edge-rounded in silty sand matrix, locally laminated. Top and bottom contacts partly covered.
5. Interbedded wavy-laminated sand and silt in beds <20cm thick, and thin diamicts with stones <10cm across. Unit is streaked out (collapsed) down dip.
6. Interbedded coarse sand, grit and very fine gravel, locally oversteepened to dip c.70°.
7. Unsorted, massive fine gravel.
8. Laminated yellow medium sand <50cm thick, overlain by 60cm of thinly interbedded laminated sand and fine gravel. To the right these beds descend steeply into V-shaped fold, partly by step-faulting. Faults dip E at 50-65°; throw mainly reverse, 5-10cm (overturned extensional faults).
9. V-fold filled with very fine gravel with isolated stones <8cm across, commonly aligned parallel to fold margins.
10. Laminated yellow medium sand draped over boulders in underlying diamict. Faults (inaccessible) roughly parallel to those at 2. Sand streaked-out down edge of V-fold, to maximum width of 20cm.
11. Lens of laminated sand. Irregularities at left end probably due to small faults. Lens overlies massive pebbly grit.
12. Vertical erosion surface truncates laminated sand. Massive pebbly grit to left.
13. Base of diamict here dips WSW at c.25° truncating underlying grit beds (1).
14. Local depression in top surface of diamict; relief to top of boulder on right is c.60cm. Sand laminae abut and thin over upstanding boulders. Top 10cm of diamict includes pockets of laminated very coarse sand and grit, which drape stones, suggesting some reworking of the diamict. Some boulders in this vicinity >60cm across.
15. Mainly parallel-laminated fine sand and silt, with some ripple-lamination in bottom half (currents to N). Upper half includes some clay laminae. Some highly convoluted beds present, 5-10cm thick, with folds sharply truncated by overlying beds. Rare fine diamicts and very fine gravel beds c.10cm thick, locally with thickened basal lobes 25cm deep, 30-40cm across, overlying contorted laminated beds. Top bed 30cm thick, convoluted, containing isolated cobble, probably a dropstone. Top contact practically horizontal. Unit immediately overlain by 15cm bed of fine gravel, then 15cm of horizontal sand. Laminated unit thickens to >5m further to right, as diamict continues to descend.
16. Face several metres back from main one; 4m of section over laminated beds, lower half covered. Dirty gravel with cryoturbated sand lobes. Field just south of face has round marshy pond, probably a kettle hole.

One feature of interest is that progradation, thinning and fining were towards the east in the most easterly pit (now rehabilitated). Ground surface here fell gently in the same direction, and east of the map-area of figure 7 lobes of sediment with steep outer margins a few metres high extend out into a low-lying basin that now drains south. These lobes look like the final delta lobes of a shallow lake (altitude c.300 ft), which was suddenly drained before it was fully silted up. The contemporary outlet for this lake is still to be identified. Presumably the water doubled back and drained westwards further north. The channel crossed by the Mallow road (Figure 7) seems a too high for this.

Climatic Oscillations

The sequence of terraces probably mainly reflects pauses in the retreat of the ice-front, although steady retreat past successively lower potential lake-water outlets might produce a similar effect. Pauses in ice retreat were inferred by Wright (1920, 1927) from the succession of arcuate terminal moraines in the Killarney-Glenbeigh area and in the Kenmare valley. Wright (1920) also noted a major and minor periodicity in moraine building and attempted to calculate their duration. Details of minor moraine and solifluction terraces on the northern slopes of the Reeks have been recorded by Warren (1979); these also suggest smaller scale climatic fluctuations.

The glaciotectonic features and associated tills within the delta terraces north-east of Killarney appear also to reflect minor climatic oscillations, or more specifically, ice re-advances. There is also some indication, as yet unsubstantiated, for a temporary fall in lake level of some 8-10 m, possibly more, towards the end of the development of terrace T1. An old sub-pit along the centre of the northern margin of Doyle's pit complex, parallel to the road, exposes gravel forsets dipping NE at 15-20¡, which appear to have deeply truncated horizontal bottomset sands immediately to the south. The contact itself is/was not exposed, so actual truncation is not yet proven.

SITE 1.2 ROSS ISLAND
SITE 1.3 INISHFALLEN

VEGETATION HISTORY OF THE KILLARNEY VALLEY: AN OVERVIEW (FM)

The greatest concentration of native woodland in Ireland is located in the Killarney Valley and hence there has been considerable activity by researchers attempting to elucidate its history. Jessen (1949) carried out the earliest work in the region. He produced five pollen diagrams but only one (from the Long Range) covered most of the Holocene; the others were confined to Jessen's zone VII (Atlantic and Sub-Boreal zones).

Watts (1963) published a Lateglacial pollen diagram from the Long Range which was sited about 400 m SW of Jessen's site. The diagram was not dated but was characterised by high values of *Betula* and *Juniperus* pollen during the Lateglacial Interstadial indicating the occurrence of stands of tree birch and juniper scrub. Vokes (1966) also confirmed this from her site on the Muckross Peninsula. This diagram is also undated but it is apparent that aquatic taxa appeared earlier here than in other Irish sites. The palynological evidence thus suggests that the Killarney valley had a milder climate during the Lateglacial Interstadial than other sites to the east and north. Analysis of coleopteran remains from Lateglacial sediments from Killarney currently being undertaken by the University of London will provide valuable additional data in this regard.

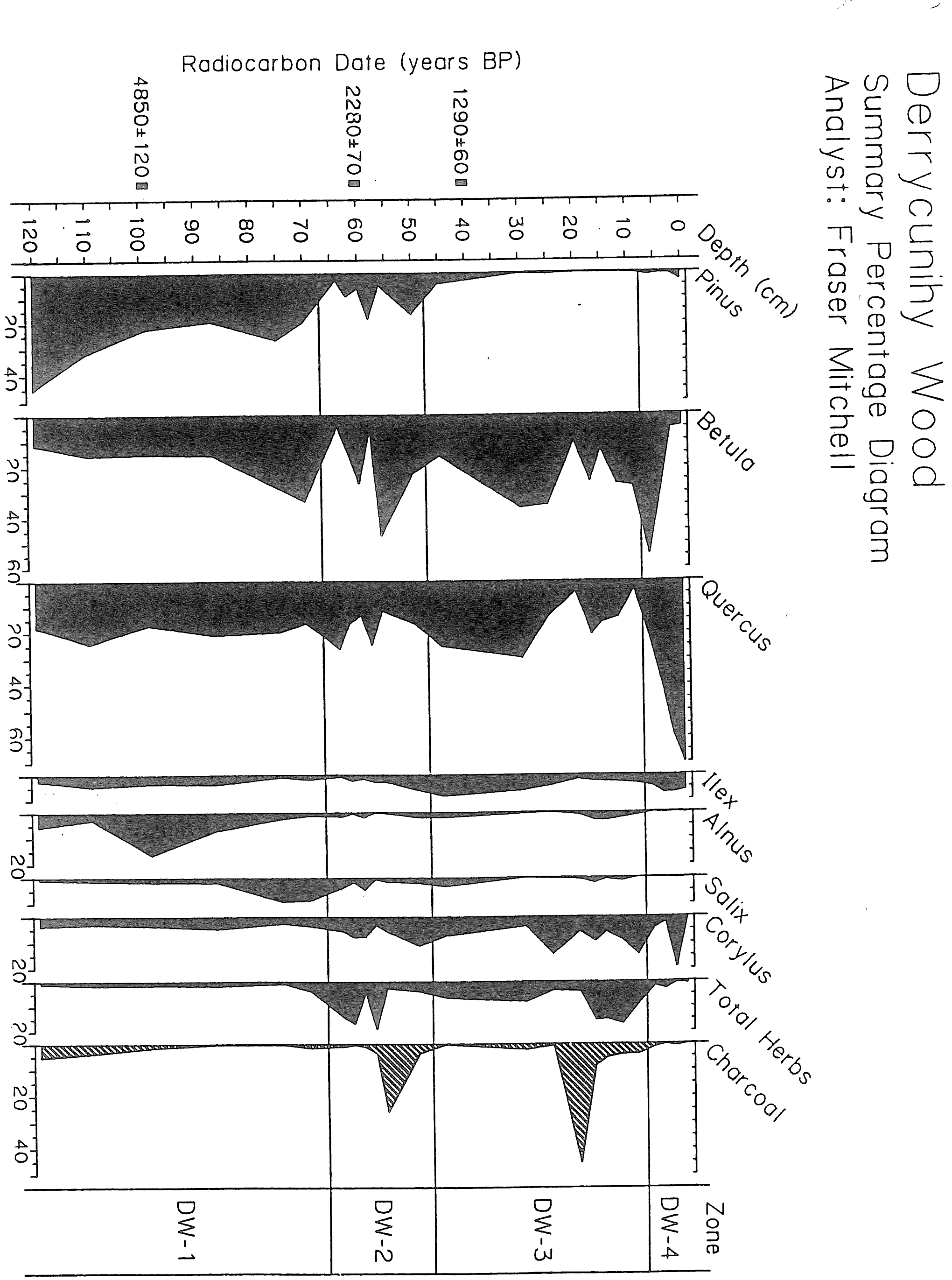
Vokes (1966) produced two Holocene pollen diagrams; one from a raised bog at Muckross and the other from blanket bog at Ladies View. Neither were dated but summaries of each appear in Mitchell (1988). The work of Jessen and Vokes demonstrates the typical early Holocene succession of *Juniperus* being replaced by *Betula* which were in turn replaced by *Corylus*. O'Sullivan (1991) found substantial *Alnus* at her small hollow site prior to 9300 BP. This is the earliest recorded date for *Alnus* in Ireland and may represent an isolated population that existed before the *Alnus* expansion later in the Holocene.

The regional pollen records indicate that the landscape then became dominated by *Pinus* for much of the Holocene. With the absence of radiocarbon dates and very poor representation of *Ulmus* (hence no clear elm decline), it is difficult to establish when *Pinus* actually declined. Two *Pinus* stumps at Ladies View were dated by Watts (pers. comm.) to 1790±95 BP and 1810±95 BP indicating that the taxon was still present comparatively recently. Vokes' site on Muckross is adjacent to the extensive yew (*Taxus*) wood that covers the Limestone pavement on the peninsula. The pollen diagram from this site shows the expansion of *Taxus* during the mid-Holocene with a concomitant decline in *Pinus,* although *Pinus* still remained the dominant pollen type in the diagram. Mitchell (1990a) has established a date of around 5000 BP for the establishment of the yew wood from a small hollow profile. The final decline of *Pinus* in Derrycunihy Wood was dated to around 2000 BP by Mitchell (1988) and this correlates with the pine stump dates. O'Sullivan (1991) also dated the final *Pinus* decline to around 2000 BP at her small hollow site in Glaisín na Marbh, a high altitude wood on the south eastern slope of Shehy Mountain. However, the final decline of *Pinus* in Camillan Wood on the Muckross Peninsula was 3700 BP (Mitchell 1988). These dates are from small hollow pollen diagrams which record very local vegetation changes. Evidently the history of *Pinus* in the Killarney area is complex and some dating from regional pollen sites would facilitate its elucidation.

Following the final *Pinus* decline, *Betula, Quercus* and herbs all expand in Vokes' diagrams. None of Jessen's diagrams cover the late-Holocene but this period was covered by Welten (1952) who published four pollen diagrams which formed a transect up an altitudinal gradient from the present day tree line (270m) to 1010m, almost the summit of Carrantuohill. The pollen record was thus dominated by non-arboreal components, apart from a rise in *Pinus* in each diagram indicating the reintroduction of this taxon as a plantation tree. At the highest altitude site 3% *Arbutus* pollen was recorded. This tree is very sensitive to frost and today is confined to altitudes below 225 m so this record is unlikely to represent local presence of the tree but may reflect long distance dispersal. However, *Arbutus* also has extremely poor pollen representation (Mitchell 1988). The difficulty of distinguishing *Arbutus* pollen from that of *Erica cinerea* and *Arctostaphylos uva-ursi*, together with its poor dispersal cast some doubt on these identifications, particularly as no other ericales taxa were distinguished.

Both Vokes' diagrams are complete to the present day and the most recent records show an expansion of herbaceous taxa but no dramatic declines in arboreal taxa. This is in contrast to documentary records which indicate widespread exploitation and destruction of woodland since the mid seventeenth century (McCracken 1971, Watts 1984). The remaining woods in the Killarney Valley came under effective estate management at the beginning of the nineteenth century and much of the woodland present today owes its origin to this era of replanting and silviculture. It appears that regional pollen data lack sufficiently fine spatial resolution to detect the dramatic change in woodland status over the last three hundred years. For this reason a series of pollen diagrams from sites within the woods (small hollows and mor humus profiles) have been produced (Mitchell 1988, 1990a, 1990b, O'Sullivan 1991). These sites provide data on a small spatial scale, akin to a forest stand, from which past forest composition and dynamics can be elucidated. The records range in length from the whole Postglacial to the last 200 years.

O'Sullivan's (1991) small hollow site at Glaisín na Marbh covers the full Postglacial. In addition to recording *Alnus* in the early Holocene, this site also records the importance of fire as a regulatory factor in the early and mid Holocene *Pinus* dominated forests. Small hollow sites at lower altitudes in Killarney indicate that *Pinus* was a main constituent of the forest canopy alongside *Quercus* (Mitchell 1988). The record from Derrycunihy Wood (Figure 14) illustrates the lack of any long term stability in woodland composition. The decline in *Pinus* around 2,000 BP is associated with a charcoal peak suggestive of human disturbance dating to the



Iron Age. Other evidence for human exploitation in the region at this time is poor (Monk 1993).

Increases in charcoal and disturbances to the woodland canopy towards the top of the diagram (Figure 14) relate to human activity in the eighteenth and early nineteenth centuries. This evidence for disturbance coincides with documentary records of charcoal production for iron smelting, timber extraction and grazing in Derrycunihy Wood (Mitchell 1988). Assessment of the complete pollen records from Derrycunihy Wood and the other sites in Killarney indicate that following disturbance, the botanical and structural diversity of the woods were reduced. The almost monospecific *Quercus petraea* (sessile oak) canopy at Derrycunihy Wood today reflects this and the early nineteenth century silvicultural preference for this species. The development of this oak dominated canopy is clearly illustrated in the top of the pollen diagram (Figure 14). At no time over the last 5,000 years has *Quercus* had such a dominance in Derrycunihy Wood.

One tree that has benefited from woodland disturbance in the past is *Arbutus unedo* (the strawberry tree). *Arbutus unedo* is essentially a Mediterranean shrub with a disjunct distribution up the Atlantic coast of Europe. In Ireland it is confined to a few isolated locations in the west. It reaches its greatest abundance in Killarney where it is restricted to the edges of woods due to its intolerance of shade. It has not been possible to elucidate the history of this tree using conventional pollen analytical methods due to its very poor pollen dispersal. However, most mor humus pollen profiles in Killarney record the local presence of the tree indicating that it was particularly favoured following woodland felling and burning (Mitchell 1990b). It appears that *Arbutus unedo* was more widespread and abundant in the past prior to the re-establishment of closed canopy forest at many sites in Killarney and elsewhere (Mitchell 1993).

Archaeological Investigations at Ross Island
(BO'B)

The Ross Island early copper mine is located on the eastern shore of Lough Leane, the largest of the Killarney lakes in Co. Kerry. The site has a long history of mining, beginning in Final Neolithic/Copper Age times and concluding with large-scale industrial operations in the early 19th century. Of particular interest is the evidence for copper mining in the period 2400-2200 BC which can be linked to the use of early Beaker pottery in this site. The site is currently the subject of a multi-disciplinary research programme, established in University College, Galway, in 1992 and funded by the Office of Public Works through the Royal Irish Academy.

Mining in the 18-19th centuries at Ross Island uncovered a series of primitive 'Danes Mines', associated with the use of fire-setting and of stone hammers in rock extraction. While much of this record was subsequently destroyed, recent investigation has confirmed that a large cave-like opening and an underlying mine in the western part of this site are of Bronze Age date. A similar age is suspected for primitive mine evidence associated with the 'Blue Hole', a large open-cut working in the Eastern Mine area. These mine workings are located in a copper-rich horizon of the Lower Carboniferous limestone associated with calcite veining.

The archaeological investigation at Ross Island is currently focused on a work camp site, located on a level escarpment immediately next to Bronze Age workings in what is known as the Western Mine area. Excavation here has uncovered spreads of crushed mineralized limestone, associated with stone hammers and anvil blocks. The foundation traces of at least four hut structures have been identified, together with animal bone food waste, sherds of Beaker pottery and a small quantity of worked flint. Of particular interest is the discovery of pit features and copper smelting slag connected with on-site metallurgy, the first such find from any early Irish or British copper mine.

Radiocarbon dates now available for charcoal, wood and animal bone residues associated with primitive copper mining at Ross Island. These point to an early phase of mining linked to the use of Beaker pottery in the period 2500-2000 BC. At present Ross Island is the oldest copper mine known in north-western Europe and the first metal source to be identified from the early Beaker copper-using phase. The chronology of this mine, its connection with the use of Beaker pottery, the type of metallurgy practised and the subsequent history of the copper produced are all highly relevant to any discussion on the origins of Irish-British metallurgy.

Vegetation changes associated with Late-Neolithic copper mining in Killarney
(TC)

The following account presents preliminary results of ongoing research that is being carried out at Killarney, Co. Kerry. A principal aim of this research is to try and detect the ecological impact which may have been caused by the recently identified Late Neolithic copper mines on Ross Island. The method of mining used, known as fire-setting, is generally considered to have involved the consumption of large quantities of wood (O'Brien 1994). To date there has been no conclusive evidence of a direct impact on vegetation by mining activity. Palynological investigations at prehistoric mines at Cwmystwyth in Wales (Timberlake & Mighall 1992) and Mount Gabriel, Co. Cork (Mighall & Chambers 1994) suggest that the impact on the landscape may only be detected in local pollen diagrams. In the present study, small hollow sediments from Ross Island are being used to detect possible impacts on the local vegetation. Analysis is also being carried out on sediments from Sheheree Bog, approximately 3km south-east from the mine, to detect possible changes in the regional vegetation due to a supporting agricultural base.

Ross Island

A small hollow monolith (50cm) of predominantly Mull Humus was retrieved from Ross Island. This site is located less than 1km from the Bronze Age mining area. Analyses to date indicate an abrupt but long term vegetation change that may be due to disturbance in local hydrology caused by mining. A radiocarbon date for the base of the monolith indicates that accumulation of organic material began at about 4130±50 BP (uncalib). However it is unclear at this stage if this accumulation is related to the early mining activity. Figure 15 presents the principal features observed in the Ross Island pollen diagram, the main points of which are outlined below.

(1) Zone RC-1 is dominated by a dense scrub of *Alnus* and *Corylus* with smaller quantities of other arboreal taxa mainly *Pinus* and *Quercus*. This interpretation of the data is supported by the relatively low percentages of open ground herbs and grasses. Also in this zone *Pinus* appears to decline in three phases, at 33cm, 29cm and finally at 25cm. The decrease in *Pinus* pollen at 29cm possibly reflects a more general pattern of decline in the Killarney region which has been dated at about 2000 BP (see Mitchell this volume). One of the main features of this core is the dramatic decline of *Alnus* and replacement by *Salix* in zone RC-2.

(2) *Salix* replaces *Alnus* as the dominant taxon in zone RC-2. The sudden appearance of *Salix* at about 24cm coincides with increased values for herbaceous taxa, Cyperaceae and grasses indicating a more open habitat. In addition *Osmunda* replaces Filicales.

(3) Zone RC-3 is characterised by the re-appearance of *Pinus* pollen due to its reintroduction in recent historic times.

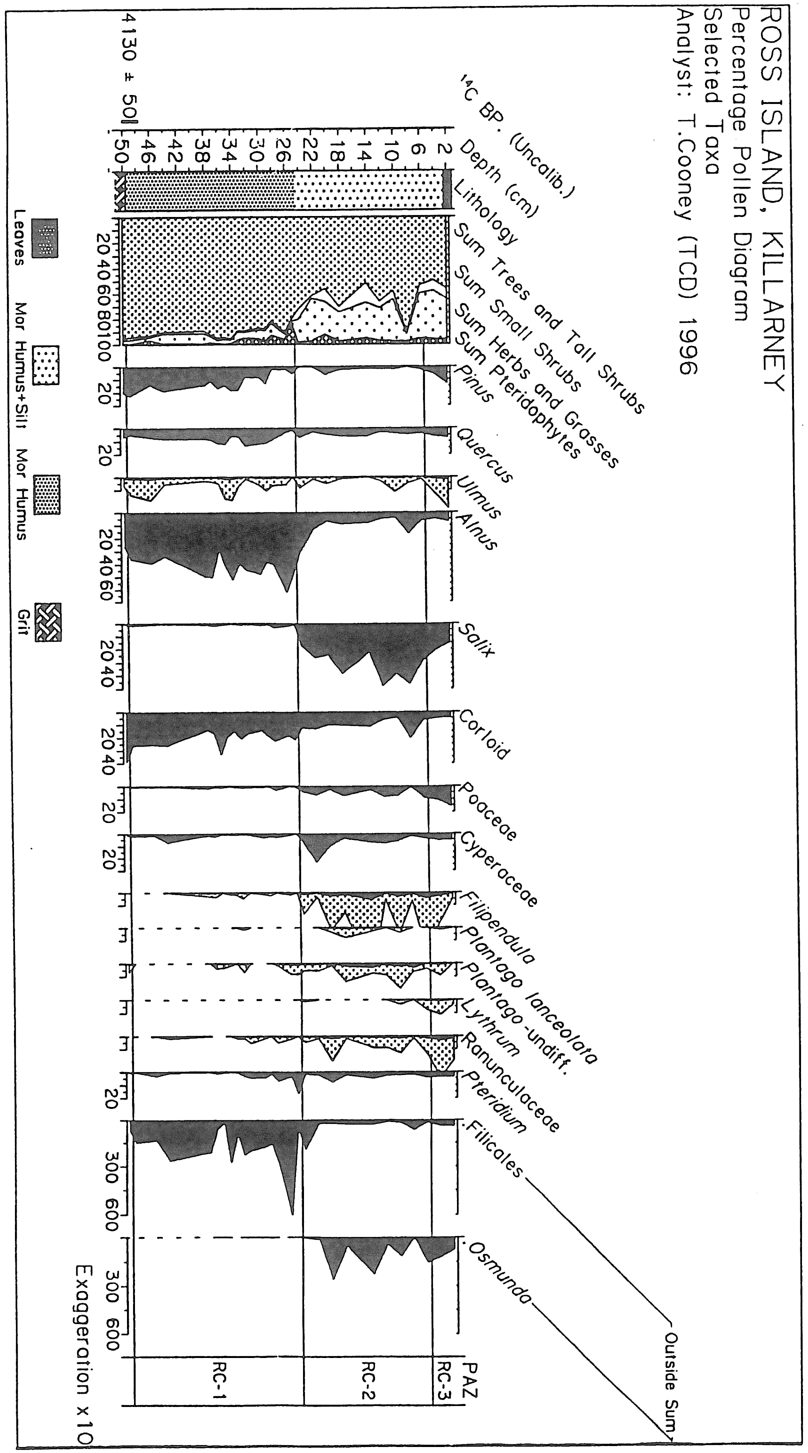


Figure 15: Summary percentage pollen diagram, Ross Island, Killarney

Sheheree Bog

Although much work remains to be completed on these sediments a fairly clear pattern is beginning to emerge. A full Holocene record has been recorded at this site. Figure 16 indicates some of the main features observed at Sheheree Bog which are outlined below.

(1) A highly compact silty sediment in zone SH-1 contains a record of post-Glacial flora dominated in sequence by *Juniperus*, *Salix* and finally *Betula*. Zone SH-2 contains a typical early Holocene rise of *Corylus* with corresponding decreases in open ground herbs and grasses. *Quercus* is the first of the main tree taxa to arrive with an extrapolated date of about 9000 BP.

(2) *Pinus* and *Ulmus* arrive at the site almost simultaneously at about 7600 BP (Zone SH-3). All major tree species increase at the beginning of this zone and eventually form a closed forest canopy dominated by *Corylus-Quercus-Pinus-Ulmus*. *Alnus* arrives at about 7000 BP and remains relatively stable throughout the zone with pollen values below 10%. Of particular note is the pollen curve for *Ulmus* as this site records the highest values for this taxon in the Killarney region during the early Holocene. Also of particular interest is the record of *Pinus* pollen and stomata. Although the percentages for *Pinus* pollen presented here are considerably lower than the values reported elsewhere in the Killarney region (*e.g.* Vokes 1966; O'Sullivan 1991), the presence of *Pinus* stomata confirms that *Pinus* was growing locally with pollen values ranging from 18% to as low as 2.3%. A similar pattern of low pollen representation with stomata has recently been reported from Donegal (Fossitt 1994).

(3) The impact of human activity on the landscape is the most important feature of zone SH-4. The first significant opening of the forest canopy occurs at this point with an expansion of herbs and grasses illustrated in the cumulative pollen curves. This clearance appears to reflect declines principally in *Corylus* and *Ulmus*. Disturbance taxa that are indicative of the presence of agriculture *e.g. Plantago lanceolata*, *Urtica* and grasses, appear and expand rapidly from the beginning of this zone. The radiocarbon date of 3800±60 BP for these changes gives a calibrated date of 2200 BC. This falls within the earliest period for mining which has been dated to *c.* 2500 to 2200 BC (O'Brien 1995).

Conclusion

Results to date indicate several events which may have been related to early mining activity on Ross Island. It is possible that the sediment accumulation in the small hollow on Ross Island and subsequent vegetation/hydrology changes may have been influenced by mining activity. However this has yet to be established.

The type of mining activity which was carried out in the Bronze Age is considered to have been labour intensive (O'Brien 1994). It is also considered that those engaged in mining operations would have required a supporting agricultural base. Although the woodland clearance and agricultural activity at Sheheree Bog and the mining activity occurred at about the same time, it is unclear if they are related. However the woodland clearance at Sheheree does demonstrate that there was agricultural activity in the Killarney region at the time of the mining.

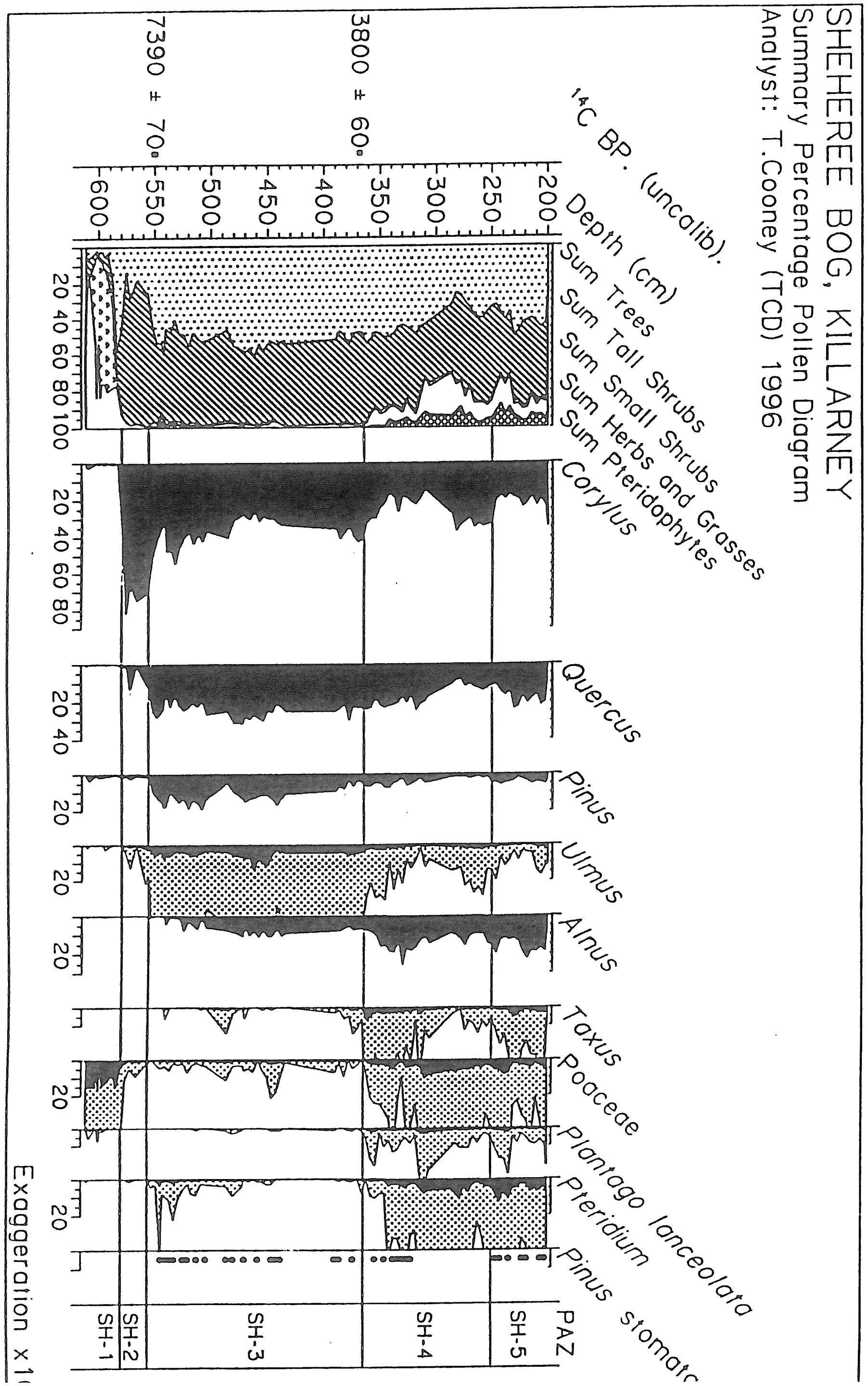


Figure 16: Summary percentage pollen diagram, Sheheree Bog, Killarney

The pollen and stomata record of *Pinus* at Sheheree Bog sheds new light on the interpretation of the history of this species in the Killarney region. Unlike previous pollen diagrams for Killarney (*e.g.* Vokes 1966; Mitchell 1988) *Pinus* does not appear to have been a dominant component of the forests throughout most of the Holocene in the Sheheree area. In addition *Ulmus* was in greater abundance than at other sites in the South West.

INNISFALLEN
(BO'B)

This monastery is situated in the Lower Lake of Killarney, to which it gives the name Lough Lein ("Lake of Learning"). Traditionally, the earliest monastery here was founded by Faithleann son of Aedh Damhain, king of Iar-muman in the seventh century. The monastery is popularly associated with St. Finian the Leper and the monks are believed to have built a hospital here in the ninth century. The island grew to become an important centre of learning in the 10th century and is associated with the monk Maelsuthain O'Carroll "chief doctor of the western world" and a friend of Brian Boru. The monastery has a troubled history, twice raided by the Vikings and subsequently plundered in 1180 by the local O'Donoghue clan. Despite this, the monastery flourished in the 12th and 13th centuries. In 1320, the monks adopted the Augustinian rule and the monastery became the priory of St. Mary. The monks probably abandoned the island shortly after the suppression of the Kerry monasteries in 1542. In the early 17th century, the island and monastery became the property of Valentine Browne, ancestor of the later earls of Kenmare.

Despite origins extending back to the 7th century, there are no archaeological remains visible today earlier than the 10th century. The complex of ruined buildings which greets visitors consists of a large church, with attached domestic buildings around a cloister on the north range and a kitchen building located a short distance away. The architecture here is post-Romanesque and probably dates to 13-14th century. The church from that period is of simple nave-and-chancel design and was built by enlarging an earlier rectangular stone church, the west front of which survives complete with trabeate doorway and projecting antae. This early stone church is likely to be of 10th- or 11th- century date and may well have followed a succession of earlier stone and possibly timber churches. A short distance to the west of the main church building, there is a row of buildings, mostly domestic in function, with a small Romanesque oratory at the eastern end. Two more oratories are located flanking the north-east and south-east sides of the main church complex. The north-eastern oratory above a low cliff overlooking the lake has a well-preserved Romanesque door with animal head designs. The style of Romanesque architecture seen here compares closely to the west front of Aghadoe 'cathedral' overlooking the Lower lake to the north of Killarney town.

This monastery is most famous for its association with an important historical source, the Annals of Innisfallen, which were partly written here around 1215. This early manuscript, now in the Bodleian Library in Oxford, provides much detail on the political history of early medieval Munster.

SITE 1.4: THE GADDAGH RIVER MORAINES

THE TERRACES OF THE GADDAGH VALLEY
(EA, DP, SH, TM)

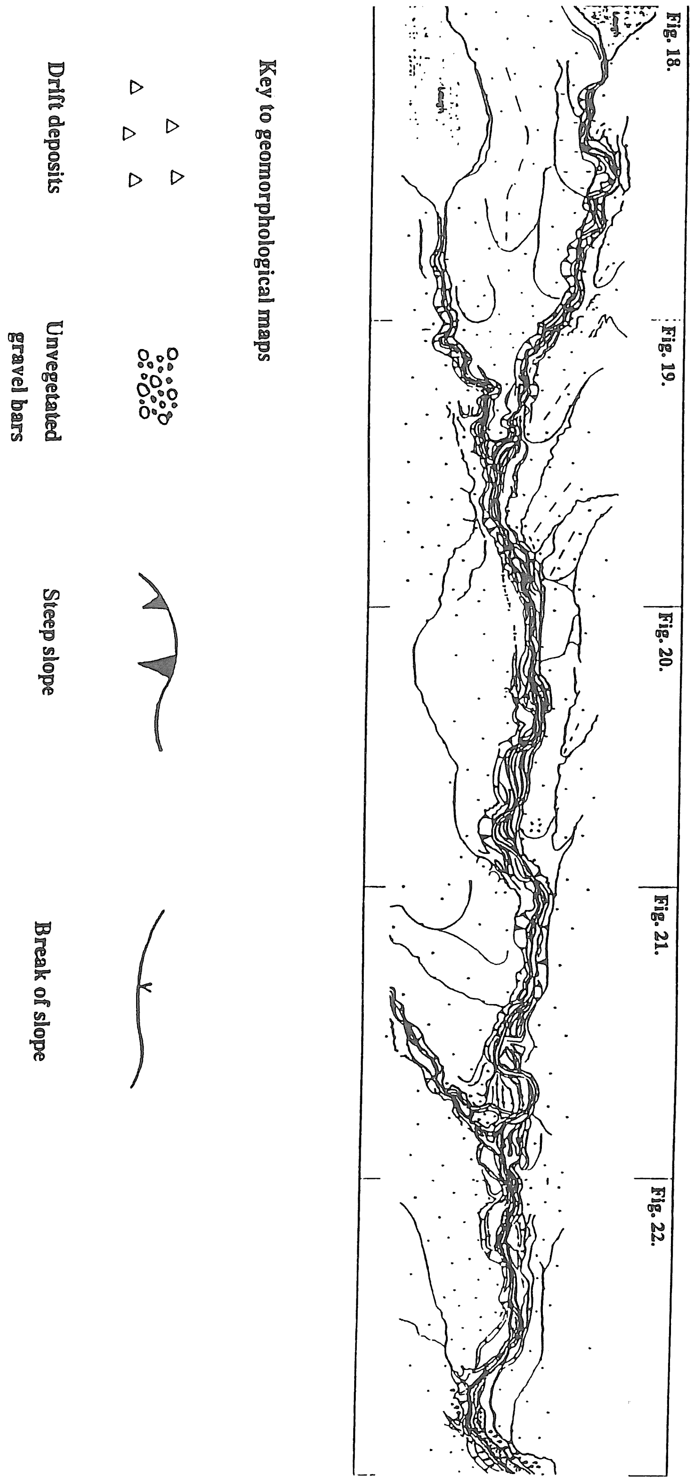
Introduction

Very little is know about the nature and chronology of alluvial landforms in upland regions of Ireland during the last glacial-interglacial transition and the Holocene. This contrasts with other upland areas of the British Isles where over the last two decades increasing attention has focused on the lithostratigraphy, biostratigraphy and chronology of Late Quaternary alluvial sequences (Harvey *et al.* 1981, Harvey *et al.* 1984, Macklin & Lewin 1986, Robertson-Rintoul 1986, Harvey & Fenwick 1987, Brazier *et al.* 1988, Brazier & Ballantyne 1989; Maizels 1991, Ballantyne 1991, Macklin *et al.* 1992, Tipping and Halliday 1994). This research has been driven by geomorphologists seeking to elucidate the dynamics, timing and palaeoenvironmental significance of alluvial activity following the retreat of the last major icesheets and also by palaeoecologists and archaeologists examining river valley vegetation histories and the environmental impact of prehistoric and historic cultures (Passmore *et al.* 1992). The results of these investigations are broadly twofold.

1. Though the chronology has yet to be firmly established, it is believed that alluvial landform development during the last glacial-interglacial transition was primarily controlled by glaciofluvial activity and paraglacial responses during the retreat of the Late Devensian icesheets, periglacial activity and renewed glacial activity and subsequent paraglacial response during and after the Loch Lomond Stadial Readvance (Younger Dryas: 11-10ka. BP).

2. During the Holocene the rate of alluvial landform development has not been uniform, but has fluctuated between periods of accelerated activity and relative stability in response to changing anthropogenic landuse practices coupled with episodes of climatic deterioration.

In an attempt to address the lack of information on Late Quaternary alluvial landforms in upland regions of Ireland an investigation of well developed alluvial terraces, alluvial fan deposits and debris cones in the Macgillycuddy's Reeks, Co. Kerry is currently in progress. This report outlines the work undertaken on a sequence of alluvial terraces in the Gaddagh Valley and features a brief summary of our initial findings.



ig. 17. Gaddagh Terraces

The Gaddagh Valley and Glacial History

The Gaddagh River is one of the principle catchments of the Macgillycuddy's Reeks and drains a substantial area of the northern flank of the massif. At the head of the valley streams from four distinct cirque basins, Coomcallee, Coomgouragh, Cummeenmore and Cummeenoughter flow into two lakes, Lough Callee and Lough Gouragh. Further downstream a tributary, which drains two adjacent cirque basins, Cummeengrin and Cummeenpeasta, joins the Gaddagh River immediately south of the Hag's Teeth Moraine. Warren (1979) established that much of the Gaddagh basin was occupied by a valley glacier during the Late Fenitian (Warren 1985: Late Midlandian c.f. McCabe, 1986) which merged with the main Kerry-Cork icesheet in the vicinity of the Gearha Moraine. The margins of this glacier are clearly distinguished by the presence of lateral moraines on the lower northern slope of Meallis. Thick deposits of till associated with this phase of glaciation can be readily observed in exposed sections of a prominent strath terrace which flanks both sides of the Gaddagh River. However, the outwash gravels and glaciodeltaic deposits described by Warren (1979) have not been identified. During the retreat of the Late Fenitian valley glacier a major readvance occurred resulting in the formation of the prominent Hag's Teeth Moraine.

At present the status of Younger Dryas glaciation in the Macgillycuddy's Reeks is uncertain. Warren (1979) noted the presence of prominent, well preserved moraine ridges in a number of north facing cirque basins which closely resemble glacial landforms associated with Younger Dryas glaciation in upland Britain, but considered that there was insufficient evidence to establish the true age of these features. However, on the basis of on-going research (geomorphological mapping, pollen stratigraphy and Schmidt Hammer analysis) we believe small Younger Dryas glaciers formed in Cummeenmore, Cummeenoughter and Cummeengrin.

The Terraces of the Gaddagh Valley

The terraces of the Gaddagh Valley can be best seen along a 3km reach extending downvalley from its headwater source at the cirque basin lakes of Lough Callee and Lough Gouragh (Figure 17). Here a sequence of four major alluvial terraces have been differentiated on the basis of relative elevation, morphostratigraphic relationships and the degree of pedogeneseis of observed sediment sections (Figures 18-22). These terraces lie respectively 4m, 2.5-3.5m, 1.5m and 1m above the current channel bed and are inset within a prominent strath terrace composed of glacial till (Figures 18-22). The fluvial terraces typically comprise massive poorly sorted gravel and cobble sediments with frequent large boulders. The sedimentology and pedogenic properties of the Gaddagh terraces is summarised below.

Fig. 19. River Gaddagh Terraces

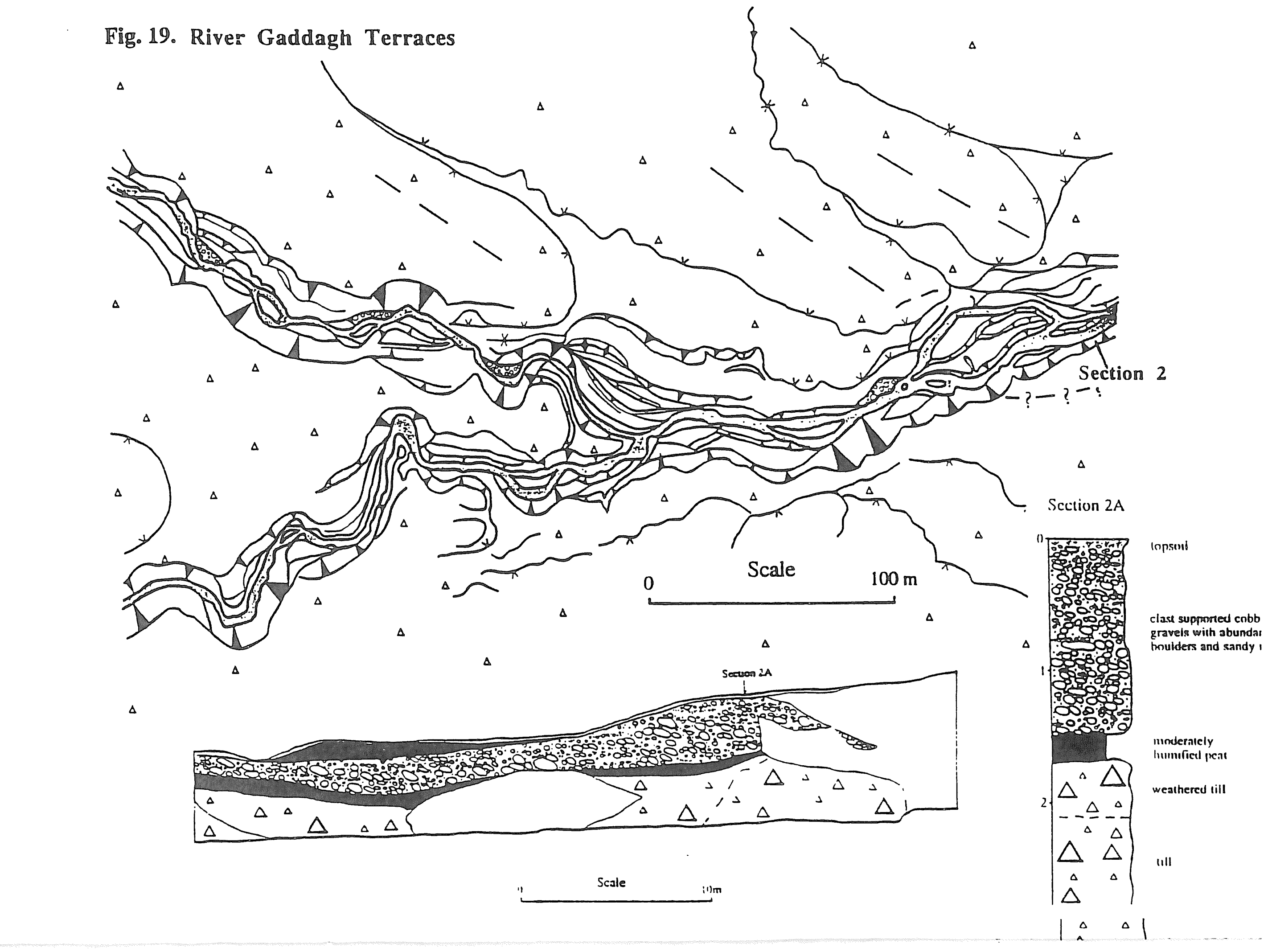


Fig. 18. River Gaddagh Terraces

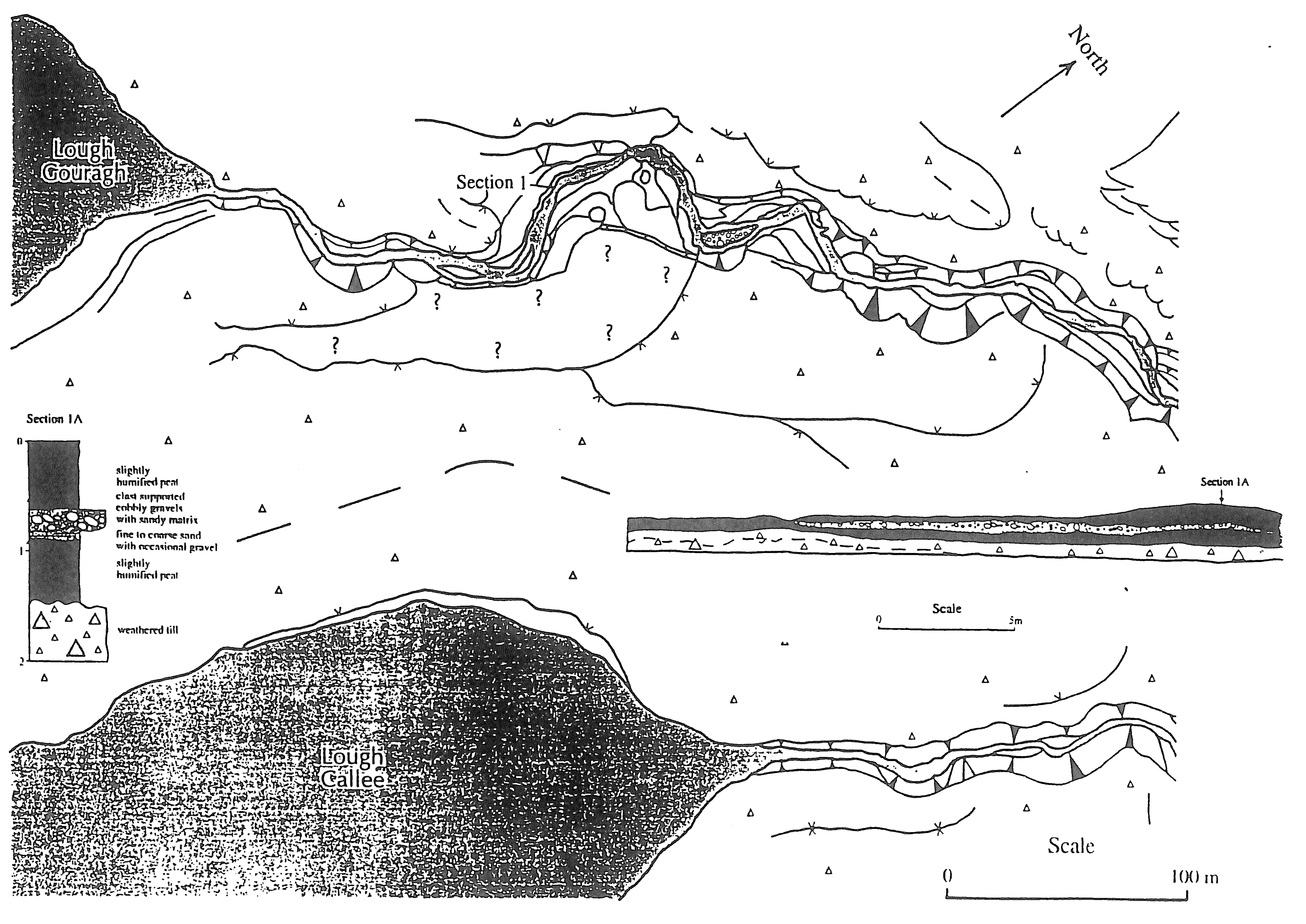


Table 1: Sedimentology and pedogenic development of the Gaddagh terraces

Terrace	Height above present channel	Sedimentology	Pedogenic Development
1	5-8m	massive, matrix supported glacial diamict	prominent A and B horizons max. solum depth: 1-1.5m
2	4m	Massive, fining upwards clast supported gravelly boulders	prominent A and B horizons max. solum depth: 2.5-3m
3	2.5-3.5m	massive clast supported boulder gravels with interstratified moderately humified peat	distinct A and B horizons solum depth: 0.5-1.2m
4	1.5m	massive clast supported boulder gravels with interstratified moderately humified peat	distinct A and B horizons solum depth: 0.65 - 0.75m
5	1m	imbricated cobbly gravels	distinct A horizon solum depth: 0.10 - 0.35m

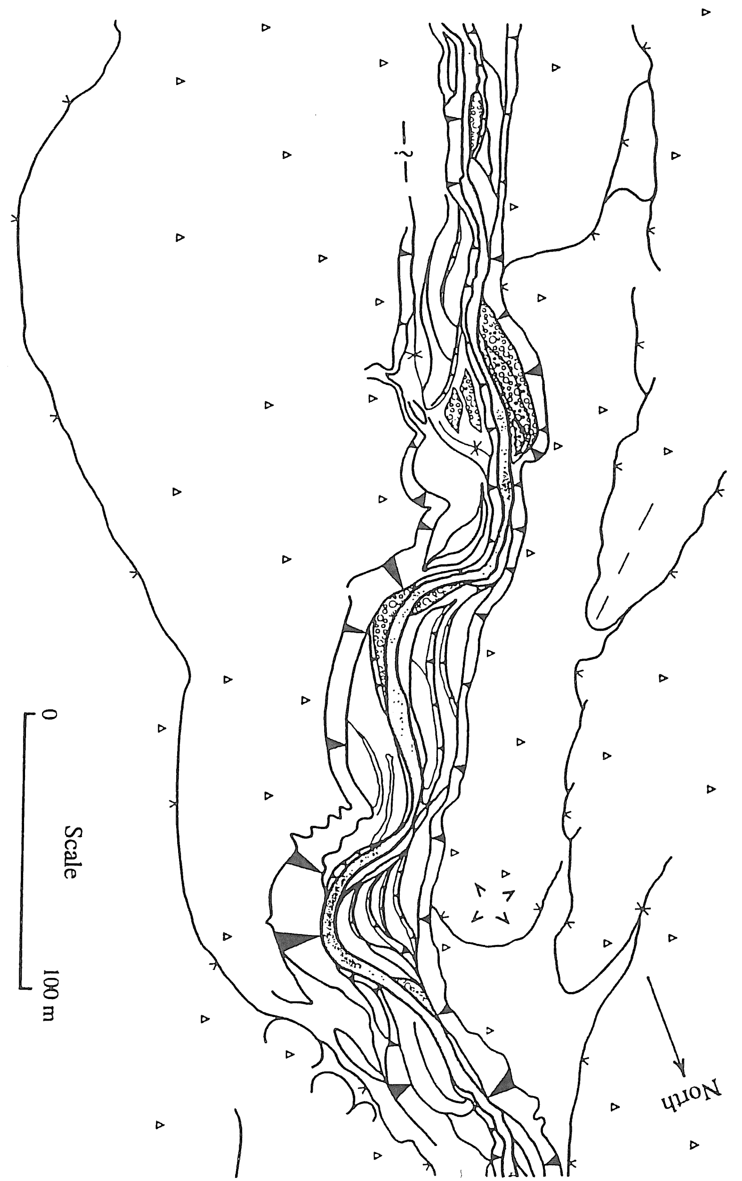


Fig. 20. River Gaddagh Terraces

Discussion and Interpretation

The alluvial sediments comprising these terraces are indicative of rapid deposition during high magnitude floods, while marked differences in the degree of pedogenesis suggests phases of aggradation were separated by lengthy periods. At present the chronology of the terraces is uncertain, but primarily pollen analysis of samples extracted from the peat horizons in Terraces 3 (Figures 19 and 22) and 4 (Figure 18) has demonstrated the presence of cereal grains and abundant charcoal fragments indicating that they are probably post-Mesolithic in age (H. Tinsley, pers. comm). Since Terrace 5 is inset within Terraces 3 and 4 and has a poorly developed soil horizon we tentatively propose that this is a Late Holocene landform and possibly formed during historic times. The palaeoenvironmental significance of these Holocene alluvial events has yet to be established, but pollen and radiocarbon analysis of interstratified peat horizons and complete Holocene sediment cores, extracted from local lake basins, is currently in progress. The approximate age and palaeoenvironmental significance of Terrace 2 is more difficult to establish because of the lack of datable materials. Since this is the earliest evidence of alluvial sedimentation following the retreat of the Late Fenitian valley glacier it is tempting to argue that this landform is related to glaciofluvial activity, but at present this is pure speculation.

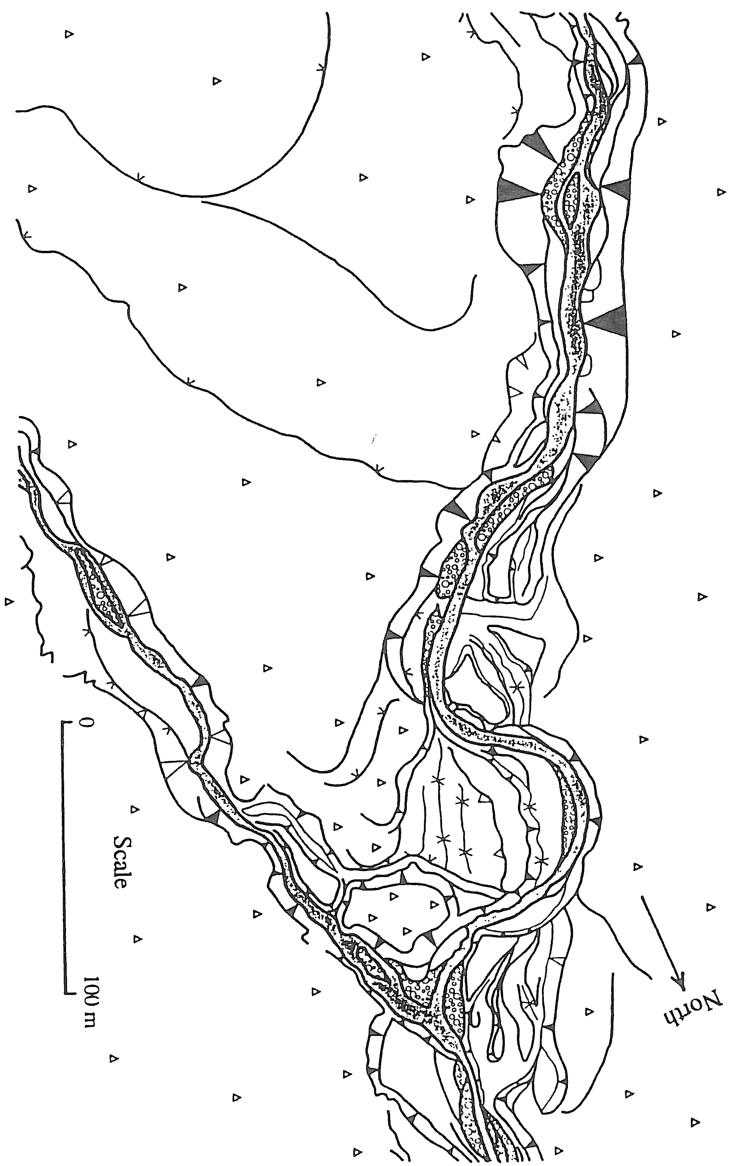
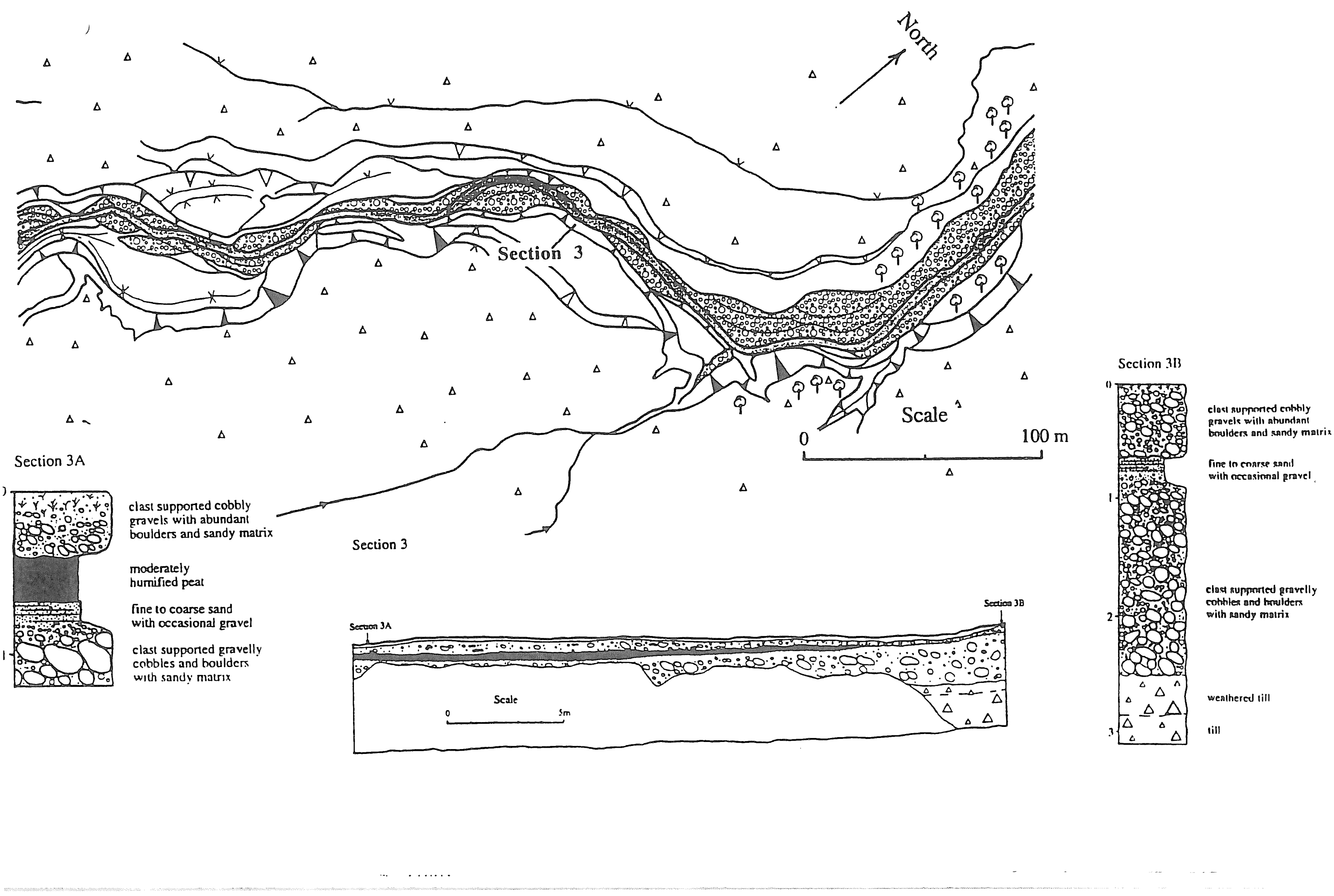


Fig. 21. River Gaddagh Terraces

22. River Gaddagh Terraces



Site 2.1: Castlemaine Harbour

The location of this site is shown on Figure 1. The site was selected for ease of access to the saltmarshes along this shore.

. Coastal Sediments in Castlemaine Harbour: An Overview (CD, RJD)

Castlemaine Harbour, which forms the inner part of Dingle Bay, has been partly infilled during the Holocene by a complex suite of coastal sedimentary landforms. This harbour is protected from the open sea by the two large spits at Inch and Rossbehy (Figure 1), and by the moraine and spit at Cromane, forming an almost enclosed intertidal basin. East of Cromane the centre of the harbour is mostly infilled by intertidal sand bars, separated by channels through which the Laune, Maine and Tullig rivers drain. Whilst the north shore of the harbour is relatively steep, and is fringed by a poorly developed, narrow shingle beach, the shouth shore is fringed by extensive saltmarshes which have broken up into islands in places.

An earlier palynological study by Carter and others (1989) of the saltmarsh sediments indicated that at Knockaunaglashy (Figure 23A) a freshwater, woody peat became dominantly herbacaeous over time, and was inundated by marine water at around 3,000bp, and was subsequently overlain by silt dominated saltmarsh peats. Extensive coring over the past three years indicates that this basal freshwater peat extends along the south shore of the harbour as far as the Laune river (Figure 23B), but is absent in the immediate vicinity of the Laune and Tullig rivers. Although absent from cores on the north shore of the basin, historical records indicate that the peat also underlies the intertidal sand bars in the centre of the harbour. Dates from cores taken at Garrane and Lonart indicate that the transition from a wood-dominated to a herb-dominated peat occurred at some point after 4,193+/-86BP, and that at both sites silt deposition indicating regular inundation commenced at around 2,800BP. Between Tullig and Lonart the freshwater peat is visible on the foreshore where pine stumps are exposed in the intertidal zone. Two of these stumps have been dated at 3,845 +/-35bp and 3667+/-34bp.

This evidence suggests that prior to 3,000bp, Castlemaine Harbour was primarily a freshwater environment, infilled with peat and drained by a number of rivers, which probably exited seawards along the northern fringe of the peat basin. The inundation of this basin after 3,000bp is thought to have been driven by sea-level rise. Whilst differential compaction of the peat has distorted the height at which transgression is recorded, it appears that sea level at this time was between 1-2m below its modern level. The consistent dating of the start of silt deposition in the basin indicates that the transgression must have happened quite rapidly over the entire basin, aided by the level surface.

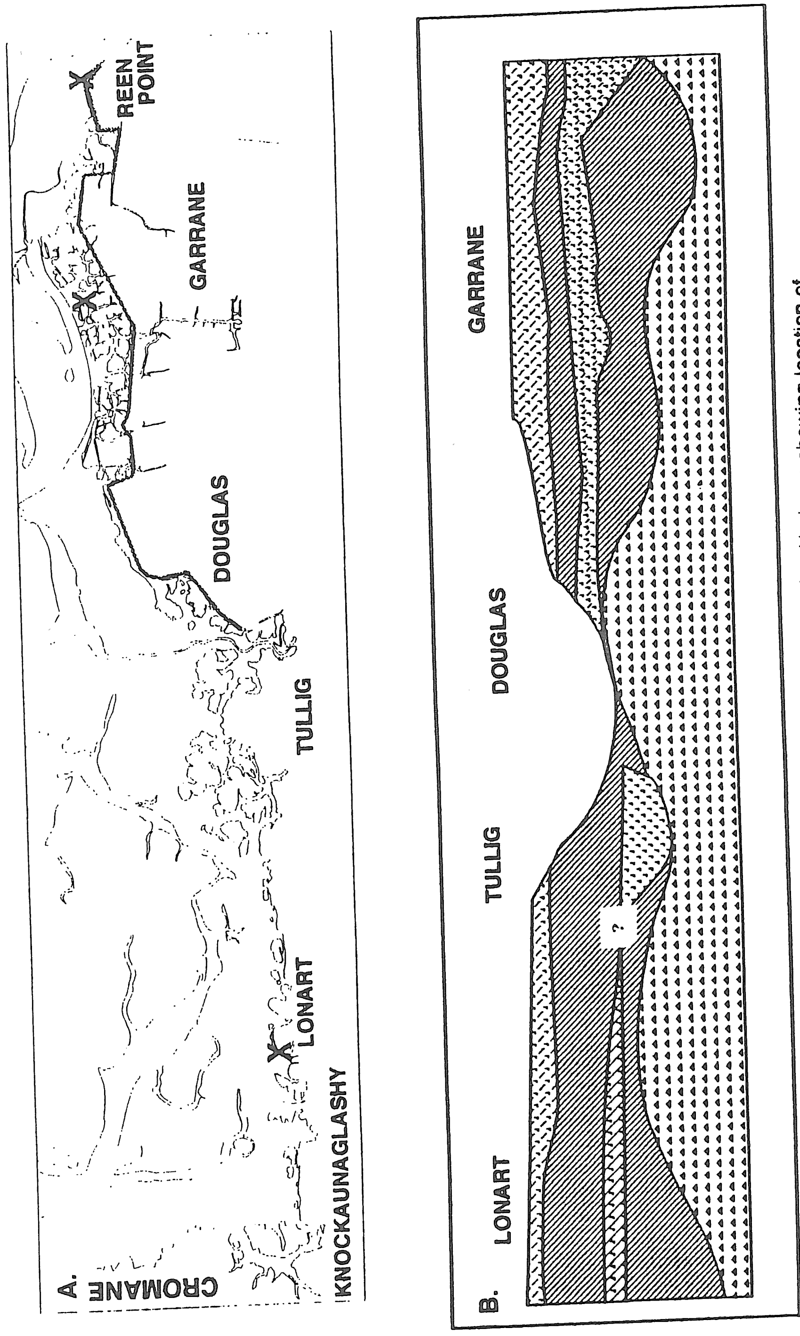


Figure 23: A. Map of south shore of Castlemaine Harbour, showing location of places named in text. Position of sample cores illustrated in Figure 26 is indicated. B. General stratigraphy of late Holocene coastal sediments along the south shore of Castlemaine Harbour (not to scale).

The saltmarsh deposits overlying the peat consist of a series of organic to inorganic silts and clays, with some sand. Variability in the amount of inorganic sediment in the boreholes along the south shore is thought to reflect proximity to the various sediment sources, including proximity to the saltmarsh edge and to intertidal creeks in the marshes, to river mouths and to exposures of pre-Holocene sediment. Consistently, inorganic content increases eastwards, reflecting the more 'open' nature of the marshes in this area.

Results from pollen, diatom and sediment analysis are discussed separately below.

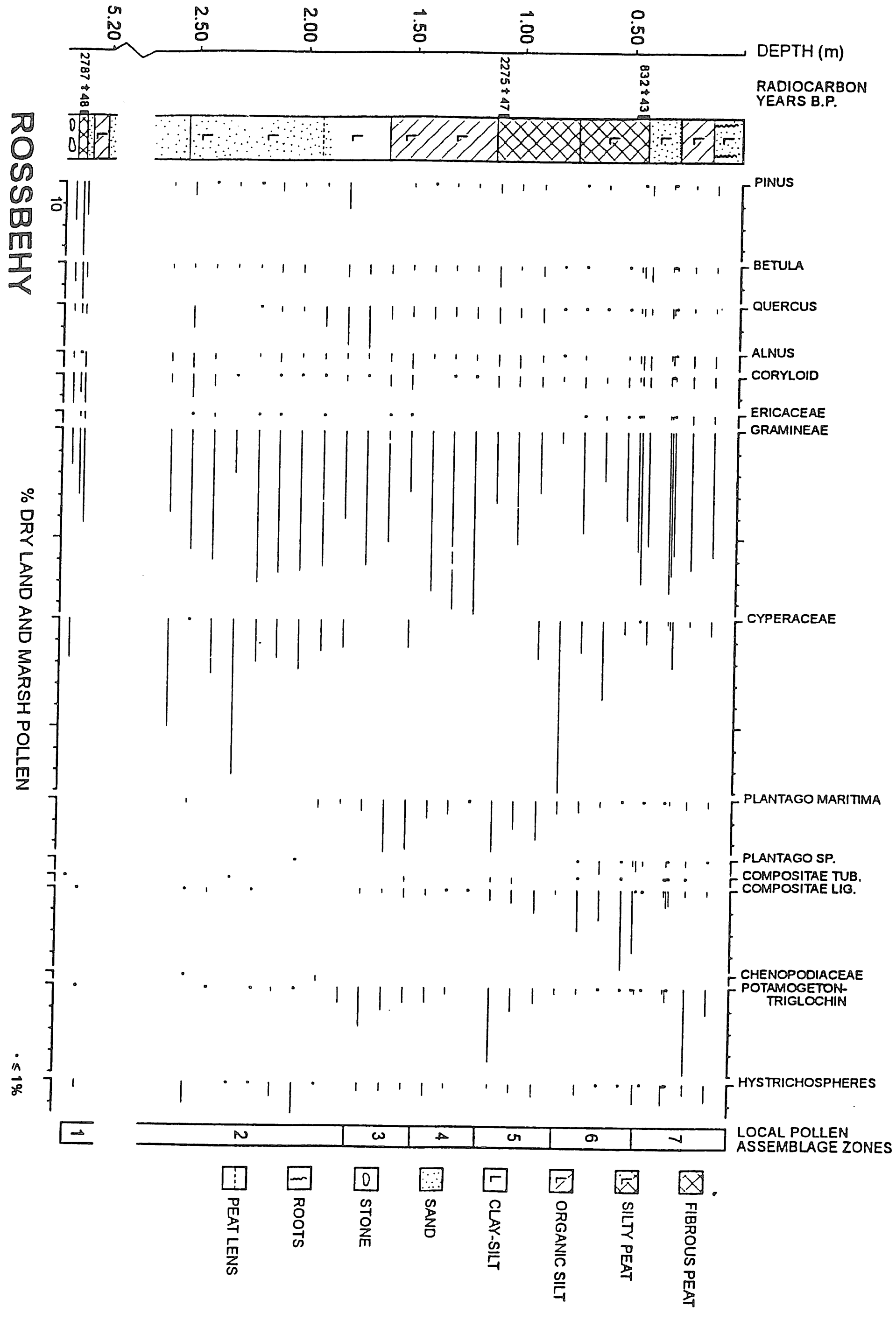
Pollen and Diatom Evidence, Garrane Marshes (CB)

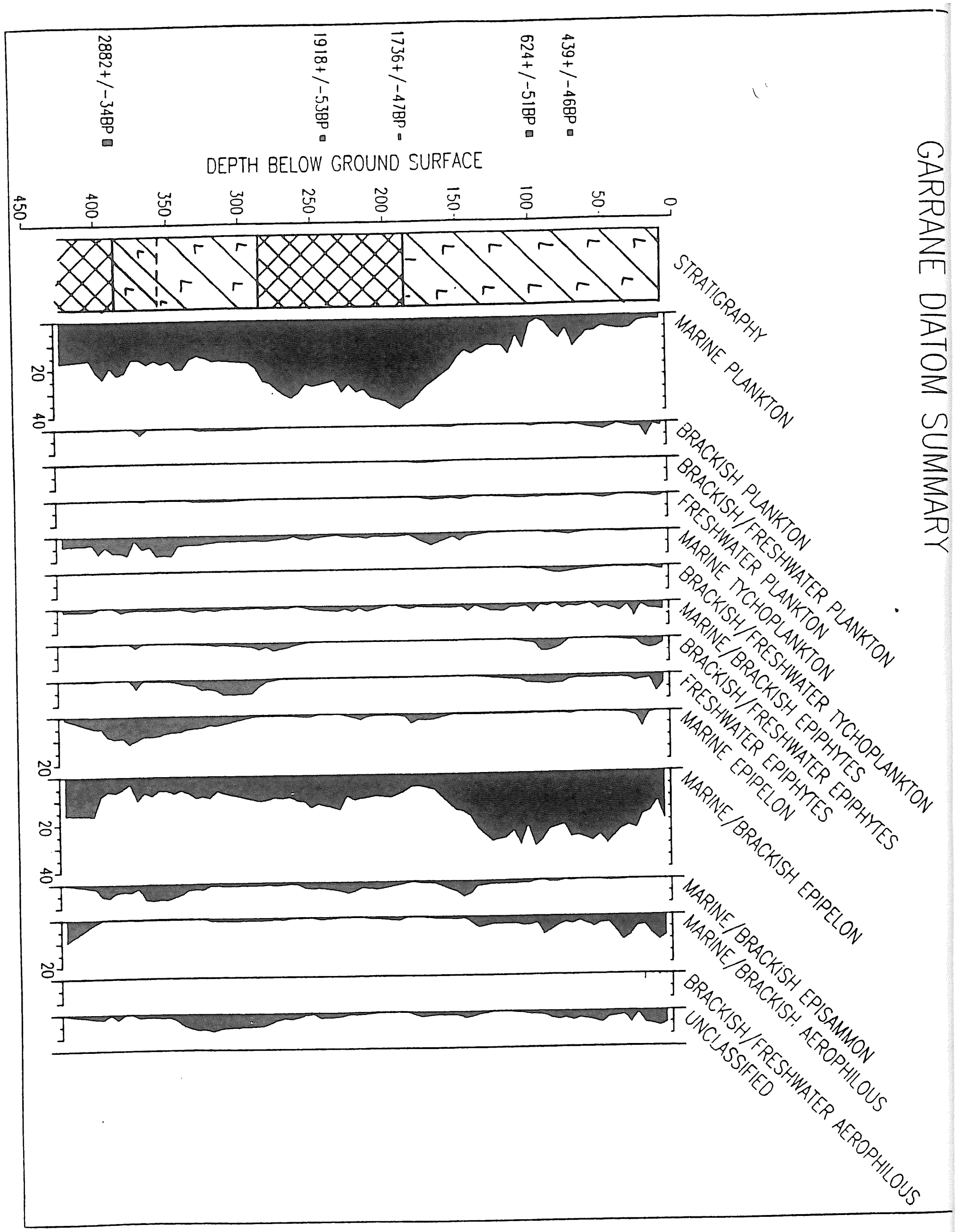
The Garrane pollen record suggests that prior to 2,882bp the area was colonised by a deciduous woodland, dominated by *Betula* and *Corylus* (Figure 24). Soon after this date, the woodland declined and was replaced by taxa associated with saltmarsh development, although *Alnus* continues to be present at or near the site in some quantity (5-10% total pollen). Following the decline in woodland the pollen record is dominated by Gramineae pollen with Chenopodiaceae and Cruciferae also present in significant amounts (5-10%).

At around the same time, shortly after 2,882bp, the diatom record shows an increase in marine planktonic taxa, dominated by *Paralia sulcata* (Figure 25). This rise may be associated with the initial sea-level rise induced flood event over the woodland environment. Also of interest within the upper 20cm of peat is the presence of a small (<5%) number of aerophilous marine/brackish diatoms (esp. *Diploneis interrupta*). These forms live on the surface of sediments in relatively dry conditions and this may be a reflection of the diatom community on the surface of the woodland floor prior to its inundation. From the point of the initial inundation shortly after 2,882bp to a point after 1,736bp the diatom record of the core is dominated by marine planktonic diatoms, although within this, fluctuations exist which suggest that the environment at Garrane varied in nature during this period.

Using the environmental classification of Vos & de Wolf (1993) and the environmental information which this classification suggests, the habitat/environment at Garrane shows little variation in broad category with almost all of the assemblages fitting into the category of saltmarsh around the high water mark. However, work on modern samples has suggested that this classification is not accurately applicable to many samples within the Castlemaine Harbour environment.

From the point of the peak in marine diatoms at -2.6m O.D.B. (Ordance datum, Belfast), the high levels of planktonic diatoms are accompanied by significant numbers of episammic (sand grain-dwelling) taxa, notably *Dimmerogramma marina* var. nana and *Dimmerogramma minor* (-2.6 - -2.0m





O.D.B.) as well as numbers of marine tychoplanktonic taxa (e.g. *Cymatosira belgica* and *Raphoneis* spp.) and marine epipelic (mud-dwelling) taxa, dominantly *Navicula distans*. This assemblage suggests that the area was one of low intertidal (possibly subtidal) mud and sand flats.

Above a depth of -0.1m O.D.B. the dominant group in the diatom assemblage changes from marine plankton to marine/brackish epipelon, the latter group being dominated by *Navicula peregrina* and *Navicula cincta*, with significant numbers of *Diploneis smithii* present in places. In addition to the marine brackish epipelon, numbers of marine brackish aerophilous species area also present above -0.1m O.D.B., this group being dominated by *Diploneis ovalis* and *Diploneis ovalis* var. oblongella. *Diploneis ovalis* is known to prefer salinity conditions towards the freshwater end of the brackish spectrum, and this, together with the decrease in marine planktonic forms may suggest a lessening of marine influence above this point. Within the Vos and de Wolf classification, all samples above this level have an assemblage which fits into the group classified as being above or around the high water mark in a saltmarsh environment, whilst peaks of epiphytic taxa (e.g. *Cocconeis scutellum*) such as those between 0.3-0.5m O.D.B. and above 1.2m O.D.B. may suggest the development of pools within this salt marsh environment. The top 30cm of the core shows low levels of marine planktonic taxa and correspondingly higher levels of marine brackish epipelon and aerophilous species, associated with the development and growth of the saltmarsh surface to the present day.

Whilst the pollen data from Garrane gives very little new information to add to the history suggested by the diatom, it does support the idea of saltmarsh development in the period following marine inundation of the basal peats. The pollen taxa present are those found in a high saltmarsh environment, and the two records together suggest that after the initial flooding event, high saltmarsh had developed by 1,918 bp, although fluctuations within it suggest slight changes in environment.

The pollen record also shows what may be interpreted as evidence for the impact of humans in the form of peaks in the *Compositae* pollen. At between -1.15 and -0.8m O.D.B. there is a peak in both *Compositae* (lig.) and *Compositae* (tub.) pollen. This, together with a smaller peak at 1.1-0.6m O.D.B. may be indicative of periods when the saltmarsh was grazed, as we know it is at times today and has been in the historical past. At the point of the lower *Compositae* peak, the diatom record suggests a reduction in marine plankton, and the assemblage can be classified as one which is of saltmarsh above or at the high water mark. This may be a reflection of a slightly 'drier' period of less frequent marine inundation, which encouraged grazing of the saltmarsh.

Sediment analysis
(CD)

A combination of particle size analysis and loss-on-ignition (L.O.I.) tests were carried out on cores from Lonart, Garrane and Reen Point (at the mouth of the Laune) in order to provide further information on saltmarsh development throughout the late Holocene. The Lonart and Garrane cores show an initial increase in silt content after 3,000bp (Figure 26), followed by a return to highly organic peat deposition (>60% organics at Garrane; >80% at Lonart) and then to more variable organic/silt ratios. As pollen and diatom evidence indicates that a saltmarsh environment prevailed throughout this period, it is likely that the phase of highly organic deposition is associated with sediment starvation rather than a return to afreshwater environment. Radiocarbon dates indicate that this phase was not synchronous, and most likely reflects local variations in sediment supply, such as distance from saltmarsh creeks over time.

Particle size analysis of the inorganic fraction in the Garrane core indicates that between 2882bp and 1918bp a cyclic variation in mean grain size occurred (Figure 26). Dating indicates that each cycle spanned between 120-160 years. Although a number of possible controls exist, the most likely explanation is that the grain size variation reflects variation in storm surge frequencies over time. A similar mechanism has been proposed as a control on saltmarsh advance and retreat in the Severn Estuary (Allen 1987).

Cyclicity on a similar scale to that seen at Garrane was also measured in the Reen Point core. After 1,060bp a sudden increase in the size of sediment being deposited occurred. The low rounding of pebbles and the absence of shells in this part of the core indicates that this sediment is likely to be of fluvial origin. This change in sedimentation is thought to be associated with changes in the catchment area of the Laune, possibly due to the release of sediment by deafforestation.

In summary, it appears that sediment influx on the saltmarshes in Castlemaine Harbour was controlled by a combination of factors during the late Holocene, including sea-level rise, proximity to source, climatic variation and human impacts.

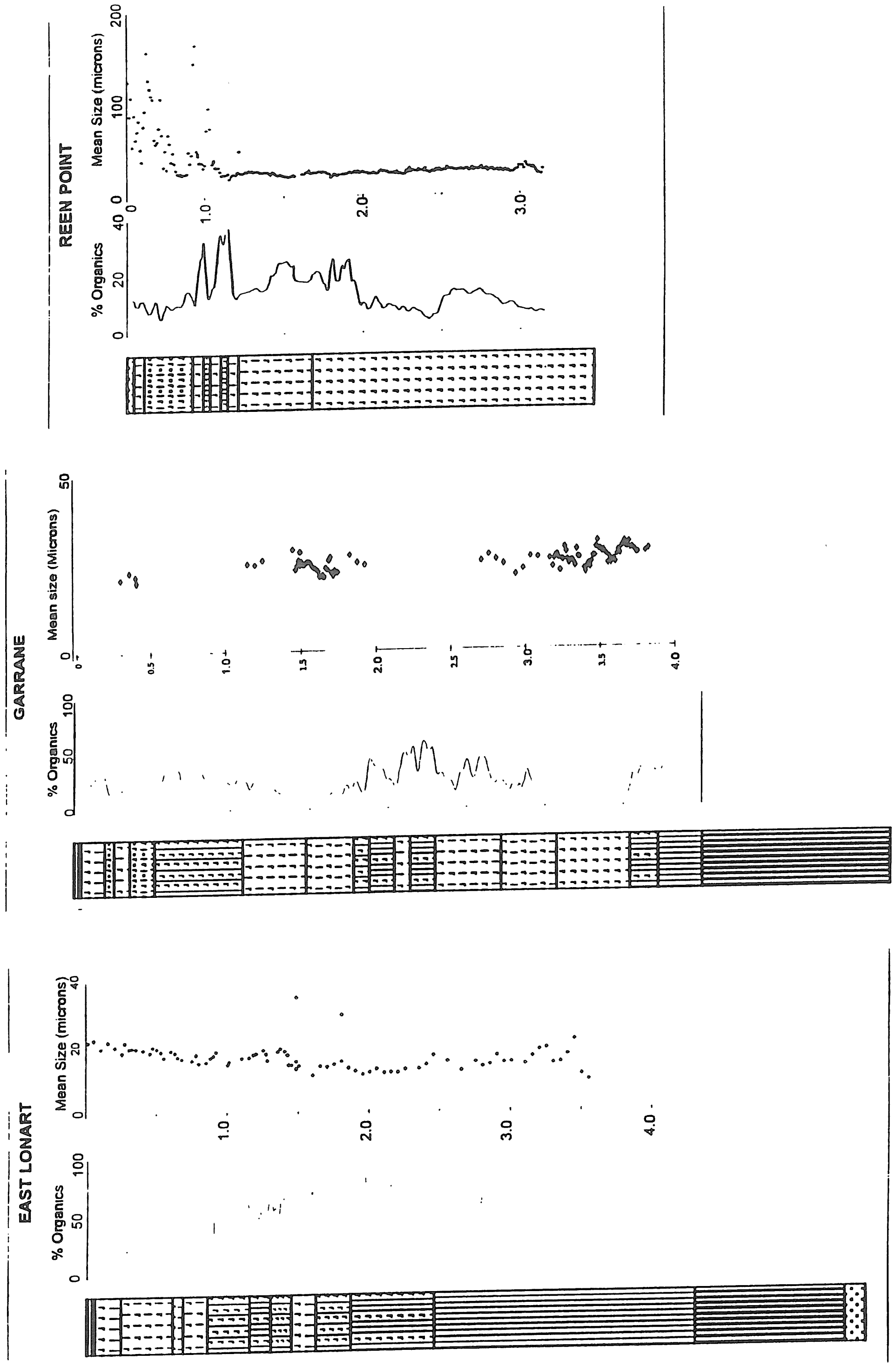


Figure 26: Stratigraphy, organic content and mean particle size of saltmarsh sediments at Lonart, Garrane and Reen Point, Castlemaine Harbour

SITE 2.2: THE QUATERNARY DEPOSITS BETWEEN FENIT AND SPA (PC)

The localities that we shall visit along these sections are shown on Figure 27. We start out from locality C.

Introduction

The Quaternary deposits along this part of the Kerry coast were the subject of an important paper by Mitchell (1970) in which he described in detail extensive cliff sections along the north shore of Tralee Bay. The sequence (from the base of the section) of a raised wave-cut platform in bedrock overlain by (in turn) raised beach sediments, biogenic sediments, lower solifluction deposit (*Lower Head*), glacigenic sediments and upper solifluction deposit (*Upper Head*) are by now well known and have been summarised by Mitchell (1970 and 1981) in diagrammatic form (see Figure 28). The significance of the interpretation of the site in Mitchell's work is clear. The raised marine platform is essentially the same as the undated "pre-glacial shore platform" of Wright and Muff (1904) and the overlying fossiliferous deposits were assigned to the close of the Gortian and the onset of a succeeding cold stage which saw the deposition of the lower solifluction deposit. Later work by Mitchell (1981) refers to the marine platform, raised beach and organics as being Gortian and the overlying sediments as dating from a "succeeding cold stage or stages".

Given the stratigraphic importance, palaeoenvironmental significance and excellent exposure of the deposits at Fenit (highlighted by Mitchell's 1970 paper) it is incredible that the 1977 INQUA guide to the area gives only passing reference to the site in a half page list of units that are exposed (Lewis, 1977, p. 51).

Warren (1985) used the cliff sections between Fenit and Spa as the stratotype of his "Fenit Formation". In the same publication he goes on to say that the stratotype for the "Fenitian Stage" is *"...the coastal section between Fenit and Spa, Co.Kerry where it is represented by the Fenit Formation".* To date the terms "Fenitian Stage" and "Fenit Formation" have not gained wide acceptance and they remain poorly defined by international standards (e.g. Hedberg, 1976). They are not used here.

The significance of the Quaternary sequence in this area has led to more research being carried out here to complement Mitchell's studies. Some of this later research is discussed below. The coastal cliffs still warrant further work, especially on the sedimentology of the soliflucted units and the biogenic sediments west of Kilfenora.

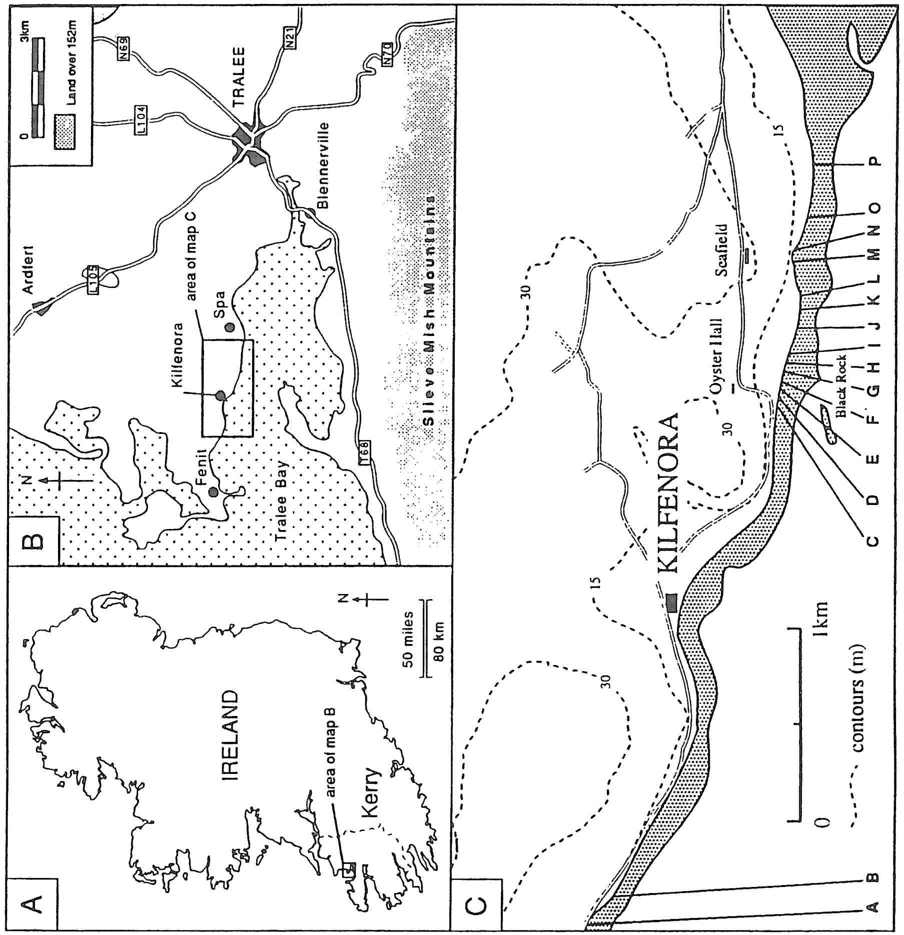


Figure 27: Location of the sites between Fenit and Spa referred to in the text. From Heijnis *et al.* 1993 © *Journal of Quaternary Science*. Reproduced by kind permission.

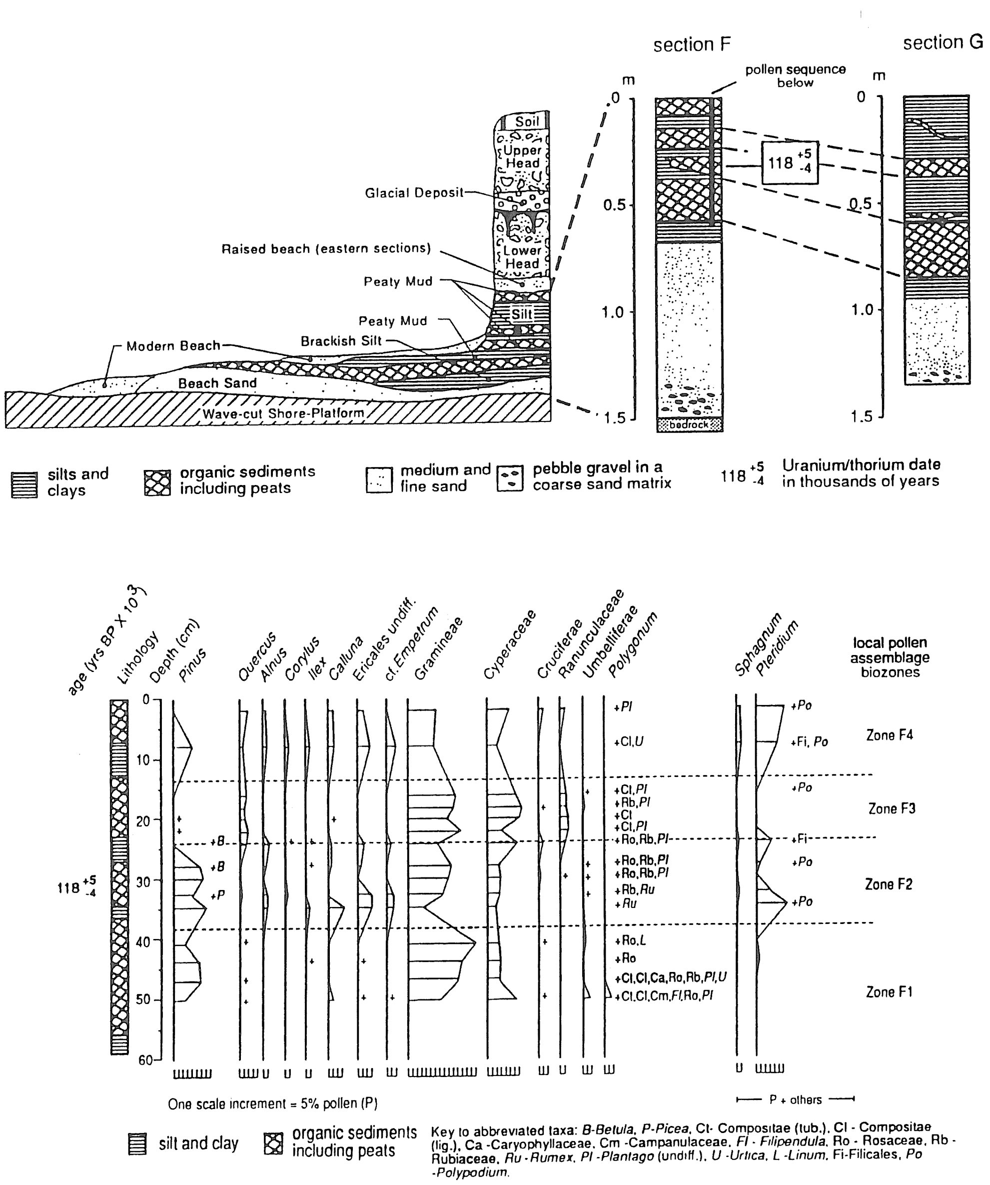


Figure 28: Stratigraphy and pollen record from the Late Pleistocene (Kilfenora Interstadial), Fenit, Co. Kerry (after Heijnis *et al.* 1993)

Recent research (up to 1996)

Julie Ruddock (1990) carried out palynological and sedimentological work on the organic sediments in collaboration with Henk Heijnis (Heijnis, 1992) who pioneered uranium-thorium disequilibrium dating (UTD) on peat deposits. Their work culminated in the publication of the paper by Heijnis *et al.* (1993), whilst very detailed work on the overlying soliflucted deposits was initiated by Richards (1993). The latter research has included analyses of fabrics and SEM work on the sediments.

The following account of the more recent research draws heavily on that of Heijnis *et al.* (1993).

Basic stratigraphy and sedimentology of the Fenit/Spa sections

As noted by Mitchell (1970), the stratigraphy of the Fenit/Spa site is complex. In general the organic sediments along the base of the coastal sections and in the foreshore are interdigitated with clay and silt layers which lie within raised beach deposits resting directly on a rock platform. To the eastern end of the sections (sites N, O and P on Figures 27 and 29) the organic sediments are overlain by raised beach sediments which coarsen up into the lower diamicton.

The sequence of deposits described here is similar to that of Mitchell (1970):

6. Succession of diamicts including solifluction deposits
5. Raised beach facies (eastern end of the sections)
4. Biogenic sediments
3. Clay and silt horizons
2. Raised beach facies
1. Wave cut platform

1. Wave cut platform

The wave cut platform at Fenit is most likely equivalent to that which runs right around the coast of Cork and into Waterford described by Wright and Muff (1904). Wright and Muff described a "pre-glacial" beach which incorporated a shore platform with a wave worn surface overlain by beach gravels about 3m above the modern wave level.

Between Spa and Fenit the platform is cut in shales and cherts and it extends out from the present cliff and below modern m.s.l.. The platform undulates along the section, occurring at the surface of the modern beach in some places, and just below the surface at other points. Mitchell (1970) recorded the inner edge of the platform as being 3.5m above mean sea level (m.s.l.). In places knolls of shale and chert rise above the general level of the platform, for example just west of Kilfenora where there is a rock outcrop which rises 3m above the modern beach level.

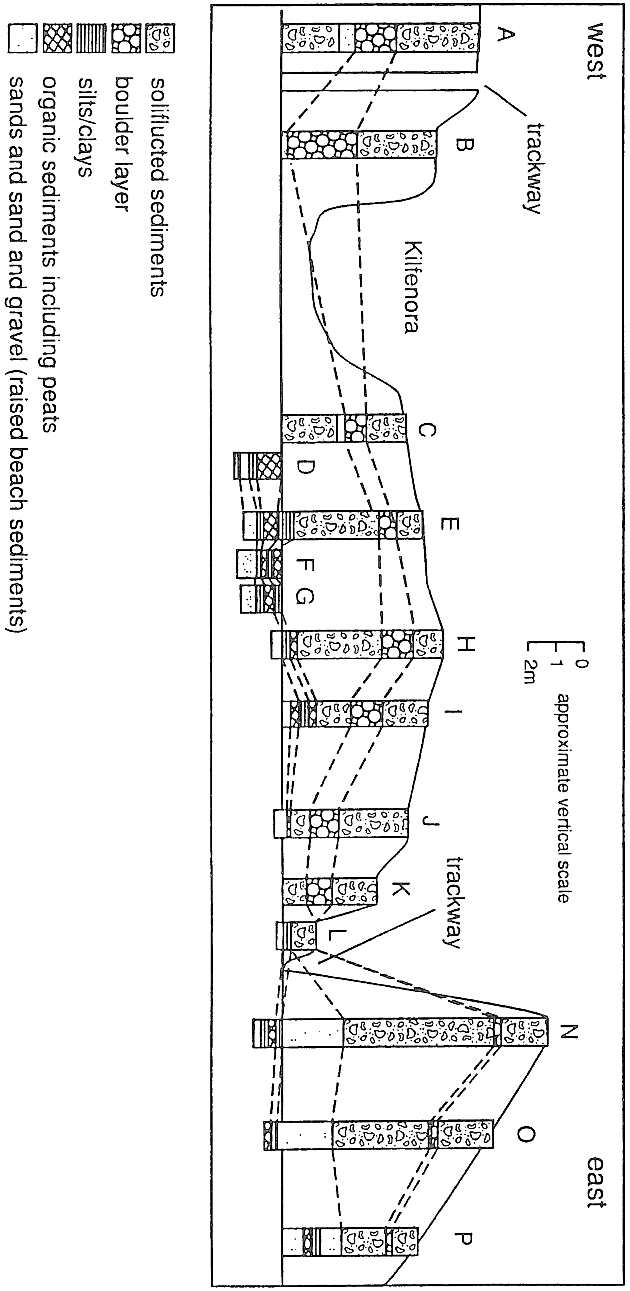


Figure 29: Composite sketch of logs from sections along the coast (not to scale). The length of the cliff exposure is over 4km. From Heijnis *et al.* 1993. ©*Journal of Quaternary Science*. Reproduced by kind permission

Despite considerable debate the age of the rock platform remains unknown. It is probably a composite feature of considerable age, reoccupied on a number of occasions (Mitchell, 1976; McCabe, 1987, Coxon 1993). It is evident that the shore platform was formed during a period when sea level was several metres higher than at present. In numerous locations around the south eastern coast the rock platform has been overrun by ice and in places its surface contains impressive striations, gouges and p-forms (McCabe and O'Cofaigh, 1996).

2. Raised beach facies

The raised beach facies is equivalent to the raised beach of Synge (1977) and to the beach gravels described by Wright and Muff (1904) which overlie the wave cut platform and form part of the 'preglacial' beach. The raised beach around the south coast falls within the range of 6-8m above m.s.l., Synge, 1977. At Fenit it stands at up to 6m above m.s.l.

The beach deposits vary in height and facies along the coast between Fenit and Spa. The nature of the deposit varies in grain size from medium sand in the vicinity of section F to polymodal with cobble and pebble sized clasts further east. In the western part of the study area (west of Section B, Figure 27) it is generally found to be below the level of the modern beach except at one or two points where it rises in height and is exposed in the cliff, for example at the trackway west of Kilfenora, where Mitchell's (1970) DP4 section was located. Here the beach is fairly coarse and comprises cobble sized clasts of (mainly) sandstone with some shale pebbles. At the two main sections considered by Heijnis *et al.* (*ibid.*), Sections F and G, Figures 27 and 29, where the organic sediments are thickest the beach sediments are much finer. At section F there is a lower unit of coarse sand with shale pebble inclusions which directly overlies the bedrock. This is overlain by a finer unit of medium grained sand. The sequence is essentially the same at Section G (Figure 27) with 5cm of the lower coarse sand and 35cm of the medium grained sand unit. At this point there is an additional 10cm of fine silty sand above this.

The raised beach is exposed east of this at Section E (Figures 27 and 29) where it forms the lower 64cm of the cliff section. Though only a short distance east, it is much coarser being represented by a pebble gravel with some subangular shale and sandstone cobbles in a coarse sand matrix.

The raised beach facies overlies the wave cut platform and it has been suggested that its unfossiliferous nature may imply that the beach was formed under cold palaeoenvironmental conditions (Wright and Muff, 1904) a suggestion corroborated by recent findings (McCabe and O'Cofaigh, 1996). Mitchell (1972) considered the raised beach at Fenit to belong to the penultimate interglacial in accordance with his correlation of the organic deposits with the Gortian. As a result of the uranium-thorium dating it is now evident that some of the raised beach sediment was deposited during the Early Midlandian and a Gortian age is ruled out.

3. Clay and silt horizons

The raised beach deposits grade upwards into clays and silty clays which intervene between the beach facies and the organic deposits along most of the coastal section (see Figures 27 and 29). At some sections (to the east) the organics rest directly on the beach facies with no intervening clay but at most points the clay layers are interdigitated with the peat layers as at sections F and G. In general the clay occurs below the level of the modern beach and is not visible but at some points it rises and is exposed in the cliff face. It is these sections that we should be able to study on this excursion.

In the deepest sections, F and G, the clay underlies the main biogenic deposit and also forms lenses within the biogenic sediment (Figure 27, 28 and 29). Towards the western part of the study area the peat thins away laterally and is replaced by the clay which has thin organic lenses within it.

Mitchell (1970) originally interpreted these clay layers as soil which was moved downslope by solifluction. However, there are no pebble sized clasts incorporated in this fine grained deposit and the grain size is fairly uniform. Heijnis *et al.* (1993) believed these sediments were probably deposited in standing water, possibly in a lagoon with occasional inwashing of inorganic material accounting for the interdigitation of inorganic and organic materials.

The clay rests directly on the beach sediment indicating that environmental conditions changed from beach deposition to sedimentation within a standing water body. Presumably this water body must have been deepest in the vicinity of Sections F and G as the clay and peat are thickest at this point and then become thinner laterally to the east and west.

4. Biogenic sediments

The main reason the Fenit sections are so important is that, unlike the many sites on the south coast which were described by Wright and Muff (1904), there are organic sediments between the raised beach and the head deposits.

The organic deposits at Fenit are quite extensive along the coastal section. They vary from 1 or 2cm in thickness at both the eastern and western extremities to 30cm or more in thickness in the central part, in particular at the two main sections described by Heijnis *et al.* (1993). Here there are three or four separate peat layers, the thickest being 30cm, with intervening bands of silty clay. The peat layers are predominantly composed of plant detritus.

<u>Section F of Heijnis *et al.* (1993)</u> Figure 28

Four separate peat layers. The lowest one is the thickest at 19cm and appears to be *in situ*. This is separated from the coarse grained raised beach sediment by a layer of clay and fine sand. The peat lens above this is not continuous across the section but is 8cm thick at the point at which the section was logged. This is surrounded on three sides by clay. The next peat layer above the clay is 10cm thick and this is overlain, with an intervening clay band, by 8cm of peat at the top.

The peat is thinner directly west of this section as at Section C where there are three peat layers. West of Section C the peat thins away again.

<u>Section G of Heijnis *et al.* (1993)</u>

2m east of section F, there are three main peat horizons (Figure 29). The lower peat layer, which is equivalent to the lower peat layer at section F, is 25cm thick at this point. There is also a thin lens of peat above this. The second peat layer is 22cm above this and is 8cm thick with the top 2cm being a lighter sedge peat. Above this is a clay layer 30cm thick to the top of the section, with a 1cm thick incorporated peat unit.

Just west of section G, at Section E, the main peat deposit has risen above the level of the modern beach and consists of two organic horizons 7cm and 2cm thick with an intervening band of clay. The peat here is considerably thinner than at Sections F and G. Even further east the organic deposit almost disappears and is just a thin 1cm band overlying the raised beach facies. The palynology of these biogenic materials is discussed below.

The detrital peats are associated with the silty clays and as such appear to be inwashed plant detritus settling in shallow standing water that underwent occasional inwashing of fine inorganic sediments. The sediment sequence suggests a lagoon environment with frequent inundation by the sea.

5. Raised beach facies (eastern end of the sections)

In the sections to the east of section L (Figures 27 and 29) further, well exposed, sandstones overlie the organic and clay rich facies. These sediments are over 2m thick in places and consist of stratified coarse and medium sands interbedded with horizons of matrix supported pebble and cobble gravels. The sandstones and gravels are interpreted as raised marine sequences.

The sediments have been heavily cemented with iron post-depositionally and are very indurated.

6. Succession of diamicts including solifluction deposits

The deposits overlying the biogenic sediments and the raised beach unit are predominantly poorly sorted and are composed of angular debris (pebble to cobble size) in a sandy matrix. The clasts are mainly shale and are of local origin and exhibit a strong (downslope) fabric. The bulk of the deposit resembles a typical solifluction deposit (or head) although it is sorted in discrete horizons and it is stratified (very clearly in places). The soliflucted sediment at this site was classified into an upper and lower head by Mitchell (1970) who identified a concentration of sandstone boulders dividing these two separate units.

The diamicton sequence between Fenit and Spa varies in height and morphology along the coastal section. At low points in the cliff there may be only 3 or 4m of diamicton whereas at the higher sections there is up to 9m. The grain size varies from pebble gravel in most places to a coarser cobble gravel at some sections with clasts up to 10cm in length. The lithology of the clasts within the diamicton is mainly local shale with some Devonian sandstone erratics and occasional quartz pebbles.

Between the upper and lower diamictons there is a layer of subangular Devonian sandstone boulders and cobbles (Figure 29) which is found along the length of the coastal section. The layer varies in thickness and grain size, in places consisting of large boulders up to 1m in length and the layer being up to 3m in thickness, and at other points being a thin layer of cobble sized clasts. The cobbles and boulders are in a sand matrix with some angular pebbles and in some sections (e.g. at the trackway between sites L and N, Figure 29) there is sedimentological evidence that some of the clasts are dropstones. In recent years this section has degraded but we should still be able to visit it.. This unit was interpreted by Heijnis *et al.* (1993) as a partially soliflucted and remobilised glacigenic deposit, probably formed by the deposition of ice-rafted material.

Within the lower diamicton there are ice wedge casts occurring just below the level of the boulders indicating intense (subaerial) freezing of the ground. There are also layers of peat mud within the lower diamicton which can be seen in the cliff at Section E. This peat unit is thickest at Section D (22cm) and thins away both to the east and west. East of Section E the peat unit is replaced by clay which eventually tapers out completely. The pollen content within this upper peat mud reflects a period when conditions must have been cooler than during the formation of the lower peat (see below). The upper peat is dominated by Gramineae with lesser amounts of Cyperaceae. There was some *Pinus* pollen at the base and traces of Ericaceae pollen throughout. In the stratigraphically higher lenses of the upper peat Cyperaceae was found to be the main pollen contributor and levels of Gramineae had declined. *Salix* and *Pinus* were both present towards the top and *Sphagnum* values were high.

The vegetation was mainly Gramineae and Cyperaceae with very little arboreal pollen reflecting a treeless tundra type environment. Conditions must have been either too cold or not warm for long enough for more temperate forest to develop. Some of this material may be reworked into the soliflucted material.

The character of the lower soliflucted diamicton changes very markedly towards the eastern end of the sections (e.g., site N and P, Figure 29) where it thickens, becomes highly stratified, contains large, low angled, faults, is overlain only by occasional sandstone boulders and appears to be conformable with the raised beach facies below which coarsen up into the diamicton. Heijnis *et al.* (1993) suggested that the diamicton may have formed as solifluction lobes entered the sea during a period of high relative sea level possibly caused by glacially induced isostatic depression.

Pollen assemblages and the vegetational history

Heijnis *et al.* (1993) give details of palynological work from two sites (F and G, Figure 27). The two sites present similar data and these are summarised. The pollen diagram for site F is reproduced as Figure 28.

The pollen record from site F can be zoned (p.a.b. = pollen assemblage biozone) as follows:

Zone F4 Gramineae-Ericaceae-*Pinus* p.a.b.
Zone F3 Gramineae-Cyperaceae-*Quercus* p.a.b.
Zone F2 Gramineae-*Pinus* - Ericaceae p.a.b.
Zone F1 Gramineae-*Pinus* p.a.b.

The lithofacies present and their associations suggest that the organic sediments represent deposition in small pools or lagoons frequently inundated with inorganic material.

Zone 1 reflects a period when there were open pinewoods in the area with a field layer composed of grasses, sedges and other herbs with some heather. *Pinus* is also the dominant tree in Zone 2 but here there is also some *Alnus* pollen. The heaths have increased indicating that conditions were possibly becoming more oceanic or cool. In the peat layer above this level (Zone 3) pine pollen has disappeared and herb pollen has increased. However *Quercus* pollen is present in greater quantities than below and at site G *Alnus* is also recorded. Zone 4 at both sites records *Quercus, Alnus* , *Corylus* and *Ilex* indicating a possible amelioration in climate towards the top of the sequence.

The pollen assemblages from these sections do not resemble those of previously recorded sites in Ireland and they cannot be characterised as belonging to the Gortian stage (Coxon, 1993). As such they appear to represent cool temperate, sparsely wooded, conditions with a predominance of open ground possibly with increasing thermophilous taxa late in the depositional phase. The pollen sequences may represent the onset of interstadial conditions early in the Midlandian glaciation or a minor transition to warmer conditions during the end of an interglacial. The pollen assemblages recorded at Fenit are however unique and do not appear similar to interstadial floras recorded from the Early Midlandian substage (e.g. at Aghnadarragh, McCabe *et al.* , 1987).

The pollen record from this site is not unlike post- Eemian records from some European sites (e.g. Oerel in northwest Germany. Here the end of the interglacial (or EVII) is a period dominated by *Pinus* with lesser amounts of Cyperaceae and other herbs with heath pollen increasing toward the end of the zone (Behre, 1989). In Zone EVI *Pinus* increases rapidly and becomes dominant and the initial breakdown of the forests occurs indicated by the rise in herb pollen. In Zone EVII the forest break up continues and the soils become acidified).

The age of the organic sequences at Fenit/Spa and their importance

The UTD methodology employed at the site is discussed in full in Heijnis *et al.* (1993). The results of the UTD measurements from site F are shown diagrammatically on Figure 30. For a variety of reasons (particularly open system behaviour) the dating of the central part of the peat layers proved the most accurate with the three single peat layers indicate a more or less constant age, between 110 and 120 ka. Isochron plots (also shown on Figure 30) allowed an age estimate of between 114,000 and 123,000 years (118,000 (+5,000/-4,000) to be made.

The palynological evidence suggests that the organic sediments between Fenit and Spa were deposited in cool temperate conditions. The uranium -thorium dating of the biogenics gives an age of between 114,000 and 123,000 years (118,000 (+5,000/-4,000)) and this age implies that the organic part of the deposit belongs within Oxygen-Isotope Stage 5, possibly after the end of Substage 5e.

The pollen assemblages obtained from the sediments at sites F and G (Figure 28) are unique in an Irish context (Coxon, 1993) and as such they do not allow biostratigraphical correlations to be made. The taxa suggest an open environment with cool conditions predominating, but probably not excessively cold. The pollen diagram indicates a possible amelioration in climate towards the top of the sequence. The uranium-thorium dates (centred at 118,000 years) would place the organic sediments within Oxygen-Isotope Substage 5d (Edwards *et al.*, 1987 and Bowen *et al.*, 1986). The nearest (complete) sequences of this age come from France at Les Echets, near Lyon (de Beaulieu and Reille, 1984) and La Grande Pile (Woillard, 1978; de Beaulieu and Reille, 1992) where Substage 5d is represented by a transitional period of cold climatic conditions of the Melisey I stadial. After a short period at these sites (de Beaulieu and Reille, 1992) the climate ameliorated slightly into the St-Germain I period during which there is a sequence of forest types. The climatically complex St-Germain I interstadial has been correlated to Substage 5c (Guiot *et al.*, 1989) and further, biostratigraphical, correlations can be made with deposits in the rest of Europe (e.g. with the Brörup interstadial of Denmark, Behre, 1989).

The evidence from the dating and the pollen record make it likely that the organic sediments at Fenit were deposited after the Eemian (Substage 5e) and during the transition between Substages 5d and 5c. However, the pollen record at this site is not directly comparable to those from central France, nor is it complete enough to be entirely certain about sequences proving climatic amelioration into interstadial conditions.

Heijnis *et al.* (1993) suggested that the biogenic sediments represented a cool temperate episode (correlated to Substage 5d/5c) and that they should be known informally as the Kilfenora interstadial until further information can be gathered.

The importance of the dating of this sequence is very clear. Firstly the upper facies of the marine sediments, lying above the organic beds, at this site can be

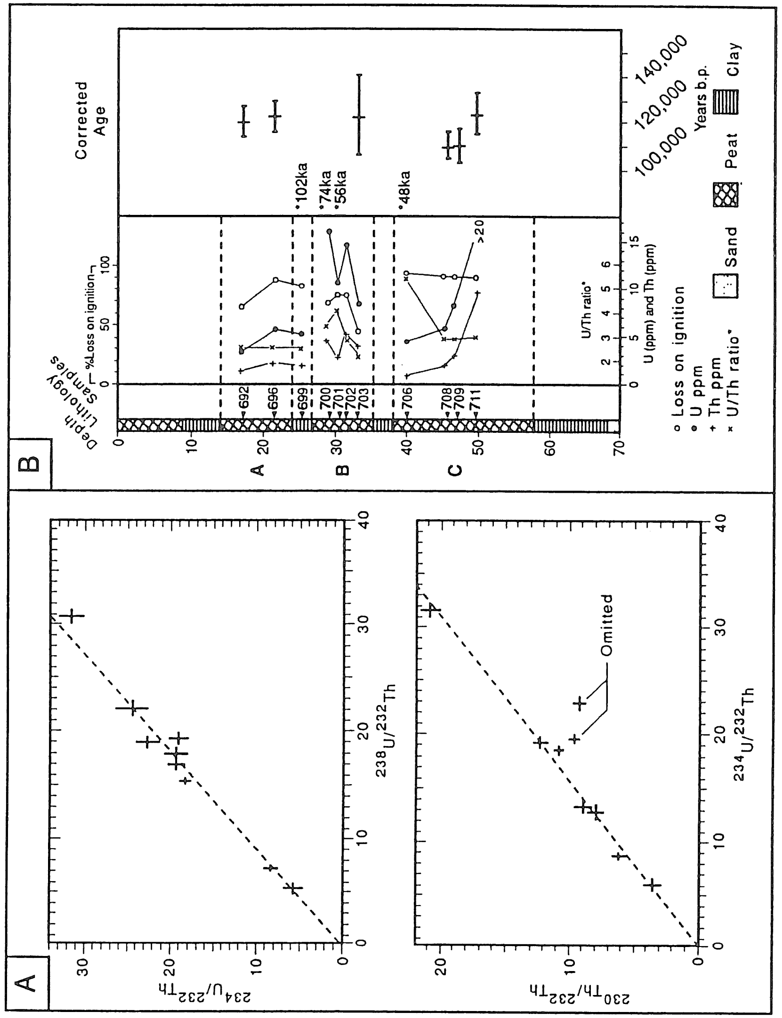


Figure 30:
A. Plots of ^{230}Th/^{232}Th vs. ^{234}U/^{232}Th and ^{234}U/^{232}Th vs. ^{238}U/^{232}Th for leachates of the Fenit samples; 230^{230}Th/^{234}U and ^{234}U/^{238}U as determined from the slopes of the respective lines give an apparent age of 118ka (+5/-4).
B. Age/depth diagram and the relationships between sediment, age (corrected after table 1 (Heijnis *et al.* 1993), uranium and thorium isotopes of the site F samples. After Heijnis *et al.* 1993.

dated to the Early Midlandian. If the marine sediments on the platform at Fenit are correlatable to the Courtmacsherry Raised Beach then it is apparent that this extensive coastal feature must date from within the Midlandian cold stage. High stands of global sea level are recorded and dated from many areas during the last interglacial, Substage 5e (e.g. Bermuda, Edwards *et al., 1987*; Vacher and Hearty, 1989 and Spitsbergen, Mangerud and Svendson, 1992). Smart and Richards (1992) have argued that the high sea levels of Substage 5e are not a single event and may span some 12,000 years between 119.2±1.5 to 130.8±1.5ka. The evidence from Fenit suggests that sea level was still higher than present at 118ka which has been correlated here to Substage 5d or 5c and the palaeobotanical work shows that, at least in part, the raised marine sediments were laid down under cool climatic conditions. The apparently conformable transition from raised beach sediments up into stratified diamictons is one that confirms the cold nature of much of the sedimentation and it is a record that is repeated around the south eastern coast of Ireland (McCabe and O'Cofaigh, 1996). However, as McCabe (1987) pointed out, it has not been demonstrated conclusively that the raised beach deposits around the Irish coast are of the same age and further dating projects will be necessary.

The diamictons that overlie the organic sequence at Fenit represent the onset of colder climate conditions with soliflucted material, under periglacial conditions, possibly entering the sea in lobes. The large boulder bed between the upper and lower diamictons at Fenit represents glacial rafting of debris, possibly by a piedmont lobe of ice (Mitchell, 1970) from the south. Such a floating ice mass would explain the contained erratics and a high sea level would be necessary. The lower diamicton and the ice-rafted boulders may represent deposition during a period of local glacial isostatic depression after 118ka. The upper diamicton represents a return to solifluction under cold climate conditions.

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